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Dipartimento di
Ingegneria Industriale

PROCEEDINGS OF THE FIRST INTERNATIONAL COMFORT CONGRESS

ICC2017

comfort congress

salerno 2017



June 7th and 8th

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UNIVERSITÀ DEGLI STUDI DI SALERNO

Dipartimento di Ingegneria Industriale

Comfort congress

SALERNO 2017



June 7th and 8th

comfort congress
salerno 2017

June 7th

@Salerno City Hall

from 09:30 Registration

10:30-11:00 Opening Ceremony

11:00-12:00 Keynotes speechs

12:00-12:30 Transfer to UNISA

@University of Salerno

12:30-13:45 Lunch

13:45-15:45 **Session 1A - Methodology**
Session 1B - Tools

15:45-16:15 Talks & Coffee

16:15-18:15 **Session 2A - Modeling**
Session 2B - Thermal

18:30 Transfer to Salerno and free dinner

June 8th

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@University of Salerno

9:15-11:15 **Session 3A - Psychophysic**
Session 3B - Seating

11:15-11:45 Talks & Coffee

11:45-13:45 **Session 4A - Dynamics**
Session 4B - Applications

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15:00-17:00 Plenary presentations

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19:00 Transfer to Cetara for visiting Amalfi coast

20:00 Congress dinner

June 9th

Social activities

Visit to Pompei (Historical site and Vesuvio volcano)

Visit to Paestum (Historical site and Museum)

Now is the time for a Comfort Congress

Naddeo A.[1], Mansfield, N.[1], Frohriep, S.[3], Vink, P.[4]

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A knowledge based approach to the machinery design

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Abstract

The technological development is pushing the industrial world toward a new paradigm, the "Industry 4.0", which embeds topics such as data digitalization, predictive maintenance and cyber-physical systems. It entails significant changes in the human resources management, without reducing their importance. The man was part of the manufacturing system from the first industrial revolution and no automation or digitalization can be possible without human control. For this reason, even in this new manufacturing era plants have to be socially sustainable. Then, industry can no longer underestimate the reasonable application of ergonomics to the work place, also due to stricter regulations on this matter. The additional knowledge of prevention through design principles of the machines and practices would be helpful when a regulation or a standard is in place that sets forth the principles and the methodologies to address hazards and risks in the design processes. To integrate ergonomic and human factors in the design of production is essential the involvement of production engineers to understand the importance of a guidance for decisions during the development of machinery to enable them to design machines that are safe for their intended use. In this perspective, this paper is aimed at developing an agile method for a proper integration of social sustainability aspect during the design phase. Through this tool, designers can focus both on performance and human aspects while developing a machine. The method, which is presented in this paper, is a preliminary approach to illustrate the application of the International Standards about "safety machinery" and "ergonomics" according to a knowledge based approach. The framework permits to guide engineers in the decision making at the design phase about the standards to adopt to achieve the safety and ergonomics requirements and assure the optimal working condition. In particular, standards related to ergonomics concern the workplace organization, the work station design using the "human centred design" approach, the job design and the implementation of a sustainable working performance comfortable to the stakeholders. The method tends to be valid during design and re-design phase also. With three multilevel checkpoints, the designer can understand weather or not its project respects human needs. The method will be validated through a case study where the approach is exploited during the development of a wood machine tool. Keeping employees healthy while improving productivity has been one of the main issues discussed facing the aging of the working population.

Keywords: design method, safety, ergonomics, machinery, social sustainability

1 Introduction

The human performance is one of the most significant human factors that assess the comfort value of a working condition. With a focus on production systems, design engineers and production engineers need to integrate

their technical knowledge with the comfort design strategies. This should be possible developing solutions according to the national and international laws to maintain human performance considering occupational risk factors.
To manufacture a product that satisfies the design constrictions, it is necessary to accede to the information at the design stage about comfort and safety requirements.
During the design phase, engineers have rarely information about the workplace where the machine has to be located and who the stakeholders, workers, are (e.g. which country the system will be dealt? Between different countries ergonomics requirements should vary). Thus, the machine system has to fulfill the best design to be integrated at different plants. Actually, design engineers' knowledge about technical constrains is solid but does not match completely with comfort and safety aspects according to International Standards.
Good safety and comfort design has to be organized in a practical design process to improve a system of requirements and constrictions that guides engineers at the design stage.
The present paper proposes an approach to assist a designer during the development of a machinery system. The approach permits to assess and quantify comfort during the design phase. This will integrate tips and best practices coming from ergonomics and safety standards.
The approach permits to avoid deficiencies, and let the designer identify which are the criticalities of the machine before the worker is exposed to any uncomfortable and unsafety working condition. The method will be tested through a case study. The latter concern the development of a wood machining system.

2 State of art

During last years, several studies focused on the effects of the workplace and environmental conditions on the working performance were developed.
For example, ambient environmental conditions (lighting, acoustics, ventilation and thermal comfort) affect individual performance. Individual tasks' performance has been studied through traditional experimental designs measuring the effects of different lighting levels, for example, on speed and accuracy of individual task performance. Researches about Indoor Air Quality (IAQ) and Thermal Comfort in office buildings ask individuals to rate their comfort, satisfaction and health levels [1,2,3].
Ergonomics issue studies pointed out features of the furniture and the performance of tasks are linked to the comfort and performance of the individual in a given workstation. Individual tasks performance, or productivity, can be analyzed in to a positive and negative point of view. Fast, more accurate output, faster and more effective employees, better quality service or product to clients, faster and better quality organization represent the positive measures of productivity. Negative measures of productivity should be changing workers to perform the same amount of work, employee turnover, rate of absenteeism and illness, product returns or service complaints, error and customer complaint rates. In order to keep an effective work environment, the aim is to avoid these effects, reducing their incidence and prevalence, even considering some previously calculated error rate or the production quality results.
All those studies referred to a post design comfort and safety assessment into the office workplace environment. The comfort design declined into an industrial plant specifically to a machine, needs to consider all the design restriction which are not only dictated by the technical design knowledge but also by the international normative about health and safety [ISO 12100]. The latter are associated with the concept of comfort in the workplace. Furthermore, comfort issue is composed of physical comfort, psychological and functional comfort [4] (Figure 1).

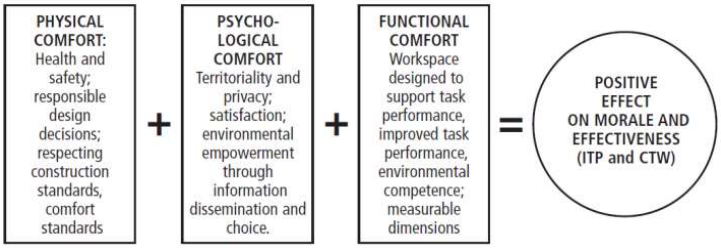


Figure 1 Comfort design composition (Visher, 2003)

Considering the physical and functional comfort a relation with the design constrains is considerable. The comfort level of the workers' performance is usually not previously considered. The matter is design engineers should be able to access at the information, which allow the best machinery design concerning the aspects illustrated in the section below which are also indicated in the international standards.

Functional Constraints
The machine dimensions and the overall geometry are dictated by the producer of the machine considering the workplace environment, the human factors requirements and the standards about safety of machineries. Also the motion of parts – type, direction, velocities, acceleration, kinematics – is fundamental in order to prevent the possible impact with parts of the human body. Other design limits are due to forces involved, energy needed, as heating, cooling, pressure, materials to be used, control system, such as electrical, hydraulic, mechanical or pneumatic, and flow information.

Safety Constraints
The objective of the safety constrains is the hazard elimination. The risk assessment and the actuation of the corrective actions are a part in order to prevent possible accidents or injuries. Warning signals and human training are fundamentals to prevent workers' health and safety. The parameters to consider of workplace environment are air quality, noise, light, radiation, vibration and thermal comfort.

Quality Constraints
Regulations, standards and codes assure the standard quality requirements. At the same time those have to be controlled during the machine life cycle though need inspections, testing and labeling. The application of the standard quality respond to the reliability of the system designed such as predicting design life, failures and statistics.

Manufacturing Constraints
Manufacturing is also a constrain because points the technical limits of the production. The production of components, factory limitations, means of production and wastes determine the features to control even in the design phase.

Timing Constraints
Timing constrains are related to the time and the pace of the machine given to the worker which is dedicated to that machine. The trend of the machinery is also related to the assembly line setting or other production processes.

Ergonomic Constraints – Ergonomic Comfort Design (ECD)
The parameters of human factors in design are respected when respond positively to the ergonomics assessment. Ergonomics concern physical and cognitive aspects. Ergonomic design comprehend both physical and cognitive elements based on the job design, instructions, warnings, man-machine relationships, operation, height, layout, lighting, controls, layout, clarity and interactions.

The design of machinery constrains could have an impact on the workplace environment and promote the working condition.
Comfort could be guaranteed considering the aspects shown below in a prevention perspective of workers' health and safety.

Human Factors and Ergonomics
A comfortable workplace, machinery or workstation should be designed for and around people, flexible and support productivity over time. The concept of "human centered design" takes into account the needs and limitations of the people who occupy them. Human factors issue is a topic of workplaces which focuses on a range of elements including ergonomics, workplace safety, the reduction of human error, product design, human capability and human-computer interaction.
Musculoskeletal diseases (MSDs), which include back pain, arthritis, bodily injuries and osteoporosis, are reported by people more than any other health condition. In 2016 in Italy, the MSDs complaints was about 40000 of the total 60000 occupational diseases complaints (INAIL Annual Report, 2016). Furthermore, MSDs have

one of the most invalidating consequences in terms of Disability Adjusted Life Year (Dalys) and Years of Life lived with Disability (Ylds). The topic has also a relevance considering the increase of aging of the working population. The latter is a new issue, which companies must deal with in order to integrate those people getting older with the new production strategies. Various international standards outlined references about anthropometric measurements and risk assessment strategies concerning the safety and comfort requirements of the workplace and in particular of machinery design (ISO 12100).

Noise Control

Noise annoyance is one of the biggest issues in most workplace environments. It can reinforce productivity or disable it, depending on individual preferences and the type of task performed. The importance of noise reduction in workplaces derives also from findings about hypoacusia. The latter constitutes one of the most common occupational diseases and a major health, social and economic issue. Noise reduction is needed to create an ergonomic working environment: indeed, noise can negatively affect the workers' performance and productivity [5,6].

Furthermore, persistent noise during complex work, however, require a longer period to reorient, and continued interruptions are likely to have negative effects on mood that reduce the motivation to resume work. [7]

Machinery design, according to the international standards, should analyze the noise factor in the perspective of workers protection. Design engineers meets the safety requirements placing on the market products which respects the maximum noise levels, if provided for that kind of machine or equipment, and need to guarantee the sound power level of machinery according to Standard test and measurement procedure (UNI EN ISO 11690 - 1:1998).

Thermal Comfort

The combination of temperatures characterizes the thermal comfort, humidity and airflow. Physical comfort in the workplace is possible thanks to the combination of these elements. The airflow and humidity are often part of the reason of thermal distress.

Personal control over ambient conditions, especially temperature, increases productivity. One research study tracked workers in an insurance company as they moved to a new building with advanced thermal controls in their workstations. The study found that productivity increases of 2.8 percent could be attributed to the new workstations. [8]

The ideal temperature in office environments is 21.6°C with a 1-2 percent decrease in performance for every 1° C above or below. [9]

Slightly lower temperatures are associated with higher accuracy on simulated tasks and reduced sick leave [10].

The international standards provide a risk assessment to control this parameter in order to maintain the thermal comfort.

Lightening

The use of daylight is important for both the vision quality and the pleasure and acceptance of the occupants, as well as for energy saving. The contribution of natural light to interior lighting provides to regulate circadian rhythms, the daily cycles of waking and sleeping hours. [11] (Daylight Glare Index, UNI 10840:2000).

Artificial lightening is produced by illuminating bodies intentionally introduced to perform the visual tasks required in particular working condition. Artificial lightening should compensate the absence of natural lighting. The international standard UNI EN 12464-1:2004 suggests the best material surfaces to prevent the glare effect. In a workplace or at a workstation these are some of the features to take into account: luminance (influences the visual effort and consequently visibility and comfort), illumination (calculated threshold value below which the average illumination on a specific surface cannot drop below), glare (distracting and potentially disabling effect of bright light in an otherwise relatively dark scene which interferes with visual attention and selection), apparent light heat (different shade of light depending on the spectral distribution of the emitted radiation and is characterized by its own color temperature). Glare effect assessment and threshold values referred to the Unified Glare Rating (UNI 12464-1:2004).

Indoor Air Quality

Today's organizations are a focused on healthy, safety and comfortable workplaces. Consequences of poor investments on health and safety issues are the productivity reduction and the quality of life [12]. The sick building syndrome depends on the indoor workplace. Pollutants can be five times higher than the outdoor levels.

The causes are related to the maintenance of the air condition system (heating, cooling and humidification), possible material combustion depending on the manufacturing sector, building materials, machinery and equipment materials. Furthermore, the final materials, or intermediate materials, of production processes might contaminate the air. The latter have to be controlled and measured through a risk analysis following the procedures of the international standard (EN ISO 14123-1:2015, EN ISO 14123-2:2015).
In office workplaces the parameters detected are CO, CO_2, VOCs, PM10, PM2.5. In other workplaces contexts the parameters considered depends on the production sector.

An example of social sustainable workstation has been designed by some students of the University of Wuppertal [13]. The workstation has an adaptive system which consist in a lifting module which height changes depending on the worker/user characteristics. Interesting is the automatic workstation adjustment thanks to an Ergo profile system. The entire facility is connected with a smooth transition between the system and the manufacturer.
Industrial workplace environment is more complex than the office. This could be the reason why there is a lack of studies about comfort design about.
The possibility to consider comfort design features into the manufacturing setting can have a positive influence on workers' health, safety and productivity.
Such parameters are measurable with *a priori* job analysis and machine design analysis by the proposed CDM as a valid design tool. What is important to prevent for work related disturbs, is the application of the threshold limit values during the machine design stage.

3 Method and tool

The proposed method provides a guide to design engineers to integrate the technical design knowledge with the health, safety and comfort design strategies. The knowledge-based design is an early stage of the product manufacture that permits to prevent inappropriate working condition.
The design method is set on the international standards, in particular on the Machinery Directive 2006/42/EC.
The steps of the method to perform a knowledge based design are the following.
1.*Type of product selection:* it allows to select the application area of the specific machinery standards. The machinery selected has many health and safety requirements, which are responsible of the comfort working condition.
2. *Standards selection*: it focuses on the selection of the standards related to the new manufacturing system. It consists of the definition of the machine/s purpose and requirements and the identification of the technical solutions. It considers health, safety and social aspects (i.e., workers' skills, workers' physical and cognitive issues or limitations) to find the most suitable trade-off between the company needs. A new solution able to optimize the involved manufacturing processes (e.g., time and cost reduction, lower environmental impact, higher product quality), ensure safety (e.g., less risks, less accidents, higher maintainability), and increase the employees wellbeing (e.g., healthier working conditions, less stress, higher satisfaction) is proposed. According to the human centered design (HCD) approach, human factors are considered (i.e., tasks to be carried out, interactions with devices, machines and interfaces). A list of specific parameters related to risks factors mentioned has been defined in a "comfort design matrix" (CDM) that represents the main innovation of the proposed method. CDM (Fig.1) is proposed as an effective tool to drive the design on the basis of the specific social issues characterizing the context of use. According to such matrix, different scenarios can be analyzed and simulated on the virtual model to identify the most useful corrective actions. This is accordance with the statement of Peruzzini et al. [14] : "Immersive and interactive virtual environments can be used for a more effective system simulation by also involving real users'".
The CDM is a "decision matrix" since it considers different parameters, and it has been called "comfort" since it is inspired by the literature concerning the assessment of comfort topics.
Considering the most impacting comfort variables the method proposes the analysis of thermal comfort, noise control, air pollution and ergonomics.
Table 1 shows a simplified scheme of the entire matrix defined by authors. The complete matrix was not reported due to space limits.

The CDM can be used by designers during the virtual prototype definition and simulation to identify possible design solutions and the main criticalities from a safety and comfort point of view.

Table 1 – Comfort Design Matrix

Parameter	General considerations	Comfort Strategies
Thermal comfort	21.6°C with a 1-2 percent decrease in performance for every 1° C above or below Regardless of business size, the minimum temperature for indoor workplaces is 20°C and the maximum is 24°C. The acceptable range for indoor humidity is between 20 and 60 percent.	- Provide individual control of air flow - Provide zoned temperature controlled - Optimize sunlight, airflow and temperature control providing windows which could be opened if necessary
Noise	− minimum noise exposure: <85 dB(A) 8 hour per day − moderately high noise exposure: 85−90 dB(A) − high noise exposure: >90 dB(A)	− the work process (including tools and machinery): for example, install quieter equipment, promote good maintenance; − the workplace: for example, use noise enclosures or acoustic equipment; − the workers: for example, set up work practices and other administrative controls on noise exposures, and provide audiometry tests and hearing protection, and workers' education programs. - Provide protective equipment
Lightening	- Surface materials - Windows position - Artificial lightening disposition - Lightening control and progressive regulation based on the natural light intensity	- Windows should be located where do not represent a risk for workers - Use glass where visual privacy is not required. - Give preference of natural views - Local lightening support the task
Indoor air quality	- Final product materials - Intermediate product materials - Airborne materials - VOCs - CO - CO2 - PM10 - PM2.5	- Enclose processes with dangerous volatile material - Consider intake systems - Use alternative material to the dangerous ones
Human factors and ergonomics	- Postures (neck, back, upper limbs, lower limbs) due to workstation design - Anthropometric measures - Working spaces specification - Physical effort - Cognitive effort - Work organization - Job design - Human-machinery interaction - Protection systems	- Provide adjustable furniture such as adjustable chairs, task lights, sit-to-stand desks and keyboard trays - Provide technologic aid lifting equipment - Provide efficient technology to enable efficient work in all work settings provided - Ensure technology is "user-friendly" and provide instructions clearly visible to the user - Equip employees with tools and technologies that encourage mobility in the workplace - Provide employees with laptops and mobile devices - Provide VoIP phones that allow workers to easily move between desks or rooms and still make a call - Provide technologic protection systems to prevent impacts with human part of the body

4 Case study

The proposed method is firstly implemented to support the design of a new system, a woodworking machine tool. Firstly, a light layout assessment of the plant has to be done to identify available space for the new system, according to step 1 of the method. Then, the design requirements and the production constraints have to be defined to develop a virtual prototype. At the design stage engineers have to analyze the safety and comfort design requirements matching the CDM. Following considerations were developed according to the matrix.
Considering the thermal comfort the workplace environment should respect the range of 20-24°C temperature and the limit of 60% of humidity. Consequently the machinery functioning should not generate more heat.
Design engineers have to consider the hypothesis the machinery is functioning almost 8 hours per day, thus the worker exposition at the noise risk factor could be constant. The rotating tools are the most relevant source of noise since the best noise level is at the lowest value of 85dB. Then, the engineers should enclosure the source with noise protection barriers. The latter, should not obstacle the production process.
The woodworking machine tool does not require a specific type of local lightening. Natural light is preferred to the artificial light. Furthermore, the material used to manufacture the machine has to avoid glare risk.
This type of machine produces dusts which if inhaled could cause allergic responses, asthma or occupational disease such as sinuses cancer. It is reasonable provide an intake system. The intake system should not increase the noise level of the machine.
Human factors and ergonomics aspect have to reduce worker operation and zero worker movements. The workstation has to be designed in order to respect the anthropometric measures, the working area limits due to the working protection measures and protection barriers. Simultaneously, the worker has not to have effort experience and assume awkward postures. For example, if the worker lifts manually a wood panel would be interesting use a conveyor to introduce it in the machine. In this way, physical effort is avoided and awkward postures, too.
The machine design also involve the safety control system. A machinery control system respects requisites dictated in the international standards concerning the start, stop and the emergency stop. Those commands have specific measures and ergonomic measures in order to be easy to reach. Design requisites are used in human-machinery interface. An ergonomic communication between the machinery and the worker is desirable. When the machine is easy to use and the information is clear, the machine efficiency and humane performance would be positive at the same time.
The machine functions determine its overall structure. This aspect has to lead with the ergonomics working areas defined by the international standards.
At the end design decision about the machine, characteristics are the following:

- maximum area: 50m^2
- maximum size of parts to be processed: 140x160x3200 mm
- reduce worker operation and zero worker movements
- maximum dust pollution: 3mg/m^3
- maximum noise pollution: 82Db

Those machine features were carried out in a simple way thanks to the CDM that supported the work of designers. Moreover with this approach all the potential criticalities from a social point of view have been removed from the machine. The social focus of the machine with this approach has reduced the time of development of 30% (Figure 2).

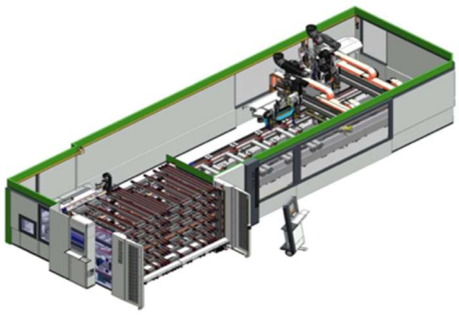


Figure 2 The 3D system prototype

5 Conclusion

This paper presented a method to promote comfort design in industries. The designers should consider workers and their performances during the design and development process of a new production system. A comfort matrix has been proposed by the authors. The matrix embeds all the best practices according to standards related to safety, security and healthy risks for humans in a working place. Thanks to the matrix, designers and engineers can implement efficient decision within the system prototype in order to overcome potential comfort and social limits of the model. The matrix can be enriched by new decision in order to improve the knowledge of the company on the social topic. The method suggests the definition of parameters such as thermal comfort, noise, lightening, pollution and ergonomics. The respect of those guarantees a safer and healthier working environment. The case study permitted to validate the method meaning the reduction of risk with a faster approach (30% faster than the traditional approach). A next step will consist in improving the matrix extending the application field of the latter.

References

1. Becker, F. O. (1981). Workspace creating environments in organisation. New York: Praeger; Humphries, M. (2005). Quantifying occupant comfort: Are combined indices of the indoor environment practicable? Building Research and Information, 33(4), 317-325;
2. Veitch, J.A., Charles, K.E., Newsham, G.R., Marquardt, C.J.G., & Geerts, J. (2004). Workstation characteristics and environmental satisfaction in open-plan offices. COPE Field Findings (NRCC-47629) Ottawa, Canada: National Research Council;
3. Karasek, R., & Theorell, T. (1990). Health work: Stress, productivity and the reconstruction of working life. New York: Basic Books
4. Vischer, Jacqueline C. "Designing the work environment for worker health and productivity." Proceedings of the 3rd international conference on design and health. 2003
5. Jones, D., and Broadbent, D. (1998). “Human Performance and Noise.” in Handbook of Acoustical Measurements and Noise Control, edited by C. Harris, Acoustical Society of America, Melville, NY, Chap. 24, pp. 24.1 – 24.24;
6. Errett, J., Bowden, E.E., Choiniere, M., and Wang, L.M. (2006). “Effects of noise on productivity: does performance decrease over time?” Proceedings of the 2006 Architectural Engineering Institute Conference, Omaha, NE
7. F. R. H. Zijlstra, R. A. Roe, A. B. Leonora, and I. Krediet, “Temporal Factors in Mental Work: Effects of Interrupted Activities,” Journal of Occupational and Organizational Psychology, 72 (1999): 163–185
8. W. Kroner, J. A. Stark-Martin, T. Willemain, “Using Advanced Office Technology to Increase Productivity” (Working Paper, Rensselaer Polytechnic Institute: Center for Architectural Research, 1992
9. Tanabe, S., Nishihara, N., & Haneda, M., “Indoor temperature, productivity, and fatigue in office tasks,” HVAC&R Research, 2007, 13(4), 623-633
10. Witterseh, T., Wyon, D., & Clausen, G. (2004). “The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work”. Indoor Air, 14 (Suppl 8), 30-40
11. Heerwagen, Judith H. , Ph.D., “Design, Productivity and Well Being: What Are the Links?,” March 12-14, 1998, Augustin, Sally, PhD., Place Advantage: Applied Psychology for Interior Architecture. Ed. Wiley and Sons Ltd, U.K., 2009
12. “Clearing the Air: Asthma and Indoor Air Exposures,” Committee on the Assessment of Asthma and Indoor Air, Division of Health Promotion and Disease Prevention, Institute of Medicine, Institute of Medicine, National Academy of Sciences, 2000
13. http://design-meets-movement.com/wp-content/uploads/2014/10/industrietisch_finale.pdf
14. Peruzzini M, Carassai S, Pellicciari M, Andrisano A.O. Human-centered design of ergonomic workstations for sustainable manufacturing, in Advances on Mechanics, Design Engineering and Manufacturing, 2016: 1187-1195

An overview of user experience assessment methods and tools in integrated product-process design

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Abstract The analysis of user experience (UX) is based on the combined investigation of the individual perceptions, the perceived comfort factors, as well as the human factors. Such experience cannot be objectively measured, but requires a variety of ways to capture the user-related knowledge and to define a set of experience-based descriptions to elicit the non-measurable, intangible conditions. UX analysis is helpful to both support interaction as well as to prevent and reduce human errors, with consequent advantages for product quality, company productivity, and users' wellbeing and safety. Traditionally, UX is fully analyzed on physical prototypes, where the physical and mental workload could be tested and measured by involving sample users. Nevertheless, building physical prototypes increases development cycle times and costs, and provides a late assessment. On the other hand, virtual prototyping can anticipate numerous design issues, but hardly integrate the analysis of human factors. Thus, there is a strong need for integrating UX monitoring in the design and verification stages of industrial products and processes by coupling advanced simulation techniques and user monitoring tools. This paper explores how to assess UX during product and process design by digital manufacturing tools. It provides an overview of the scientific state of art on the most common methods and tools to support the human-centered design and presents the results of a survey on more than 100 scientific and industrial papers on international journals and relevant conferences, focusing on the existing methods, tools and applications on the UX assessment to be used in product and process design by researchers and companies. The research also identifies the milestone references to support the UX assessment within industrial practices, also including ubiquitous computing, wearable technologies and low-cost connected devices, and points out the main open issues.

Keywords: User experience, Human-centred design, Human factors, Assessment methods and tools.

1 Introduction

In the last few years, the assessment of perceived comfort gained a growing attention within companies, which are increasingly focusing not only on the way their products work, but also on how the users interact with them and how users feel during the use. However, the investigation of perceived comfort and quality is not a trivial task since it includes a multitude of factors that are reciprocal connected and influence each other. Designers and engineers have to consider both physical and psychological comfort perceived by the product users, as well as usability and the overall human-product interaction in order to design a successful product. In this context, the analysis of the so-called User eXperience (UX) on digital prototypes is helpful to prevent and reduce human mistakes, with consequent advantages for quality and productivity beyond workers safety, but also to strategically reduce the development process times and cost. Nevertheless, traditionally UX analysis is based on physical prototypes, which creation increases development times and cost. Thus, there is a strong need

for integrating human factors in the design and verification of industrial processes using advanced simulation techniques [1]. Nowadays, with the constantly increase of the computational power and the decrease of equipment size, there is a lot of products able to assess human physiological parameters and available at a reasonable price. Wearable instruments are designed for hands-free operation in order to reduce the intrusiveness and this allows the wearer to stay focused on their main task and be assisted by the wearable rather than be distracted, recording continuously biometric data without additional effort [2]. However some devices are not suitable for research purposes, because they don't allow extracting and manipulating data easily.

The aim of this review paper is to explore how UX can be monitored for design purposes in order to include the preventive analysis of human factors and how human-related knowledge can be applied to support integrated product-process design. The paper provides an overview of the scientific and industrial state of art on the most common methodologies for UX analysis and investigates the monitoring tools to be adopted for UX monitoring in human-centered design. The paper scope is to provide a structured overview of the on-going research about UX assessment and to point out the main open issues to face to include UX analysis into integrated product-process design practices using digital modeling and advanced simulation techniques.

2 Literary review

2.1 Research approach

The research background is represented by the investigation of the available methods and tools for UX assessment during the design of human-system interaction, considering both industrial product and process. The research stared with a detailed survey that included scientific and industrial papers available on Science Direct and Scopus databases, retrieved by using the following keywords: "user experience", "perceived comfort" and "human-centred/-centered design". The analysis included more than 100 paper published in the last 10 years (2007-2017). The review focused on 80 selected papers published on international journals and foremost conference proceedings, which were chosen according to the content quality and the relevance of the editorial publication mainly. Firstly, papers were selected and grouped according to the main topic and the context of application, related to both product design and process design. Secondly, they were classified considering the methodologies and tools presented or adopted for UX analysis. To further investigate the proposed application, every paper was classified according to its objective, the approach, the addressed human data, the human factors metrics, the hardware and software tools used, and the innovative findings and contribution to research. This survey allowed mapping the on-going research on such topic, to identify the existing methods and tools in a structured way, and to highlight the main open issues of the current research and to define the future developments needed for efficient industrial applications.

2.2 Research survey

The 80 selected papers were divided into groups, according to on the design area: ergonomics, manufacturing, computers and sensors, social and psychology, engineering, perceived comfort. For each topic, papers were mainly published on the following journals:

- Related to manufacturing: Procedia Manufacturing, Procedia CIRP and Robotics and Computer Integrated Manufacturing;
- Related to ergonomics: International Journal of Industrial Ergonomics and Applied Ergonomics;
- Related to computers and sensors: Computers in Industry, Interacting with Computers, Entertainment Computing, Computer methods and programs in biomedicine, Applied Soft Computing and Sensors;

- Related to social and psychology: Behaviour & Information Technology, Behavior ResearchMethods, International Journal of Human-Computer Studies, International Journal of Human Factors Modelling and Simulation and Procedia - Social and Behavioral Sciences;

- Related to engineering: Procedia Engineering and Computers & Industrial Engineering;

- Related to perceived comfort: Transport Policy, Transportation Research, international conferences about Human Factors and Comfort;

The category "others" collected papers out of the above-mentioned groups.

Table 1 synthetized the papers classification into groups. An interesting preliminary finding was related to the limited number of papers published into journals dealing with engineering as well as perceived comfort. As expected, a lot of papers are published into ergonomics-related journals. The high number of papers related to computers and sensors journals remarked the high attention to technological aspects in this field. Contemporarily, the high number of papers related to manufacturing topics highlighted the strong interest to manufacturing ergonomics and the design of socially-sustainable processes.

Table 1. Editorial placement of the analyzed papers about UX topics

Group	Number	Percentage
Related to manufacturing	18	23%
Related to ergonomics	19	24%
Related to computers and sensors	13	16%
Related to social and psychology	7	9%
Related to engineering	3	4%
Related with perceived comfort	4	5%
Others	16	20%
Total	80	100

About the context of application, the interest on UX is widely diffused in manufacturing and assembly, in automotive driving experience and in aircraft deck design but there is a growing interest in human-machine interface design and videogames. Table 2 sums up the specific context of application for the selected papers.

Table 2. Context of application of the analyzed papers about UX topics

Context of application	Number of papers	Percentage
Manufacturing ergonomics	11	14
Automotive	10	13
Videogames, entertainment	7	9
HM interface	8	10
Assembly ergonomics	6	8
Product design	5	6
Stress assessment and detection	3	4
Military drivers	3	4
Aircraft	4	5
Office ergonomics	2	3
Ergonomics in general	3	4
Shopping and navigation context	2	3
Gesture/Activity recognition	2	3
Maintenance	1	1
Others	13	16
Total	80	100

Regarding the papers' objectives, most of the papers focused on UX and comfort assessment concerned assembly operations, in particular they try to integrate ergonomic design guidelines into a manual assembly process modeling and simulation, and human-machine interaction, where they aim at obtaining more usable ergonomic human-machine interfaces. The common feature is the understanding of how human behaviors and human workloads, both physical and cognitive, are influenced by design features and surrounding conditions and which physiological measurements can be used to evaluate the UX in a reliable way. About this last point, no clear and robust practices are still identified, and the proliferation of new technologies for human monitoring, both wearable and without contact, risks to be confusing. Indeed, the attention is frequently paid on the technological issues instead of on the assessment needs. Further, the survey highlighted the lack ok comprehension about reliable measurement techniques and tools and to objectify the users' feelings.

3 Survey results and discussion

3.1 Research about human factors' monitoring

From the analysis of the state of the art, the evaluation of UX is still mainly based on assessment of human factor in the context of use. Traditionally, it is mainly based on the subjective assessments involving real users by questionnaires or interviews. However, such techniques could not provide objective results and are hardly executed in real-time. More structured subjective assessments like NASA-TLX, SWAT and CH have been developed. Among them, NASA-TLX is the most widely used to evaluate the mental workload. It consists in six evaluators, which are Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration Level and is divided in two steps, ratings and weights. It collects raw data from the subject and calculates the weighted workload score, which is output to a text file [3]. Zheng et al. (2011) [4] also adopted NASA-TLX for human factors assessment during the design phase.

Unfortunately subjective data, when used alone, do not provide sufficient information to evaluate the human stress and the mental effort during task execution [5]. To overcome such limitations, in the last years the monitoring of physiological parameters is entering also in the design area. However, the main issue is to find a robust correlation between the monitored physiological parameters and the UX, the perceived quality and the obtained level of comfort. Main examples of data collection during on-filed testing refer to heart rate (HR) and heart rate variability (HRV), electro-encephalogram (EEG) and electro-dermal activity (EDA) also monitored by the galvanic skin response (GSR). Logically, the parameters should be selected according to the analysis purposes, and consequently the monitoring tools chosen. For physiological measures like heart rate or respiration, there are relatively simple and low cost instrumentation that allow recording of vital parameters and track the human activity.

About physiological parameters monitoring, various researches showed the correlation between vital signs and mental workload. It is not new that HR and HRV can be used as the simplest indicators of users' workload; in particular the increase of the HR and the decrease in the HRV can indicate an increase in the mental effort [6]. Moreover, EDA can be used to assess the cognitive workload during and, combined with the HR, can represent a good indicator of changes in the users' workload. Interesting results an on-road driving were described by [7] and confirmed by [8] which used GSR as a nonintrusive way to easily capture physiological signal as cognitive load measures. Also respiration measurement (i.e., rate and volume of respiration) was used to assess the levels of human stress, generally in conjunction with other physiological measures. However, the main drawback of respiration monitoring systems is the intrusiveness since they require users to wear a belt around their chest. About this topics, Lopez-Meyer et al. (2012) [9] showed that a miniaturized piezoelectric belt could be used for a reliable analysis, but only for sedentary activities like sitting and reading, because the quality of signal can be affected by strongly dynamics activity.

Regarding pupillometry and electrooculography, eye-tracker technologies are widely diffused for users' monitoring, thanks to more ergonomic-shape glasses and non-contacting camera that observes the eyeball plus image processing techniques. A lot of studies have recently focused on its application for human workload analysis and the correlation between eye-based signals and human factors. Martin et al. (2011) [10] applied eye tracking to analyze mental workload characteristics in air traffic controllers' activity. Similarly, Sharma e Gedeon (2012)

[11] found out that eye gaze and pupil dilatation provide useful information on the individual's attention source and stress. Also Marquart et al. (2015) [12] found that the human workload increases with the increase of the blink latency and, on the contrary, decreases with the increase of blink duration and gaze variability. Results confirmed that eye-tracking technique is a powerful approach to study mental workload during a complex activity.
Thanks to sensors' miniaturization and affordability, body worn activity recognition has gained popularity, especially using inertial measurement units (IMUs) and, in particular, accelerometers. These sensors demonstrated good potentiality in the recognition of the activities typology. However, the number of sensors to be worn has to be minimized to limit their intrusiveness and not to interfere with activity performance. Many existing devices already include accelerometers and gyroscopes, like smart watches and smartphones [13]. A review of different classification techniques used to recognize human activities from wearable inertial sensor data was presented by [14].

3.2 Research about UX assessment tools

One of the key issues of UX assessment using human monitoring devices is the definition of reliable workload assessment tools to be adopted during design activities. Popovic et al. (2013) [15] introduced a workload assessment tool (namely PHYSIOPRINT) that is based on the combination of electroencephalography (EEG) and electrocardiography (ECG) to distinguish between different workload types relevant for driving by incorporating complementary sensor modalities recorded in real-time on a realistic driving simulator. Furthermore, Zongmin et al. (2014) [16] developed an ergonomic evaluation model applied for mental task design of aircraft cockpit display interface, which seems able to effectively discriminate and predict the levels of mental workload, preserve the selected indexes by avoiding information loss, and obtain a stable discrimination result. Ohtsuka et al. (2015) [17] suggested a method for the mental workload estimation during motorcycle driving, based on eye tracking and, specifically, the monitoring of saccades (duration and amplitude) and fixation. Paletta et al. (2015) [18] used eye tracking for the analysis of the navigation paths in retails during shopping activity, finding that the specific context and the cause of arousal lead to different reactions of the psychophysiological system as well as in the eye movement behavior.
Various authors [19-20] considered the implementation of quantitative analysis methods into virtual environments with the purpose of a real-time and continuous ergonomic evaluations, considering two different approach: the first approach provides the use of established, off-the shelf tools integrated with the virtual environment to create hybrid applications; the second approach provides the capability to carry out ergonomic evaluations in a self-contained virtual application. Further developments of virtual reality have to outcome the issues of lack of tool weight or collision, in order to give at users a multisensory feedback, considered essential for some manufacturing tasks [21].

3.3 Research about UX assessment in product design

UX assessment in product design is frequently related to HMI design. Indeed, nowadays human-product interaction includes the interaction with a huge amount of electronic devices and interfaces play a fundamental role in human-product communication. Contemporarily, product design is frequently based on virtual models used to anticipate the user impression. Both aspects can be merged for the UX analysis. Recent studies used a non-invasive brain-computer interface using only EEG technology to study the interaction with the virtual representation products and environments [22]. However, UX is not related only with interfaces, but is fully develop in design product and both the human experience and the influence of the context of use on users' understanding are crucial [23]. Honglun et al. (2007) [24] used a virtual human model to reproduce the real human characteristics in virtual environments for product ergonomics analysis and demonstrated that digital simulations allow to detect design problems in advance, with the reduction of time and cost in prototype making. Also Aromaa and Väänänen (2016) [25] proved the importance of using virtual prototypes in human-centred design supported by virtual reality environment to assess visibility, climbing, postures, space, reach and use of tools. Abidi et al. (2013) [26] performed ergonomics analyses of a sport utility vehicle in a semi-immersive virtual

environment, which help to make the users aware about their own feeling inside the real car. From the various studies, it can be proved that VR offers flexibility to designer to test the different aesthetics for the interior as well as exterior of the car, without the building of physical prototype, saving time and cost of product design. In automotive sector, UX and perceived comfort analyses of drivers are nowadays indispensable to build products that are increasingly improving road safety. The majority of recent studies focused on the analysis of the driver's state to detect short-term driving performance deviations. The experimental and commercial implementations often consisted of multiple devices that contribute to the goal of valid and reliable evaluation of drivers' state, and, to some extent, are capable of estimating up to four driver state constructs like cognitive distraction, mental workload, mental fatigue, and emotions [27], the so-called driver state monitoring (DSM). The interest in understanding how users perceive the final product is nowadays crucial for the product success. Naddeo et al. (2016) [28] focused on how perceived comfort and demonstrated that the feeling of comfort/discomfort perceived can be determined only if complex interactions within the user, the objects and the surrounding environment, which affects the interaction modalities. In this context, Karali et al. (2017) [29] investigated the needs of old car drivers, understanding how declining physical capability can affect driving related tasks, while Ahmadpour (2016) [30] suggested the existence of "elements of comfort experience", universally understood, so specific comfort conditions, sensitive to individual differences.

3.4 Research about UX assessment in process design

Introduction of UX in process design is mainly oriented to he evaluation of worker's well-being and health and safety measures. In combination with virtual assembly and digital manufacturing tools, the UX assessment can give an enormous advantage in the process of design and new tool implementations in improving product quality and reducing time-to-market. Feasibility and usefulness of a virtual experimentation approach for supporting the planning of assembly processes is not a novel concept [31]. Moreover, the capabilities provided by virtual environment simulation to realistic and intuitive process performance simulation can justify the advantages of this approach against current desktop-based set-ups. Many studies demonstrated a clear relationship between ergonomics and assembly quality: Falck and Rosenqvist (2012) [32] created a list for sustainable and cost-beneficial assembly solutions to relate production ergonomics to process quality. Shaub et al. (2012) [33] applied ergonomic assessment worksheets (EAWS) and digital human modeling (DHM) to integrate the ergonomic process design in the pre-production planning. Marzano (2012) [33] developed a methodology to support feasibility analyses of assembly tasks, in order to simulate either a manufacturing process or a single work-cell in which digital human models act, by simulating both mechanical and human performance in a virtual environment and, consequently, to avoid critical errors.

4. Conclusions

This research aimed to identify the milestone references to support the assessment of UX for product-process design purposes. The research motivation directly comes from the increasing importance of human factors analysis in product and process design, the need to anticipate the UX and comfort assessment during the design stages to move from a validation approach to a preventive approach, and the lack of common and widely recognized methods for UX analysis in the industrial practices. Indeed, the recent advances in ubiquitous computing, wearable technologies and low-cost connected devices offer a huge amount of new interesting technologies and tools to be applied for human factors' monitoring, but the main open issue is interpreting and properly exploiting the collected information content to be applied in industrial design practice. Ongoing research on human factors' monitoring and UX assessment highlighted a huge quantity of available technologies, but the lack of structured methods to interpret and relate the collected data to UX quality and comfort assessment. Virtual reality has been proved as a useful instrument for UX analysis during both product and process design stages: such a technology allows to simulate in a virtual environment a product or a process in early design phases, in order to prevent mistakes and to foresee eventually issues not considered in design, with the consequent decrease of the costs. The first approach using virtual reality provided the use of established, off-the shelf tools integrated with the virtual environment to create hybrid applications. The second approach provided the

capability to carry out ergonomic evaluations in a self-contained virtual application. Both approaches presented enhanced the functionality of the virtual environments by allowing more rigorous ergonomic analysis functionality and eliminating manual and paper/pencil data capture process.
To carry out a good UX assessment, the ergonomics expertise should be included into technical design practice to ensure usable product design, ease of assembly, good assembly quality, and to proactively consider new product and assembly concepts from the early design phases. Proper methods to integrate ergonomic considerations into product-process modeling and simulation are necessary to provide design changes and achieve an automatic generation and optimization of product features and process sequencing to promote assemblability, serviceability, etc. For these purposes, the integration of structured methods is still limited and cannot offer an overall ergonomic analysis including also novel technologies for human parameters' monitoring (i.e., HR and HRV, EEG, EDA, eye tracking).

References

1. Chryssolouris G. Manufacturing systems, theory and practice, 1992, Springer, New York.
2. Bauer D., Wutzke R. and Bauernhansl T. Wear@Work – A new approach for data acquisition using wearables, 26th CIRP Design Conference, Procedia CIRP vol. 50, 2016, pp. 529-534.
3. Cao A., Keshav Chintamani K., Abhilash Pandya K. and Ellis D. NASA TLX: Software for assessing subjective mental workload, Behavior Research Methods, vol. 41 (1), 2009, pp.113-117.
4. Zheng Y., Yin T., Dong D. and Fu S. Using NASA-TLX to evaluate the flight deck design in Design Phase of Aircraft, The 2nd International Symposium on Aircraft Airworthiness (ISAA 2011), Procedia Engineering, vol. 17, 2011, pp.77-83.
5. Mandryk R.L., Inkpen K.M. and Calvert T.W. Using psychophysiological techniques to measure user experience with entertainment technologies, Journal of Behaviour and Information Technology, Vol. 25 (2), 2005, pp. 141-158.
6. Mulder L.J.M., De Waard D. and Brookhuis K.A. Estimating mental effort using heart rate and heart rate variability. Stanton, N., Hedge, A., Hendrick, H.W., Brookhuis, K.A., Salas, E. (Eds.), Handbook of Ergonomics and Human Factors Methods. Taylor & Francis, London, 2004, pp. 201–208.
7. Reimer B., Mehler B., Coughlin J.F., Godfrey K.M. and Tan C. An On-Road Assessment of the Impact of Cognitive Workload on Physiological Arousal in Young Adult Drivers, Proc. International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI 2009), Sep 21-22 2009, Essen, Germany.
8. Nourbakhsh N., Wang Y., Chen F. and Calvo R.A. Using Galvanic Skin Response for Cognitive Load Measurement in Arithmetic and Reading Tasks, Proc. 24th Australian Computer-Human Interaction conference, 2012, pp. 420-423.
9. Lopez-Meyer P., Sazonov E. and Cheung B. Comparative sensor analysis for an electronic wearable and non-invasive respiratory signal acquisition system, Proc. International Conference on Sensing Technology, 2012, pp. 811-814.
10. Martin C., Cegarra J. and Averty P. Analysis of Mental Workload during En-route Air Traffic Control Task Execution Based on Eye-Tracking Technique, Engineering Psychology and Cognitive Ergonomics, HCII 2011, LNAI 6781, 2011, pp. 592-597.
11. Sharma N. and Gedeon T. Objective measures, sensors and computational techniques for stress recognition and classification: A survey, Computers method and programs in biomedicine, vol. 108, 2012, pp.1287-1301.
12. Marquart G., Cabrall C. and De Winter J. Review of eye-related measures of drivers' mental workload, Proc. International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015, Procedia Manufacturing, vol. 3, 2015, pp. 2854-2861.
13. Moschetti A., Fiorini L., Esposito D., Dario P. and Cavallo F. Recognition of Daily Gestures with Wearable Inertial Rings and Bracelets, Sensors (Basel), Vol. 16 (8), 2016.
14. Attal F., Mohammed S., Dedabrishvili M., Chamroukhi F., Oukhellou L. and Amirat Y. Physical Human Activity Recognition Using Wearable Sensors, Sensors, Vol. 15, 2015, pp. 31314-31338.
15. Popovic D., Stikic M., Berka C., Klyde D. and Rosenthal T. PHYSIOPRINT: A Workload Assessment Tool Based on Physiological Signals, Proc. Automotive UI', 2013, Eindhoven, The Netherlands.
16. Zongmin W., Damin Z., Xiaoru W., Chen L., Huan Z. A model for discrimination and prediction of mental workload of aircraft cockpit display interface, Chinese Journal of Aeronautics, vol. 27(5), 2014, pp. 1070-1077.
17. Ohtsuka R., Wang J., Chihara T., Yamanaka K., Morishima K. and Daimoto H. Estimation of Mental Workload during Motorcycle Operation, Procedia Manufacturing, vol. 3, 2015, pp. 5313-5318.
18. Paletta L., Pittinoa N.M., Schwarza M., Wagnerb V. and Kallusb K.W. Human factors analysis using wearable sensors in the context of cognitive and emotional arousal, Procedia Manufacturing, vol.3, 2015, pp. 3782-3787.
19. Jayaram U., Jayaram S., Shaikh I., Kim Y.J. and Craig Palmer C. Introducing quantitative analysis methods into virtual environments for real-time and continuous ergonomic evaluations, Computers in Industry vol. 57, 2006, pp. 283-296.
20. Peruzzini M., Mengoni M. and Raponi D. How to use virtual prototyping to design Product- Service Systems, Proc. 12th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA), Auckland, 29-31 August, 2016.
21. Lawson G., Salanitri D. and Waterfield B. Future directions for the development of virtual reality within an automotive manufacturer, Applied Ergonomics, vol. 53, 2016, pp. 323–330.
22. Liarokapis F., Debattista K., Vourvopoulos A., Petridis P. and Ene A. Comparing interaction techniques for serious games through brain–computer interfaces: A user perception evaluation study, Entertainment Computing, vol.5, 2014, pp. 391-399.

23. Chamorro-Koc M., Popovic V. and Emmison M. Human experience and product usability: Principles to assist the design of user–product interactions, Applied Ergonomics, vol. 40, 2009, pp. 648-656.
24. Honglun H., Shouqian S. and Yunhe P. Research on virtual human in ergonomic simulation, Computers & Industrial Engineering, vol. 53, 2007, pp. 350–356.
25. Aromaa S. and Vaananen K. Suitability of virtual prototypes to support human factors/ergonomics evaluation during the design, Applied Ergonomics vol. 56, 2016, pp.11-18.
26. Abidi M.H., El-Tamimia A.M., Al-Ahmaria A.M., Darwisha S.M. and Rasheeda M.S. Virtual Ergonomic Assessment of First Saudi Arabian Designed Car in a Semi-Immersive Environment, Procedia Engineering, vol. 64, 2013, pp. 622-631.
27. Melnicuk V., Birrell S., Crundall E. and Jennings P. Towards Hybrid Driver State Monitoring: Review, Future Perspectives and the Role of Consumer Electronics, Proc. IEEE Intelligent Vehicle Symposium (IV), Gothenburg, Sweden, 2016.
28. Naddeo A., Califano R., Cappetti N. and Vallone M. The effect of external and environmental factors on perceived comfort: the car-seat experience, In D. de Waard, K.A. Brookhuis, A. Toffetti, A. Stuiver, C. Weikert, D. Coelho, D. Manzey, A.B. Ünal, S. Röttger, and N. Merat (Eds.) (2016). Proc. Human Factors and Ergonomics Society Europe Chapter 2015 Annual Conference. ISSN 2333-4959 (online), 2016.
29. Karali S., Mansfield N.J. and Gyi D.E. An approach to vehicle design: In-depth audit to understand the needs of older drivers, Applied Ergonomics, vol. 58, 2017, pp. 461-470.
30. Ahmadpour N. Comfort experience in everyday life events, Proc. International Conference on Applied Human Factors and Ergonomics 2016, Advances in Affective and Pleasurable Design, Springer, 2016.
31. Chryssolouris G., Mavrikios D., Fragos D. and Karabatsou V. A virtual reality-based experimentation environment for the verification of human-related factors in assembly processes, Robotics and Computer Integrated Manufacturing, vol. 16, 2000, pp. 267-276.
32. Falck A.C. and Rosenqvist M. What are the obstacles and needs of proactive ergonomics measures at early product development stages? – An interview study in five Swedish companies, International Journal of Industrial Ergonomics, vol. 42, 2012, pp.406-415.
33. Schaub K.G., Mühlstedt J., Illmann B., Bauer S., Fritzsche L., Wagner T., Bullinger-Hoffmann A.C. and Bruder R. Ergonomic assessment of automotive assembly tasks with digital human modelling and the 'ergonomics assessment worksheet (EAWS)', International Journal of Human Factors Modelling and Simulation, Vol. 3, 2012, pp. 398-426.
34. Marzano A., Agyapong-Kodua K. and Ratchev S. Virtual Ergonomics and Time Optimization of a Railway Coach Assembly Line, Procedia CIRP vol. 3, 2012, pp. 555-560.

A systematic analysis of seating research knowledge based on Multispace design model

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Abstract A person has spent most of the day in a sitting posture. In recent years, there has been a growing attention to the "seating comfort" researches. However, research topics are complicated and vary widely, it is difficult for a designer to use accurately design knowledge during the development of chairs. Therefore, in this study, "seating comfort" researches based on the literature were systematically analyzed by the elements extracted and classified using Multispace design model. From consideration based on the analysis results, researches about the human mechanism of seating comfort and long-term sitting analysis including the postural change have been proposed as demanded research topics for future knowledge expansion.

Keywords: Seating comfort, Multispace design model, Chair, Seat.

1 Introduction

A person has spent most of the day in a sitting posture. In recent years, it has been reported that seating time of an adult accounts for about 60% of waking time [1]. Therefore, the attention to "seating comfort" is increasing, and many kinds of research have been conducted. However, since the research contents and subjects are diverse, the knowledge is complicated and not organized, so it is difficult for the designer to properly incorporate knowledge when designing and developing a chair. In addition, it is difficult to get guidelines how to improve the comfort, what kind of research knowledge is lacking, and what kind of research can be done to obtain better seating comfort. In this study, we aimed to systematically analyze seating comfort researches to clarify these features, extract the future research subjects.

2 Methods for analyzing seating comfort researches

2.1 Candidates for analysis

In order to systematize the seating comfort researches, the candidates for analysis were defined.

At first, we define "sitting" as an activity for supporting self-weight when carrying out a specific activity, “chair" or "seat" as things for using for the purpose of sitting. Therefore, things that straddling such as bicycle saddles were excluded. "Seating comfort" is defined as "comfort felt at the time of sitting". Following four

comforts are included. "Postural comfort", "Initial comfort", "Thermal comfort" and "Vibration comfort". "Initial comfort" is comfortable feeling from the moment of contact with a chair, it is an element that is felt by a touch feeling.

2.2 Multispace design model

Sitting comfort is composed of psychological characteristics such as comfort feeling and physical characteristics such as physical loads. Therefore, in this research, we applied M method [2, 3, 4] which can consider both psychological and physical characteristics at the same time.

The M method is a design method based on a Multispace design model (M model) that enables comprehensive handling of various design acts.

The multi-space design model shown in Figure 1 is composed of a thinking space and a knowledge space, and defines a designing act as the inference of thinking space based on knowledge of knowledge space. In this research, we focused mainly on thinking space. Space is a collection of design elements and design knowledge used in design thinking, and by using this space, it is possible to describe the relationship between them. The thinking space is composed of mainly the following four spaces.

Value space: cultural value and functional value

Meaning space: functionality and image

State space: relationship between things and circumstances

Attribute space: shape, size, color such as design parameters

Here, psychological characteristics are constructed from the value space and the meaning space, and the physical characteristics are constructed from the state space and the attribute space. In addition, we use multispace and circumstance perspective, and the circumstance is the environment surrounding the user. Circumstance elements influence elements of value space, meaning space, and state space, but they are not affected by elements of four spaces.

In order to visualize the relationships between elements belonging to each space, elements that are organized in value space, meaning space, state space, attribute space, and circumstance are referred to as inter-element relationship diagrams.

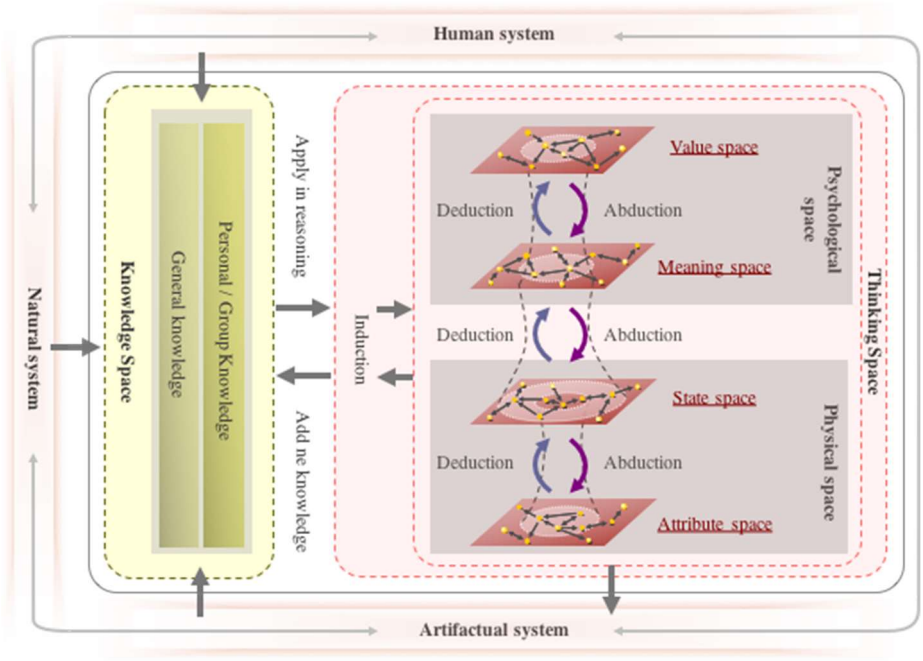


Fig. 1. Multispace design model.

In this research, we use the above multispace design model to classify research contents of individual papers into circumstances and each space, and to obtain evaluation items to be used for analysis by extracting elements constituting each space respectively. Then, we read multiple research papers for extracting elements that can be mentioned as common items, and organized them by article.

2.3 Timeaxis

Various timeaxis elements are involved in sitting, such as the posture changes with the lapse of time. Therefore, in this study, we adopted the concept of the timeaxis and classified the time course during sitting into three based on described experiment conditions in the literature, SHORT, MEDIUM and LONG. SHORT is a moment from the start of sitting to the seat surface until it reaches the mechanical stable state, MEDIUM is a short time sitting for less than about 15 minutes from sitting to posture stabilization, LONG is over 15 minutes including posture changes for a long-term sitting. Also, when studying elements that are not related to the timeaxis, they were classified as TIMELESS.

2.4 Methods for collecting research literature

In order to search and collect published seating research papers, science and technology literature information databases such as “JDream III” and “Web of Science” used with search words "Seat Comfort, Sitting Comfort”, "Sitting Posture”. And, also relevant seating comfort related papers from SAE publications were added. Based on the literature collected, excluding anything other than those targeted for any of the four comforts, total 504 papers published since 1953 to 2017 (340 English and 164 Japanese literature) were analyzed.

To verify retrieved research literature exhaustively contain the literature representing the seating comfort research knowledge, the validity was confirmed by the following method.

The literature has been cited by at least 5 other papers in “Web of science” citation data are included.

Documents cited in many research literature should be included in citation network analysis using search results. Specifically, we analyzed using free software CitNetExplorer [5] which calculates and visualizes mutual relations between articles by using bibliographic information of search results of “Web of Science”. Papers extracted as “Core publication” are included.

In this research, it is assumed that the literature knowledge confirmed by many researchers is included because the research papers extracted by the above method are included in the analysis. In addition, the review articles drawn as a summary of research knowledge was excluded in order to avoid duplication.

2.5 Methods of statistical analysis

Using the multispace design model, we used statistical classification to classify the research using extracted elements. Specifically, we describe extracted elements as 0/1 binary data and build data for each literature that consists of all elements data of value space, meaning space, state space, attribute space, circumstance, and timeaxis.

3 Results

From the whole research literatures, the extracted elements are shown in Tables 1 and 2. In the value space, we set the element "comfort" and “lack of discomfort” corresponding to the research purpose, and extracted four comforts and the accompanying objective elements in the meaning space. In addition, the state space is divided mainly into elements related to seat characteristics and elements related to physical characteristics. In relation to these, the user's sitting posture and physique, the use of the chair, the use environment were extracted

Table 1. Results of extracted research elements.

Sapce	Elements			Ratio
Value	Comfort			53.3%
	Lack of discomfort			46.9%
Meaning	Postural comfort			61.7%
		Postural ability	Able to take comfortable posture	22.2%
		Motion ability	High degrees of freedom for posture	6.8%
			Wide seat	1.1%
			Loose feeling	1.5%
		Low physical loads		31.3%
			Less fatigue	10.6%
			Less pressure feeling	4.8%
			Good support	8.4%
		Fitting performance	Good pressure distribution	10.1%
			Fits to body	9.3%
		Cushion performance	Good sinking feeling	2.6%
			Good hardness	6.6%
			Less bottom feeling	0.7%
			Moderate resilience performance	1.5%
	Thermal comfort			8.6%
		Not stuffy		1.8%
			High air-permeability	1.1%
		Moderate temperature		6.2%
			High heat dissipation	0.7%
	Vibratory comfort			24.2%
		Low transmissibility		4.8%
		High damping		4.0%
	Initial comfort			5.9%
		Good touch feeling		0.9%
State	Seat	Loads		9.7%
		Stress		3.1%
	Human-Seat interaction	Pressure distribution		29.1%
		Contour		2.2%
		Contact area		5.5%
		Friction coefficient		1.1%
		Vibration		22.2%
		Surface temperature		4.2%
		Humidity		2.2%
	Body	Posture		24.0%
		Postural change		4.0%
		Spinal shape		4.0%
		Fatigue		9.7%
		Body loads		5.5%
		EMG		3.5%
		EEG		0.4%
		Blood flow		0.2%
		Leg swelling		3.1%
		Skin temperature		4.8%
		Inner body temperature		0.7%
		Perspiration		0.2%

Table 2. Results of extracted research elements (Continued).

Sapce	Elements			Ratio
Attribute	Dimesions	Size		18.7%
		Shape		11.5%
		Angle		20.3%
	Materials	Cushion		20.9%
		Frame		0.2%
		Cover		4.0%
	Material properties	Hardness		9.3%
		Stress		2.2%
		Vibration transmissibility		20.0%
		Resilience		7.0%
		Air permeability		1.5%
		Heat conductivity		2.2%
		Moisture absorption & permeability		0.7%
	Structures	Backrest		30.4%
		Seat		41.2%
		Foot rest		1.5%
		Head restraint		2.0%
		Arm rest		1.5%
		Adjustment mechanism		4.0%
		Support mechanism		5.1%
		Frame		0.9%
		Wadding		0.2%
		Spring		2.0%
		Suspention		4.0%
		Other mechanisms	Air-conditioner	2.9%
			Feedback control system	0.2%
			Motor	0.4%
			Steamer	1.3%
			Masage	0.4%
			Arrangement	1.1%
Circumstance	Various user	Physique		11.9%
		Gender		5.7%
		Sitting posture		20.7%
		Disabled person		5.3%
		Elderly person		4.0%
	Environment for use	Transportation		56.6%
	Usage	Work chair		59.7%
		Relax chair		17.4%
Timeaxis	TIMELESS			21.6%
	SHORT			4.6%
	MEDIUM			42.7%
	LONG			35.0%

in the circumstance. In the attribute space, factors related to design values were extracted such as seat dimensions, materials, structures, etc.

Next, the extracted elements are grouped and organized for each space, and an element inter-element relation diagram shown in Figure 2 is created. Furthermore, the concept of timeaxis introduced into the meaning space

and rearranged diagram. Figure 3 shows the relationship between the created elements. In consideration of the timeaxis, SHORT, MEDIUM, LONG resulted in changes in elements accompanying comfort.

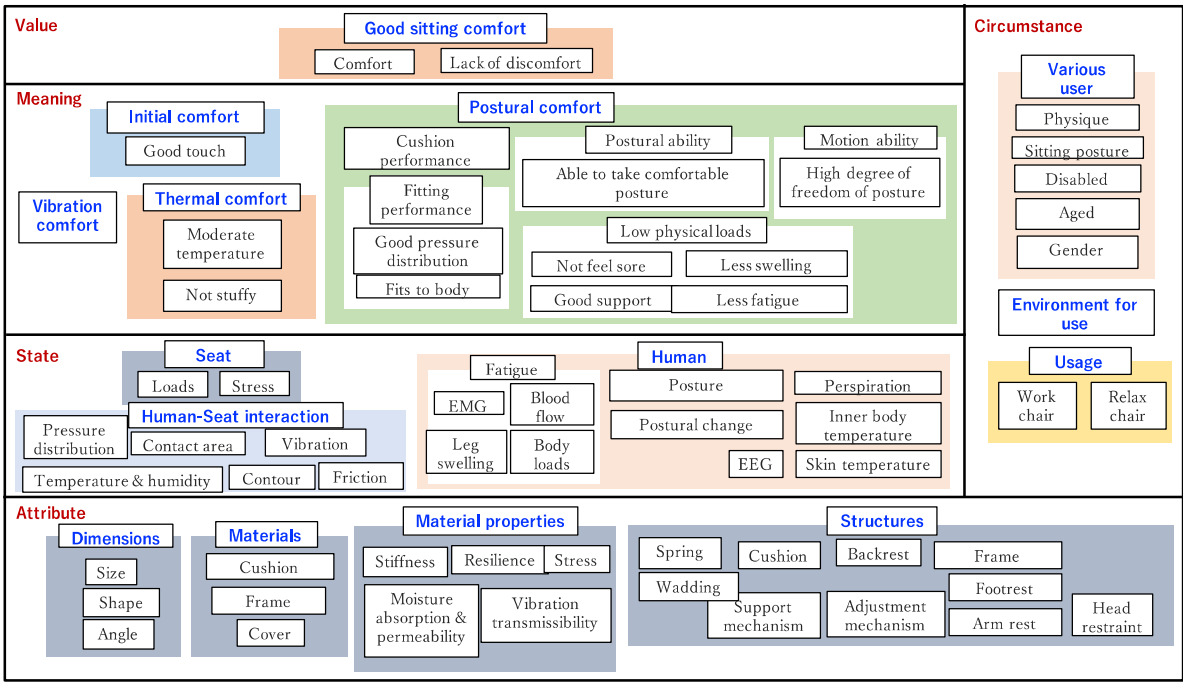


Fig. 2. Element inter-relationship diagram.

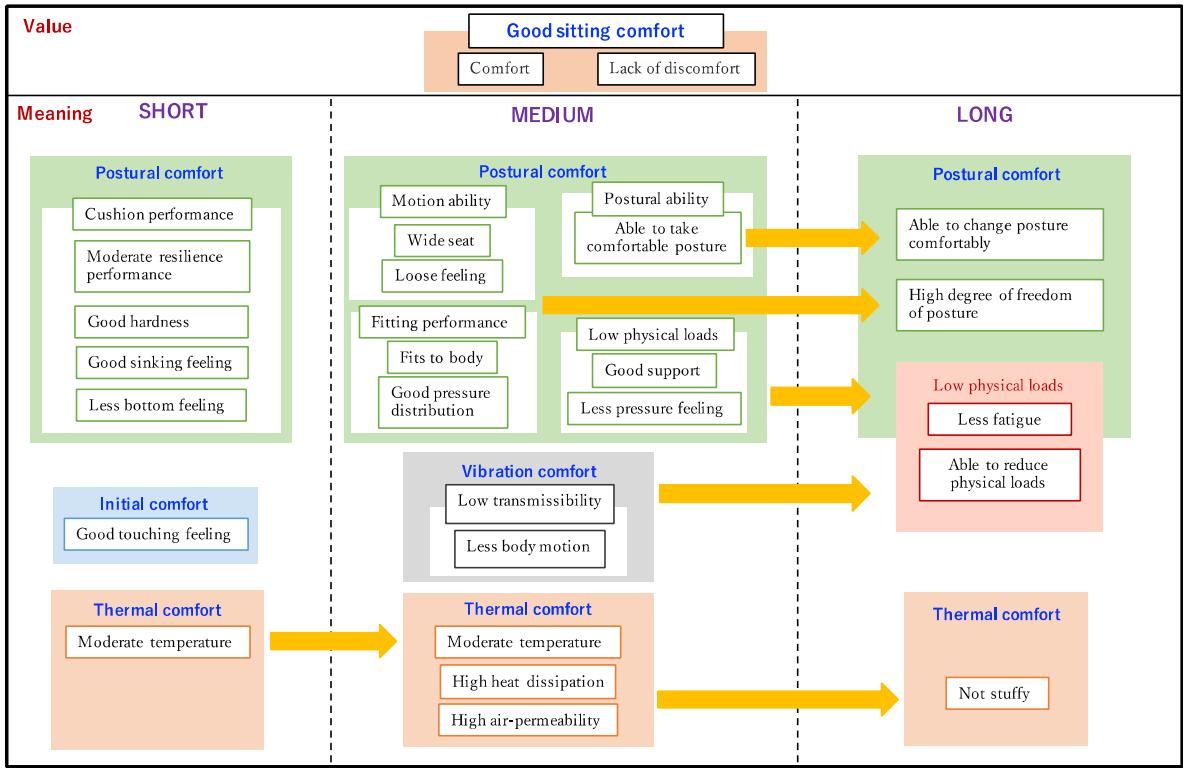


Fig. 3. Element inter-relationship diagram of the meaning space considering with change along timeaxis.

In postural comfort, “Cushion performance" appeared only in SHORT, MEDIUM had “Fitting performance”, “Able to take comfortable posture" and “Less physical loads" elements were placed. In addition, the element "Able to take comfortable posture" changes to LONG's “Able to change posture comfortably” element.

In addition, “Initial comfort” appeared only in SHORT, elements such as “Good touch feeling" were placed. Vibration comfort appeared from MEDIUM, and it could be considered as appearing as “Fatigue" in LONG with the lapse of time with factors related to the physical loads of postural comfort.

In terms of "Thermal comfort”, “Moderate temperature" put in SHORT, and in MEDIUM it accompanies with a factor of “High heat dissipation ", “High air-permeability", and in LONG it changed to an element “Not stuffy”.

4 Discussion

4.1 Extracted elements and inter-relationship diagram

We consider the features of elements extracted from all research literature. As shown in Tables 1 and 2, in the meaning space, the elements relating to “Postural comfort" were extracted most and found to be the main research subjects. In particular, there are many elements that related “Postural ability”, “Less physical loads”. And, also “Vibration comfort” was extracted another key element.

In the state space, “Pressure distribution", “Posture", “Vibration" were extracted in many researches, and the attribute space is found to be “Size”, “Shape", “Angle", “Cushion material”, “Vibration transmissibility” in many cases.

These are thought to be particularly important elements when researching and developing a chair. Therefore, to realize “Good sitting comfort", there are many research examples focusing on loads of the seated person and seeking the chair specifications to realize it. And, a pressure distribution measurement system which is generally popular as a sensor for the chair evaluations used as an indicator expressing the sitting condition in many cases.

On the other hand, in the state space, the case focusing on the state of the human body is extremely few except for “Posture”, and there are few researches to clarify the mechanism of the human body in seating comfort by quantitative measurement about the state of comfort. This is in agreement with Kolich's pointed out that “a lack of theory" [6]. It is necessary to investigate the mechanism of the human body in the comfortable sitting and put them into design knowledge.

As shown in Table 2, in this analysis, about a third part of the literature were studies targeting the LONG timeaxis. That is, it covers comfort in sitting for 15 minutes or more. In view of the act of sitting considering the timeaxis, it is considered that the human does not take the same posture for a long time, but the posture changes with the passage of time. Therefore, “Postural change" is considered to be an important factor in posture comfort in the LONG timeaxis.

It has also been confirmed that by altering posture it is possible to promote blood flow and to reduce the physical loads during sitting, such as distributing pressure [7]. However, in the current situation, even in the research assuming the LONG timeaxis, there are many things that are focused only on one attitude, and as shown in Table 3, There was only 18 literature which was focusing on "posture change" in 159 articles on the LONG timeaxis.

Also, some studies said that a chair that can sit for a long time without changing its posture is good, contradicting the element “Able to change posture comfortably" cited in inter-element relationship diagram with timeaxis considered. In other words, many of the current studies are based on the hypothesis that sitting for a long time is an integral of a sitting for a short time, it is said that there are many things that have been verified in a long time, improving seating comfort for a short time seating. Therefore, it can be said that it is necessary to verify how "Able to change posture comfortably" and “High degrees of freedom for posture" affect seating comfort and realize further improved comfort.

Table 3. Results of extracted research elements.

	Number of research	Percentage
Posture	159	69%
Postural change	18	11%

4.2 Proposal of demanded research topics for the further study

Based on the above consideration, it is considered that the following two items are insufficient as research knowledge, and to be research topics in the future.

(1) Design knowledge by investigating the human mechanism of sitting comfort

Many studies are optimization of the chair condition depending on the targeted circumstance, whereas the human mechanism is difficult to depend on the circumstance such as the chair conditions and it can be applied in a wide range. By designing the chair based on the mechanism, it seems that it is possible to improve seating comfort more essentially.

(2) Design knowledge by research focused on long-term sitting including posture changes

A design solution based on optimization of seating comfort in a static posture can be said to be a partial optimization in a long-term sitting. And, overall optimization on the timeaxis such as reduction of the physical loads factor by body movement the posture is considered that there is a possibility of further improving sitting comfort. For that reason, research about long-term sitting including posture change are necessary for the future.

5 Conclusions

In this research, elements were extracted and classified using multi-space design model from the literature retrieved by "seating comfort", and evaluation items were obtained. Then, by considering the timeaxis, elements that change within the meaning space over time are extracted. Based on the results, research on long-term sitting including investigation of the human mechanism of sitting comfort and postural change was proposed as demanded research topics to expand knowledge in the future.

In the further study, we will add knowledge by further expanding the literature, rearrange relationships between elements, extract design knowledge and arrange it as a knowledge system on sitting comfort.

References

1. Oka, K., Sugiyama, T., Inoue, S., Shibata, A., Ishii, K., Owen, N., Science of sedentary behavior: application of the behavioral epidemiology framework, Journal of Japanese Society of Health Education and Promotion (in Japanese), 2013, 21(2), 142-153.
2. Matsuoka, Y., Multispace Design Model as Framework for Design Science towards Integration of Design, The 2nd International Conference on Design Engineering and Science, 2010, CD-ROM.
3. Matsuoka, Y., Design Science, 2010, (Maruzen, Tokyo).
4. Matsuoka, Y., M Method Design Thinking on Multispace, 2013, (Kindai-Kagaku-Sha, Tokyo).
5. Van Eck, N.J., Waltman, L., CitNetExplorer: A new software tool for analyzing and visualizing citation networks. Journal of Informetrics, 2014, 8(4), 802-823.
6. Kolich, M, A conceptual framework proposed to formalize the scientific investigation of automobile seat comfort, Applied Ergonomics, 2008, 39, 15–27.
7. Lueder, R., Ergonomics of seated movement A review of the scientific literature Considerations relevant to the SumTM chair written for Allsteel, Humanics Ergo Systems, Inc., 2004, 1-33.

Analysis of Body Pressure Distribution on Car Seats through Machine Learning

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Abstract This study was conducted for the purpose of extracting information from body pressure distribution such as comfort and seat characteristics using machine learning. The body pressure data of 18 participants and 19 kinds of car seats was used for the analysis. In addition, sensory evaluation of nine items concerning cushion characteristics and comfort of each seat was carried out. As a result of the analysis, we understood that we could classify the body size and the kinds of seat with extremely high precision from the body pressure distribution data. On the other hand, regarding the rate of correctly predicting seat characteristics from the data, a tendency of over fitting was found concerning items of the sensory evaluation. From these results, it is expected that this study will be applied in the field of seat development.

Keywords: Body Pressure Distribution, Car seat, Machine Learning, Deep Learning, Characteristics Extraction

1 Introduction

This study has its origin in the two previous researches on the analysis of body pressure distribution on seats using fuzzy estimation and neural network. In the case of the former [1], we constructed a prediction system for seat comfort related to the hardness of the cushion. Further, the latter is the thesis that clarified the relationship between sitting comfort and the change of body pressure distribution over time using the self - organizing map by Fujimaki (2004). Therefore, in this study, we focused on the deep learning that was the development of the earlier neural network and considered the usability of the deep learning to understand body pressure distribution. Concretely, the purpose of this study was to extract the characteristics concerning the seating such as the participant's body size, characteristics of the seat and the sensory evaluation from the body pressure distribution data.

2 Data for the analysis

2.1 The participants

The participants were 18 adults, 7 females and 11 males, who were of healthy mind and body. All participants gave their informed consent to participate in the experiment.
Figure1 shows the distribution of height and weight of the participants.

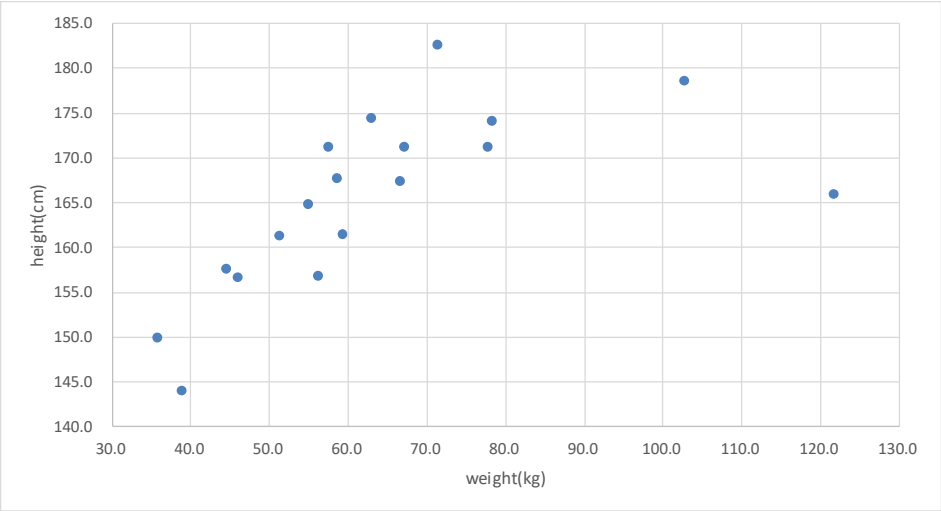


Fig.1. Distribution of height and weight of the participants

2.2 Experiment conditions

For this experiment, we put a body pressure mat with 48 by 48 sensors on the seat back and 40 by 40 sensors on the seat cushion of an actual car seat, and measured the body pressure distribution of the seat and the back separately when experiment participants sat on the seat. The participants could set the position of the slide rails, lifter and recliner of the seat and the steering wheel. Referencing the right driving posture in the HP of Nissan Motor Co., Ltd [2], we taught participants how to maintain a comfortable and correct posture while driving. We prepared 19 kinds of actual car seats, and measured the body pressure distribution for all 19 kinds of seats for each participant.

2.3 Experimental device

The characteristics of the 19 seats are shown in Figure 2. The body pressure measurement device which we used to measure body pressure distribution was LX100 of X-sensor company. The experiment setup is shown in Figure 3.

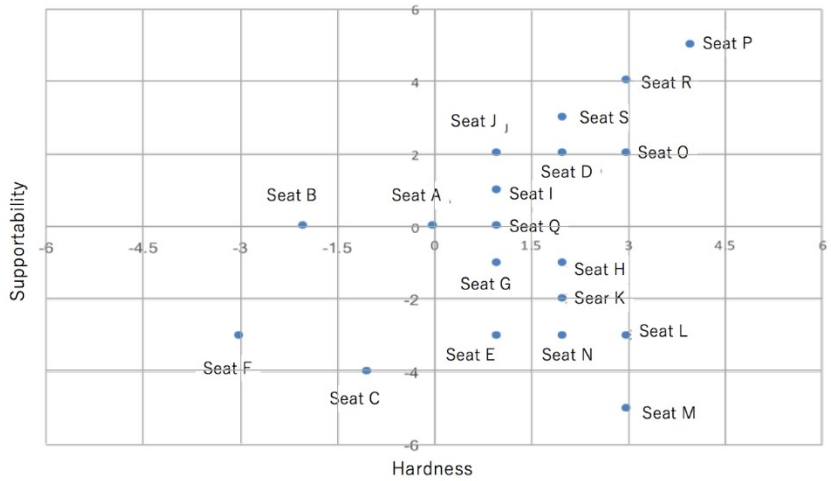


Fig.2. Characteristics of the 19 seats



Fig.3. Experimental setup

2.4 Sensory evaluation

We conducted a subjective evaluation with a seven-point score scale for the seat and measured body pressure distribution. We made a questionnaire shown in Figure 4 referencing the seat feeling check sheet developed through the collaborative investigation of DAI-ICHI-LIFE-FOUNDATION and the Waseda University Noro laboratory.

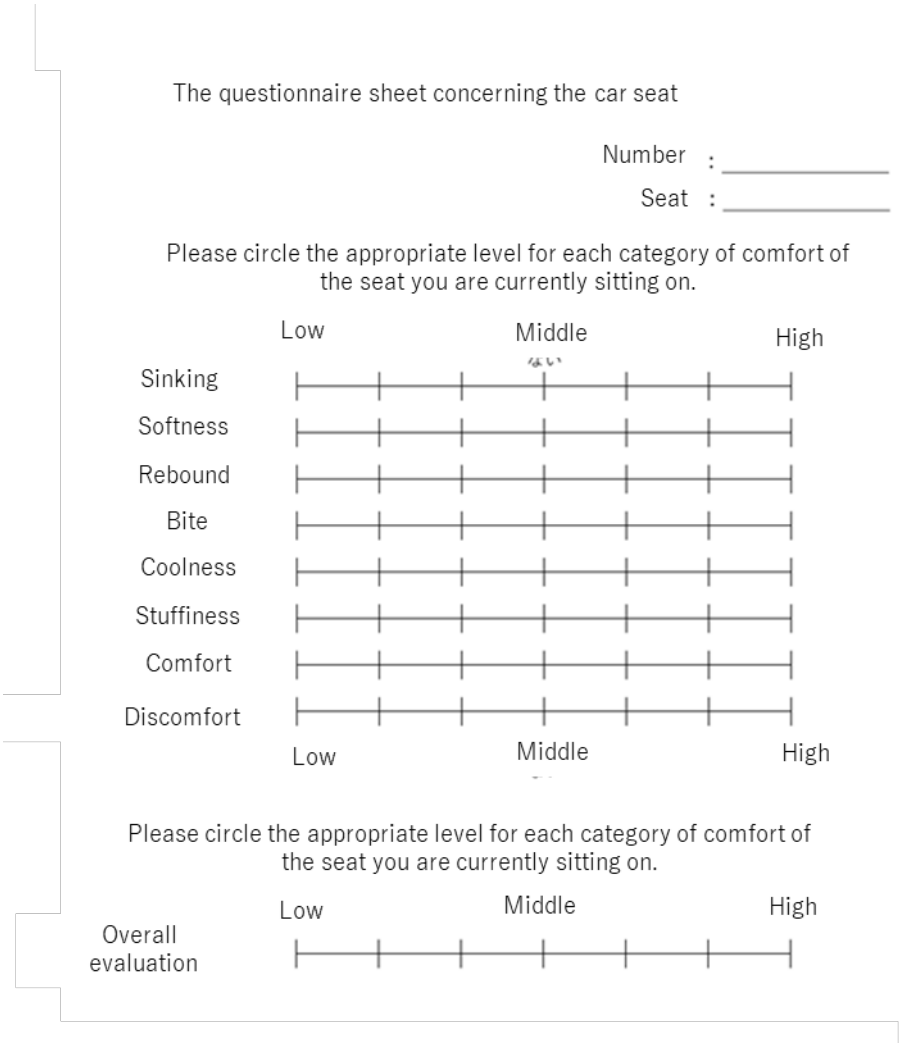


Fig.4. The questionnaire sheet

3 Method of analysis

3.1 Conversion of body pressure data

We converted each data of 40 by 40 for a seat cushion and data of 48 by 48 for the backrest by experimental measurement into the vector of one line. Then we integrated these two and treated as the vector of 3,904 dimensions of one line, and made total 342 data which is 19 kinds of car seats and 18 participants. After that, a total of 11286 data was prepared for deep learning through data augmentation. Translation and/or inversion was applied to the body pressure distribution data.

3.2 Deep Learning

Deep learning is a method that previously fell out of favor, but has recently been gaining traction as an advanced neural network method. The construction of the neural network is classified roughly into the input

layer, the middle class (hidden layer), and the output layer. The output is obtained by training each layer. In addition, it can find parameters by itself in the learning process, and this is one of the reasons that deep learning is said to be so powerful. In this study, we adopted the deep learning with supervisor in which input data and label data was used as training data [3-7].

The analysis was operated by h2o (the package) of R version 3.3.2. The deep learning in a h2o package consists of the neural network of the feedforward type. We adopted the following main designs where generalization performance was the highest as the result of cross validation: 3 hidden layers, with 200 units in each of the hidden layer; the "tanh" activation function was adopted; the number of learning times was set at 20. From 11,286 analysis data, we chose 10,000 random data as training data and the remaining 1,286 data was set as test data. We tested the validity of the learning result with the accuracy of test data.

3.3 The definition of the label

This data was learnt with the labels car seat, body size and a total 9 items of sensory evaluations each. The definition of labels is shown in Table 1.

Table1. The definition of the label

Label	Definition
Body size	On the basis of human body measurement database, a female in the lower 5%ile of weight and height is classified as S, and greater than male's 95%ile is L, and the middle is M
Car seat	19 kinds of car seat
Sensory evaluation	7 rating system

4 Results

4.1 Comparison with other analytics

We tried Fuzzy c-means clustering method beforehand to compare deep learning with other methods. The object data was the 16 conditions created by four kinds of seat and four postures. K-means method is a kind of hard clustering method which means that some samples belong to 1 or 0 and on the other hand the Fuzzy c method means that it's possible for some samples to be distributed among several clusters at the same time . The error - rate of each method is shown in Tables 2 and 3. In addition, the group number means the result of clustering by participant body size.

The difference in these results means that deep learning method by itself can make a new parameter whereas Fuzzy c-means clustering method depends on the existing parameter. The new parameter found by this system was more effective in classifying the data than using only the existing parameter or parameters already defined by a human. Therefore, it may be said that deep learning is suitable for the method of this study.

Table 2. Error rate of the classification by Fuzzy c-means clustering

Cluster No.	Error rate
1	0.06
2	0.38
3	0.55
4	0.35
5	0.81
6	NA

Table 3. Error rate of the classification by Deep Learning

Cluster No.	Error rate
1	0.00
2	0.00
3	0.00
4	0.00
5	0.00
6	0.00

4.2 Results of deep learning

The correct answer rate from the test data of each label and the error rate from the cross validation are shown in Table4.
The accuracy of the body size and each car model shows high percentages - a little less than 100%. Although the number differs between each item, the result of the sensory evaluation was approximately 90%. However, the error rate of the body size and the car model were limited to 1% using cross validation, the result of the other sensory evaluations was around 10%, and the overall evaluation was slightly less than 10%.

Table 4. Learning results concerning each label

Label	Accuracy (%)	Error rate by cross validation (%)
Body size	99.7	0.3
Car seat	98.8	1.7
Sinking	91.4	10.4
Softness	90.3	10.5
Rebound	88.9	13
Bite	92.0	10.6
Coldness	91.6	11.5
Stuffiness	91.2	10.8
Comfort	81.2	13.9
Discomfort	88.6	13.3
Overall	93.2	7.6

5 Discussion

As accuracy was approximately 100% concerning body size and type of car seat, it seems that the characteristic of body size, especially, contact area or pressure, by learning process can be associated to body pres-

sure distribution data, and can be learnt. Furthermore, importantly it can be said that the system can classify type of car seat and body size even if the person sits on any seat or in any posture, by applying training using augmented datasets. On the other hand, regarding sensory evaluation, the "overall evaluation" was 93.2%, "comfort" was 81.2%, and "discomfort" was 88.6%.

It is difficult to extract information relating to human being's feelings from the body pressure data as its evaluation scale is objective. However, the results of this study showed a considerably high accuracy. On the other hand, the result of cross validation was around 10%. As one thought, this could be called overlearning. "Bite", "Rebound", "Softness", "Sinking", all depend on the seam and support properties of the seat, so, in fact, they are items concerning the cushion characteristics of the seat. It is thought that the evaluation of the participant and real body pressure distribution match, especially with regards to "Bite", "Sinking", and "Softness". In other words, the difference between the objective real body pressure distribution data and the subjective evaluation of the participant is comparatively small and that leads to the learning result. "Coldness" and "Stuffiness" were items concerned with comfort, however the accuracy was comparatively high. It is thought that they were items which did not relate to cushion characteristics primarily but rather were affected by seat materials, shape or texture so that it suggests some correspondence with body pressure distribution. In other words, it is thought that seat materials, shape and texture affect body pressure distribution.

6 Conclusions

This study was carried out to extract the characteristics on body size, car seat and sensory evaluation by the participants from body pressure distribution using deep learning with supervisor. As a result, we found that we could predict body size and the kind of car seat with extreme accuracy by body pressure distribution data. Regarding the sensory evaluation, three items, "Bite", "Sinking", and "Softness" concerning cushion characteristics, and another three items, "Overall evaluation", "Coldness", and "Stuffiness", were comparatively accurate at 90%～93%. However only "Rebound" was below 90% at 89%. The "Comfort" and "Discomfort" items relating to the comfort of the seat were 81.2% and 88.6%. Unfortunately, the result of cross validation does not lead to the existence of versatility. It is difficult to generalize the characteristics and comfort from body pressure distribution data alone, and this affects the accuracy result of deep learning. In the future, we will reconstruct the deep learning to improve the prediction of highly-detailed body pressure parts and then apply it to the development of seats. Based on this study it would be possible to predict which existing seats resemble a newly developed seat and the feeling of the seat, and this would accelerate the development of comfortable seats in the future. In addition, though static body pressure distribution was used in this study, it is desirable to measure body pressure distribution after driving for a fixed time to analyze whether or not the seat was comfortable for the person. Furthermore, by measuring body pressure distribution while driving for a long time, rather than only the static body pressure distribution, and investigating the relationship between the changing pattern of pressure distribution and sensory evaluation, we can improve the comfort of the seat by analyzing more realistic driving conditions.

References

1. Mitsuya, R.: Construction of Prediction System for Seating Comfort by Fuzzy Inference; doctor thesis (ergonomics), 2004
2. Nissan, "Right driving posture", "http://drive.nissan.co.jp/USEFUL/0804/", (Access Dec 1,2016)
3. Okaya, T.: Deep Learning, Kodansha, 2015.
4. Morita, S. et al.: The Suggestion of Classifying Body Pressure Distribution in Car Seat, Human Interface 2016, Human Interface Society, 2016, pp.369-374.
5. Quoc V. Le et al.: Building High-level Features Using Large Scale Unsupervised Learning, 2013 IEEE International Conference on Acoustics, Speech and Signal Processing, 2013, pp.8595-8598.
6. Dan Claudiu Ciresan, et al.: Deep Big Simple Neural Nets Excel on Handwritten Digit Recognition, Neural Computation, 2010, Volume 22 No.12.
7. Hinton, G. E.et al.: Improving neural networks by preventing co-adaptation of feature detectors, The Computing Research Repository, 2012, vol. abs/1207.0580.

'The evaluation of medical devices with healthy people?'

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Abstract

Much of the research of thermal and physical comfort is completed with healthy participants in regular life scenarios. The translation of these findings into clinical settings for people with disease, deficiency or restrictions adds a level of complexity. As an example this study evaluated the effectiveness of a patient warming mattress device on body temperature and ratings of thermal comfort/sensation.

Hypothermia has been linked to higher mortality rates in trauma patients admitted to hospital. Patient warming devices have been developed to assist the temperature of the patient and studies on these report varied effects. Laboratory trials with shivering inhibition (Goheen et al, 1997, Greif et al, 2000) found improvements from forced air and resistive blankets but without shivering inhibition (Williams et al, 2005) showed no benefit in warming from 35°C.

A physical evaluation of the warming mattress device with a thermal manikin reported an energy contribution to the user (~70W). To support the physical evaluation a user trial was conducted. Nine healthy volunteer participants (27.78±4.99 Years) were exposed to three conditions using a repeated measures counterbalanced design. The participants were cooled in an environment with an air temperature of 0°C (60 minutes) then exposed to 30 minutes of a warming intervention.

1. Hot mattress HM. Mattress preheated to 18°C, under standard blankets
2. Warmed mattress WM. Mattress turned on at start of warming period, under standard blankets
3. Cold mattress CM. Control condition, no power to mattress, under standard blankets.

During the cooling phase, aural and mean skin temperature (T_{sk}) significantly decreased for all conditions ($p<0.01$). T_{sk} increased following each warming intervention but aural temperature continued to decline. Significant increase in overall mean thermal comfort was seen during the first ten minutes of the warming phase for HM in comparison to CM and WM ($p<0.05$) but not at 20 and 30 minutes. This was mirrored by the overall mean thermal sensation rating across the same timeframe. HM increased thermal sensation from very cold to cool with CM and WM showing and increase from very cold to cold.

This study revealed the effect of the device (HM) gave short term comfort and sensation gains at the start of the warming phase but the passive insulation provided (CM) also allowed re-warming to occur. This was the expected thermoregulatory response for a group of healthy participants. This group does not necessarily represent the hospital population with pathology that inhibits their normal responses to cold, e.g. circulatory shutdown, shock or trauma. For accurate application, the trial data needs to be closely matched with the limitations of the health condition in the target population.

The challenge is now to explore the relationship between data from healthy cohorts and how that can be used for groups of patients with known physical and physiological conditions and limitations. The validity of a patient's subjective assessment of their condition lying in a hospital bed is currently unclear. Evidence needs to show whether a patient in a hospital bed can accurately report joint position, thermal comfort, skin wettedness, pressure points etc to assist in the management of their condition.

Keywords: Experimental design, Bed comfort, Thermal comfort, Warming, Healthcare.

1 Introduction

Hypothermia has been linked to higher mortality rates [1, 2, 3] and worse outcomes [4] in trauma patients admitted to hospital and is a health risk in itself. The National Institute for Health and Care Excellence (NICE) have published guidance on the management of inadvertent perioperative hypothermia [5] and on the use of a patient warming mattress in the management of the condition [6]. This study aims to evaluate the effectiveness of a patient warming mattress and the impact it has on body temperature and ratings of thermal sensation.

The human body has highly effective thermoregulatory responses to the cold [7], however, hypothermia can occur in severe environments or as a result of illness or accident [8]. The elderly are at an increased risk of hypothermia due to an elevated risk of falls [9] potentially leaving them immobile in a cold environment and a possible diminished thermoregulatory response, lowering their ability to defend their internal temperature [10, 11, 12, 13]. Medical patients are at risk from drops in internal temperature during the perioperative period as a consequence of loss of behavioural responses to cold and the inhibition of thermoregulatory response mechanisms caused by anaesthesia [5, 7].

Technology has been developed to re-warm patients already in a state of hypothermia. Resistive warming blankets [14] and hot packs [15] have been found to heat patients more effectively than control conditions, whereas heat pads [16] have previously failed to demonstrate an additional benefit. Laboratory trials investigating the use of warming devices in patient re-warming included investigations with participants shivering response inhibited through meperidine administration [17, 18]. These studies have found forced-air and resistive blankets to be more effective than control methods in re-warming participants. In comparison, a previous laboratory study without shivering inhibition [19] failed to find an additional benefit of forced air warming, compared with passive warming with blankets.

The avoidance of inadvertent hypothermia during operations has been the subject of a number of investigations and a review by NICE [5]. Forced air warming is currently the most commonly used method of warming and is supported by several studies [20, 21, 22].

Previous research has tended to concentrate on the effects warming devices have on core temperature and there is a lack of investigations into the effects on subjective measures of thermal comfort and thermal sensation, important in the consideration of overall patient comfort. Much of the research of thermal and physical comfort is completed with healthy participants in regular life scenarios. The translation of these findings into clinical settings for people with disease, deficiency or restrictions adds a level of complexity. As an example this study evaluated the effectiveness of a patient warming mattress device on body temperature and ratings of thermal comfort/sensation.

2 Methods

This study evaluated a Patient Warming Device (PWD) which constituted a heating pad and an air-filled suspension mattress. This market available device offered thermal warming and pressure reduction technology aimed at healthcare applications. The device had variable power (32°-40°) which were both evaluated. The study employed a two stage laboratory evaluation of the patient warming device. Firstly, a thermal manikin was used to measure the energy transfer capability of the device. Secondly, a user trial was conducted to explore the heating effects in a group of adults in a climatic chamber.

2.1 Thermal Manikin Evaluation

The PWD was evaluated using a thermal manikin ('Newton', North Western Measurement Technology, Seattle, USA) in a climate controlled environmental chamber in Environmental Ergonomics Research Centre at Loughborough University. The manikin has 32 individual zones; each can measure temperature and be powered to maintain a set surface temperature. The following environmental conditions were used for the evaluation:

- Air temperature (t_a) 22°C, 50% Relative Humidity, Air Velocity 0.4 m/s^{-1}
- Air temperature (t_a) 10°C, 50% Relative Humidity, Air Velocity 0.4 m/s^{-1}

The thermal manikin was used in both passive and active conditions. The passive condition is when the manikin effectively acts a human shaped temperature sensor and indicates body parts which are being directly heated by the mattress. The active condition is when the manikin has a surface (skin) temperature of 34°C similar to that of a person. This gives a measure of the amount of energy required to maintain the surface temperature. The manikin was minimally clothed, (T shirt and boxer shorts) and was additionally covered with a light hospital blanket for all test conditions.

The test protocol was for the manikin to be placed on to the PWD which was unheated and then at the start of the test the PWD was switched on. Duration was for nominally 120 minutes for the passive tests and 70 minutes for the active tests. Two temperatures, 32°C (lowest) and 40°C (highest), were evaluated.

2.2 User Trial

A repeat measures within-subjects design was used for the experiment. Participants took part in three trials of different conditions; the order of the trials was counterbalanced with a Latin square design to negate order effects. All three trial conditions were preceded by 60 minutes cooling in 0°C conditions in a controlled chamber, participants were then re-warmed for 30 minutes within this chamber in one of three ways:

1. Hot mattress condition (HM). On the pre-heated warming mattress (surface temperature 17.7 ± 2.8°C) under standard blankets (pre-heat trial).
2. Warmed mattress condition (WM). On the device under standard blankets with the device turned on at the start of the warming period.
3. Cold mattress condition (CM). On the device under standard blankets with the device turned off (control trial).

2.2.1 Participants.

Nine healthy volunteers participated in the study; five males and four females. The participants were 27.78 ± 4.99 years of age, with a height of 1.70 ± 0.08m, a mass of 69.31 ± 25.36kg and a Dubois body surface area (Parsons, 2003) of 1.78 ± 0.32m^2. The participants wore their own clothing for the experiments and were required to dress in the following ensemble: underwear (briefs for males, bra and pants for females), socks, shorts, t-shirt, gloves. This ensemble gave an estimated clothing and thermal insulation value (CLO) of 0.26 [23].

2.2.2 Data Collection

- Climatic chamber conditions were recorded by Testo 350-454 data logger every 60 secs.
- PWD surface temperature was monitored with 6 x Grant surface temperature thermistors every 60 secs.
- Skin temperature of the participants were recorded in accordance with ISO 9886 [24] at 8 points every 60 secs.
- Internal temperature was measured aurally with Grant aural thermistors in both ears and averaged every 60 secs.
- Subjective measures were collected for thermal comfort on a 7 point scale [25] and thermal sensation on an 11 point scale [25] for overall, and thermal sensation only for chest, abdomen, upper back, lower back, hands and feet every 10 minutes.

2.2.3 Data Analysis

Analysis was conducted on the participant data to compare the start and finish of the cooling period and the effect over time of the warming period. Skin temperatures and aural temperatures were analysed using paired samples t-tests and repeated measures ANOVA, with Wilks' Lambda used to test for significance

where the assumption of sphericity was not met. Subjective measures were analysed using Friedman tests and Wilcoxon Signed Rank Tests. P <0.05 identified statistically significant differences.

3 Results:

3.1 Thermal Manikin Evaluation

The PWD had the effect of increasing the zones in contact with it by approximately 7°C for the 32°C surface temperature condition and by 10°C for the 40ºC surface temperature conditions. The heating effect over time is shown in figure 1. The graphs include all data from all the manikin zones; this is for illustrative purposes only. It can be seen that the heating of the manikin zones in contact with the PWD, (blue lines), starts almost immediately, (0 – 5 minutes). After which there is a steady increase in the temperature of the zones until approximately 65 minutes when some plateauing of the temperature increase occurs. The magnitude of the zone temperature increases were similar for both the 10 and 22°C air temperature conditions (Fig 1a, 1b).

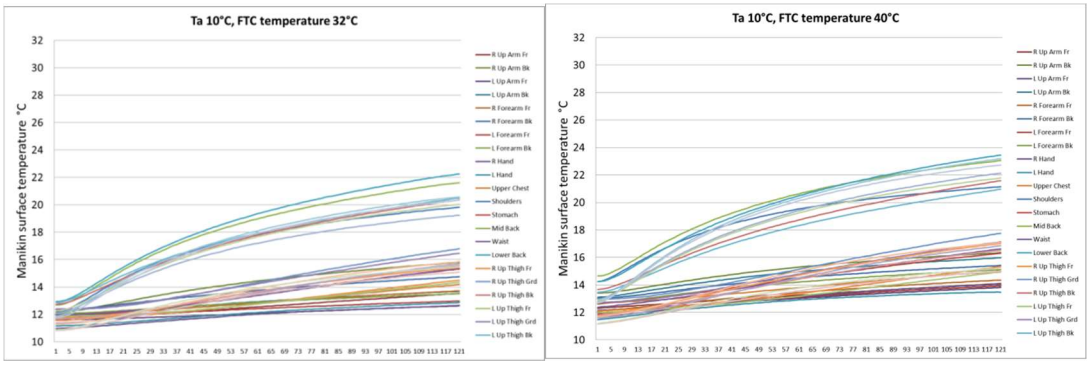


Fig 1. Manikin Skin Temperature. a) t_a 10°C – PWD temp 32°C b) t_a 10°C – PWD temp 40°C.

Figure 2 present's graphs plotting the energy required (Wm-2) to maintain a manikin surface temperature of 34°C over the duration of the test. When the PWD had a 32°C surface temperature all of the zones remained active. The effect of the PWD was seen with a reduction in the amount of power required to maintain the surface temperature of the zones in contact with it at 34°C (Figure 2a). With a surface temperature of 40°C for the PWD, a number of the zones in contact with it rose above 34°C, (Figure 2 b). This resulted in the power decreasing, if it went down to 0 Wm^{-2} then this would result in the temperature of the zone increasing beyond the set point of 34°C. Final temperatures of the back zones did get as high as 37°C after the 70 minute duration. It can be seen from the graphs that most of the zones reach a steady state by 12 to 15 minutes, with additional changes only occurring in those zones in contact with the PWD. The majority of the other zones are using approximately 50Wm^{-2} to maintain the required 34°C surface temperature; this indicates that the PWD is giving the zones in contact with it a similar amount of energy. These results match to the patterns seen in the passive tests and confirm that the PWD is capable of adding heat to a static body.

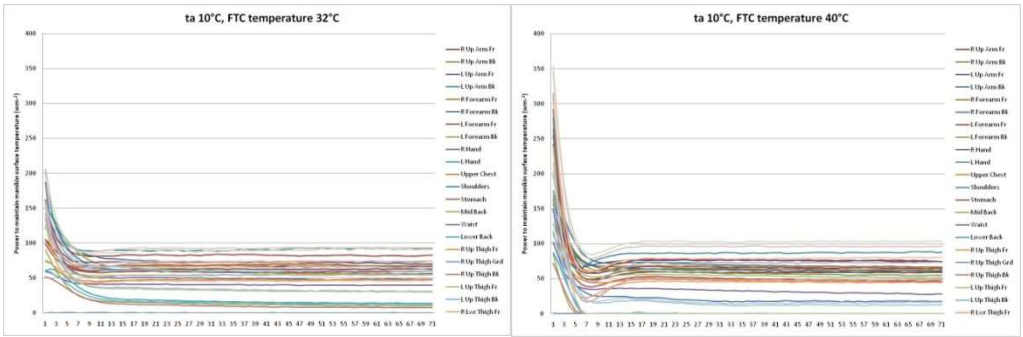


Fig 2. Energy required to maintain skin temperature. a) t_a 10°C – PWD temp 32°C. b) t_a 10°C – PWD temp 40°C

3.2 User Trial

The environmental conditions data for the three trial conditions (Cold mattress CM, Warmed mattress WM, Hot mattress HM) over the 90 minute experiment period were similar (Table 1).

Table 1. Environmental conditions

Condition	CM	WM	HM
Air temperature (°C)	0.3 (±0.46)	0.3 (±0.38)	0.2 (±0.64)
Air velocity (m/s^{-1})	0.2 (±0.07)	0.1 (±0.03)	0.1 (±0.04)
Relative Humidity	46.9	45.9	42.4

The mattress temperatures were recorded (Table 2) across the area of the mattress. The HM condition showed unequal heating particularly in the lower region of the device. CM and WM were similar.

Table 2. Mattress Surface Temperatures at commencement of warming period.

Condition	CM	WM	HM
Overall (°C)	4.8 (±2.1)	3.6 (±1.4)	17.7 (±2.8)
Top (°C)	6.64 (±2.91)	4.78 (±2.04)	18.68 (±4.15)
Middle	4.48	3.50	24.51
Bottom	3.30	2.39	9.91

3.2.1 Skin Temperature

The skin temperatures from all 8 points were combined to give mean skin temperature Figure 3 shows the mean of the overall skin temperature across the exposure through cooling and warming.

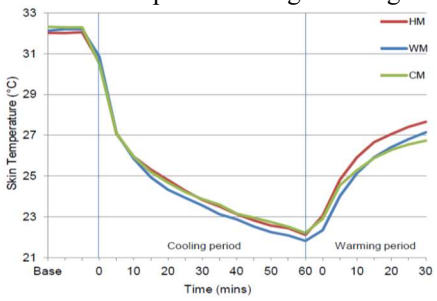


Fig 3. Mean of 8 point combined and weighted skin temperatures for CM WM HM conditions (n=9)

Figure 3 shows the mean T_{sk} across the cooling and warming periods. There is a reduction in T_{sk} during cooling period, with significant differences between baseline and the end of cooling ($p<0.01$). There were no significant differences between T_{sk} in the three conditions at baseline ($p=0.696$) or at the end of cooling ($p=0.431$). All three warming conditions impacted on T_{sk}, with significant differences in T_{sk} between the 60 minute cooling point and the end of warming ($p<0.05$). All warming conditions significantly increased mean skin temperature across all time sections, 0-10, 10-20, 20-30 minutes ($p<0.01$). Though there were differences between conditions across all time sections, only significant differences found between the HM and CM trials at 20 and 30 minutes of warming ($p<0.05$). ANOVA analysis suggested significance between conditions for the end of cooling to start of warming sections ($p<0.05$), Pairwise comparison with a Bonferroni correction did not show significance.

3.2.2 Aural Temperature

The mean aural temperatures (T_a) are presented in Figure 4.

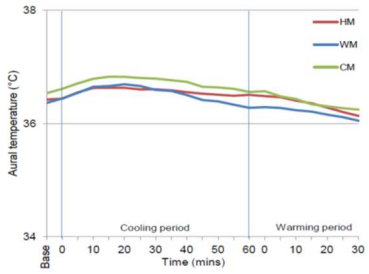


Fig 4. Mean aural temperatures (T_a)during the cooling and warming periods (n=9)

There was no significant difference in T_a between the three conditions prior to the cooling period ($p=0.313$), however, at the end of the cooling period WM condition (36.28°C) was lower than the CM trial (36.56°C, $p<0.05$). Mean T_a did not significantly change with cooling ($p=0.898$). There was a drop in mean T_a observed during the warming period, with differences found at the end of cooling compared with end of warming in all conditions ($p<0.01$). No significant differences were found between baseline and end of warming. The drop in T_a during the warming period was not significantly different between conditions ($p=0.420$). A significant effect of time was found throughout the warming period, with significant differences between all the time sections 0-10, 10-20 and 20-30 minutes of warming($p<0.01$).

3.3.3 Thermal Comfort and Thermal Sensation

The participants' ratings of thermal comfort were recorded every ten minutes throughout the trial, mean ratings of overall thermal comfort are presented in Figure 5. There were significant differences in thermal comfort ratings between the end of cooling and the end of warming in both HM and WM ($p<0.05$) but not in the CM condition ($p=0.084$). Ratings of thermal comfort at the end of cooling period and at initiation of warming were significantly different in both HM and WM conditions ($p<0.05$) but not in the CM condition ($p=0.317$). Significant differences between end of cooling ratings and ratings after 10 minutes of warming were found in all conditions ($p<0.05$), but at 20 minutes of warming, only the ratings in the HM and WM conditions were significantly different from at the end of the cooling period. Though there was an improvement in comfort across all time frames in favour of HM there was no significance other than at the start of warming ($p<0.05$).

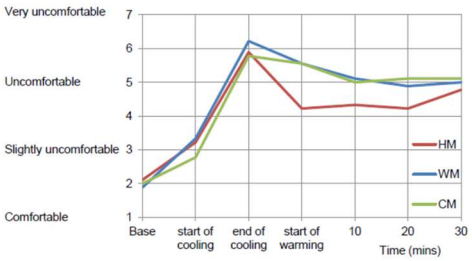


Fig 5. Mean overall thermal comfort during cooling and warming periods (n=9)

Figure 6 shows the mean overall thermal sensation. There were no significant differences in thermal sensation between conditions at baseline. The cooling period had a significant effect on thermal sensation in all conditions ($p<0.01$) between baseline and end of cooling period. There were no significant differences between conditions at the end of the cooling period ($p=0.446$), meaning participants started in a similar state for the warming. All warming conditions had a significant impact on thermal sensation. Improvements in participants ratings were significant between conditions at at the start of warming, after 10, 20 and 30 minutes of warming in all conditions ($p<0.05$). During the warming period there was a difference between HM and both of the other conditions at 10 minutes only ($p<0.05$).

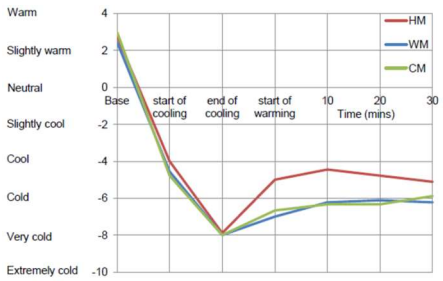


Fig 6. Mean overall thermal sensation during cooling and warming periods (n=9)

3.3.4 Body Part Differences

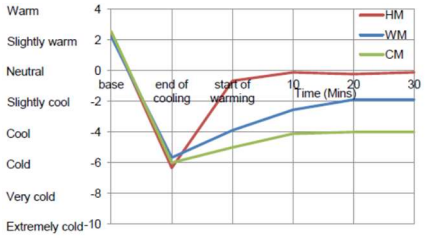


Fig 7. Mean thermal sensation at the lower back (n=9)

The participants' thermal sensation and thermal comfort ratings for specific areas of the body (chest, abdomen, upper back, lower back, hands and feet) were recorded. All warming conditions had an impact on local thermal sensation e.g. Figure 7. There were expected differences between the body part locations due to the proximity of the heat sources and blanket coverage in Table 3.

Table 3. Body part differences in thermal sensation (n=9)

Body Part	End Sensation	Sig.
Chest	Slightly Cool	<0.05
Abdomen	Slightly Cool	<0.05
Upper Back	Neutral	<0.01
Lower Back	Neutral	<0.025
Hands	Cool	N.S.
Feet	Cold/V Cold	N.S.

4 Conclusion

The evaluation of this Patient Warming Device (PWD) has identified an interesting contradiction. The manikin evaluation clearly identified that the PWD with its heat pad embedded next to the air-filled suspension mattress had the capability of adding heat to the individual laying on it. Both the passive and active modes of the manikin showed clear energy transfer to raise skin temperature and allow a patient to keep their core temperature at a reasonable level (Fig 1 and 2). This data lead to the second user trial evaluation to measure the effect on real people in a cold environment.

The user trial evaluation in tightly controlled environmental conditions (0ºC) allowed the response in the participants to be observed. During the cooling phase, aural and mean skin temperature (T_{sk}) significantly decreased for all conditions ($p<0.01$). T_{sk} increased following each warming intervention but aural temperature continued to decline. Significant increase in overall mean thermal comfort was seen during the first ten minutes of the warming phase for HM in comparison to CM and WM ($p<0.05$) but not at 20 and 30 minutes. This was mirrored by the overall mean thermal sensation rating across the same timeframe. HM increased thermal sensation from very cold to cool with CM and WM showing and increase from very cold to cold.

This study revealed the effect of the device (HM) gave short term comfort and sensation gains at the start of the warming phase but the passive insulation provided (CM) also allowed re-warming to occur. The re-warming was particularly noted between cooling and warming phases of the protocol. This was the expected thermoregulatory response for a group of healthy participants. This group does not necessarily represent the hospital population with pathology that inhibits their normal responses to cold, e.g. circulatory shut-down,

shock or trauma. For accurate application, the trial data needs to be closely matched with the limitations of the health condition in the target population.

The challenge is now to explore the relationship between data from healthy cohorts and how that can be used for groups of patients with known physical and physiological conditions and limitations. The validity of a patient's subjective assessment of their condition lying in a hospital bed is currently unclear. Evidence needs to show whether a patient in a hospital bed can accurately report joint position, thermal comfort, skin wetted-ness, pressure points etc. to assist in the management of their condition.

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References

1. Ireland, S., Endacott, R., Cameron, P., Fitzgerald, M. and Paul, E. 2011, The incidence and significance of accidental hypothermia in major trauma- a prospective observational study. *Resuscitation*. 82, 300-306.
2. Martin, R., Kilgo, P., Miller, P., Hoth, J., Meredith, J., and Chang, M. 2005, Injury-associated hypothermia: an analysis of the 2004 National Trauma Data Bank. *Shock.* 24, 114-118.
3. Wang, H., Callaway, C., Peitzman, A., and Tisherman, S. 2005, Admission hypothermia and outcome after major trauma. *Critical Care Medicine.* 33, 1296-1301.
4. Beilman, G., Blondet, J., Nelson, T., Nathens, A., Moore, F., Rhee, P., Puyana, J., Moore, E., and Cohn, S. 2009, Early hypothermia in severely injured trauma patients is a significant risk factor for multiple organ dysfunction syndrome but not mortality. *Annals of Surgery.* 249, 845-850.
5. National Institute for Health and Clinical Excellence (NICE). 2008, *The management of inadvertent perioperative hypothermia in adults.* http://www.nice.org.uk/nicemedia/live/11962/40429/40429.pdf. Accessed 2nd September 2013 [online].
6. National Institute for Health and Clinical Excellence (NICE). 2011, *Inditherm patient warming mattress for the prevention of inadvertent hypothermia.* http://www.nice.org.uk/nicemedia/live/13564/56118/56118.pdf. Accessed 2nd September 2013 [online].
7. Parsons, K. 2003, *Human thermal environments.* 2nd Ed. (London: Taylor & Francis).
8. Clark, R., and Edholm, O. 1985, *Man and his thermal environment.* (London: Edward Arnold).
9. World Health Organisation (WHO). 2007, *Global Report on Falls Prevention in Older Age*. http://www.who.int/violence_injury_prevention/publications/other_injury/falls_p revention.pdf Accessed 13th April 2013 [*online*].
10. Kingma, B., Frijns, A., Saris, W., van Steenhoven, A., and van Marken Lichtenbelt, W. 2011, Increased systolic blood pressure after mild cold and rewarming: relation to cold-induced thermogenesis and age. *Acta Physiologica.* 203, 419-427.
11. DeGroot, D., and Kenney, L. 2007, Impaired defense of core temperature in aged humans during mild cold stress. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology.* 292, 103-108.
12. Potkanowicz, E., Caine-Bish, N., Otterstetter, R., and Glickman, E. 2003, Age effects on thermal, metabolic, and perceptual responses to acute cold exposure. *Aviation, Space and Environmental Medicine.* 74, 1157-1162.
13. Frank, S., Raja, S., Bulcao, C., and Goldstein, D. 2000, Age-related thermoregulatory differences during core cooling in humans. *American Journal of Physiology- Regulatory, Integrative, and Comparative Physiology.* 349-354.
14. Kober, A., Scheck, T., Fulesdi, B., Lieba, F., Vlach, W., Friedman, A., and Sessler, D. 2001, Effectiveness of Resistive Heating Compared With Passive Warming in Treating Hypothermia Associated With Minor Trauma: A Randomized Trial. *Mayo Clinic Proceedings*. 76, 369-375.
15. Watts, D., Roche, M., Tricarico, R., Poole, F., Brown, J., Colson, G., Trask, A., and Fakhry, S. 1999, The Utility of Traditional Prehospital Interventions in Maintaining Thermostasis. *Prehospital Emergency Care*. 3, 115-122.
16. Lundgren, P., Henriksson, O., Naredi, P., and Bjornstig, U. 2011, The effect of active warming in prehospital trauma care during road and air ambulance transportation- a clinical randomized trial. *Scandinavian Journal of trauma, resuscitation & emergency medicine*. 19, 1-7.
17. Goheen, M., Ducharme, M., Kenny, G., Johnston, C., Frim, J., Bristow, G., and Giesbrecht, G. 1997, Efficacy of forced-air and inhalation rewarming by using a human model for severe hypothermia. *Journal of Applied Physiology*, 83, 1635-1640.
18. Greif, R., Rajek, A., Laciny, S., Bastanmehr, H., and Sessler, D. 2000, Resistive Heating Is More Effective Than Metallic-Foil Insulation in an Experimental Model of Accidental Hypothermia: A Randomized Controlled Trial. *Annals of Emergency Medicine*. 35, 337-345.
19. Williams, A., Salmon, A., Graham, P., Galler, D., Payton, M., and Bradley, M. 2005, Rewarming of healthy volunteers after induced mild hypothermia: a healthy volunteer study. *Emergency Medicine Journal*. 22,

182-184.
20. Taguchi, A., Arkilic, C., Ahluwalia, A., Sessler, D., and Kurz, A. 2001, Negative pressure rewarming vs. forced air warming in hypothermic post-anesthetic volunteers. *Anesthesia & Analgesia*. 92, 261-266
21. Andrzejowski, J., Hoyle, J., Eapen, G., and Turnbull, D. 2008, Effect of pre-warming on post-induction core temperature and the incidence of inadvertent perioperative hypothermia in patients undergoing general anaesthesia. *British Journal of Anaesthesia*. 101, 627-631.
22. Brandt, S., Oguz, R., Huttner, H., Waglechner, G., Chiari, A., Greif, R., Kurz, A., and Kimberger, O. 2010, Resistive-polymer versus forced air warming: Comparable efficacy in orthopaedic patients. *Anesthesia & Analgesia.* 110, 834-838.
23. BSI (2009) BS EN ISO 9920: *Ergonomics of the thermal environment- Estimation of thermal insulation and water vapour resistance of a clothing ensemble.* London: BSI.
24. BSI (2004) BS EN ISO 9886: *Ergonomics- Evaluation of thermal strain by physiological measurements*. London:BSI.
25. BSI (2001) BS EN ISO 10551: *Ergonomics of the thermal environment- Assessment of the influence of the thermal environment using subjective judgement scales*. London: BSI.

A multifactorial approach combining driving simulation and motion capture to evaluate the seat comfort for a driver

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Abstract Biomechanical study of a car driver is one of the most referenced aspects for the ergonomic and safety related design process of a whole vehicle. Actually, many of the techniques used to analyse the driving posture and the resulting interactions of driver with seat and car control, could be used to assess biomechanical and ergonomic factors, providing indications on the possible mechanisms of involved in determining the seat comfort. This paper presents a multifactorial methodology based on driving simulation and its combined use with an optoelectronic system for motion capture, an EMG and matrix of pressure sensors, which altogether allow to assess a large set of biomechanical features and the specific muscular strategies characterising the driving posture. Results point out that using the virtual reality of a drive simulator joint to biomechanical techniques may give a relevant impulse to the assessment of ergonomic factors.

1 Introduction

Driving a car is a tasks that involves a wide range of perceptual-motor skills, including a blend of visual-motor coordination abilities, motor planning, cognition, as well as haptic and kinesthetic sensitivities.
Automotive industry strongly encourages research in the field of biomechanics assessment, especially devoted to seat and related postures, since the positions of the driver's body segment are among the most important issues to be considered in the vehicle design process, to improve both safety and comfort of users. *(Porter & Gyi, 1998)*
Some methodologies are extensively applied in the automotive field to the design process, by developing accurate models of human body and methods for quantitative analysis. Furthermore, the positions of the vehicle occupants may significantly interact with the performances of the safety systems.
Even if it is clear that the real progress of the vehicle ergonomics strongly depends on the biomechanics details of the car design, to assess criteria to measure and analyze the interactions between driver and car could play a key role. *(Yamazaki, 1992)*
The driver's biomechanics introduce additional complexity with respect, to the study of a traditional sitting posture. First, the feet of a car driver are primarily involved in pedals operation thus not really supporting the driver's body. Body balance and its control have thus to be assured by a seat equipped with a long inclined backrest and lateral supports, although those elements produce some constrains in the posture.
Driver's posture and movements are the result of multiparametric interactions. It is evident that an integrated analysis of all the aspects involved in the car driver posture is fairly complex and practically impossible to propose as much as researcher often tackles only one component of the whole problem.

A need arises to develop a multi-factor method for studying the car driver's posture, specifically addressed to the dynamic analysis of the driver comfort.
One attempt to integrate different parameters was done in the Project "*Apps4Safety"*, with an experimental approach, not addressed to driving, but appropriate for any typology of sitting postures. In this experimental protocol, bilateral kinematics data from a motion analysis system, kinetics data from pneumatic force-sensing cells, and EMG data from six pairs of upper-limb muscles were collected for different driving situations involving encounters with obstacles and thus requiring drivers to act on steering or brake pedal.
The experimental protocol was applied on a limited and structured sample of 12 subjects to verify feasibility and validity before being transferred to the automotive industry that was in charge of the extended analysis.
By integration of different measures to study the seated the car driver's posture, this approach seems to have the potential to provide new instruments for the design and the assessment of seat prototypes and could also be very important for the development of a new models or dummies with improved features.
As the objective assessment of comfort involves identification and remediation of specific areas of difficulty, measures of biomechanical factors have to be included in complete evaluation protocol, allowing experts to better refine their comfort outcome measures, also usable to monitor design effectiveness.

2 Biomechanics Assessment Setup

The aim of this paper is to report some biomechanical recordings and related analysis methods of human posture and movements. The focus is directed towards physiological, kinetic and kinematics recordings during simulated driving. Further, the existing technology and analyzing methods are discussed their uses in ergonomics to delineate the basic aspects of seat comfort during driving simulation. Modelling approaches based on experimental data will be also presented.
In this experimental framework, a measure of muscular activation have been performed by utilizing a driving simulator, dynamometer and EMG devices with human volunteers.
The subjects of the study were recruited among peoples who voluntarily wanted to participate to the activities. Based on the principles of the Declaration of Helsinki, the purpose and contents of the study were sufficiently explained to the subjects before they participated in the experiment, and the subjects were required to submit their written informed consent. The subjects had no history of neuro-musculo-skeletal system disease.
Among the recruited subjects, six able-bodied elderly individuals (>65 yrs), three young students (<30 yrs) and three adult participants, gave informed consent to contribute in data collection.
The experimental protocol has been implemented on both "ReAsonably Priced Immersive Driving Simulator" (RAPIDS) and "Sim-Panda" of the Department Pharmacy of the University of Salerno (DIFARMA), both developed in the DriveIn2 Projects in cooperation with FIAT Chrysler Automobiles.

2.1 Virtual Environment

The RAPID Simulator (Figure 1A) has a display system composed by 3 projectors with 3D capabilities and a curved screen with more than 180 degrees of field of view. The simulation physical engine is a specialized version of the popular software for entertainment "rFactor" (Image Space Incorporated) and the user interface is a modified version of commercial grade steering wheels, pedals and gearshift (ARC Team – Pavia). RAPIDS is equipped with D-Box motion system "2200i - 4 Actuator Kit" capable to deliver motion cues in a wide range of frequency, within three axes of movement (pitch, roll and heave).
The Sim-Panda Simulation Setup correspond to a real FIAT Panda car with right hand drive, equipped on left side with a full interface for driving simulator and a G-Seat, so is possible to drive virtually in immersive scenarios by the inside of a real car. (Figure 1B)



Figure 1: Simulation Setups – A: *The ReAsonably Priced Immersive Driving Simulator* ***– B:*** *The Sim-Panda*

For this test, virtual driving scenarios have been developed, especially designed to study the features of the neuro-muscular feedback control and postural at the disturbance response.
The first one provides a hard braking to avoid a collision against a parked car, thus it is focused on longitudinal accelerations (see Figure 2). Participants are instructed to drive at limited speed until they reach the road marker, (Figure 2.b), then to brake to avoid the collision.

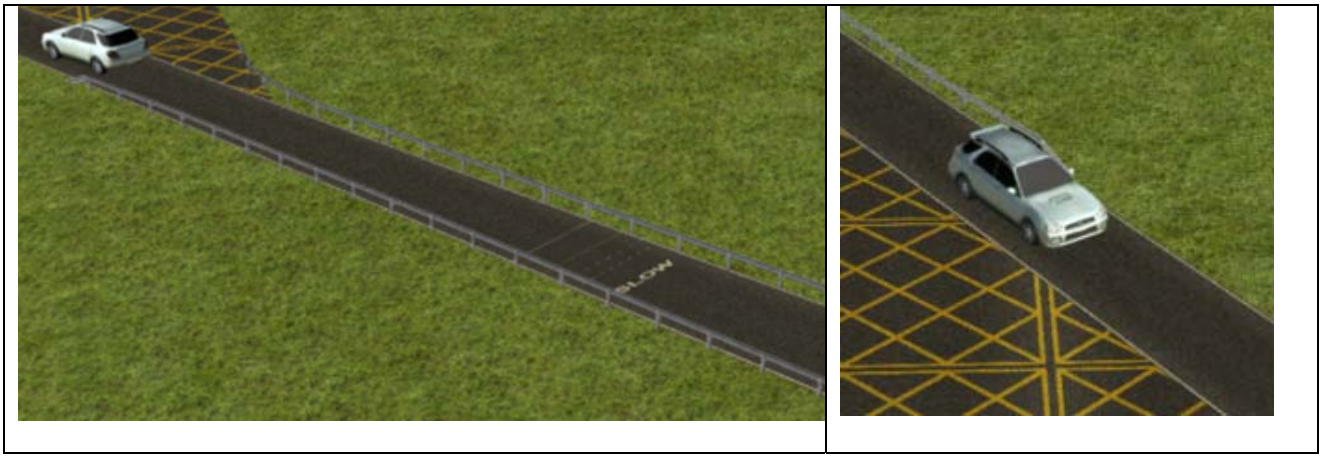


Figure 2: Test Scenario 1 – *Obstacle on the road – Road Marker for start braking*

The second scenario designed involves an obstacle on the road that is tardily visible to the driver. This latter is instructed to drive at limited speed (80Km/h) trying to avoid collisions (see Figure 3). The presences of the unexpected obstacle leads to an action on the steering wheel, with lateral accelerations.



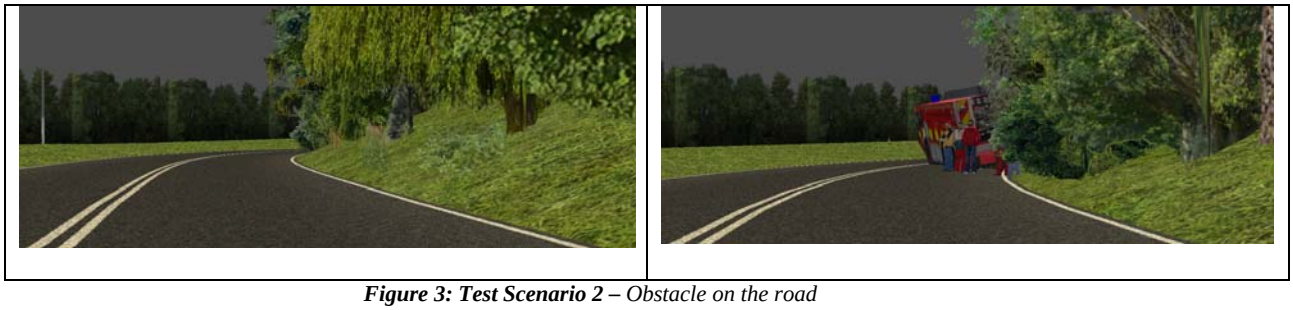


Figure 3: Test Scenario 2 – *Obstacle on the road*

The previous scenarios has been specifically designed to track movements and to collect muscular activities during dynamic postural perturbation, dues to tilting and vertical displacement of the simulator motion platform, related to speed variation and lateral swelling.

2.2 Motion Tracking and Anthropometry

Each participant underwent a full anthropometric assessment, then was outfitted with 21 light markers so that a 3-camera motion capture system (Andoeder) could record the 3-D trajectory data of his body during each driving scenario. Markers were placed bilaterally on main body landmarks.
Kinematics and kinetics data for participants were collected at 100 Hz and were pipelined by two free software: Kinovea (www.kinovea.org) and Tracker (www.opensourcephysics.org) to Microsoft Excel for further processing. The Motion Tracking Coordinate System, and related Trajectories Axis, are determined by using a common reference point, with each camera tracking motion in a 2D plane (see figure 5).
The driver position then was measured, and the reference point for motion tracking was taken as origin of axis for trajectories.

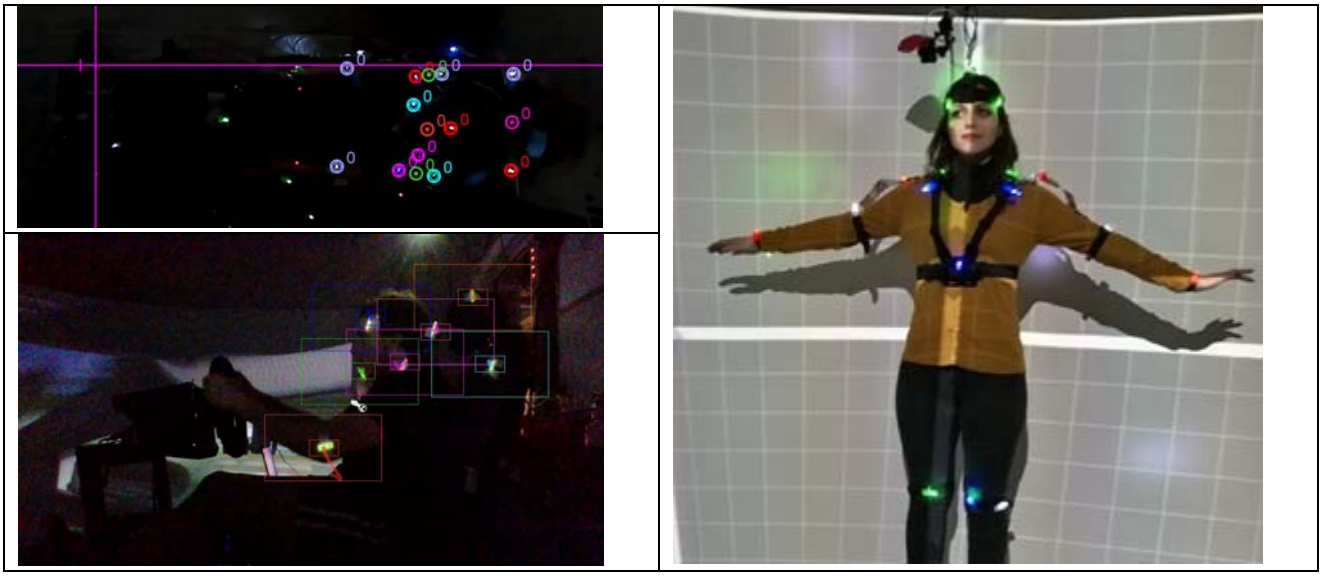


Figure 4:*Motion Tracking and Anthropometry*

2.3 Electro-Myo-Graphy

Muscle activities were recorded with 12 tripolar surface electrodes that were placed bilaterally on shoulder (anterior and posterior deltoids), neck (cervical paravertebral muscle at level of c4 and sternocleidomastoid) and arm muscles (biceps brachii and the long head of the triceps). Prior to driving scenarios data collection, electromyographic activity was obtained during maximal voluntary contraction (MVC).
Previously tested and calibrated reaction forces - pneumatic sensing system (NPX semi-conductor) were used to collect the kinetic data of each participant as they drove the simulator (see Figure 2.12). Each participant was given ample time to become acquainted to the sensing seat, and then was asked to push on a dynamometer to the maximum volume contraction. Bilateral seat kinetic data were collected at a sampling frequency of 60Hz. With this pneumatic system, the Ground Reaction Forces derives by pressure measures, so the force value could be obtained by multiplying the pressure read from a sensor by its measurement area.

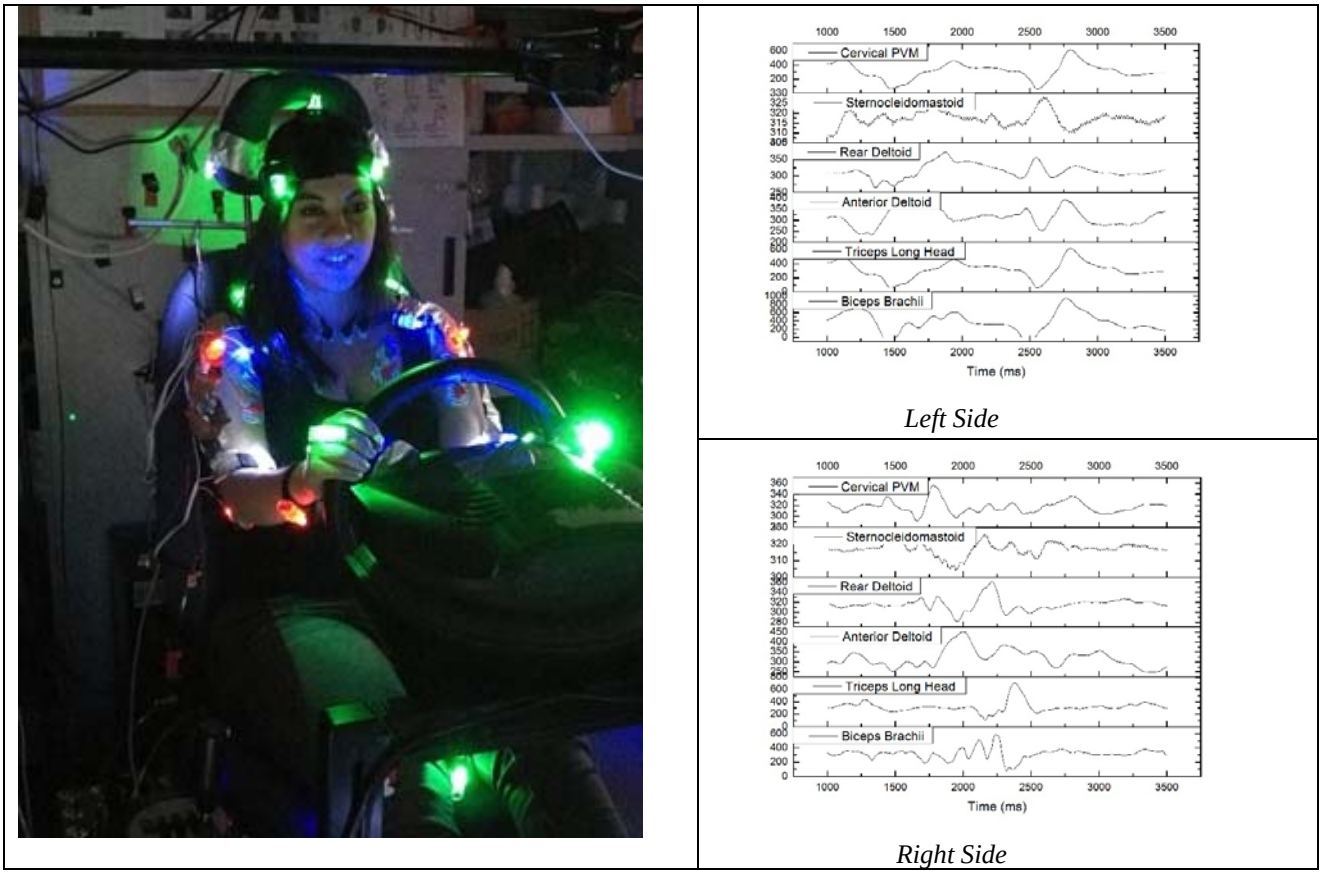


Figure 5: *EMG recordings*

3 Examples of dynamic biomechanical comfort evaluation

Analysis of the seating posture could be approached by considering parameters (see for instance postural angles) obtainable by digital video recording techniques or by opto-electronic systems, which could be very helpful to evaluate of the ranges of comfort attained. *(Judic et Al.,1993; Matsuoka & Hanai,1988)*
Positions of the major body segments at different time, could be represented by a right shift offset in a series of 2D scatter plots, that greatly facilitate to evidence the differences between subjects. (Figure 5)

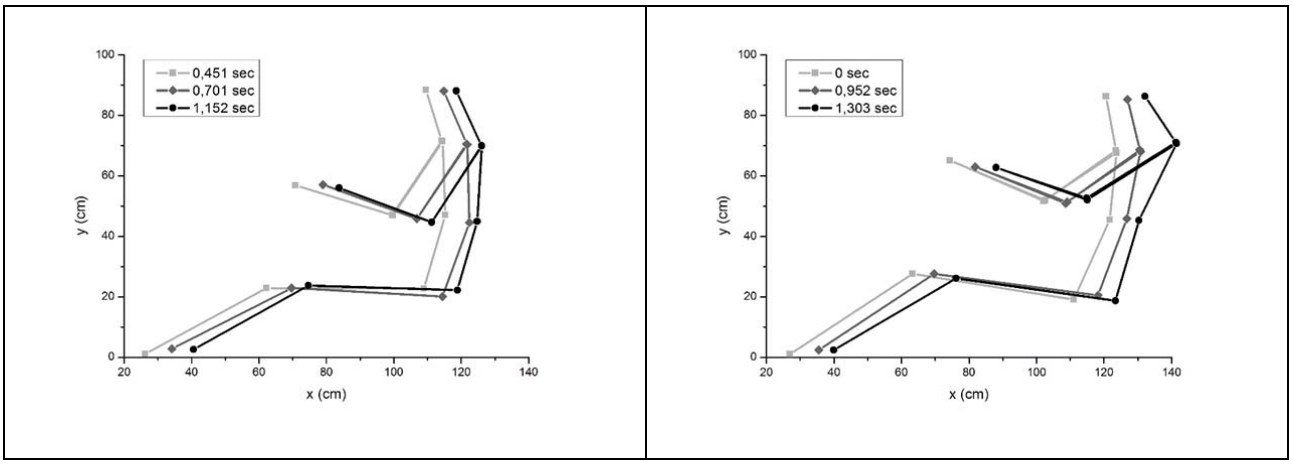
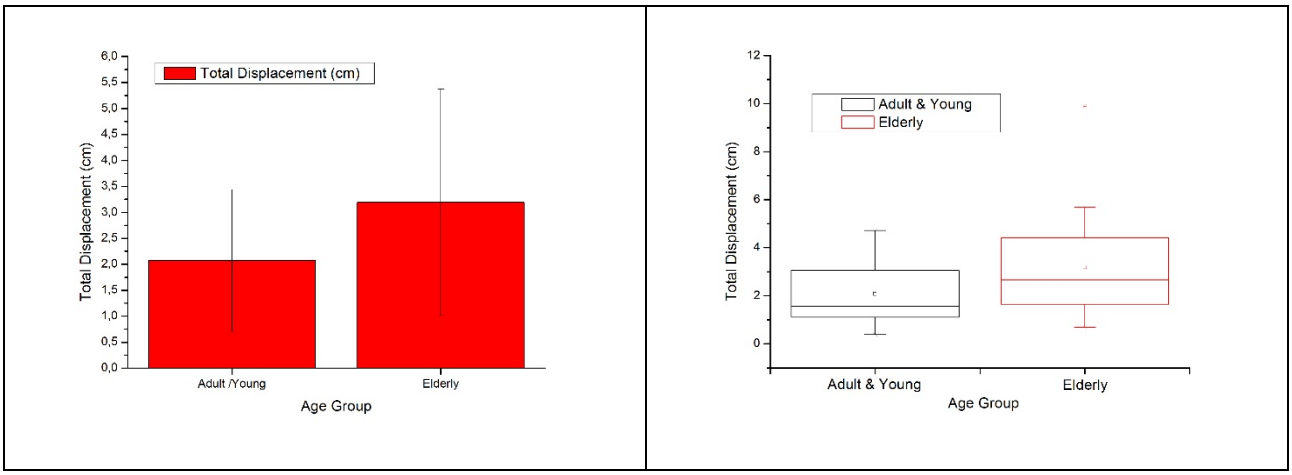
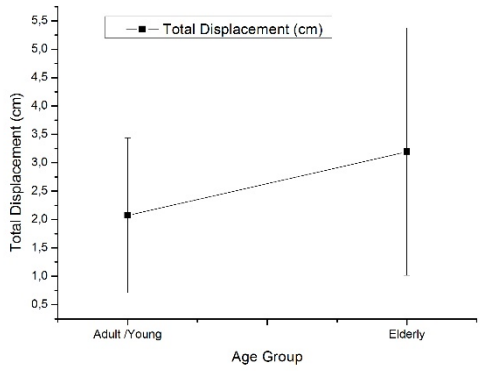


Figure 6: *Graphical analysis modality of driver's posture dynamics*

A relevant outcome of the comparison between elderly and young peoples is that the overall displacements were similar for males and females in magnitude, but significantly differ between elderly subjects and under 65. In particular the head total displacement, either during steady state braking and in the course of evasive maneuvers appears to be significantly larger for aged peoples. The shoulder movements are also considerably more extended than in the group constituted by young and adult subjects.

In the following figure (fig. 7), aggregate data obtained by the Analysis of Variance (ANOVA) performed on total displacement of the head in the first scenario are reported for each age group with the relevant box charts, bars and line plots.

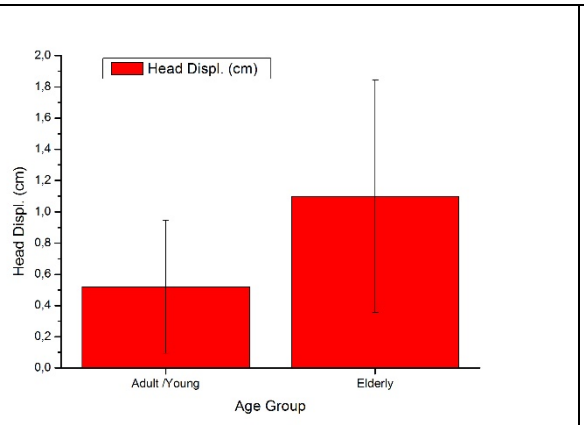


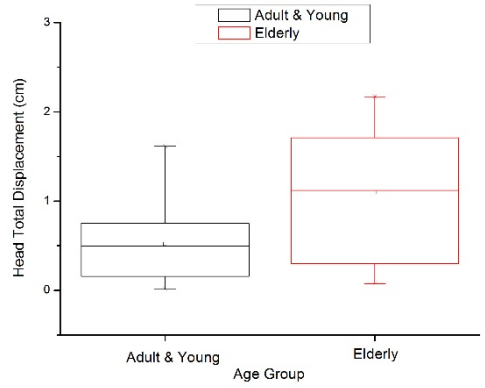


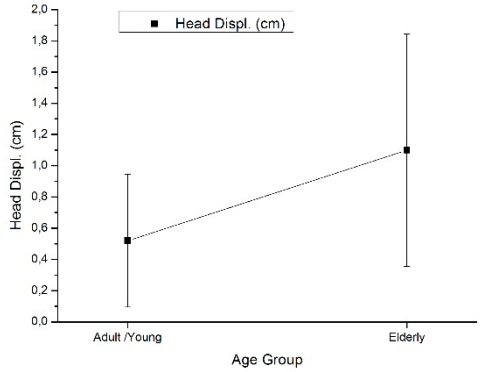
Age Group	Total Displacement (cm)	SD	Significativity
Adult / Young	2,07278	1,36658	0,07318
Elderly	3,19389	2,17957	

Figure 7: Head Total Displacement Vs Age Group – Scenario 1

Figure 8, aggregate data obtained by the ANOVA performed on total displacement of the head in the second scenario are reported for each age group with the relevant box charts, bars and line plots.



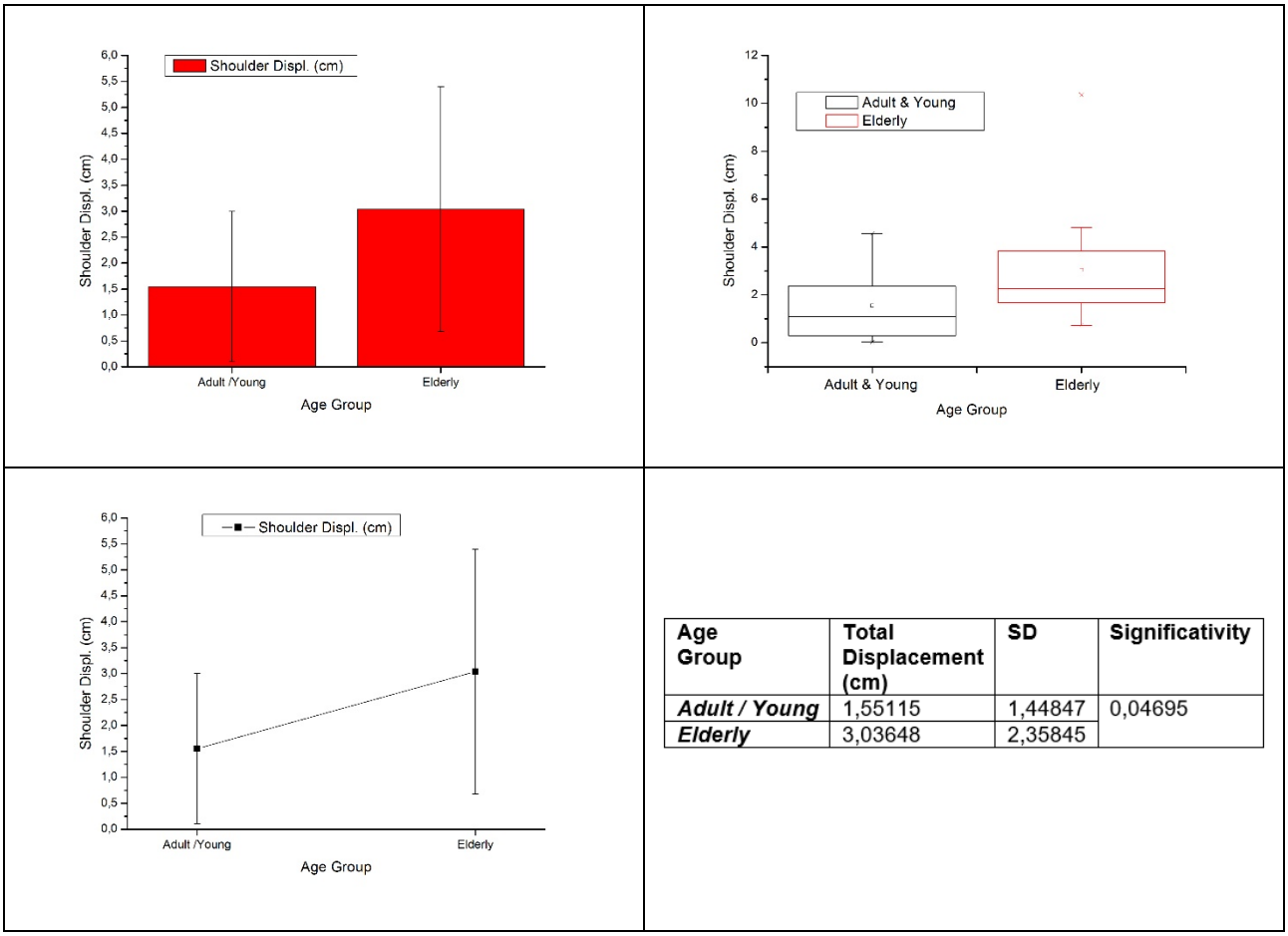




Age Group	Total Displacement (cm)	SD	Significativity
Adult / Young	0,51973	0,4258	0,01418
Elderly	1,099	0,74453	

Figure 8: Head Total Displacement Vs Age Group – Scenario 2

In figure 9, aggregate data obtained by the ANOVA performed on total displacement of the shoulder in the second scenario are reported for each age group with relative box chart, bar and line plots.



Age Group	Total Displacement (cm)	SD	Significativity
Adult / Young	1,55115	1,44847	0,04695
Elderly	3,03648	2,35845	

Figure 9: Shoulder Total Displacement Vs Age Group – Scenario 2

Despite the evidence of a general decline of sensory and motor functioning in elderly people due to the aging, elderly people seems to have an unusually strong postural response the low postural disturbance derived by simulator platform movements and actions on virtual vehicle commands.

This interpretation agrees with the increased and perhaps maladaptive reliance on the functional stretch reflex in the elderly population, that could point out the presence of overactive stretch reflexes in many of the elderly subjects, being also consistent, with the present findings.

The more extreme response evoked in the elderly population by an impulsive disturbance, such as that used in this study, is more likely to be within the subject's maximal capacity to respond (even if in presence of a deterioration of the sensorimotor function), with a potential for the response to a mild perturbation to be fairly above what is normal or optimal.

Also the pressure maps at the body–seat interface (Figure 10), that describe how forces are exchanged between man and seats helps automotive researcher and designer in understanding the pressure patterns that are appropriate for the human body and that improve what is called comfort. *(Guenaelle, 1995)*

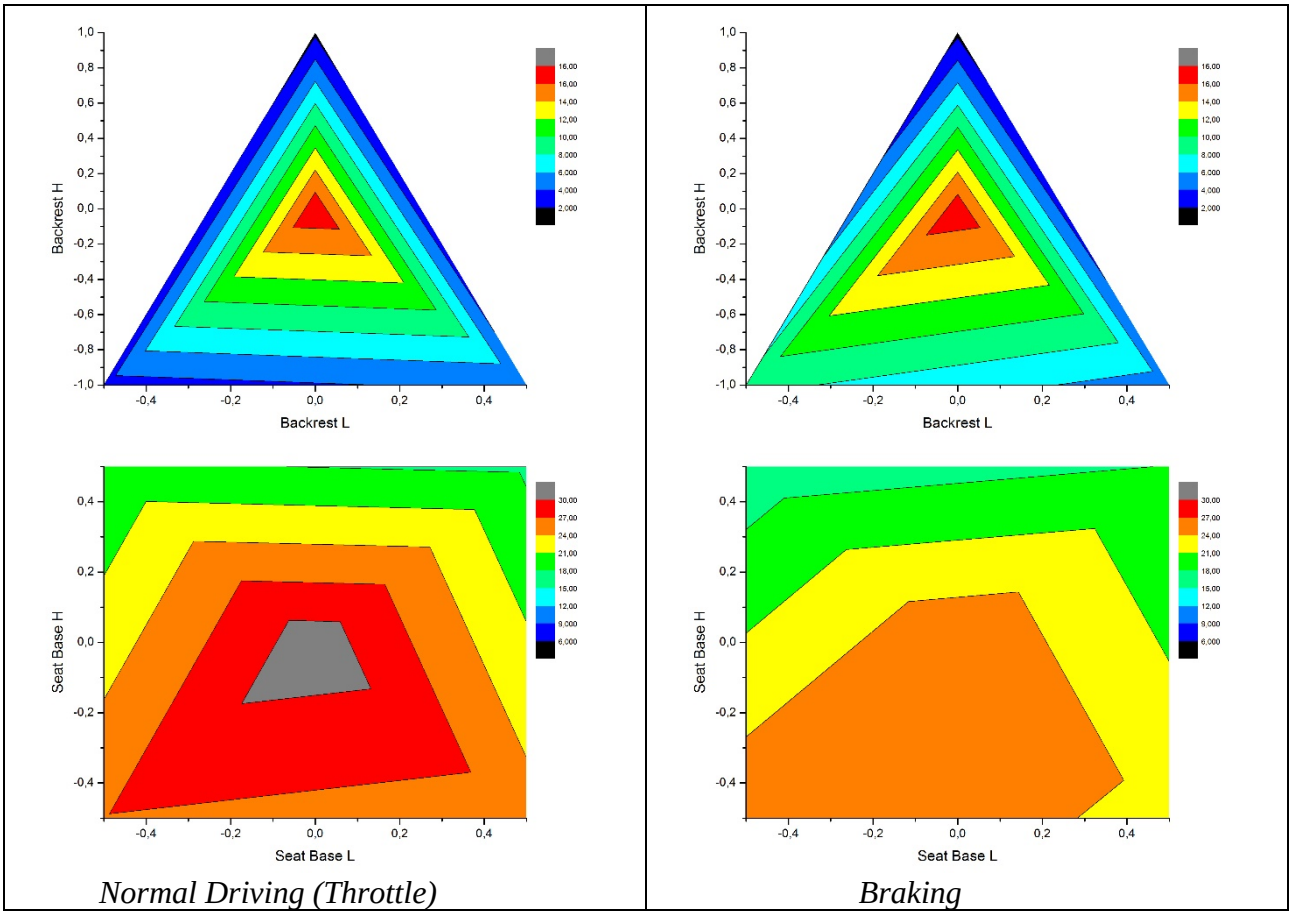


Figure 10: *Reaction Forces on the backrest and the seat base before during the braking event, reported as "color-map" and expressed in terms of pressure (kPa) – Note the weight transfer from seat base to backrest dues to driver's bracing during braking and the asymmetries dues to pedal pressing*

Also Electro-Myo-Graphy (EMG) of the upper body muscles may be also applied to the ergonomic analysis, to find the proper balance in the muscular activities. Great attention has to be paid to avoid ambiguous interpretation of the EMG activity.

Indeed, a too low muscular activity is associated with an unfavorable posture immobility, and a too high muscular activity is evidently related to muscular fatigue. *(Colombini et al.,1986)*

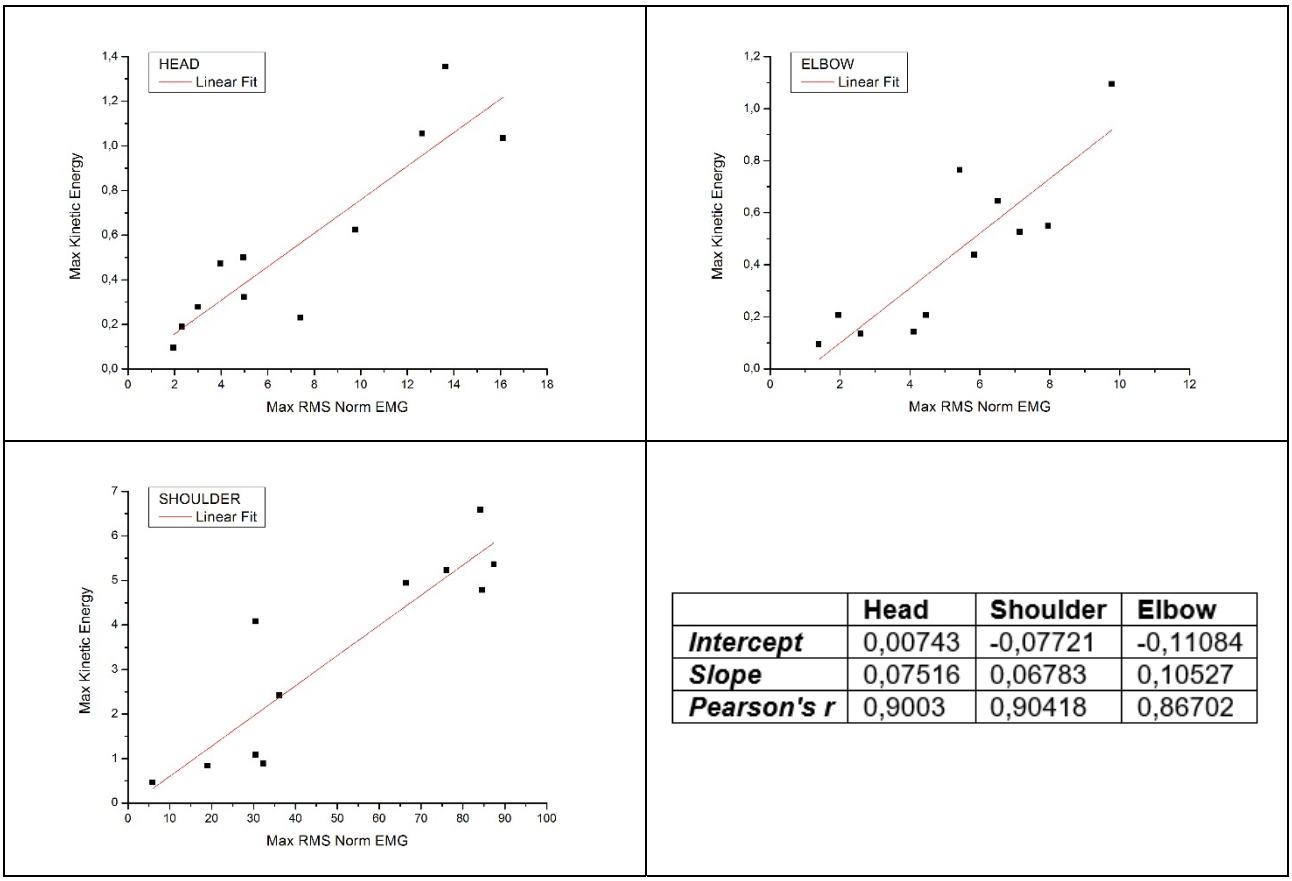
Nevertheless, in the present study we found very interesting signs by studying the activation strategies of head, shoulder and arm muscles, in spite of the small number of subjects involved in the experiments. One remarkable evidence was obtained in the first virtual driving scenario. This driving task culminates with the arrest of the vehicle that is reproduced by the simulator motion system with a reverse tilting pulse. So, the experiment can be used to assess the synergistic patterns present in the forces causing joint moments and those associated with the generation, absorption and transfer of mechanical energy.

The observed patterns of generation, absorption and transfer of mechanical energy at the joints demonstrate inter-segment transmissions of energy through the joint centers, and through the muscles, as well as generation and absorption by the muscles themselves.

As a result, the maximum values of these patterns has been compared with the ones from the EMG signal, so as to achieve a fundamental relationships derived from the biomechanical experiment likely to be applied beyond the driving movements.

In the following graphs (figure 11) the Pearson's, parameters are reported, with the relevant scatter plots and interpolations, related to the aggregate data collected, in the scenario 2 and on all subject. The correlation analysis has been performed between the maximum RMS value of the normalized EMG signals of neck, arm

and shoulder muscles and the maximal mechanical power of the relative body segment. Mechanical power is derived from the kinetic energy of upper body parts, calculated by estimating masses of body segment by whole body weight, using the parameters provided by Plagenhoef et Al. (1983)



	Head	Shoulder	Elbow
Intercept	0,00743	-0,07721	-0,11084
Slope	0,07516	0,06783	0,10527
Pearson's r	0,9003	0,90418	0,86702

Figure 11: *EMG Maximal Amplitude and Mechanical Power Relationship*

The patterns of generation, absorption and transfer of mechanical energy at the joints during the pulse reaction involves intersegment transfers of energy through the joint centers, and transfers of energy through the muscles in addition to the generation and absorption by the muscles.

It is also interesting to note that the CNS uses those mechanical interactions among limb segments in its control strategies. As a matter of fact, the mechanical interactions among the limb segments that are exhibited by interactive torques are generated by the movement of each segment at all other joints of the limb. The effect of this interactive torques has be taken into account by the neuro-muscular system, during the control of limb movements. For instance, during single-joint movements, a specific muscle effort is necessary to prevent motion caused by the interactive torques at the other joints when only one joint of the limb is actively rotated. During multijoint movements, the effect of interactive torques can result in different complexity of movements, depending on the coordination pattern. *(Almeida et Al., 1995)*

Whereas interactive torques seem to be the dominant biomechanical factor responsible for differential complexity of arm movements, movement might be additionally influenced by other biomechanical factors arising from the complexity of the structure of this effector.

4 Human body modelling for dynamic comfort assessment

Data obtained by the above described methodology makes possible to generate a Neuro-Muscular-Skeletal (NMS) model based on experimental data, that could be useful in developing active models for comfort assessment simulations.

Indeed, the methodology based on simulator experiments is designed to obtain parameters for modelling and simulation of whole NMS system, by a two stages approach.

The first phase is aimed to achieve a set of subject-specific parameters that describe muscle properties, and the second one has the purpose of tuning the model's parameters to fit the driver kinematic response to perturbation recorded in the experiments, taking into account the feedback control of muscles operated by the Central Nervous System (CNS) with a combination of high-level supraspinal and low-level spinal signals in controlling human muscles.

The first stage of this methodology is aimed to obtain a set of parameters of NMS model for an individual to accurately estimate the net joint moments by a hybrid forward and inverse dynamic optimization method, as represented in the following scheme.

Position data from markers and the external reaction forces on steering wheel, pedals, foot support and seat are collected, so joint angles are calculated and differentiated to obtain angular velocities and accelerations so, by using the scaled model and rigid body dynamics, joint moments can be estimated. Then the inverse dynamic joint moment is used to calibrate the musculoskeletal parameters that are perturbed and the forward dynamic loop is rerun until the difference between the two joint moments is minimized.

The modelling phase in the fixed based set-up could be considered a specific "calibration process" that uses a set of standard trials to learn the muscle dynamics across different muscle contractile conditions to alter the initial uncalibrated parameters. Thus the moments estimated by the NMS model fits the net joint moments experimentally measured, minimizing the root mean squared error.

In this calibration process, musculoskeletal parameters are tuned to individual subjects. The estimated muscle forces can be determined by a hybrid forward and inverse dynamic optimization method, as represented in the following scheme.

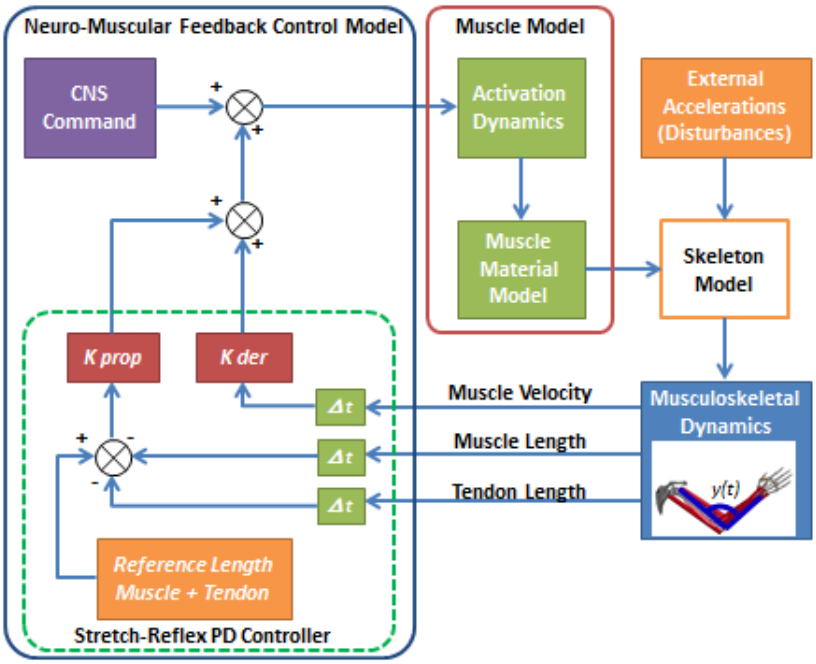


Figure 12: *Proposed model to neuromuscular feedback control to posture perturbations*

The high-level control signals from the brain are believed to be a part of the CNS, that is responsible for tracking specific tasks by integration of multiple sensory inputs such as vestibular, visual, and proprioceptive signals.
The proposed methodology is an attempt to estimate and modelling muscle excitations, in terms of peripheral nerve action potential, which initiates the muscles excitation-to-activation process leading to the execution of the movement, taking into account the anticipatory postural control.
By combination of feedback control, static optimization and forward dynamics the muscles excitations required to drive a model that replicates the experimental joint motion will be estimated.
The low-level controller is referred to the stretch-reflex relative to the feed-back signals originated by muscle spindles and Golgi-Tendon Organ (GTO). The muscle spindle provides the CNS with information about length and contraction velocity of muscles, while GTO provides the CNS with information about forces in muscle-tendon complex (MTC) and helps to stabilize posture and movements.

$$Excitation(t) = CNS(t) + Kp\left[L_{MT-Ref} - l_M(t-\Delta t) - l_T(t-\Delta t)\right] + Kd\left[-\overline{V_M}(t-\Delta t)\right]$$

Where:
$L_{MT\text{-}Ref}$ = the reference length of muscle-tendon complex;
l_M = the muscle fiber length;
lT = the tendon length;
VM = the muscle velocity;
Δt = the monosynaptic latency (25ms)
Kp and Kd = the position and velocity gains for the stretch-reflex

The gains Kp and Kd are calculated by using an optimization algorithm that minimize position and velocity errors between simulated and experimental segments displacements.
Estimation and consequent optimization of proportional and derivative gains could become the final stage of the comfort evaluation, not just by considering the those gains as a comfort rating method, but also using reduction of Kp and Kd as a criteria to design interface between occupant and seat.
The proposed methodology could be furthermore used to isolate, by “difference in differences” estimation, the different contributes in the overall body kinematics by taking into account not only the neural command coming to the high-level (CNS) control system, but also the inputs to the musculoskeletal model based on the low-level stretch-reflex controller and disturbances as real world acceleration, introduced to the system as inputs.

5 Conclusions

The simple description of sitting position during driving done by assuming the relative orientation of body segment as indicators for comfort evaluation is unsatisfactory. Thus an extended parametric exploration to draw significant conclusions to postural assessment in comfort evaluation has been proposed, using methods that can overcome the subtle complexities of comfort measurement furtherly complicated by factors as user subjectivity, anthropometry and interface geometry.
Research performed in recent years aimed to find proven analytical metrics and objective measures that could be representative of the relative effects related to comfort.
These objective measures, that includes pressure distribution, posture analysis, computer-aided design (CAD), thermography and electromyography (EMG), shown that some of the main factors that affect seating comfort are seat-interface pressure dynamics and whole-body vibration. *(Parakkat et Al., 2006)*

Furthermore, the body reaction depends on a range of structures and mechanisms that regulate transmission of motion through the body itself: bones, cartilage, synovial fluids, soft tissues, joint kinematics and muscular activity.

So human response to postural perturbations is a very complex phenomenon that, nevertheless, has significant implication in comfort analysis because vibration encountered during driving are stochastic and they contain transient events that are perceived much more unpleasant by human body. *(Mansfield et Al., 2000)*

The proposed methodology can study the human body response to postural perturbations by analysis of motion tracking, reaction forces and muscular activities, specialized for driving comfort assessment. The perturbation are reproduced in a driving simulator equipped with an advanced motion system to allow the dynamic displacement of the muscles involved vary in a naturalistic way and be subjected to different vibration frequencies and different time of vibration exposure, as happen to perfectly simulate a comfort status .of the driver can thus be objectively evaluated.

References

1. Almeida GL, Hong DA, Corcos D, Gottlieb GL (1995) Organizing principles for voluntary movement: extending single-joint rules. J Neurophysiol 74:1374–1381
2. Colombini,D.,Occhipinti,E.,Frigo,C.,Pedotti,A.,Grieco,A.,1986. Biomechanical, electromyographical and radiological study of seated postures. In: Corlett, N., Wilson, J., Manenica, I. (Eds.), The Ergonomics of Working Postures. Taylor & Francis, London, pp. 331–344.
3. Guenaelle, P., 1995. One methodology to evaluate Automotive Seat Comfort. In: Proceedings of the Third International Conference on Vehicle Comfort and Ergonomics, Bologna, Italy, 29–31 March, pp. 231–240.
4. Judic, J.M., Cooper, J.A., Truchot, P., Van Effenterre, P., Duchamp, R., 1993. More objectives tools for the integration of postural comfort in automotive seat design. SAE Technical Paper Series 930113
5. Matsuoka, Y., Hanai, T., 1988. Study of comfortable sitting posture. SAE Technical Paper Series 880054
6. Plagenhoef, S., Evans, F.G. and Abdelnour, T. (1983) Anatomical data for analyzing human motion. Research Quarterly for Exercise and Sport 54, 169-178.
7. Porter, J.M., Gyi, D.E. (1998). Interface pressure and the prediction of car seat discomfort. Int. J. Vehicle Des. 19 (3), 255–266
8. Schillings JJ, Meulenbroek RGJ, Thomassen AJWM (1996). Limb segment recruitments as a function of movement direction, amplitude and speed. J Mot Behav 28:241–254
9. Yamazaki, N., 1992. Analysis of sitting comfortability of driver's seat by contact shape. Ergonomics 35 (5–6), 677–692.
10. Parakkat, J., Pallettiere, J., Reynolds, D., Sasidharan, M., El-Zoghb, M., "Quatitative methods for determining U.S. Air Force crew cushion comfort", Society of Automotive Engineers, Inc., Warrendale, PA, USA, 2006, Technical Paper No. 2006-01-2339
11. Mansfield, N.J., Griffin M.J. Difference Thresholds for Automobile Seat Vibration, App. Ergonomics 31, pp. 255-261, 2000

PRESSURE SENSING AND CONTROL OF AN AIRCRAFT PASSENGER SEAT

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Abstract This paper presents the development of an automatic morphing seat backrest intended to reduce the surface pressure experienced by the passenger from the seat. Uncomfortable, high surface pressure zones on the backrest can be alleviated by decentralizing the occupant's weight. This is difficult to achieve in a conventional static seat design due to the large variations in passenger anthropometry. In this paper, a morphing seat design is proposed to adjust the seat's surface curvature with the purpose of decentralizing the pressure distribution. In turn, such adjustment of the backrest surface curvature in real time can help to create a more comfortable (less discomfortable) seat contour that is specific to the passenger. The improved pressure distribution is intended to decrease discomfort during flight while taking different comfort/discomfort models into consideration.

Discrete pressure distribution data is obtained from a custom-made sensor mat embedded within the backrest cushion. The data is used to compute the seat's cushion deflection and corresponding backrest contour caused by the passenger's weight and given physique. The surfaces of interest - the passenger's back and the seat, are modelled and discretized. The discretized surface contact pressure is integrated into a hyperelastic contact model to determine the loading profile. From this analysis, the current pressure distribution and the backrest cushion's surface changes are computed and used in the control system to create the corresponding actuation signal of the surface. The required actuation corresponds to the difference between the deformed surface contour caused by the applied load of the passenger's weight over the ground state of the seat cushion and the 'ideal' contour of the seat's surface based on the ideal pressure distribution. The end goal is to produce a change in the backrest so that such change in contour creates a pressure distribution closely resembling the reference value, while keeping the Backrest Distribution Percentage (BRD%) as the parameter to evaluate the effectiveness of the adjustment.

Keywords: Seat design, Pressure sensing, Morphing backrest, Ideal pressure distribution.

1 Introduction

Many factors influence the design of aircraft seats which in turn directly affect their comfort rating. These factors include design requirements such as light weight, thin design, and mandatory safety aviation regulations [1]. The objective of this work is to develop an automatic backrest adjustment system for a passenger aircraft seat. The automatic adjustment is intended to decrease passenger discomfort due to centralized loading on the backrest. The decentralization of the load can be achieved by increasing the contact area between the passenger and the seat via surface morphing. However, as discussed in Section 2, the change in the contact area must result in the ideal pressure distribution. Moreover, the pressure distribution will be evaluated in terms of Seat Pressure Distribution Percentage (SPD%) adapted to the backrest (BRD%). Ultimately, the pressure distribution will be the sole measurement to evaluate discomfort.

The effectiveness of lumbar support in a seat's backrest can be diminished by dimensional mismatch between the user and the seat design. The traditional approach to designing a "comfortable" seat is to use anthropometry data along with surface scanning of the whole-body with the purpose of improving the "static" seat design, such as in [2]–[4]. However, efforts to parametrize the human body contour have been unsuccessful in developing new methodologies that can implement such anthropometry data in static designs of seats in a manner that can accommodate the majority of the passengers [5]. This can alternatively be accomplished by designing a morphing seat contour that aims to adapt to the human body automatically, by constantly taking into consideration anthropometry, seating position and loading profile of the passenger's weight. This paper focuses only on the lumbar morphing part of the seat. This concept can be expanded to the rest of the body. The theory of pressure distribution and anthropometric data is used in this research to develop such automatic adjustment system.

Additionally, this investigation explores the mechanical properties and interactions of materials used to manufacture aircraft seats (such as polyurethane, PU for short) when in contact with the human body, in particularly, the resultant pressure distribution between these two surfaces. The purpose of this work is to expand on the theoretical knowledge of the ideal pressure distribution, previously proposed by Mergl [6], Zenk [7] and Hartung [8]. The theoretical knowledge of the ideal pressure distribution has been limited to be used only in the seat design itself. This is particularly true in the design aspects such as seat contour and material selection based on optimization methods. However, a practical application of this knowledge has not been applied in real time for morphing the shape of the seat to approach the discomfort problem.

1.1 Comfort: An Overview

Before proceeding further, it is important to have a clear definition of comfort and discomfort. Even though there is some debate in the literature about the exact scientific definition of comfort and discomfort, the most agreed upon definitions will be used in this work. These definitions were developed based on subjective and objective reports from different researchers and were first used in [9] and they are as follows: *Comfort* is related to luxury, aesthetics, feeling refreshed, and is highly influenced by expectations, pre-flight and previous flight experiences. Conversely, *discomfort* deals with muscular fatigue factors, pressure points on the body and stiffness. Fundamentally, comfort and discomfort are separate entities, and unlike common believe, they are not opposites of each other. Moreover, comfort is not necessary present in the absence of discomfort [1].

Comfort has been studied significantly more than discomfort. Particularly, the subjective aspects of air-travel comfort have been explored to a good degree such as in [10]. Thus, this paper focuses on the methods needed to reduce discomfort rather than to create comfort. Psychological and subjective aspect (i.e. passengers' perception) of comfort will not be used to determine discomfort. This is because unlike comfort, discomfort can be objectively measured (i.e. via pressure readings, oxygen level in muscles, muscle activity, movement etc.) and it is related to biomechanical, ergonomic and physiological factors across all heathy individuals. These factors include joint angles, tissue pressure, muscle contractions, blood pooling and circulation blockage [9].

2 Seat Modeling and Analysis

In this section, the design of the seat curvature can be derived from the ideal pressure distribution and ergonomics in order to match the curvature of the human body in the most comfortable (least discomfortable) sitting posture. Such interaction should produce an optimal pressure distribution. The seat's cushion *ground state* (initial, unloaded geometry) design and its recline angle affect the seat's comfort (discomfort) rating more than its material properties. Thus, it is better to focus on the seat's contour curvature rather than its material properties.

This is difficult to achieve in a conventional static seat design because passengers' weight and anthropometry is significantly different between the population. Alternatively, a seat design can be created to adjust its surface curvature with the purpose of decentralizing the pressure distribution. In turn, this adjustment of the surface curvature in real time can create a more comfortable (less discomfortable) seat that is specific to each passenger.

Furthermore, the problem can be subdivided into developing a surface contour model with a reference value that can be used as a feedback to the control system. The reference value must work for any reclined configuration. The required actuation must correspond to the difference between the deformed surface contour (caused

by the applied load of the passenger's weight over the ground state of the seat cushion) and the 'ideal' contour of the seat's surface based on the ideal pressure distribution. The end goal should be to produce a change in the backrest surface so that such change in contour creates a pressure distribution closely resembling the reference value, while keeping the BRD% as the parameter used to evaluate the effectiveness of the adjustment.

2.1 Seat and Sitting Models

Firstly, as seen in Figure 1, the origin of the coordinate system used throughout this work is located to coincide with the position of sensor $e_{1,1}$. The pressure distribution, P, on the seat's ground state, S^0, are both defined on the *coronal plane* (YZ plane). Moreover, the reaction force can be divided into perpendicular and parallel components referred to as the normal and shear forces.

The assumption is that the load on the seat is produced only as the result of the passenger's gravitational force on contact with the supporting surface. In other words, no load is generated from muscle or ligament tension. Furthermore, the recline angle is the main factor that affects the load distribution (for a given sitting position) since the normal force and shear force are functions of the recline angle.

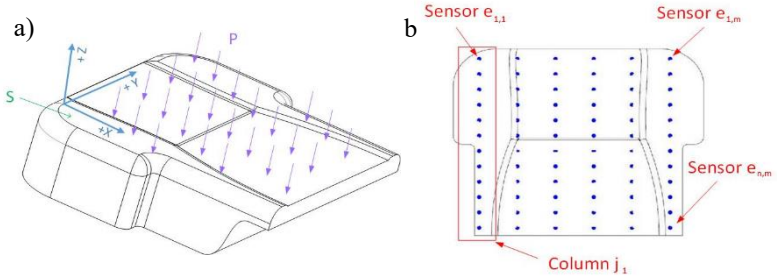


Fig. 1. a) Coordinate system on the PU cushion, b) Sensor elements locations.

The cushion's ground state curvature must be obtained for the specific seat design. The surface is approximated with a series of cubic natural splines since this model works best in this scenario. Since the deflection at the actuated control points change significantly during operation, a high order polynomial fit can be ill-conditioned when a change in curvature occurs. The general seat's ground state curvature is represented by:

$$S^0 = f(x, y, z) \tag{1}$$

where the upper indices indicate the state of the seat's surface (i.e. the upper index '0' denotes the ground state).

Both the seat's curvature and pressure distribution are continuous inside the contact area. However, the sensors can only measure discrete points on the surface of the backrest. For this reason, the surface is discretized to make use of the sensor data. The entire surface can be discretized into m cross-sectional (m being the total number of control points in the y-axis) curves on the XZ plane. Each cross-sectional curve can be approximated by a cubic natural spline with the general form:

$$s_j(x) = \begin{cases} s_{j,1} = a_{j,1} + b_{j,1}(x - x_{j,1}) + c_{j,1}(x - x_{j,1})^2 + d_{j,1}(x - x_{j,1})^3, x\epsilon\,[e_1, e_2] \\ \vdots \\ s_{j,n-1} = a_{j,n-1} + b_{j,n-1}(x - x_{j,n-1}) + c_{j,n-1}(x - x_{j,n-1})^2 + \\ d_{j,n-1}(x - x_{j,n-1})^3, x\epsilon\,[e_{n-2}, e_{n-1}] \\ j \in \{1, m\} \end{cases} \tag{2}$$

where a_j, b_j, c_j and d_j are the cubic polynomial coefficients for each jth curve, $e_{i,j}$ is the sensor's location on the seat surface and m is the number of control points on each sensor row. For n control points (on the x axis), there are n-1 interval in each s_j spline. Each interval requires a cubic polynomial to approximate the curvature between two adjacent control points ($x_{i,j}$ and $x_{i+1,j+1}$). Since n must equal to the number of sensors, it is important to keep in mind the cost of the sensors (approx. $9 USD per Force Sensitive Resistor (FSR) sensor) when selecting the size of n. The magnitude of $s_j(x)$ can be interpolation at any point, (x,y), to obtain the cushion thickness, s(x,y).

Furthermore, there exist two different types of control points in this design - the passive and actuated control points. The passive control points are only affected by the applied point load, $f_{i,j}$, at $x_{i,j}$, and the seat cushion's stiffness, k_c. While the actuated control points are additionally affected by the internal pressure of the air-spring(s), p_s, – which is the control variable and provides the air-spring stiffness k_s.

Following this methodology, the pressure distribution on the backrest caused by F, on the seat's surface is:

$$P = g(x, y, z) \tag{3}$$

In a similar manner as with the backrest curvature, the pressure distribution can be approximated as:

$$p_j(x) = \begin{cases} p_{j,1} = \breve{a}_{j,1} + \breve{b}_{j,1}(x - x_{j,1}) + \breve{c}_{j,1}(x - x_{j,1})^2 + \breve{d}_{j,1}(x - x_{j,1})^3, x \in [e_1, e_2] \\ \vdots \\ p_{j,n-1} = \breve{a}_{j,n-1} + \breve{b}_{j,n-1}(x - x_{j,n-1}) + \breve{c}_{j,n-1}(x - x_{j,n-1})^2 + \\ \breve{d}_{j,n-1}(x - x_{j,n-1})^3, \quad x \in [e_{n-2}, e_{n-1}] \\ j \in \{1, m\} \end{cases} \tag{4}$$

where $\breve{a}_j, \breve{b}_j, \breve{c}_j, \breve{d}_j$ are the coefficients for the internal cubic polynomials connecting two adjacent control points. The coefficients a, b, c, d are related hyperelastically to the coefficients $\breve{a}, \breve{b}, \breve{c}, \breve{d}$ for the $f_{i,j}$ and p_s parameters. The 3D surfaces are obtained by multidimensional interpolation, that is:

$$\tilde{S} = < s_j >, \quad j \in \{1, m\} \tag{5}$$

and

$$\tilde{P} = < p_j >, \quad j \in \{1, m\} \tag{6}$$

where tilde denotes the multidimensional interpolation approximation (from the discrete control points) of the surface. The interpolation method for eqn. (5) and (6) is also done via cubic natural splines for consistency of the method and to avoid instabilities. Thus, the approximate foam thickness, s(x,y), and pressure distribution p(x,y) at any point χ=(x,y) can be computed by interpolating from $\tilde{S}$ and $\tilde{P}$, respectively.

It is now possible to relate those functions to the actual discrete data gathered from a pressure mat. Let P_M be the measured pressure distribution from the applied measured force, F_M, which is a function of recline angle, δ, seat cushion stiffness k_c, the air-spring stiffness k_s, the internal gauge pressure of the air-spring(s), p_s, and human anthropometry and positions (biomechanics) ζ.

$$P_M = f(F_M) = f(\delta, S^0, k_c, k_s, p_s, \zeta) \tag{7}$$

However, only the discrete force distribution $\tilde{F}_M$ can be obtained as point forces from each of the FSR sensing elements in the pressure mat. That is, given an evenly distributed set of data from the pressure mat, arranged in a n x m matrix, the point force for the pressure mat can be expressed as:

$$\tilde{F}_M = \begin{bmatrix} f_{1,1} & \cdots & f_{1,m} \\ \vdots & \ddots & \vdots \\ f_{n,1} & \cdots & f_{n,m} \end{bmatrix} \tag{8}$$

where $f_{i,j}$, is the output in Newtons from element $e_{i,j}$. Naturally, the pressure distribution can be discretized as:

$$\tilde{P}_M = f(\tilde{F}_M, A_a) \tag{9}$$

where A_a is the active area of the sensor's element. This is possible only if the force acts in a small finite area. It can be concluded that this is generally a good assumption for this case since the FSR active area, A_a, is significantly smaller than the overall force distribution area of the seat's backrest. Additionally, since the surfaces are not rigid, uneven distributions are not likely to be encountered. Lastly, since FSR sensors are inherently pressure sensors and have a finite active area, it is adequate to assume (9) holds for this application. The change from force to pressure is simply given by:

$$\tilde{P}_M \approx \frac{1}{A_a} \begin{bmatrix} f_{1,1} & \cdots & f_{1,m} \\ \vdots & \ddots & \vdots \\ f_{n,1} & \cdots & f_{n,m} \end{bmatrix} \tag{10}$$

Subsequently, an ideal or target pressure must be defined. Such target pressure, P_i, must result in the most comfortable pressure distribution. Recalling the ideal pressure distribution (as proposed by [6], [7]), P_i can be used as a starting reference target pressure. To do so, the target pressure distribution must be represented in percentage per body region (PBR for short), represented by $\%P_i$. For simplicity, the backrest is limited to 4 main regions, in this study (Figure 2b) where A_2 and A_3 are assumed to be nearly identical.

The control problem is simply a set point regulator that will use the pressure PBR, $\%P_i$, as the reference with the BRD% as an evaluation of discomfort. $\%P_i$ is derived from the ideal pressure distribution theory. That is:

$$\%P_i = k_1 F + \cdots + k_w F, \ \ \forall \delta, \kappa_c, \kappa_s, \zeta \ \ and \ \ \sum_i^w k_i = 1 \tag{11}$$

where w is the number of regions in the backrest (w=4 for this case). And the PBR must approach the reference:

$$\%P_M \rightarrow \%P_i \tag{12}$$

in a finite time and with the control variable, p_s. The distribution of the actuated surface pressure on the lumbar support is a function of:

$$P_a = h(p_s, F_M) \tag{13}$$

which is part of the resultant pressure due to the passenger's weight, F, k_c and k_s are the stiffness of backrest cushion and the air-spring, respectively. Overall, the measured pressure distribution (from the passenger's weight) can be seen as the combined pressure of the static and actuated surfaces of the seat, that is:

$$P_M = P_s + P_a = f(\delta, S^0, k_c, \zeta) + h(p_b, \delta, S^0, k_c, k_s, \zeta) \tag{14}$$

where P_b, is the resultant pressure distribution when the load F is applied and before the actuation of the air-spring(s). However, there is no need to compute the function P_b and p_s for the parameter δ, S^0, k_c, k_s since F_M and p_s are directly measured. Thus (14) can be simplified as:

$$P_M = P_{b_M} + P_{s_M} + f(p_s) \tag{15}$$

where p_s is the internal gauge pressure from the air-spring(s) that in turn exerts a pressure on the lumbar support area due to a change in geometry and stiffness.

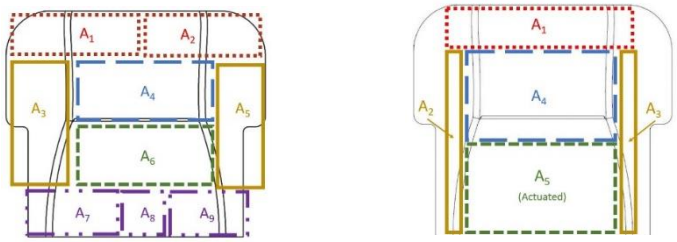


Fig. 2. a) Optimal number of backrest regions b) Backrest divided into 4 sub-regions.

In order to keep or achieve $\%P_M = \%P_i$, the actuator (air-spring) must deflect the surface of interest – the lumbar area. For the controller to know the desired deflection, two relationships (models) must be known, 1) Deformation of the PU foam core, ΔS^F, when the load F is applied, 2) Deformation of the air-spring(s) with p_s.

Furthermore, F is divided into m force distributions, f_j on the XZ plane. Each f_j is a 2D curve represented by a spline (similar to (4)) and when the curves are multidimensionally interpolated using (6), the 3D surface, F, is approximated as $\tilde{F}$. This approximation increases in accuracy as the sensor density, ρ_{sensor}, increases.

The interpolation can be improved by knowing the biomechanical model along with the anthropometry model (or actual body measurements of the passenger) for a more precise interpolation between curves. After obtaining f_j from all the sensor elements from all columns, $\tilde{F}$ can be written as a 3D surface in the form of:

$$\tilde{F} =< f_j >=< e_{i,j} >, \quad j \in \{1, m\}, \ i \in \{1, n\} \tag{16}$$

For $\tilde{F}$, the pressure distribution can be inferred from the individual force measurements, $e_{i,j}$. The measured pressure distribution as $\%P_M$ can be obtained from the pressure sensor data as:

$$\%P_M \approx \frac{\%F_M}{A_a} = \frac{1}{A_a}(q_{1,m}f_1 + \cdots + q_{w,m}f_m), \qquad \sum_i^w q_i = 1 \tag{17}$$

where $q_{i,m}$, is the backrest region coefficient for the measured pressure distribution as $\%P_M$.

The values ranges for q_i are good estimates for determining the ideal pressure distribution. However, the downside of having a range of values instead of a unique value for each q_i is that the controller complexity increases. To simplify the controller design, it is recommended to find a unique solution, if it exist. To do so, a biomechanical model can be combined with P_i to reduce the range of q_i or possibly find the unique solution. It is equally likely that for some passengers' anthropometry and/or position, no solution exists that satisfy both models. Thus, the model can be *relaxed* to find a possible solution for the ideal pressure distribution, P_i, that serves as the set point. A simple biomechanical model can integrate the joint angles that are found to be the least discomfortable whilst sitting. These joint angles and their curves are obtained in a similar way as in [11].

2.2 Pressure Distribution Parameters

The recline angle for the backrest is studied in this work for three reasons. The main reason is to investigate the relationship between recline angle and comfort/discomfort. Secondly, to understand the influence of the recline angle on the resultant pressure distribution – since the load is dependent on it. Finally, it is important to define the preferred angle for the specific tasks while seating (i.e. reading, watching a screen, sleeping, etc.).

A lot of research has been conducted on the relationship between comfort and recline angle. The research on this topic extends from NASA's study on the neutral body positon (occasionally referred to as the zero-gravity

positon) [12] to synchro-tilt, relationships between shear force and optimal backrest recline angle in relation to seat pan recline angle [13]. Other studies focused on specific seating activities and their corresponding optimal backrest recline angle and the importance of lumbar support with recline angle.

An additional parameter often used to evaluate sitting comfort is the seat pan distribution percentage:

$$SPD\% = \frac{\sum_{i=1}^{e_a}(p_{i,j} - \bar{p}_{e_a})^2}{4e_a\left(\bar{p}_{e_a}\right)^2} \times 100\% \tag{18}$$

where e_a, is the number of active elements and $\bar{p}_{e_a}$ is the mean of the active elements (SPD% was originally defined in [14]). This 'comfort' evaluation parameter is often used combination with peak and average seat pressure. A similar pressure percentage parameter (backrest distribution percentage) BRD% can be applied to the backrest. The BRD% has the same form of (18) and is used along with the ideal pressure distribution and biomechanical model in the control method to evaluate the target pressure distribution.

3 Mathematical Deformation and Deflection Models

For this study, the contact behavior resulting from the interaction between the human body and the seat is of great importance to evaluate discomfort objectively. The contact model must be understood to approximate the effect on the seat's curvature from the pressure distribution. The actuator deflection in the control system also requires the model to decentralize the weight of the passenger in order to decrease discomfort.

Materials such as rubbers, foams and most biological materials (such as muscle and skin) tend to exhibit nonlinear stress-strain behavior when loaded. The accuracy of the theoretical deformation depends on the selection of the right hyperelastic material model. Materials such as PU that can achieve large deformations are best modeled with Ogden's large deformation isotropic elasticity model. The criterion to determine the fidelity of the model depends on the model's ability to best fit experimental data of the strain energy function. The Ogden hyperelastic material model, (19), describes the non-linear stress-strain behavior of complex materials, such as rubbers, polymers and some biological tissues. The derivation of the Ogden's equation is quite involved and thus it will be excluded from the present work but it can be found in [15].

$$\psi = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) \tag{19}$$

where ψ, is the strain-energy, λ, are the principal stretches used as independent variables (when the material is incompressible the constrain $\lambda_1 \lambda_2 \lambda_3 = 1$) and the pair ($\alpha$, μ) are the material parameters obtained from experimental data. Principal stretches are relative to a given reference configuration, S^0. If α has a value greater than 2, the material's stiffness will increase with increasing strain. And if α has a value less than 2, the material will soften with increasing strain.

For this work, simple uniaxial compression tests were carried out for each of the materials to determine their coefficients, and were fitted with Ogden's model. Pure shear tests were not carried out since the backrest experiences negligible shear, and with synchro-tilt, both the backrest and seat pan are intended to have no shear. Lastly, the FSRs used to measure the pressure distribution do not respond to shear loads. Thus, it is not essential to know the shear behaviour of the material for this case. However, knowing the shear behaviour can improve the model fitting.

PU foams in particular are network-forming cell materials with low stiffness, low poisson's ratio, low density and have the ability to absorb strain energy and slowly recover to their S^0. PU foams typically have three distinct phases in the strain deformations. On the other hand, muscle, skin and adipose tissues are practically incompressible. Equation (19) can be modified for compressible materials, such as PU foams.

For the seat cushion's material, PU foam, the "Ogden Compressible Foam model" such as in [16] could be used for the analysis if the previous model does not fit well the experimental data:

$$\psi = \frac{2\mu}{\alpha^2}\left(\lambda_1^{\alpha} + \lambda_2^{\alpha} + \lambda_3^{\alpha} - 3 + \frac{1}{\beta}\left(J^{-\alpha\beta} - 1\right)\right), \quad \beta = \frac{\nu}{(1-2\nu)} \tag{20}$$

where ν being the Poisson's ratio.

Ogden's model is used in the HyperFit© software to identify the model parameters of the hyperelastic constitutive models based on nonlinear regression and optimization methods from the experimental data. The first

experiment on the seat cushion was used to test the compression behavior of the PU foam under a load on a solid surface, Figure 3a. These tests were performed seven times at different locations on the backrest foam. The number of experiments was chosen to coincide with the sensors calibrated in the normalization processes of the pressure mat. However, since the PU foam can be assumed to be isotropic, similar responses were expected.

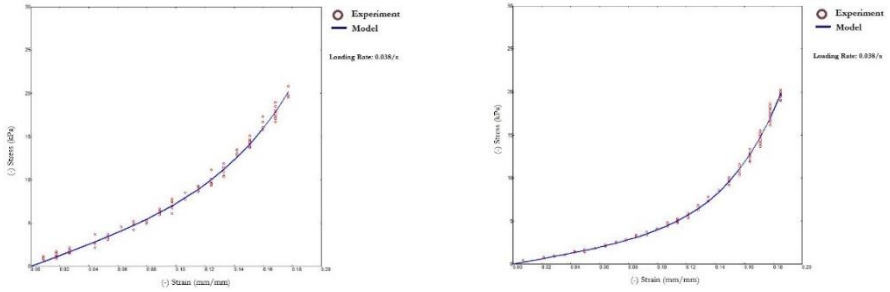


Fig. 3. Stress-strain compression tests a) PU foam b) PU foam-ballistic gel.

The results from this experiment agree with the theoretical data for hyperfoam polyurethane seat-cushion like materials in [17]. However, as observed from Figure 3a, some data points deviate from the model. As previously discussed, the accuracy of the model can be increased by performing pure shear and tensile tests. The discrepancy can be attributed to the fact that the real foam experiences compressibility and shear during a compression test – two factors that are not accounted for in this model. Therefore, it is best to use Ogden's hyperfoam constitutive model (20) for the case where load is applied directly to the foam from a rigid surface.

In the second test (Figure 3b), the PU foam and ballistic gel were tested under compression. The sample (ballistic gel on top of the foam) was tested for the pressure range of 0 – 112 kPa. However, only the range of 0 – 20 kPa was considered, as pressures higher than 20 kPa are assumed to be uncomfortable as discussed in [18]. This experiment was performed to better represent the specific loading profile encountered in the seat (human-seat contact model). There is better correlation between the data and model mostly because the ballistic gel is incompressible and shear is negligible. Thus, for the control system, the data from the second experiment will be used in the deflection contact model.

4 Seat Actuation and Sensing Development

In order for the seat to have automatic lumbar control, pressure sensing elements and pneumatic air-springs had to be installed on the seat as seen in Figure 4. The design for the seat in this work has been equipped with 2 overlaid air-springs to account for the contour of the lumbar gap between the seat and the occupant. Both air-springs work together for most configurations. The lower air-spring can be configured to accommodate occupants with lower lumbar support needs (i.e. children).

4.1 Development of Surface Pressure Mat

For this study, a pressure mat was developed to allow real time surface pressure data gathering from the occupant when seated. The sensor element selected was the Interlink's FSR Standard 402. An FSR works as an open circuit when no load is applied and when a load is applied to its active area the substrate deforms causing a decrease in resistance. The change in resistance can be utilized to calculate the load applied to the FSR element. The typical configuration for this passive sensor is in a voltage divider as shown in Figure 5, with voltage V_e as the output. The sensor mat contains a total of 72 sensing elements arranged in an evenly distributed pattern 6 by 12. The arrangement of the sensors focuses only on the 4 different areas of the backrest (Figure 2b).

The pressure mat was normalized and calibrated. The initial part of this calibration process is intended to evaluate the basic response of the sensors and observe the drift and repeatability. The dynamic calibration was performed on a hyperplastic surface with a load from a linear actuator with a specific loading profile.

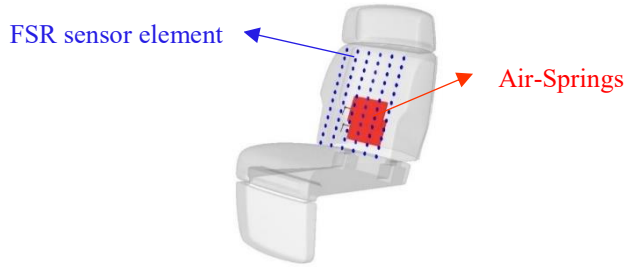


Fig. 4. Sensors and actuator positions on the seat's cushion.

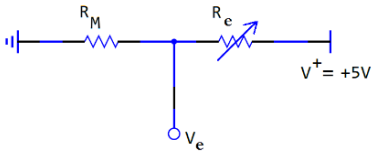


Fig. 5. FSR's voltage diver basic circuitry.

During operation (Figure 6), the measurement from the pressure mat comes with certain error even after calibration. These errors originate mainly from drift, saturation and hysteresis. The pressure, $p_{i,j}$ for sensor $e_{i,j}$ sampled at time t_n is: (Note: the exponents in brakes denote the value sample at time (t_n), at sample number n).

$$p_{i,j}{}^{(t_n)} = \frac{f_{i,j}{}^{(t_n)}(V_e)}{A_a} \tag{21}$$

However, $f_{i,j}$ (which is a function of voltage, V_e) comes with certain static and dynamic errors. Thus, $p_{i,j}$ can be modified such that the error is accounted for in each sampling reading with sampling time interval, Δt (~25Hz):

$$p_{i,j}{}^{(t_n)} = \frac{f_{i,j}{}^{(t_n)}}{A_a} + \Delta p_{i,j}{}^{(t_n)} \tag{22}$$

where $\Delta p_{i,j}{}^{(t_n)}$, is the error from sensor $e_{i,j}$ at time t_n composed of the dynamic behaviors only. Firstly, the undesired static behavior of the sensor (known as drift) which is a result of creep must be compensated for as:

$$p_{i,j}{}^{(t_n)} = \begin{cases} \dfrac{f_{i,j}{}^{(t_n)}}{A_a} + \Delta p_{i,j}{}^{(t_n)}, & \forall \dfrac{dV_e(t)}{dt} \geq 0.2\ V/s \\ \dfrac{f_{i,j}{}^{(t_n - \Delta t)}}{A_a} + \Delta p_{i,j}{}^{(t_n - \Delta t)}, & \forall \dfrac{dV_e(t)}{dt} \leq 0.2\ V/s \end{cases} \tag{23}$$

Furthermore, compensating for saturation, f_s, due to pressure load from F and due to the hysteresis effect, f_h, the dynamic error can be represented as a function of V_e and is obtained experimentally as in [19]:

$$\Delta p_{i,j} = \frac{(f_{s_{i,j}}(V_e) + f_{h_{i,j}}(V_e))}{A_a} - 2\frac{f_{i,j}}{A_a} \tag{24}$$



Fig. 6. Aircraft seat equipped with pressure mat and air-springs.

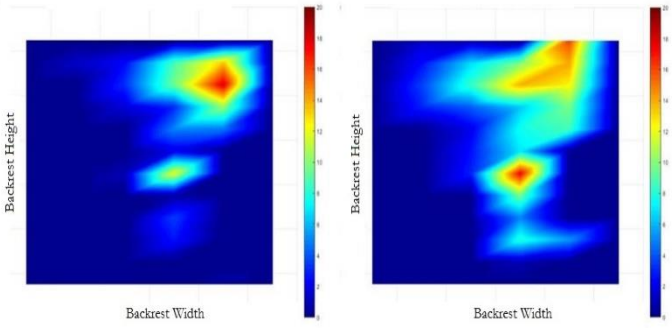


Fig. 7. Backrest pressure distribution, a) without lumbar control b) with lumbar control.

5 Conclusions

The work presented in this paper brings together three separate concepts that were incorporated to develop an automatic morphing seat system used to improve passenger sitting comfort in an aircraft cabin. The first contribution in this work was the introduction of real-time pressure mapping of the seat's surface in order to

evaluate discomfort. The second contribution in this work was the practical implementation of the ideal pressure distribution and the SPD% (BRD% for the back) on a seat design. In this work, these parameters were used as references for the control method to achieve the reduction of discomfort in a morphing seat. Lastly, the concept of automatic morphing seat during real-time (Figure 7) operation was introduced along with the automatic control approach. Morphing surfaces in seats were up to know only manually controlled or in open loop control due to lack of a reference value (ideal pressure, etc.), and lack of a practical means of measuring discomfort reliably (via pressure distribution). Previous attempts for morphing seat surfaces only employed feedback from the pneumatic pressure of the air-springs actuator(s). Such feedback method of control is highly unsatisfactory due to wide diversity of human anthropometry, postures and activities often performed on the seat (reading, sleeping, etc.).

References

[1] P. Vink and K. Brauder, *Aircraft Interior Comfort and Design*. Boca Raton: CRC Press, 2011.

[2] U. Kilincsoy, A. Wagner, P. Vink, and H. Bubb, "Application of ideal pressure distribution in development process of automobile seats," *Work*, vol. 54, no. 4, pp. 895–904, 2016.

[3] H. N. Kale and C. L. Dhamejani, "Design parameters of driver seat in an automobile," *Int. J. Res. Eng. Technol.*, vol. 4, no. 6, pp. 448–452, 2015.

[4] J. Happian-Smith, *An introduction to modern vehicle design*. Jordan Hill: Butterworth-Heinemann, 2000.

[5] J. Hu and M. Reed, "Development of a Methodology for Simulating Seat Back Interaction Using Realistic Body Contours," *SAE Int.*, vol. 6, no. 2, pp. 623–628, 2013.

[6] C. Mergl, "Entwicklung eines Verfahrens zur Optimierung des Sitzkomforts auf Automobilsitzen [Development of a Method for Optimizing the Seating Comfort of Automotive Seats]," Technical University of Munich, 2006.

[7] R. Zenk, "Objektivierung des Sitzkomforts und seine automatische Anpassung [Objectification of Seating Comfort and its Automatic Adjustment]," Technischen Universität München [Technical University of Munich], 2008.

[8] J. Hartung, "Objektivierung des statischen Sitzkomforts auf Fahrzeugsitzen durch die Kontaktkräfte zwischen Mensch und Sitz [Objectification of Static Seating Comfort on Vehicle Seats by Contact Forces Between Man and Seat]," Technischen Universität München [Technical University of Munich], 2006.

[9] M. Helander and L. Zhang, "Field studies of comfort and discomfort in sitting," *Ergonomics*, vol. 40, no. 9, pp. 895–915, Sep. 1997.

[10] N. Ahmadpour, "Aircraft Passenger Comfort Experience - Subjective Variables and Links To Emotional Responses," ÉCOLE POLYTECHNIQUE DE MONTRÉAL, 2014.

[11] F. Pingqing and S. Xinping, "Design of automotive seat surface based on ergonomics," *2009 Int. Conf. Meas. Technol. Mechatronics Autom. ICMTMA 2009*, vol. 3, pp. 51–54, 2009.

[12] "Man-Systems Integration Standards. Vol 1. Sec 3," 1995.

[13] R. H. M. Goossens and C. J. Snijders, "Design criteria for the reduction of shear forces in beds and seats," University of Jena, 1997.

[14] M. Ahmadian, T. M. Seigler, D. Clapper, and A. Sprouse, "Alternative Test Methods for Long Term Dynamic Effects of Vehicle Seats," 2002, p. 11.

[15] R. W. Ogden, "Large Deformation Isotropic Elasticity—On the Correlation of Theory and Experiment for Incompressible Rubberlike Solids," *Rubber Chem. Technol.*, vol. 46, no. 2, pp. 398–416, 1973.

[16] M. L. Ju, S. Mezghani, H. Jmal, and R. Dupuis, "Parameter Estimation of a Hyperelastic Constitutive Model for the Description of Polyurethane Foam in Large Deformation," *Cell. Polym.*, vol. 32, no. 1, 2013.

[17] M. Grujicic, B. Pandurangan, G. Arakere, W. C. Bell, T. He, and X. Xie, "Seat-cushion and soft-tissue material modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants," *Mater. Des.*, vol. 30, no. 10, pp. 4273–4285, 2009.

[18] T. Bryant, R. Pelot, J. Pinter, J. Stevenson, C. Hall, and J. Day, "Research and development of an advanced personal load carriage system phases II and III. Section E: Parametric analysis of advanced personal load carriage systems," Kingston, ON, 1997.

[19] G. H. Campos and F. (Jeff) Xi, "Calibration Methodology for a Pressure Sensing Mat in Aircraft Passenger Seat," in *AERO17*, 2017, pp. 1–10.

Parametric modelling of optimal aircraft seat surface and seat pressure distribution

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Abstract: Current research on seat pressure distribution is predominantly on the associations between pressure distribution and subjective discomfort, although useful, it does not provide enough information to help with the redesign of future seats. In this study, to improve airplane seat comfort, the compressed seat surface which optimizes pressure distribution was analysed using a newly built multi-adjustable experimental seat. The experimental seat had a seat pan surface of a matrix of 52 cylinders, each with a freely rotatable circular flat head of 60 mm in diameter. Each cylinder was equipped with a tri-axial force sensor, enabling the measurement of both normal and tangential forces. The height of each cylinder was adjustable with a maximum stroke length of 40 mm, making it possible to control seat pan surface thus contact force distribution. Pressure distribution on the seat pan surface was controlled using a uniform coupling law relating normal force and position for each cylinder. The backrest consisted of adjustable lumbar, thoracic and neck panels. Seat pan length, height and inclination were also adjustable. Thirty-six participants (18 males, 18 females) of varying weight (healthy BMI, obese BMI) and stature (small, medium and tall) were recruited. Participants were instructed to sit in 40 seat positions (each lasting approximately 1 minute) that simulated an economic airplane seat. Varying seat positions included: backrest angle (100°, 110°), seat pan angle (0°, 5°, freely adjustable), stroke height of seat pan cylinders (20mm, 40mm) and task (watching forward without neck support, relaxed sitting with neck support). A principal component (PC) analysis was first proceeded to reduce the dimensionality of the data. A linear regression on the main PC scores was then performed so that the seat surface and corresponding contact force distribution are predicted by anthropometric dimensions (stature, BMI, sitting height to stature ratio) and seat parameters (seat pan and back angles). It was observed that the profile of the "optimal" compressed seat pan surface in the symmetric plane showed little variability between the different body sizes, while the profile in the frontal plane showed higher variability. Contact force distribution was highly dependent on the sitter's BMI. The parametric models obtained will provide quantitative guidance to the design of airplane seats (i.e. determining the "optimal" seat pan compressed surface and pressure distribution) that would best accommodate the sitters of various anthropometric dimensions.

Keywords: Seat, Aircraft, Pressure distribution, Discomfort, Parametric modelling.

1 Introduction

According to an online survey by Ahmadpour et al. (2014) on a sample of 158 people who just had a long-haul trip (>4 hours), the seat was the most frequently mentioned one among the 22 features in the aircraft cabin which had an influence on passenger comfort. Aircraft seat suppliers are faced with two strong requirements from airline companies: seat weight must be reduced while simultaneously improve its comfort. According to

an extensive review of scientific publications, De Looze et al (2003) found that pressure distribution is the objective measure which has the clearest association with the subjective ratings of seat comfort. From a more recent review on the studies of office chairs; Zemp et al (2015) suggested that peak pressure on the seat pan, the pressure distribution on the backrest and the pressure pattern changes could be considered as reliable measures for quantifying comfort or discomfort. However, Zemp et al pointed out that very few studies have examined the optimum pressure distribution while sitting in an office chair. This is probably due to high number of factors affecting pressure distribution, such as sitter's body dimension, posture, seat geometry, material proprieties and their interaction. Mergl et al. (2005) studied the relationship between discomfort and pressure distribution on the seat pan experimentally, and suggested 'ideal' distribution for automotive seats. The 20 participants were mainly selected based on stature. The effects of BMI (Body Mass Index) were not considered as the discomfort perception may be affected by the amount of soft tissue under the buttock and thigh. Moreover, recommended pressure distribution is not necessarily applicable to aircraft passenger seats due to large differences in space requirements and sitting activities.

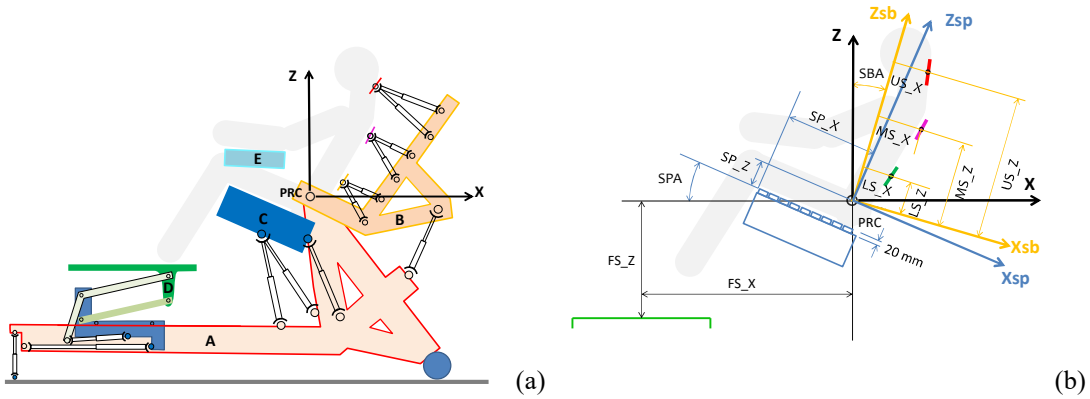
The present study aimed to develop seat design guidelines for airplane seats, based on the analysis of both "optimal" compressed seat surface and pressure distribution. The "optimal" compressed seat pan surface (i.e. contact force distributed as uniformly as possible) was experimentally investigated using a multi-adjustable experimental seat. 3D compressed surface and contact force distribution data were collected for 36 men and women of varying body dimensions. Participants sat in 40 different positions. Collected data were used to build a parametric model for predicting optimal compressed seat surface and seat pressure distribution.

2 Materials and methods

2.1 Data collection

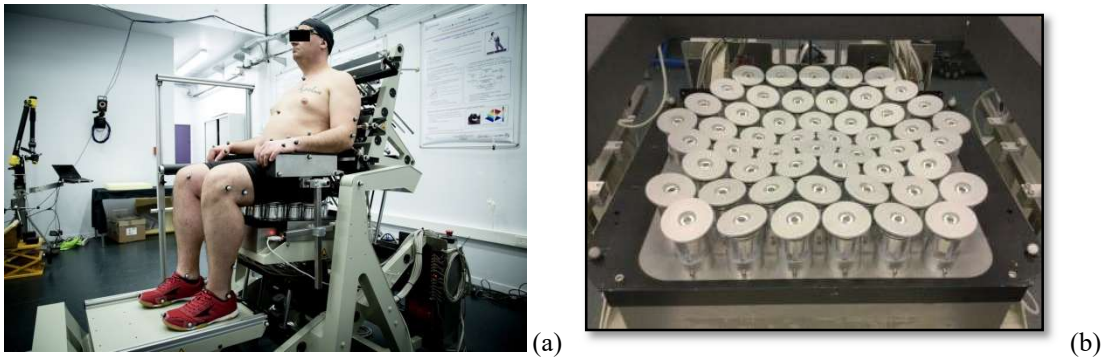
The data was collected through use of a multi-adjustable experimental seat. The experimental seat (Figure 1) was composed of four main structural components: the supporting frame (A), seat back frame (B), seat pan frame (C) and foot support (D). The supporting frame (A) was mounted on four wheels and its orientation ranged from -5° to 5° (relative to the ground) with help of an electric actuator. The backrest frame (B) articulated with the (A) frame around a lateral axis (y-axis) passing through the reference point of the experimental seat, named PRC ('Point de Référence du Conformateur'). The experimental seat had thirteen adjustable parameters (Figure 1b) directly controlled by a computer. Adjustable features included: fore-aft (x) and vertical position (z) of the foot support, seat pan and three back supports; rotational angle of the seat pan, backrest and global inclination of the whole experimental seat. Two armrests (E) were also available and adjusted manually. Force sensors were mounted to measure contact forces in xz plane on the foot support, seat pan, three back supports and two armrests. The seat pan surface was composed of a matrix of 52 cylinders, each was freely rotatable with a circular flat head of 60 mm in diameter. Each cylinder was equipped with a tri-axial force sensor, enabling the measurement of both normal and tangential forces. The height of each cylinder was adjustable with a maximum stroke length of 40 mm and pressure distribution could be controlled by changing seat surface. Figure 2 shows a subject sitting in the experiment seat and the matrix of 52 cylinders simulating seat surface. A more detailed description can be found in Beurier et al (2017).

Pressure distribution on the seat pan surface was controlled using a uniform coupling law relating normal force and position for each cylinder. The coupling law enabled us to distribute normal contact force as uniformly as possible among the 52 cylinders (given the maximum displacement of the cylinders). For a given normal contact force on the seat surface (F_n^{SP}), a target mean force ($\bar{F}_n^{SP}$) was estimated as F_n^{SP}/(0.75*52) considering that approximately ¼ of the seat surface was not in contact with the buttock or thighs. Each cylinder lowers its height once its contact force (F_n^i) reaches to the target force $\bar{F}_n^{SP}$, while it maintains its position when $F_n^i \leq \bar{F}_n^{SP}$. The movement of the cylinders had a limitation of 40 mm in stroke length, therefore the force distribution depended on the initial height of the cylinders.



(a) (b)

Fig. 1. Main structure of the experimental seat (a) and definition of thirteen adjustable parameters and different coordinate systems (b). The global coordinate system (GCS) is defined with X being directed rearward parallel to the foot support surface, Z directed upward perpendicular to the foot support surfaceas follows. Its origin is located at the mid of the lateral axis Y (experimental reference point named PRC) which articulates the backrest frame (B) with the main supporting frame (A). Two local systems of coordinate (LCS) are defined from the global coordinate system (GCS), one attached to the seat back frame (B) after a rotation of seat back angle (SBA), another attached to the seat pan frame (C) after a rotation of seat pan angle (SPA).



(a) (b)

Fig. 2. A participant sitting on the experimental seat (a) and the matrix of 52 cylinders (b)

Thirty-six participants (18 males, 18 females) were recruited based on their BMI (healthy 18.5-25, obese >30) and stature (small, medium and tall). Three stature groups were 154-157 cm, 162-166 cm and 170-175 cm for females; 168-171cm, 176-180 cm and 185-190 cm for males. A total of 12 groups were formed after considering gender, stature and height (3 individuals per group). Prior to the experiment, participants were screened using a health questionnaire. Participants who experienced any back injury or pain in the previous 3-months were excluded. The experimental protocol was approved by IFSTTAR (French Institute of Science and Technology for Transport, Development and Networks) ethics committee and informed consent was given prior to experiment.

Participants were instructed to test a total of 40 seat positions that simulated an economic airplane seat. The H-point location of an existing airplane seat was used to define the x position of the middle support with MS_X being fixed at 135mm, and the z position of the seat pan support with SP_Z=98 mm (Fig.1b). Two backrest angles (BA) from the horizontal (BA=100°, 110°) and three seat pan angles (SPA=0°, 5°, preferred) were used to define 6 different SPA/BA combinations. For each combination, 5 conditions were tested successively in the following order:

1. *Reference position with the initial cylinder height of 20 mm (CH=20mm).* This position was used to determine seat pan length, foot support height and armrests position for each participant. The three backrest panels were positioned at specific anatomical points (occipital bone, T9 and L3). Their position

in x (protrusion) was fixed at 135 mm in the seat back LCS. The seat pan length (SP_X, Figure 1b) was fixed until there was approximately 70mm (hand width) between the popliteal (behind the knee) and the front of the seat pan. Participants were asked to keep their back in contact with the lower and middle supports. The foot support was adjusted (FS_Z, Figure 1b) until the knees were set at approximately 90 degrees. Participants were also asked to place a rectangular foam of 100 mm (in thickness) between the knees to reduce postural variation. The armrests were self-positioned by subjects. Once participants were fitted to the seat, they were instructed to step off the experimental seat to zero all the force sensors. They were then asked to reposition themselves back on the experimental seat and look forward without use of the upper support. Measurements were recorded at a rate of 20 Hz for 1.25 seconds.

2. *Watching a movie with CH=20mm.* Participants were asked to re-place the 100mm foam between their knees and maintain a comfortable sitting position while looking forward. The uniform law was applied to distribute the seat contact force to the 52 cylinders. Once the pressure was distributed, the middle (T9) and lower (L3) supports needed to be repositioned. The level of lumbar protrusion (MS_X) was self-selected. Participants were required to remain in contact with the middle (thoracic) panel. Once the middle and lower back supports were appropriately positioned, participants were then instructed to step off the experimental seat to perform a complete zero of all the force sensors. Participants were then asked to reposition themselves back on the experimental seat and look forward without use of the upper support. Seat parameter and contact forces were then recorded.
3. *Relaxing with CH=20 mm.* Step 2 was repeated with the addition of the upper support. The upper support was positioned at the occipital bone and its protrusion was self-selected.
4. *Relaxing with CH=20mm.* Step 3 was repeated with now the cylinders set at a stroke height at 40mm.
5. *Watching a movie with CH=40mm*. Step 2 was repeated with now the cylinders set at a stroke height at 40mm.

In summary, in addition to seat pan (SPA) and back (BA) angles, cylinder stroke length (CH) and siting activity (task) were also considered as independent variables for the present experiment. The preferred seat pan angle was self-selected by participants for the reference position and kept unchanged for the 4 other test conditions with a fixed backrest angle. The five test conditions of the combination with SPA=5° and BA=110° were repeated three times to measure intra individual variability. In total, 40 sitting positions were measured for each participant. The test order of six SPA/BA combinations was randomized.

2.2 Data processing

The medians of the measurements of each trial were calculated at first. After eliminating all inconsistent trials, 1383 over 1440 (36 participants x 40 conditions) trials were retained. As the sum of the external forces applied to the body had to equal to zero, the total sum of forces in the horizontal (X) and vertical (Z) had to be respectively smaller than 11 and 25N.

A principal component analysis (PCA) was used to reduce the dimensionality in data. The measurements of the dependent variables, such as foot support height, seat pan length, location of the three back supports, position of the 52 cylinders after contact force distribution, all contact forces, were gathered in a matrix Ψ_{nxp} with n observations and p dependent variables. A smaller set of ordered variables, called principal component (PC) score, were obtained with PCA, so that the first PCs retained most of the variation in the original dataset. Assume that m main PCs μ_j (j =1, m) are retained. Then the ith observation (Ψ_i) containing p dependent variables can be approximated:

$$\Psi_i(1{:}p) \approx \bar{\Psi}(1{:}p) + \sum_{j=1}^{m} c_j\, \mu_j(1{:}p) \qquad (1)$$

where $\bar{\Psi}$ is the average from the sample data sets and c_j is the jth PC score. A linear regression can be performed between the m PC scores $[C]_{n\times m}$ and k predictors (see Allen et al, 2003)

$$[a]_{(k+1)\times m} = inv\big([P]_{n\times(k+1)}\big) * [C]_{n\times m} \qquad (2)$$

where $[P]_{nxk}$ is the matrix containing k predictors for n observations,

$$[P]_{n\times(k+1)} = \begin{bmatrix} 1 & P_{1,1}, \cdots & P_{k,1} \\ \vdots & \ddots & \vdots \\ 1 & P_{1,n}, \cdots & P_{k,n} \end{bmatrix}$$

Knowing the predictors from a new observation $P=[1, P_1, P_2, \ldots, P_k]$, m PC scores c_j $(j=1,m)$ can be obtained by

$$c_j = a_{0j} + \sum_i^k a_{ij} P_i \qquad (3)$$

From (1), p dependent variables of the new observation can then be predicted.

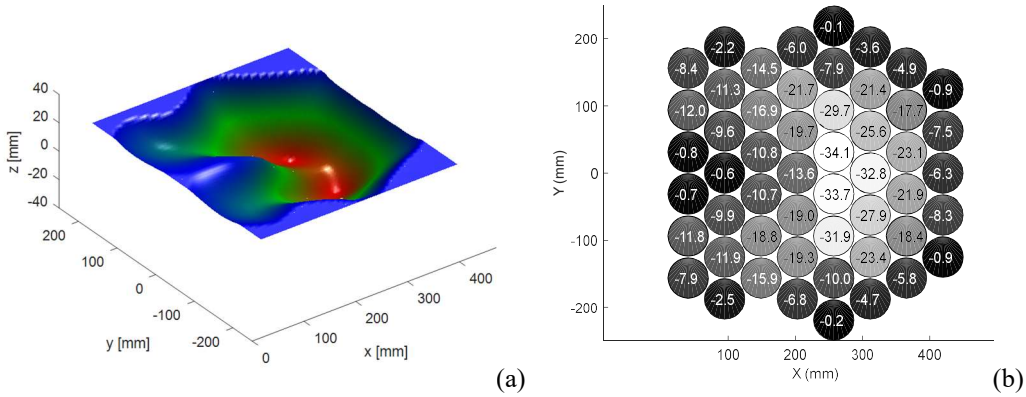
3 Results

Depending on selected dependent variables and predictors, different parametric models can be obtained. This paper will focus on seat surface and contact force distribution. Gender, stature and BMI were used as anthropometric predictors. The seat configuration with SPA=5°, BA=110°, CH=40 mm and the task "relaxing position" was used to illustrate the parametric model obtained from the collected data. 105 observations corresponding to this test condition were extracted. Seat pan length; position and contact force (three components) of the 52 cylinders were selected as dependent variables. More than 90% of variance was explained by less than 20 PCs. For building parametric models, number of PCs was selected for accounting 99% cumulative variance.

Six target sitters were defined in Table 1 to show the effects of gender, stature and BMI. Small, average and tall sitters were defined as 5th, 50th and 95th percentiles in stature from National Health and Nutrition Examination Survey (NHANES III), conducted from 1988 to 1994. For each target seat occupant, the compressed seat surface and corresponding contact force at each cylinder can be predicted. An example is provided in Figure 3 for the prediction of a 3D seat surface and distribution of contact force for an average healthy male. Note that the maximum normal contact force was located on the cylinders under the pelvis and was approximately three times of that of the first two rows of cylinders. Figure 4 compares the seat profile in XZ of the six target sitters and contact forces applied on each row of cylinders. Seat pan length was highly dependent on stature, a difference of 72 mm was obtained between the small healthy female and tall healthy male. Seat surface XZ profiles in the GCS were quite similar for the six target sitters. Noticeable differences could only be observed at the rear part when x>0. Force distribution was found highly dependent on BMI. Though almost the same seat profiles were obtained for the three tall target sitters, the force under the pelvis (around x=0) was much smaller for the sitter with high BMI ('TallMaleObese') in comparison to healthy BMI ('TallMaleHealthy'), and the contact force was much more evenly distributed. A comparison of the YZ surface profiles in the seat pan LCS (at x=50, 0, -50 and -100 mm) between the six target sitters can be found in Figure 5. Compared to XZ profiles, YZ profiles in the frontal planes had greater variability between the six sitters.

Table 1. Six target seat sitters

Predictor	*Small female healthy*	*Tall female obese*	*Average male healthy*	*Tall male underweight*	*Tall male healthy*	*Tall male obese*
Stature (mm)	1517	1737	1761	1879	1879	1879
BMI (kg/m²)	24	35	24	18	24	35



(a) (b)

Fig. 3. 3D representation of deformed seat surface in the seat pan LCS after interpolation (a) and corresponding normalized normal contact force Fn (1000/body weight) applied on each cylinder for the average male with healthy BMI (Table 1)

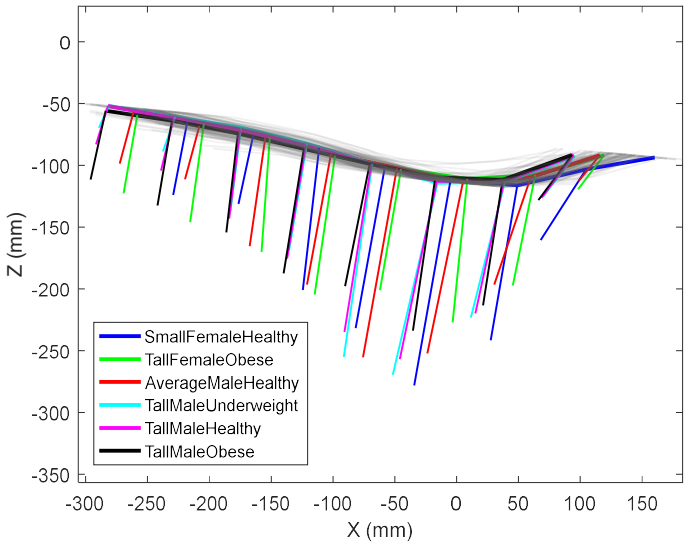
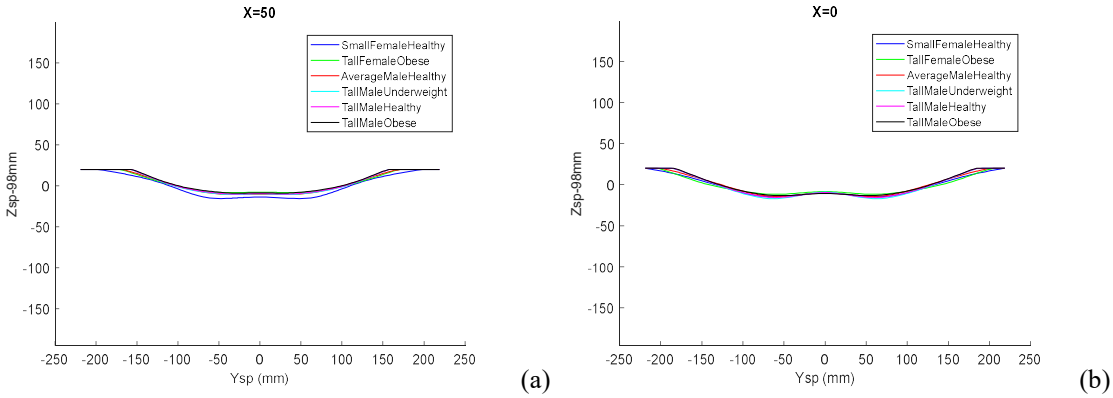


Fig. 4. Seat surface profiles and contact forces in the GCS XZ plane for the six target occupants. They are represented by the lowest position of the cylinders of each row and the sum of forces applied on the cylinders of each row. Contact forces were normalized body weight and multiplied by 1000. Grey lines are raw experimental datasets.



(a) (b)

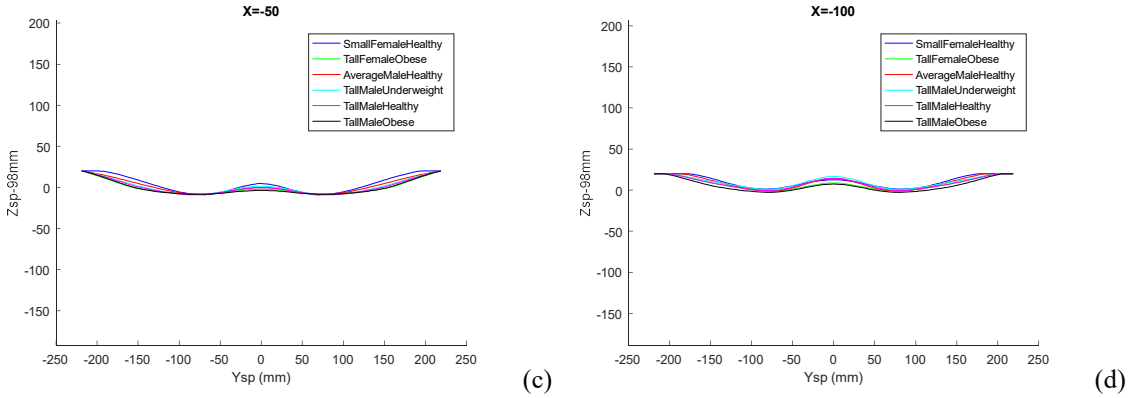


Fig. 4. Seat surface YZ profiles in the seat pan LCS of the 6 target sitters at X=50, 0, -50, -100mm

4 Discussions and conclusions

3D compressed seat pan surface was experimentally investigated using a multi-adjustable experimental seat (equipped with a matrix of 52 movable cylinders on the seat pan surface). 'Optimal' seat pan surface was defined for this study as a compressed surface that distributes normal force as uniformly as possible with minimal displacement of the initially flat surface. Parametric models were obtained from the data of 36 participants of varying anthropometries. Main effects of gender, stature and BMI on compressed seat pan surface and pressure distribution were illustrated for a specific seat configuration (seat pan angle of 5° and back angle of 110°), results are summarized as follows:

- Similar surface XZ profiles in the seat symmetric plan (body sagittal plane) were obtained for differently sized sitters, although seat pan length was highly dependent on stature.
- Surface YZ profile in the frontal plane had more variability especially for seat pan surface contact area.
- Pressure distribution was highly dependent on BMI. Pressure was less uniformly distributed for participants with a smaller BMI than those with higher BMI.

An optimal rigid seat surface is only optimal for one sitter and posture. The central question for seat suppliers is how to propose a unique seat that can accommodate multiple sitters of large varying body dimensions while performing different tasks. Predicting the effects of body size and posture is a first step which aims to provide quantitative guidance regarding optimal compressed seat pan surface and pressure distribution. Work is currently in progress to propose different target seat design solutions to improve the seat geometry and stiffness.

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References

1. Ahmadpour, A., Lindgaard, G., Robert J.M. and Pownall, B., 2014. The thematic structure of passenger comfort experience and its relationship to the context features in the aircraft cabin, Ergonomics, 57:6, 801-815, DOI: 10.1080/00140139.2014.899632
2. De Looze MP, Kuijt-Evers LF, van Dieen J, 2003. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics;46:985-97.
3. Zemp R, Taylor WR, Lorenzetti S, 2015. Are pressure measurements effective in the assessment of office chair comfort/discomfort? A review. Applied Ergonomics 2015;48:273-82.
4. Mergl C., Klendauer M., Mangen C., Bubb, H., 2004. Predicting Long Term Riding Comfort in Cars by Contact Forces between Human and Seat. SAE Technical Paper 2005-01-2690. Warrendale, PA: SAE International.

5. Beurier, G., Cardoso, M., and Wang, X., 2017. A New Multi-Adjustable Experimental Seat for Investigating Biomechanical Factors of Sitting Discomfort. SAE Technical Paper 2017-01-1393, doi:10.4271/2017-01-1393.
6. Allen, B., Curless, B., and Popovic, Z. 2003. The space of all body shapes : reconstruction and parameterization from range scans. ACM Transactions on Graphics, ACM SIGGRAPH 2003, 22(3), 587-594.

Concept of a human response model for aircraft cabin interiors design in virtual environments

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Abstract In the earliest stages of industrial products design process several tools and methods are needed for the evaluation of alternative solutions. Those methods allow designers to account for the humans that will interact with such products with the aim of enhancing the quality of the solutions from the user's point of view. This implies that designers should be able to precisely estimate the impact of any design feature on the ergonomic, usability and perceived comfort aspects. The main issues in this process are the manufacturing time and costs of physical mock-ups and the efficiency of the methods used to capture the user's perception in terms of feelings inspired by different concepts or product configurations. In several cases Virtual mock ups can be used to run simulations of the human-product interaction overcoming the need of physical specimens. On the evaluation side, it is known that in the current practice positive or negative feelings are associated to the level of comfort and well-being self reported by the user as a qualitative assessment of a product or service. Therefore, the evaluation of alternative configurations is commonly based on subjective ratings that participants perform by filling questionnaires during or after experiencing a prototype of the product. In this paper we present the concept of a human response model that has been conceived and will be implemented in the framework of the CASTLE project (CAbin Systems design Toward passenger welLbEing). The aim is to investigate how a set of physiological measures and Virtual Reality can support the early design of aircraft cabin interiors from the emotional point of view bringing advantages such as reduction of costs for the company, reduction of the time to market and improvement of the overall Human Centered Design process. The final output is the definition of innovative design methods to objectively measure the affective impact on a potential user when interacting with a product.

Keywords Human Centered Design; Emotional Design; Virtual Reality; Brain Computer Interfaces; Comfort, Aircraft Design.

1. Introduction

According to the aesthetic economical model proposed in literature [1], comfort is perceived as being in an interesting, advanced and beautiful environment, available for a reasonable price. Nevertheless, time or cost constraints force designers to face trade offs and choices affecting the level of comfort perceived by the user. In the evaluation of alternative design solutions in the earliest design stages, the main issues are the availability of large and detailed mock-ups and of methods to capture user's perception in terms of emotional feelings inspired by different proposals. In this paper we describe the approach proposed for the comfort evaluations of design solutions created in the framework of the CASTLE project, focusing on the methods to capture the comfort feedback of potential users in Virtual Environments. The first section introduces the HCD process in CASTLE. A summary of the Virtual Reality applications for participatory design of industrial products and of the systems that will be used in CASTLE is in section 3. Finally a review of the Subjective and Objective ratings methods for Comfort is presented in section 4.

1.1 The CASTLE Project

CASTLE[1] (CAbin Systems design Toward passenger welLbEing) is a project granted under the Horizon 2020 EU's research programme in the framework of the Clean Sky initiative. Clean Sky is the largest European research programme developing innovative, cutting-edge technology for aircraft. Clean Sky 2 is structured in a number of demonstrators that cover the aeronautical industrial innovation needs both for fixed and for rotary wing platforms [2]. During the development of the CASTLE project it is foreseen to provide solutions and prototypes for the Airframe Integrated Technology Demonstrator. In this context, special attention has been paid to the improvements that can be brought to the cabin interiors, and specifically to the experience that passengers can live in the aircraft of the future. The main objective of the project is to conceive, develop, prototype and test cabin interiors solutions following a HCD (Human Centered Design) approach. Such innovative and integrated approach is mainly addressing human factors issues regarding ergonomics, anthropometrics, as well as effects of vibration, noise and motion on passengers, crew and PRM (Persons with Reduced Mobility). The design flow will be defined for each cabin item keeping in mind the user's requirements and considering the evolution of requirements at the time the CASTLE solutions will be available.
The achievement of CASTLE's objectives will be pursued through the introduction of:

- Innovative evaluation methods based both on objective and subjective measures for comfort.
- Use of simulation tools, such as Virtual Reality, Digital Human Modeling and Vibro-Acoustic advanced simulation software.
- Definition of a holistic design validation approach based on the integration of different comfort, usability and ergonomics measures.

The research approach will be focused on:

- Analysis of the context of use and of the user's requirements, including PRM.
- Deployment of evaluation protocols for each cabin item, each maturity phase of the development and each type of user.
- State of the art of the tools and methods.

[1] The CASTLE Consortium comprises eleven partners, all providing a strongly multidisciplinary R&D team. The CASTLE consortium is coordinated by GEVEN S.p.A., an affirmed and established player in the Aircraft Seating and Interiors manufacturing industry located in Naples, Italy.

2. The Human Centered Response Model Proposed in CASTLE

According to the ISO 9241-210:2010[2] HCD is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users. Although such standard has been set for computer-based interactive systems, the workflow and the methods are recognized as a rule for any system interface designs [3].

There exist several methods to implement HCD in the design of systems that the human is asked to interact with. Most of these methods use similar tools and they can be used in combination being also applied in the different phases of the HCD process as depicted in Fig. 1.

In CASTLE the consortium will develop a Human Response Model to evaluate the potential design solutions at any stage of the design development. In this context, a set of evaluation criteria and evaluation measures must be defined in order to collect all the information needed to validate the design solution. This is usually performed by showing the prototypes to users, observing them as they perform specified tasks and using their feedback to improve the design. This process is iterated until design objectives are met.

In such a complex system the high number and the diverse nature of the usability and satisfaction criteria require the integration of the measures into a global index which can be used to compare the performance of the design solution with user's expectation (Fig. 2).

The tools and methods for the evaluation of solutions have been defined in CASTLE based on: (i) the maturity level of the prototype that is shown to the user and (ii) the nature of the metrics that are collected. For instance, in the early stage of the design mathematical models and analytical prototypes can be used, while in the latter phases the first physical prototypes will be available.

In the conceptual design phase the methods that allow evaluating design solutions against user's requirements through virtual simulations should be considered. This includes scenarios and conditions that can be representative of the human's experience in the cabin. In order to capture the human's feedback in such scenarios both Human Model in the Loop and Human in The Loop simulations will be performed. The first class of simulations refers to the use of mathematical models of the human body and of its behavior in a 3D environment. Virtual Manikins refer to this class and are a valuable tool to assess the ergonomics aspects such as the living space of a seat and of a specific lay out of the cabin. On the other hand, the human in the loop simulations refer to the creation of a simulated environment, mainly a virtual environment, in which a real user is immersed and is asked to perform a specific task while his or her feedback is collected. This class of simulations aims to assess the user satisfaction level of each design solution, which is a major requirement for the comfort and well being of the passenger both in regional and in business aircraft.

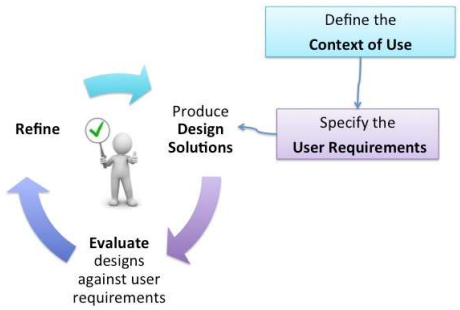


Fig. 1 The HCD Flow adapted from ISO 9421

[2] The ISO 9241-210:2010 is the International Standard that provides requirements and recommendations for Human-Centred Design.

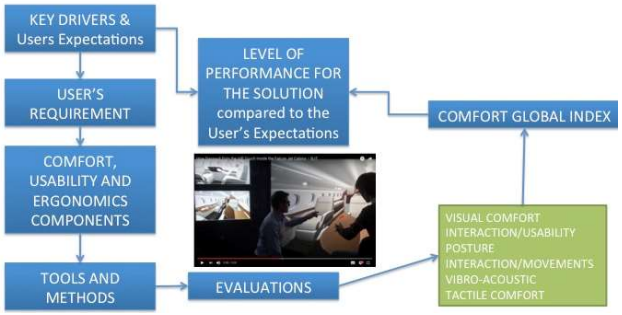


Fig. 2 CASTLE HCD Approach

3. Virtual Reality for emotional product design

The basis of HCD has been formalized in the 'ISO 9241-210 standard on human-centered design processes for interactive systems'. The standard describes six principles of HCD as follows:

1. The design is based upon an explicit understanding of users, tasks and environments;
2. Users are involved throughout design and development;
3. The design is driven and refined by user-centered evaluation;
4. The process is iterative;
5. The design addresses the whole user experience;
6. The design team includes multidisciplinary skills and perspectives.

In this framework, Virtual Reality is a valuable tool to build an evaluation and validation process that meets all these requirements since it offers the challenge to create different scenarios in order to assess and test user-product physical and emotional interaction. Several examples in literature refer to the assessment of product or environment usability or user experience through the introduction of Virtual Reality technologies since the early design stages. In [4], the authors address a novel methodology to assess the usability of a wheelchair-mounted robot manipulator. A synthetic usability index is defined, considering a multi criteria decision analysis and a scoring process for the most relevant factors. Tests have been performed in a VR environment, reducing time and costs and increasing repeatability. In [5], authors make use of Virtual Reality to assess accessibility and usability in ambient assisted living environment for people with disabilities. The activity has been performed in the framework of the VAALID European funded project, to quickly develop novel solutions and interfaces. In [6], authors make use of immersive virtual reality environments as support tools for building design and to understand end-users' lighting preferences and performances.
Virtual Reality has proven to be an effective tool for the evaluation of interfaces both in the automotive and in the aerospace fields, as well as in the evaluation of consumer products or appliances [7]. Berg and Vance provide a survey on some challenging industrial applications of Virtual Reality [9]. Authors provide an overall description of the processes to be followed in the Virtual Reality approach. Some key properties are associated to different VR technologies and techniques: Interaction, Imagination, Presence and Immersion [9]. Interaction is the capability of the user to interact with the virtual environment: user inputs are related to motion and actions within the virtual scene (motion tracking tools are commonly implemented). Imagination is related to the user's capacity to perceive nonexistent things and his/her feeling to really be within the scene. Presence is the user's subjective psychological state of being in the VE. Immersion is associated with the feeling of being inside a Virtual Environment. According to this feature, the VR systems are classified in fully immersive, semi-immersive and non-immersive systems.
In the framework of the CASTLE project different Virtual Reality systems will be available for the participatory design in simulated environments, each having different properties, in order to exploit the combination of capabilities with reference to the experimental requirements. Therefore, both fully immersive systems based on HMDs (Head Mounted Displays) and semi immersive systems based on projected screens, such as a CAVE (Cave Automatic Virtual Environment) will be used. In both systems users will be enabled to navigate the

environment, interact with the most relevant features and switch among different configurations. In HMD, the user "wears" a stereoscopic display that provides a view of the virtual world, in a high immersive environment. The goal in the technology is to provide the widest field of view at the highest quality with the least weight and at a reasonable cost. On the other side, large projection screen systems, like the CAVE, provide a navigation of the virtual scene, with a higher presence level (the user can experiment his own within the VR scene), but with a lower immersion, if compared to HMDs. Both systems can track the user's head position, so that what is displayed preserves proper perspective, adapting to movements and change of location and both systems allow the introduction of interaction systems and interfaces to easily navigate and interact with the virtual scene. Once a virtual replica of the cabin item is available, a protocol analysis must be developed in order to successfully exploit the Virtual Environments in HCD. This includes a set of tasks that the user is expected to perform and the measures that need to be collected. In [10] the authors propose a full set of metrics integrated in a combined test performed through DHM (Digital Human Models) and through user in the loop heuristic evaluation performed in a CAVE for the ergonomic assessment of a workstation.

In CASTLE the analysis that will be performed in the Virtual Environments, according to the identified key comfort drivers for regional jets, concerns the collection of data on the visual comfort and the usability of the cabin items. The visual comfort is mostly related to the degree of comfort that the user perceives through the visualization of the cabin environment in a virtual environment. This will be mainly implemented through the creation of scenarios that replicate situations like entering the cabin, walking along the aisle and ingress or egress to the seat both in the case of aisle, middle or window seat. An example of scenario to assess user interaction in Virtual Environment is proposed in **Fig. 4**, where a real passenger interacts with a virtual steward.

The interaction is related not only to the visual comfort but also to the usability of the features and attributes of the items, such as the folding tray or the stowage bin. The usability can be measured in the completion of task, the number of errors and the level of satisfaction. On the interaction side a number of methods have been applied in the field of human machine interfaces.

During the simulations in virtual environment subjective ratings will be collected and, to a certain extent, objective ratings will be collected as well. Subjective ratings will be collected in order to quantify the perceived comfort on a cognitive base. Likert scale and/or Visual Analogue scales will be used. Subjective evaluations have the advantage that the method has been widely exploited and tuned giving the evidence of its usage in different applications. On the other hand the subjective evaluations can be performed after the test conclusion and cannot reflect the punctual variations of the emotions during the cabin experiencing.

Analysis	*Metrics*	*Unit of meas.*	*Data collection techniques*
Posture	Physical comfort	RULA and REBA score (no.)	Ergonomic analysis Heuristic evaluation
Occlusion	Visibility	View cones (deg.)	Ergonomic analysis Heuristic evaluation
	Accessibility	Distance between the user and reached zones (mm)	
Mental load	Ease of use	Requests of support (no.) Action sequence steps (no.)	Ergonomic analysis Heuristic evaluation
	Mental workload	Fatigue or distraction behaviors (no.)	
Interaction	Feedback	Visual, tactile and auditory feedbacks (no.)	Ergonomic analysis Heuristic evaluation
	Interaction support	Affordances (no.) Task completion ratio (user/expert) (s)	Ergonomic analysis Heuristic evaluation
	Information quality	Errors frequency (%)	Ergonomic analysis Heuristic evaluation
Emotions	Satisfaction in use	Subjective impression score (no.)	Heuristic evaluation Interview

Fig. 3 Metrics for human factor assessment



Fig. 4 Virtual simulation of steward functions in an aircraft environment (source: http://www.vr-hyperspace.eu)

To this aim a novel approach based on objective ratings will be used to quantify the perceived comfort from a psychophysiological point of view. These metrics will include physiological parameters, such as skin conductance and/or EEG (Electroencephalography), captured during the experiment. The overall approach is depicted in fig. 5. A specific experimental protocol will be prepared for each aspect of the cabin that needs to be evaluated.

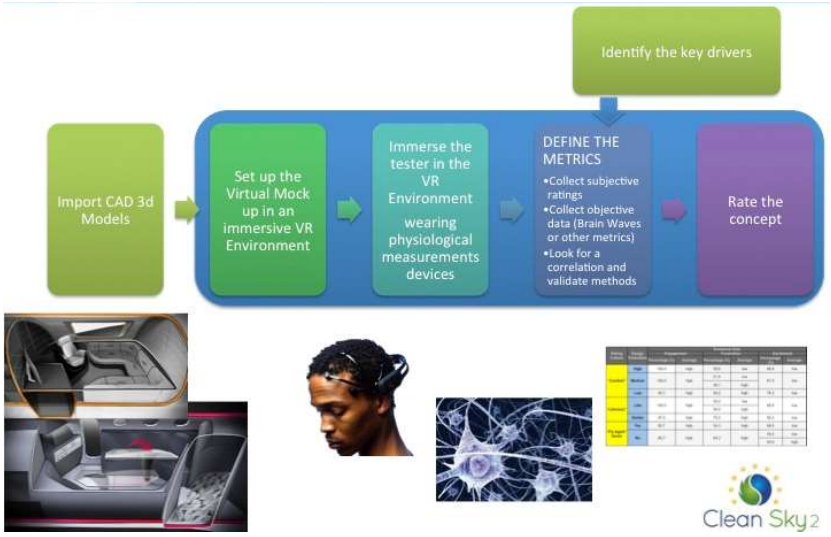


Fig. 5 CASTLE VR SIMULATIONS Concept and Approach

4. Subjective and Objective ratings methods for Comfort – a review

Subjective state of comfort and well-being can be measured through questionnaire survey using psychometric scales. Psychometric scales are the most widely used methods in survey research. They require the raters or respondents to assign a value, sometimes numeric, to the rated object, to quantify estimations of variables such as feeling, opinions or attitudes, that cannot be measured directly, or when their values cannot be observed. In the social sciences, particularly psychology, the Numeric Rating Scale (NRS), such as the Likert-type scale with discrete rating, and the graphic rating scale, such as the Visual Analogue Scale (VAS) with continuous rating, have been used most frequently worldwide because of their outstanding simplicity, and their reliability and validity have been proved. The Visual Analogue Scale (VAS) is a measure that has been widely used in the field of psychology to measure well-being. There are different types of response scales and, regardless of the type of scale, rating of more than one statement is necessary in order to obtain an index of internal reliability which represents a basic criterion for assessing the validity of a rating scale and, more generally, of a psychometric instrument.

Together with the subjective ratings of comfort also objective measures of the comfort perceived by the user during the Human in the Loop simulations in virtual environments will be studied and, once the method will be tuned, it will be implemented in CASTLE validations. These measures are defined as psychophysiological and are used to denote physiological responses of the human body, which can be monitored in a non-invasive way and are affected by psychological or mental processes. Hence, their measurement allows a quantitative assessment of cognitive states, including mental work, arousal, stress-strain processes, fatigue, discomfort and emotion. At present, analysis of psychophysiological measurements is considered the more natural way to provide a quantitative assessment of comfort, since any factor affecting stress and discomfort or fatigue has a clear impact on physiological activity. There are numerous psychophysiological measures in the literature, which provide alternative sensitivity and complementary information. They can be grouped depending on the portion of the nervous system (central or peripheral) they are related to.

Measurement of the Central Neural System (CNS) status can be achieved via electrodes placed on the scalp. They include Event Related Brain Potentials and Electroencephalography. **Event Related Brain Potentials** (ERPs) are transient voltage oscillations in the brain that can be recorded on the scalp in response to discrete stimuli. There is a wide literature on specific components of the ERP waves, usually defined in terms of their latency, amplitude and polarity [11,12]. Continuous electrical activity in the Scalp, i.e. the **Electroencephalogram** (EEG) can also be used to derive information on the neural mechanisms. In particular, starting from high-resolution EEG, with 32 or 64 electrodes, one can reconstruct the electrical activity in specific cortical areas using specific algorithms (such as sLORETA) [13]. From these data, functional connectivity among the main brain regions can also be derived, and their changes assessed during specific tasks. This actually represents the more powerful and sophisticated method to monitor neural functions in a quantitative way, in an effort to understand the neural substrates of the cognitive states. However, it is also computational demanding, and sensitive to noise artifacts. **Eye movements** provide another information strictly influenced by activity of the CNS. It is well known that the frequency of eye blinking is related with states of fatigue or emotion [14]. Finally, **eye gaze** is a direct measure of attention and vigilance [15] and, in the context of interaction between the subject and the environment, can be used to detect where subjects focalize their attention.

Other psychophysiological measurements are concerned with the activity of the autonomic neural system (ANS), i.e., the portion of the neural system that regulates and modify peripheral quantities in an involuntary way. In particular, stress and discomfort conditions induce an increase in peripheral sympathetic activity and, although less evident, a decrease in the parasympathetic one; these are reflected in many quantities, primarily heart rate, blood pressure, respiration, and sweat gland activity. Hence, various techniques can be used to monitor these alterations in the ANS.

A simple, quite inexpensive and informative measurement consists in monitoring **heart rate**; this can be derived from the electrocardiogram, via detection of the R peak. Of particular significance is not only the level of heart rate (beats/min) but also its temporal variability [16]. Strictly related with heart rate changes, sympathetic alteration cause changes in **blood pressure**. In particular, stress and mental load induce a blood pressure increase and a decrease in blood pressure variability [17]. This information can be accomplished in parallel with that on heart rate, using a device for continuous non-invasive pressure monitoring, and the two complementary measures used together. Also **respiration** is strongly related with emotion, mood and psychosomatic symptoms, hence respiratory measures can provide supplementary information on the psychophysical status of the subject [18]. Galvanic skin response is the method usually adopted to study **electrodermal activity**, which, in turn, reflects the activity of the sweat glands. The latter are regulated only by the sympathetic branch of the autonomic nervous system; hence, electrodermal measurement can be considered a good indicator of sympathetic status, linearly correlated with arousal, stress and frustration [19,20].

Finally, the activation of voluntary muscles, or even the preparation to action, can be monitored through the analysis of electrical signals produced by muscle contraction, i.e. the **electromyography** (EMG). This signal can be quite easily detected via superficial electrodes taped on the skin of the target muscles, and can be used to detect physical efforts, contractions or the reaction to emotion (for instance through measurements in the face muscles). Currently we have selected the techniques that offer the best compromise in terms of intrusiveness, response time and frequency, robustness and evidences, in literature, of being measures that provide information of perceived comfort and well being.

A first step will be to understand which parameters, among the multidimensional measurement space described above [21], are more significantly affected by the comfort/stress level experienced by the subject. Finally, we will try to derive a global index, which can be used to quantify the comfort state and summarize the measurements in a straightforward quantitative way.

Conclusions

In this paper we report the study conducted up to now on the tools and methods to measure comfort and well being in Virtual Reality environments for the assessment of the CASTLE cabin prototypes. The approach aims to enhance the human centered design and is based on the introduction of innovations in the type of measures used to collect the feedback of users involved in human in the loop simulations.
The process will be iterated along the entire duration of CASTLE. The tools and methods to capture the user's feedback in the early design phase - both subjective/qualitative and objective/quantitative - can be adapted to the high maturity level of the physical prototypes that will be produced in the late phase of the project.
Some risk could arise during the experimental phase due to the uneven response of the user in the collection of the psychophysiological response. This risk will be mitigated through the selection of test and scenario that can really benefit from the use of such measures and from the intense phase of preliminary validation of the method in laboratory test environments.

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Referencing

1. Dumur E, Barnard Y and Boy G. Designing for comfort. *Human factors in design*, pp. 111-127, 2004.
2. www.cleansky.eu
3. ISO 9241-210:2010, Ergonomics of human-system interaction -- Part 210: Human-centred design for interactive systems
4. Di Gironimo, Giuseppe, et al. "A virtual reality approach for usability assessment: case study on a wheelchair-mounted robot manipulator." Engineering with Computers 29.3 (2013): 359-373.
5. Jiménez-Mixco, Viveca, et al. "Application of virtual reality technologies in rapid development and assessment of ambient assisted living environments." Proceedings of the 1st ACM SIGMM international workshop on Media studies and implementations that help improving access to disabled users. ACM, 2009.
6. Heydarian, Arsalan, et al. "Towards Understanding End-User Lighting Preferences in Office Spaces by Using Immersive Virtual Environments." Computing in Civil Engineering 2015. 2015. 475-482.
7. Bruno, Fabio, and Maurizio Muzzupappa. "Product interface design: A participatory approach based on virtual reality." International journal of human-computer studies 68.5 (2010): 254-269.
8. Berg, Leif P., and Judy M. Vance. "Industry use of virtual reality in product design and manufacturing: a survey." Virtual Reality (2016): 1-17.
9. Rebelo, Francisco, et al. "Using virtual reality to assess user experience." Human factors 54.6 (2012): 964-982.
10. Peruzzini, Margherita, et al. "Human-centred design of ergonomic workstations on interactive digital mock-ups." Advances on Mechanics, Design Engineering and Manufacturing. Springer International Publishing, 2017. 1187-1195.
11. Kramer, A.F. and Weber, T., Application of psychophysiology to human factors, in Handbook of Psychophysiology, Cacioppo, J., Tassinary, L., and Bertson, G., Eds., Cambridge University Press, New York, pp. 794–814 (2000).
12. A. F. Kramer and A. Belopolsky. Assessing Brain Function and Mental Chronometry with Event-Related Potentials (ERP). In: Stanton, N., Hedge, A., Brookhuis, K., Salas, E., Hendrick, H. (eds.) Handbook of Human Factors and Ergonomics Methods, pp. 22-1–22-7. CRC Press, Boca Raton (2005)
13. R. D. Pascual-Marqui, ″Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details,″ Methods and Findings in Experimental and Clinical Pharmacology, vol. 24, supplement D, pp. 5–12, (2002).
14. J. Allanson, S. H. Fairclough, A research agenda for physiological computing, Interacting with Computers 16 (5) 857-878 (2004).
15. Beatty, J.: Task-Evoked Pupillary Responses, Processing Load, and the Structure of Processing Resources. Psychological Bulletin 91, 276–292 (1982)

16. Berntson, G.G. et al. (1997), Heart rate variability: origins, methods, and interpretive caveats, Psychophysiology, 34, 623−648.
17. Pickering, T.G., Applications of ambulatory blood pressure monitoring in behavioral medicine, Ann. Behavioral Med., 15, 26−32 (1993).
18. Wientjes, C.J.E., Grossman, P., and Gaillard, A.W.K. Influence of drive and timing mechanisms on breathing pattern and ventilation during mental task performance, Biol. Psychol., 49, 53−70, (1998). Electrodermal activity.
19. Boucsein, W., Electrodermal Activity, Plenum Press, New York. (1992)
20. Crider a., Personality and electrodermal response lability: an interpretation. Appl Psychophysiol Biofeedback. ;33(3):141-8 (2008).
21. G. F. Wilson, C. r A. RussellReal. Time Assessment of Mental Workload Using Psychophysiological Measures and Artificial Neural Networks. Human Factors, Vol. 45, No. 4, pp. 635-643, (2003)

Movement analysis to indicate discomfort in vehicle seats

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Abstract Long distance travel is associated with discomfort and fatigue. It is a significant challenge to design a seat that remains comfortable for the occupant over the several hours required for many long-distance journeys. When designing seats, an indication of the perception of comfort / discomfort can be useful either for research and development purposes or potentially for automated systems to take actions that might mitigate discomfort. This paper considered a system that uses measurements of body movement in a seat to provide an objective measure of perceptions of discomfort. The system uses cameras and image processing to recognize when a seat occupant makes a movement in the seat which could be associated with relief of discomfort. The system was validated using a laboratory driving simulator. 10 participants volunteered to complete a study in which they drove for 90 minutes and gave subjective ratings of discomfort every 10 minutes, whilst also being observed using the camera system. It was shown that using a simple algorithm an association could be made between the movements of the driver and subjective ratings of discomfort. However, there remain challenges to improve reliability, optimize movement detection thresholds, and to make it more robust to naturalistic driving scenarios.

Keywords: Seating, Discomfort, SFMs, Fidgets, Driving

1 Introduction

During long-term transport, drivers and passengers increase their discomfort irrespective of how good their seat is. Whilst improvements in contouring of the seat, fit to the individual and physical environment can help in maximising the comfort at any one time, there is a trend for discomfort to increase over time such that after a few hours of sitting most drivers and passengers are ready to take a break or carry out some distracting activity in order to provide some relief (Hiemstra-van Mastrigt et al., 2016; Mansfield et al., 2015; Ravnik et al. 2008). It has been shown in a variety of contexts that discomfort can be observed through 'fidgeting' motions. These have been referred to as 'SFMs', an acronym for Seat Fidgets and Movements.

Sammonds et al. (2017) classified SFMs according to their size where a Type 1 SFM can be considered as a movement of the upper limbs, Type 2 a movement of the torso and Type 3 a whole-body movement. It was hypothesised that a Type 3 movement would indicate more discomfort than a Type 1 movement – i.e. the vehicle occupant would be stimulated to make a larger movement due to greater discomfort. One problem with the SFM method is that it currently requires continual observation by an experimenter; a task that is tedious at best and potentially could be prone to inter- and intra-observer differences. When a well-trained operator is vigilant in their coding, it is possible to obtain good correlations between subjective measures of discomfort and SFMs.

Driver SFMs can be observed using a variety of techniques. At the most basic level, a simple subjective method based on pre-determined criteria is effective and correlates very well with subjective data obtained from validated discomfort questionnaires. Jackson et al. (5) used a pressure measurement system to indicate discomfort. One advantage of systems that are based on direct recording is that, if the algorithms are fit for purpose, they could be left to operate semi-autonomously. One could envisage an in-vehicle system that monitors the vehicle occupants to establish their acute level of well-being and comfort. The vehicle could then make adaptations to improve the comfort, make recommendations such as to take a break or to feed back to the manufacturer how occupants experience the product.

Whilst it might be desirable to create a system that replicates the measurements from a previous method (e.g. SFMs) this is not necessary. It is acknowledged that the SFM method has its limitations inasmuch that it is a tally system and requires the judgement of the observer. An alternative to tallying the number of SFMs could be to integrate a measurement of the comfort-relief movements made by the vehicle occupant to generate an alternative score for the discomfort.

One constant challenge in comfort research is the disconnect between the true sensations of comfort and the ability of the experimenter to elicit these in a form that is measurable. The physical environment influencing the comfort will directly affect the physiology of the subject (Figure 1). The physiological response will be interpreted with the subject psychology and this will generate a sensation of comfort. This can be considered the true feeling of well-being. However, in order to elicit this sensation, an experimental method must be used and this is often reliant on the participants being trained and capable of using the method. This is difficult to achieve for a large study using naïve subjects. The experimental data available to the experimenter is the final step of this process, after a cascade of potential variance in the data. Despite all participants being trained in an identical way, it is common for some to interpret instructions differently providing variance in data. Similarly, multi-lingual participants might have different understanding of the detailed nuances of vocabulary. It would be desirable to use a method that eliminates some of these steps.



Fig. 1. Multiple steps from the physical environment that might influence comfort through to the experimental data available to a researcher studying comfort in a user trial.

This paper presents research that has developed a camera-based system that is capable to determining the occurrence of SFMs in a driving simulator in the laboratory.

2 Camera-based analysis system approach

The demonstration system uses two HD cameras. The primary camera is mounted in front of the driver and captures their torso and head. The secondary camera acquires signals from the steering wheel and gear shifter, marked to improve contrast (Figure 2). Signals from the second camera are not considered in this paper. Images are captured to a PC and processed using MATLAB. The primary camera in front of the driver samples the image two times per second.

The demonstration system was installed onto an XPI driving simulator at Imperial College London, comprising three screens and a TFT binnacle display. The simulator was fitted with a seat from a Toyota Prius. The driving simulator includes urban scenarios representative of a UK town, including highway and urban settings, and is configured for a right-hand drive vehicle.

SFM detection software compares subsequent images in order to detect whether changes in the image have occurred. Movements of the head, shoulder, and torso are individually processed using an image recognition process. The process counts pixels in the image which have changed between subsequent frames. If the driver remains stationary in the seat then there is no difference between subsequent images and therefore a score of zero will be recorded. If there is significant movement in the relevant regions of the image then a non-zero

score will be recorded; the more pixels that have changed, the higher the score. Therefore, raw data comprises three channels of data representing movement in the left torso, right torso and head. The MATLAB algorithm filters the data using a rectangular 5s sliding window.

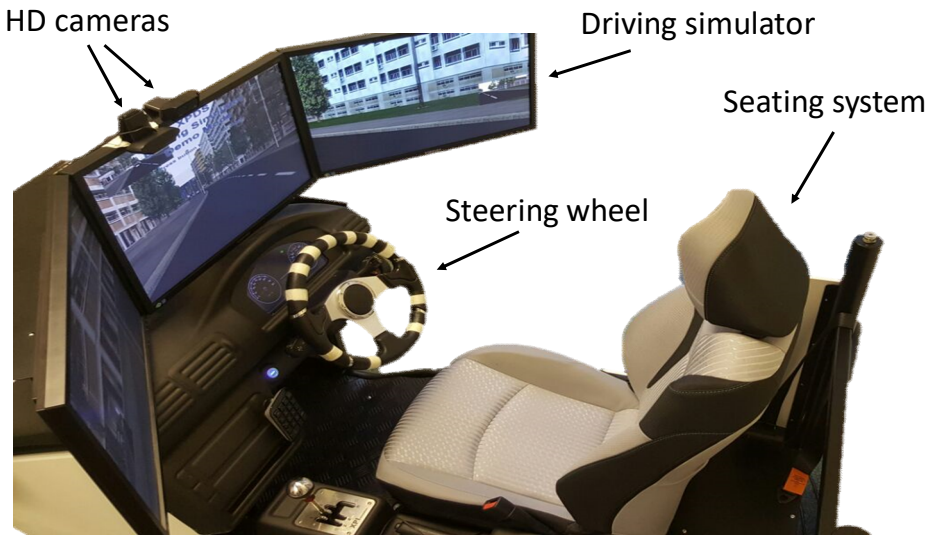


Fig. 2. Driving simulator with driver-facing cameras and high-contrast steering wheel.

3 Validation study

3.1 Method

Ten volunteers participated in a study to validate the motion analysis system. All participants were students at Imperial College London; 8 were male and 2 were female. Participants drove using the driving simulator for 90 minutes. Participant motion was measured using the camera system describe in Section 2 for the duration of the drive. Due to the camera detecting changes in pixels, participants were required to wear plain clothing as garments with a high spatial frequency would generate exaggerated motion signals.

Participants were also required to complete a two-part standardized comfort questionnaire adapted from Sammonds et al. (2017) and using the Borg CR100 scale (Figure 3). The questionnaire requires body-part discomfort to be evaluated first as priming questions and then an overall discomfort rating to be elicited. It is administered verbally and does not require participants to stop driving.

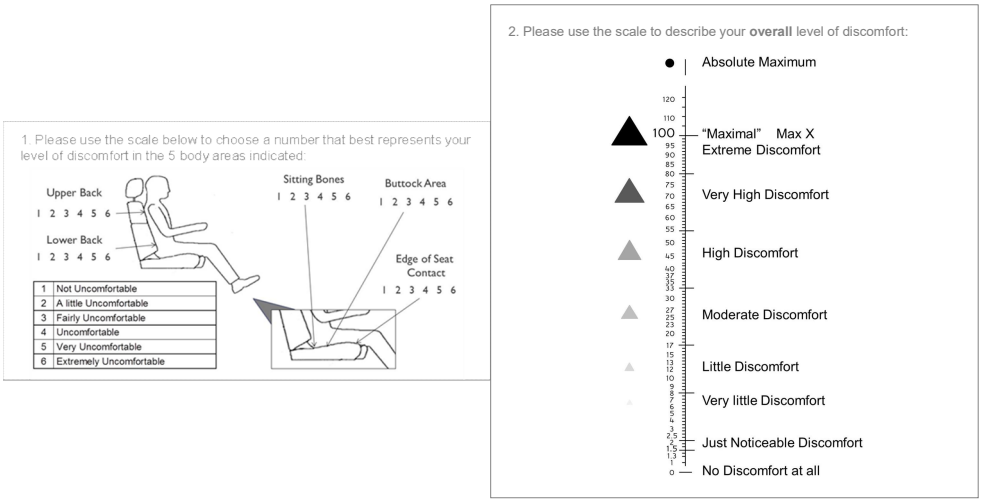


Fig. 3. Questionnaire design showing part 1; including the discomfort scale defined in ISO 2631-1 and a description of the body parts analysed, and part 2; including the adapted Borg CR100 scale (Sammonds et al., 2017)

4.2 Results

The demonstration camera-based system performed as designed for all participants, recording data for the full 90 minutes and generating plausible data for each. Similarly, participants all completed the 90 minute session and were able to complete the subjective discomfort questionnaire. Typical results for one participant is shown in Figure 4. These data comprise the sum of left and right torso squared. This squaring algorithm emphasized the movements in the data (shown as the peaks). Head data did not provide a clear indication of body motion. For most participants the frequency of the peaks in the data increased over time.

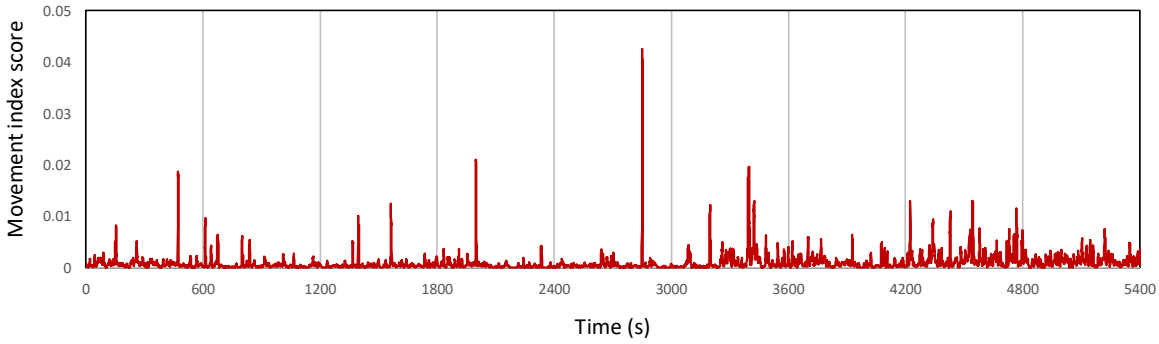


Fig. 4. Typical results for one participant – Data for left and right torso combined ^2.

As expected from the literature, the subjective discomfort generally increased over time (e.g. Mansfield et al. 2014; Figure 5). After 60 minutes all participants' discomfort was greater than at the beginning of the trial. However, scores improved for two of the participants between 60 and 90 minutes, with one returning to their score at zero minutes. Discomfort scores were significantly greater at the end of the trial than the beginning ($p < 0.001$, t-test)

Movement analysis data were split into 10 minute epochs representing each 10 minutes from 0 to 10, 10 to 20 etc. Within each epoch, the mean movement index score was calculated for the torso data squared. On average the amount of movement increased over the 90 minutes of the experiment (Figure 5). Whilst there was more variability in the movement analysis data than observed for the subjective data, the movement analysis index was significantly greater at the end of the trial than at the beginning ($p<0.05$, t-test).

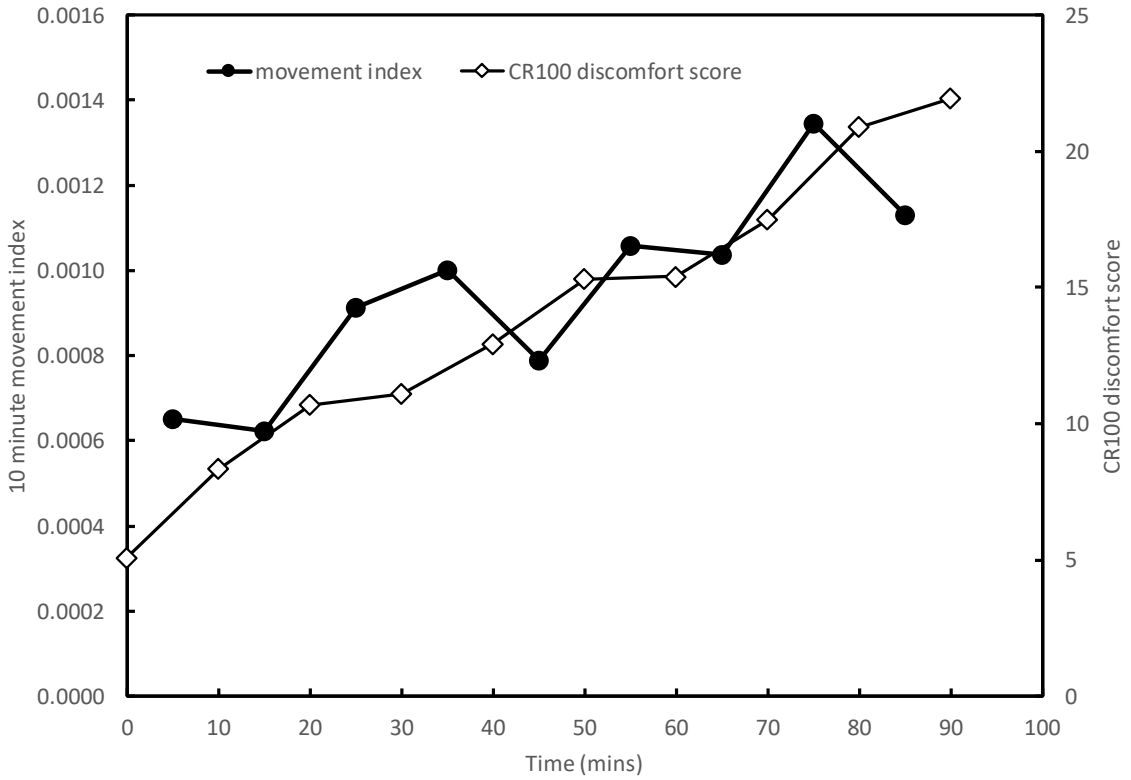


Fig. 5. Mean results for movement analysis and CR100 discomfort score. Movement analysis mean data for 10 minute epochs; movement index data points shown in figure correspond to middle minute of epoch.

5 Discussion

This investigation has demonstrated that it is possible to detect motion in a vehicle seat using a camera-based system. As hypothesized it shows that, on average, vehicle occupants move more as they have been occupying a seat for a longer period of time. Similarly, the well-established phenomenon of discomfort increasing with time has been replicated.

There are opportunities to improve the method that has been shown here. It has been argued that movements related to the driving task should not be categorized as SFMs (Sammonds et al. 2017) because they are not triggered by discomfort. The second camera system could be used to detect driving movements (i.e. steering controls and gear shifting) and to filter the motion from the primary camera to remove any driving-related movement. However, an alternative view could be that any driver movement activates muscles and improves the well-being, and thus driving-related motion could be beneficial. In autonomous or passenger transport systems, driving-related movements become irrelevant, although alternative tasks could present a similar challenge.

The algorithm used in the current version and presented here is simple and could be further optimized. The rectangular window could be improved; Hanning windows were investigated and slightly improved the ratio of the peaks in the motion to the background data, analogous to improving the signal-to-noise ratio. The optimal window design still requires validation. Using movement patterns detected by the camera to discern exact movements in the seat has also been explored. This has shown that one algorithm works very well for most participants but very poorly for others. Statistical analysis was unable to find clear associations with anthropometry and therefore this also needs exploration.

In the validation study some participants gave subjective responses that improved after one hour. This is possible but contradicts the general trends. It is possible that individuals found it difficult to interpret the

CR100 scale, and/or were unreliable in giving ratings. This is not unusual in comfort research. The phenomenon highlights a potential advantage of the camera-based system as this is less critical of the understanding of the participant and does not require specific training on interpretation of a novel concept of 'comfort rating'.

6 Conclusions and future work

- The camera-based movement analysis system worked for detecting driver movements in a laboratory setting. Further work is required to improve the computer vision system such that it can better distinguish different clothing patterns.
- The use of the secondary camera has not been considered in this study. Furthermore, primary camera positioning could also be optimized in future studies.
- On the basis on the data presented here, it is reasonable to associate driver movements with discomfort. This means that there are now three methods of generating 'discomfort' data: subjective ratings, SFMs, and driver movements; each method has its limitations. Further research is necessary to establish which method is most suitable when.
- It would be desirable to use this method in the field. For example, cameras could be installed in road, rail or air transport in order to discern growth of discomfort during long duration travel.

Acknowledgments The seats used in the experiment were supplied by The Bridgestone Corporation, Japan.

References

Hiemstra-van Mastrigt, S., Meyenborg, I. and Hoogenhout, M., 2016. The influence of activities and duration on comfort and discomfort development in time of aircraft passengers. Work, 54(4), pp.955-961.

Jackson, C., Emck, A.J., Hunston, M.J. and Jarvis, P.C., 2009. Pressure measurements and comfort of foam safety cushions for confined seating. Aviation, Space, and Environmental Medicine, 80(6), pp.565-569.

Mansfield, N., Sammonds, G. and Nguyen, L., 2015. Driver discomfort in vehicle seats–Effect of changing road conditions and seat foam composition. Applied Ergonomics, 50, pp.153-159.

Mansfield, N.J., Mackrill, J., Rimell, A.N. and MacMull, S.J., 2014. Combined effects of long-term sitting and whole-body vibration on discomfort onset for vehicle occupants. ISRN automotive engineering, 2014.

Ravnik, D., Otáhal, S., & Dodič Fikfak, M. (2008). Using different methods to assess the discomfort during car driving. Collegium antropologicum, 32(1), 267-276.

Sammonds, G.M., Fray, M. and Mansfield, N.J., 2017. Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs). Applied Ergonomics, 58, pp.119-127.

The effect of expectation on perceived comfort while using office devices

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Abstract Different tasks and activities are associated with different sitting postures. The aim of this study is to investigate the influence of anthropometric characteristics and expectations on postural comfort perception while using four office devices: a desktop computer, a laptop computer, a tablet and a smartphone. A statistical sample of healthy students was selected, and their anthropometric characteristics were measured. The postures assumed by the participants were gathered non-invasively using cameras. Angular detection was performed directly on snapshots using Kinovea® software. The angles of human joints were used for the virtual-postural analysis, using DELMIA® software. The evaluation of postural comfort for each of the devices was obtained in two ways: CaMAN® software developed by researchers from the Department of Industrial Engineering in Salerno (Italy) was used to calculate the objective comfort indexes, and a questionnaire was used to evaluate the subjective comfort indexes. The results of the analyses show a difference between subjective and objective postural comfort for all of the devices, and this difference is associated to the expectations.

Keywords: Comfort Evaluation, Non-invasive Postural Analysis, Expectations, Office Devices.

1 Introduction and the state of art

As reported by Vink and Hallbeck [1], although people use certain products on a daily basis, only a few papers have addressed the concept of localized comfort in relation to their use. Every year, many products are designed and launched; however, these are seldom redesigned to improve their comfort performance. These days, desktop and laptop computers are employed almost in every office task. Several papers have examined specific critical comfort aspects related to their use in the work environment. Berkhout et al. [2] demonstrated that elevating a notebook computer using a laptop station improves neck posture, reducing cervical spine torque and perceived strain. Workineh and Yamaura [3] designed and developed a new multi-position ergonomic computer workstation that provides much greater comfort for users, with an associated increase in productivity. Asundi et al. [4] evaluated the use of simple inclines as a means to improve head and neck postures while using notebook computers on tables. Gold et al. (2012) [5] examined how a non-seated posture leads to the discomfort of many body parts.

Comparisons between the postures assumed while using different office devices have received less attention. Among the few to address this topic, Straker et al. [6] investigated the postural implications of using a laptop instead of a desktop computer. Their statistical analysis showed significantly greater neck flexion and head tilt for laptop use, while the other body angles showed no statistical differences.

As well as desktop and laptop computers, tablet use is becoming increasingly common (e.g. Microsoft Surface). However, the literature addressing comfort issues for tablets is limited. Kim et al. [7] evaluated typing forces, muscle activity and comfort for virtual, notebook, and desktop keyboards. Todisco et al. [8] studied the effects of wearing eyeglasses upon postural comfort perception while using multi-tasking electronic devices in a sitting position. An effect on neck and shoulder posture alteration was recorded and, as a consequence, a change in discomfort perception while using different devices such as personal computers, tablets, smartphones and notebooks.
As stated above, few papers have evaluated overall comfort when using these everyday technologies, and only one considers the postures assumed in smartphone usage – another widespread device. This paper hence seeks to examine subjective and objective comfort for postures when using desktop computers, laptops, tablets and smartphones. These evaluations will then be analysed and correlated with the anthropometric characteristics of the users.
Concerning expectation, in [9], the role of expectations is viewed as a modifier (additive or subtractive) for both comfort and discomfort formulas. In a previous work, the influence of expectation on comfort evaluation while using a mattress in a short-time rest experiment [10] revealed a very strong influence on both comfort and discomfort.
In this paper, the following abbreviations/acronyms identify different body parts or types of motion (CI stands for 'Comfort Index'):

(1) SGCI: Subjective Global Comfort Index
(2) OGCI: Objective Global Comfort Index
(3) Flex: Flexion/Extension
(4) Rot: Rotation right/Rotation left
(5) Lat: Lateral left/Lateral right
(6) PS: Pronation/Supination
(7) Abd: Abduction/Adduction
(8) Dev: Radial Deviation/Ulnar Deviation.

2 Material and methods

2.1 Purpose

The aim of this study was to investigate the correlation between anthropometric characteristics and comfort perception related to the upper limbs for subjects in a sitting position using different electronic devices (desktop computer, laptop, tablet, smartphone). Comfort perception was evaluated in two different ways: subjective comfort evaluation was obtained by means of a comfort questionnaire, and the objective comfort evaluation was obtained using CaMAN® [11] software based on posture analysis and developed by the authors. The study also examines the influence of expectation on (dis)comfort evaluation.

2.2 Participants

Twenty college students, all volunteers, participated in the experiment. None had a history of musculoskeletal diseases. The main characteristics of the subjects are summarized in Table 1. The subjects were informed of the nature of the tests and their written consent was obtained, in accordance with ethical standards of the University of Salerno.

Table 1. Students' measurements.

	Age (years)	*Mass (Kg)*	*Height (cm)*
Mean	24.4	70.67	175.2
Std. Deviation	1.5	13.63	7.9
Minimum	23	46	160
Maximum	28	93	188

2.3 Testing Devices

The equipment used in this study for data acquisition and set-up was composed of a standard chair and table, four devices (desktop computer, laptop, tablet, smartphone), a photographic acquisition system and a comfort questionnaire. The seat of the chair was 46 cm high and the distance between the backrest and the table was 45 cm. The table dimensions were 74 cm high, 80 cm wide, and 140 cm long. The desktop computer used a 52 x 33 cm monitor, the edge of which was positioned 40 cm from the edge of the table at a raised height of about 12.5 cm. The monitor was tilted by 71 degrees with respect to the table. For the desktop computer, a keyboard was used, the edge of which was positioned 14 cm from the edge of the desk. The laptop (model ASUS F555L) had a 34.5 x 19.5 cm monitor, which was tilted at an angle of 60 degrees with respect to the desk. The edge of the laptop itself was about 12 cm from the edge of the table. The tablet (Samsung Galaxy Tab 4) was placed 4.5 cm from the edge of the table, and its display, tilted by 14 degrees with respect to the desk, was 10.1 inches. Finally, the smartphone (model Samsung Galaxy S5) was 5.1 inches in length and the students were asked to keep it in their hands freely. The distance between the chair (backrest) and the desk (the closer edge) was set at 45 cm in order to leave a distance between the head (for the whole sample) and the screen of 50-75 cm, as defined by VDT standards, with enough clearance (at least 15 cm) between the chest and the table edge. This distance corresponds to the average distance for the combo-desks used in the classrooms of the University of Salerno.
In the adopted configuration, the photographic acquisition system was equipped with three commercial cameras. This allowed us to acquire photos from three points of view: side (Camera C), behind (Camera B), and above (Camera A). The setup is shown in the Figure 1.

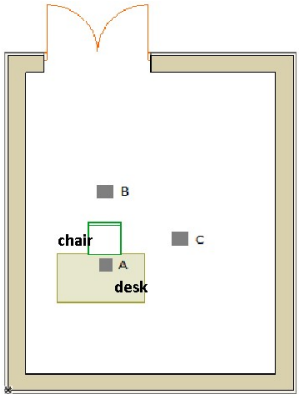
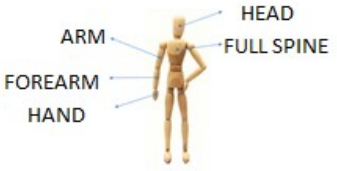


Fig. 1. Setup.

To acquire the subjective perceived comfort, a questionnaire in which the students had to give a comfort rating in a scale from 1 (minimum comfort) to 10 (maximum comfort) for each part of the body was used (Figure 2). A separate questionnaire was issued for each device. Before starting the test, subjects were also asked to state their expected comfort for the workstation in question. This information was very useful for understanding which factors may affect the expected comfort level. In the final part of the questionnaire, the authors asked the subjects to give the level of global perceived comfort during the test.



CI head	1	2	3	4	5	6	7	8	9	10
CI arm	1	2	3	4	5	6	7	8	9	10
CI forearm	1	2	3	4	5	6	7	8	9	10
CI hand	1	2	3	4	5	6	7	8	9	10
CI full spine	1	2	3	4	5	6	7	8	9	10
SGCI	1	2	3	4	5	6	7	8	9	10

Fig. 2. Comfort questionnaire

2.4 Simulation Software

CATIA® V5R16 was used for the virtual-modelling of the user environment and the devices. Several elements were modelled individually and then combined. DELMIA® Digital Human Modelling (DHM) software was used for modelling a 'dummy' based on the real subjects' anthropometric measurements [12, 13, 14, 15, 15, 16, 17]. Kinovea® software rel. 0.8.7 was used for the angular detection of users' joints while performing the required activities. Few small modifications were carried out to guarantee the accuracy of the manikin's postures, according to the photogrammetric acquisition previously verified in [18] and [19]. Comfort evaluations were performed using CaMAN® [11, 20, 21, 22, 23] – a MatLab application developed by Cappetti and Naddeo, which takes the angles describing operator posture as input, and which gives an index of postural comfort (CI) with a value range of 1-10 as output.

2.5 Procedures

Testing was conducted in a laboratory of the Faculty of Engineering at the University of Salerno. Subjects were asked to sit at a workstation and to simulate the use of the four devices. Each subject was then asked to give a score for the expected comfort of the workstation itself.
The subjects then used each of the four devices, one at a time.
The procedure for using all of the devices was the following:
(1) During the experimental phase, the subjects utilised each of the different electronic devices for a period of 15 minutes. They maintained what they determined to be the most comfortable position, with the requirement that the positions of the chair and the devices remained unaltered. After the first task (the first device) and 5 min of rest, the subjects used the second device for 15 minutes, and so on. To ensure that the sequence itself did not affect the perceived comfort values, the device sequence was random;
(2) After using each device, subjects were asked to complete the comfort questionnaire;
(3) For each device (desktop computer, laptop, smartphone and tablet), the postures of the subjects were acquired via three photos: one from the lateral side, one from the back side, and a third to reproduce each subject's binocular vision and evaluate the hand angles with more accuracy;
(4) The photos were processed using Kinovea® software to acquire the angles of the joints;
(5) The angles were then input into Delmia® to simulate each posture (Figure 3,4). In this step, some assumptions were made to ensure the correspondence between the angles evaluated by the two different softwares (Kinovea® and Delmia®). Delmia® was used to evaluate angles that were not available through the photographic acquisition, such as arm medial rotation, forearm pronation/supination and hand flexion/extension, as well as radio-ulnar deviation;
(6) The upper limb angles were processed by CaMAN® to obtain both partial comfort indices, as well as a global comfort index, by which to validate the analysis of the results. In this study, only the upper limbs were subject to postural analysis. For each device, we observed different positions of the articular joints of the upper limbs, while lower-limb posture remained similar for all the devices.

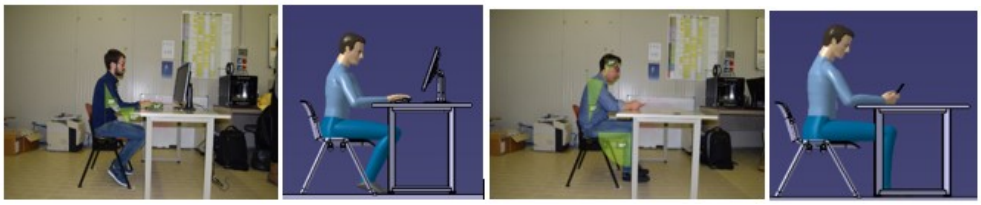


Fig. 3. Comparison between photo and human model for the desktop computer and the smartphone

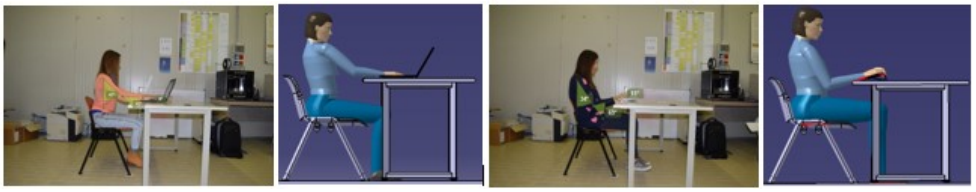


Fig. 4. Comparison between photo and human model for the laptop and the tablet.

2.6 Collected Data

For the different devices, three kinds of data were collected: anthropometric, subjective comfort perception (questionnaire), and objective comfort perception (CaMAN®). A summary of the anthropometric data is given in Table 2 below.

Table 2. Descriptive statistics of selected variables for the participant population.

	Height (cm)	*Arm (cm)*	*Forearm (cm)*	*Sleeve outseam (cm)*	*Chest height (cm)*	*Waist height (cm)*	*Chest breadth (cm)*	*Hip breadth (cm)*
Mean	175.2	32.7	26.2	56.2	125.6	88.8	32.4	37.1
Std. Deviation	7.9	1.9	1.5	2.4	6.1	3.2	3.6	2.7
Minimum	160.0	29.0	22.0	51.0	113.6	83.3	26.0	33.0
Maximum	188.0	36.0	29.0	60.0	137.0	94.9	39.2	40.8

An example of the descriptive statistics of the comfort indices (local and global, subjective and objective) is given in the Table 3.

Table 3. Descriptive statistics of local and global indices for the desktop computer.

Index	*Type*	*Mean*	*St. Deviation*	*Min*	*Max*
CI head	Subjective	6.6	1.8	3	10
CI arm	Subjective	6.8	1.8	4	10
CI forearm	Subjective	6.4	1.8	3	10
CI hand	Subjective	6.7	1.6	4	9
CI Full spine	Subjective	6.6	1.2	4	9
SGCI	Subjective	6.5	1.1	4	8
CI head (flexion & rotation)	Objective	9.7	0.3	8.9	10.0
CI head (lateral)	Objective	9.9	0.0	9.9	9.9
CI forearm (flexion)	Objective	6.2	0.6	5.5	7.3
CI forearm (PS)	Objective	5.7	0.8	3.3	6.8
CI arm (flexion)	Objective	8.1	1.0	6.5	9.9

CI arm (abduction)	Objective	8.5	1.8	5.2	10.0
CI hand (flexion)	Objective	9.8	0.6	7.9	10.0
CI hand (deviation)	Objective	7.4	3.3	1.0	10.0
OGCI	Objective	8.1	0.6	6.9	8.8

2.7 Data Analysis

Data was gathered to evaluate the impact of the subjects' anthropometric characteristics on objective/subjective comfort perception. For each device, a multivariate analysis was performed to determine possible correlations among the variables. The statistical analysis software SPSS rel.13 was used to perform these analyses. Pearson correlation coefficients were calculated to determine the strength of the relationships between all the variables. An example of the results can be seen in Table 4.

Table 4. Statistical correlations among the variables for the laptop (Pearson Index).

	Height	*Arm*	*Forearm*	*Sleeve outseam*	*Chest height*	*Waist height*	*Chest breadth*	*Hip breadth*
CI head (flexion and rotation)	-.455*	-.273	-.175	-.175	-.474*	-.422	.116	-.211
CI Forearm (flexion)	.021	.062	-.223	-.08	-.009	.019	-.009	.175
CI forearm (PS)	-.22	-.391	-.045	-.244	-.309	-.254	-.314	-.371
CI arm (flexion)	.545*	.298	.218	.226	.660**	.470*	.144	.339
CI arm (abduction)	.25	.229	.087	.071	.404	.33	.159	.388
CI hand flexion	.183	.015	.144	.074	.017	-.021	-.121	.08
CI hand (deviation)	.205	.216	-.148	.053	.215	.312	.025	.18
OGCI	.3	.22	-.071	.046	.35	.371	.045	.297

* Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

3 Results and Discussion

For the laptop, several significant correlations were found between the anthropometric characteristics and the CI, calculated using CaMAN® software (Table 4). The first correlation, individuated between height and head flexion CI, was negative. This can be explained by the fact that a taller person tilts their head more, feeling a higher degree of discomfort [6]. The second correlation was between height and arm flexion CI, which was positive. This was probably due to the fact that as the height decreases, the flexion of the arm increases, giving a higher degree of discomfort for an equal distance from the table. The same explanations can be used for the other two correlations (head flexion and arm flexion CIs with the distance between the feet and the chest). Finally, a positive correlation was found between waist height and the arm flexion CI.
For the tablet and the smartphone, the most important correlations relating to objective comfort are given in Table 5.

Table 5. Other correlations among objective CIs and anthropometric variables.

Setup	*CI CaMAN®*	*Anthropometric Variable*	*Pearson Correlation*	*Significance*
Tablet	Arm flexion	Height	.629**	0.003
Tablet	Arm flexion	Chest height	.624**	0.003
Smartphone	Hand deviation	Height	.505*	0.023

The first two correlations in Table 5 can be clarified in the same way as above. For the positive correlation between height and hand deviation CI, it may be that a taller person leans their forearm and hand on the table without any great deviation of the wrist – a trait confirmed by our analysis of videos taken during the tests. Other correlations for the subjective CIs obtained from the questionnaire are given in Table 6 below.

Table 6. Correlations between subjective CIs and anthropometric variables.

Setup	*CI (questionnaire)*	*Anthropometric Variable*	*Pearson Correlation*	*Significance*
Laptop	CI head	Arm	.578**	0.008
Laptop	CI forearm	Arm	.526*	0.017
Tablet	CI head	Arm	.680*	0.001
Tablet	CI head	Sleeve out seam	.594**	0.006
Tablet	CI full spine	Arm	.510*	0.021
Smartphone	CI arm	Arm	.607**	0.005
Smartphone	CI full spine	Arm	.674**	0.001
Smartphone	SGCI	Arm	.607**	0.005

For the positive correlations relating to the laptop and the tablet, it seems that the subjects perceive a higher comfort level for the head and full spine as arm length increases. This can be explained by the fact that people who have long arms tend to lean back in their seats. As such, the posture assumed by the full spine is more comfortable, and the head is less tilted. For the second correlation, a person with longer arms is better able to lean their forearm on the desk (given an equal distance from the table). For the smartphone, which the subjects were asked to keep it in their hands freely, there is positive correlation between arm length and CI arm, CI full spine and SGCI, indicating that arm length assumes an important role in the perception of comfort. This can be explained by the fact that subjects tend to lean back in their seats to achieve a more comfortable posture for the full spine when using a smartphone. However, this condition was difficult to assume in our configuration where the positions of the desk and the chair are fixed – if not that of the smartphone. This condition was easier to assume for the subjects with longer arms, for which the comfort increased.
For the statistical tests, there was a difference between objective and subjective comfort scores (Table 7).

Table 7. Comparison between SGCI and OGCI.

Setup	*Average SGCI*	*Average OGCI*
Desktop computer	6.50	8.15
Laptop	6.45	8.07
Tablet	6.05	8.04
Smartphone	6.80	7.96

This was due to the student's expectation. From the questionnaire, we know that the expected comfort level is 6.6. This means that subjects, before testing the workstation, believe it to be sufficiently comfortable. However, Table 7 reveals that the subjective score was lower than the objective score in all for four tests – a result confirming the hypothesis that is the basis for this work [10]. High expectation levels have a negative influence on the real perceived level of comfort.

8 Conclusion

The aim of this study was to investigate the correlation between anthropometric characteristics and the comfort perception for the upper limbs when subjects were in a sitting position. The electronic devices were a desktop computer, a laptop, a tablet, and a smartphone.
The collected data was analysed, and correlations between the anthropometric characteristics and, respectively, the subjective and objective comfort perceptions were calculated. Frequently, height was found to play a significant role. For example, regarding objective comfort and laptop usage, a taller person perceived greater head discomfort, as taller people tilt their heads more. However, these taller subjects have a more comfortable forearm position, by virtue of their longer arms. Another important result concerns the correlation between the subjective perceived comfort in relation to the head and full spine, and arm length. This can be explained by the fact that people with long arms tend to lean back in their seats for greater comfort of the full spine, which in turn means that the head is less tilted. For the smartphone, results indicate that arm length assumes an important role in the perception of comfort. This can be explained by the fact that when using the smartphone, subjects tend to lean back in their seats to achieve a more comfortable posture for the full spine. However, this condition was not possible in our configuration with its fixed distance between the desk and the chair. Discomfort was also seen to increase as the arm length increased.
The results show a gap between the subjective (questionnaire) and objective (CaMAN® software) comfort perception. Before sitting at a workstation to simulate using the four devices, each student was asked to give a score for the expected comfort of the workstation. The average score of expected comfort was 6.6, indicating that the subjects considered the workstation sufficiently comfortable prior to testing. This in turn had a negative effect on real perceived comfort. The obtained results confirmed the assessment of a model by Naddeo et al. [9] that shows an indirect correlation between expected comfort and perceived comfort: an increase in expected comfort implied a decrease in perceived comfort, and a decrease in expected comfort implied an increase in perceived comfort. Ergonomic improvements to workstations are a key factor in both increasing productivity and preventing musculoskeletal disease. This paper shows how anthropometric characteristics can influence the perception of comfort. It is therefore important to design tailored workstations with flexible, modifiable configurations.

References

1. Vink, P., Hallbeck, S., 2012. Editorial: Comfort and discomfort studies demonstrate the need for a new model. Applied Ergonomics. 43, 271–276.
2. Berkhouta, A.L., Hendriksson-Larsen, K., Bongersb, P., 2004. The effect of using a laptopstation compared to using a standard laptop PC on the cervical spine torque, perceived strain and productivity. Applied Ergonomics. 35, 147–152.
3. Workineh, S.A, Yamaura, H, 2016. Multi-position ergonomic computer workstation design to increase comfort of computer work. International Journal of Industrial Ergonomics. 53, 1-9.
4. Asundi, K., Odell, D., Luce, A., Dennerlein, J.T., 2012. Changes in posture through the use of simple inclines with notebook computers placed on a standard desk. Applied Ergonomics. 43, 400-407.
5. Gold, J.E., Driban, J.B., Yingling, V.R., Komaroff, E., 2012. Characterization of posture and comfort in laptop users in non-desk settings. Applied Ergonomics. 43, 392-399.
6. Straker, L., Jones, K.J., Miller, J., 1997. A comparison of the postures assumed when using laptop computers and desktop computers. Applied Ergonomics. 28, 263-268.
7. Kim, J.H., Aulck, L., Bartha, M.C., Harper, C.A., Johnson, P.W., 2014. Differences in typing forces, muscle activity, comfort, and typing performance among virtual, notebook, and desktop keyboards. Applied Ergonomics. 45, 1406-1413.
8. Todisco, V., Clemente, V., Califano, R., Vallone, M., 2017. The effect of wearing eyeglasses upon postural comfort perception while using multi-tasking electronic devices in sitting position. doi:10.1007/978-3-319-41685-4_49
9. Naddeo, A., Cappetti, N., Vallone, M., Califano, R., 2014. New trend line of research about comfort evaluation: Proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physio-

logic comfort perceptions. In Advances in Social and Organizational Factors, Edited by Peter Vink, Published By “Advances in Human Factors and Ergonomics” Conference 2014, ISBN: 978-1-4951-2102-9.
10. Naddeo, A., Cappetti, N., Califano, R., Vallone, M., 2015. The Role of Expectation in Comfort Perception: The Mattresses’ Evaluation Experience. Procedia Manufacturing. 3, 4784—4791.
11. Naddeo A., Cappetti N., D'Oria C., 2015. Proposal of a New Quantitative Method for Postural Comfort Evaluation. International Journal of Industrial Ergonomics. 48, 25-35.
12. Vallone, M., Naddeo, A., Cappetti N., Califano, R., 2015. Comfort Driven Redesign Methods: An Application to Mattresses Production Systems. The Open Mechanical Engineering Journal. 9, 492-507.
13. Di Pardo, M., Riccio, A., Sessa, F., Naddeo, A., Talamo, L., 2008. Methodology development for ergonomic analysis of work-cells in virtual environment. SAE Technical Papers. DOI: 10.4271/2008-01-1481.
14. Naddeo, A., Vallone, M., Cappetti, N., Califano, R., Di Napoli, F., 2017. Ergonomic-driven redesign of existing work cells: The “Oerlikon friction system” case. Lecture Notes in Mechanical Engineering. Pp. 1197-1207doi:10.1007/978-3-319-45781-9_120.
15. Bassi, C., Naddeo, F., Pulignano, C., Senatore, B., Tarantino, D., 2016. How to analyze and improve a supermarket cashier’s work cycle. International Journal of Applied Engineering Research. 11(20), 10358-10366.
16. Califano, R., Cozzitorto, P., Delmastro, M., de Vito, C., Sellitto, G., Vallone, M., 2016. Virtual ergonomic analysis and redesign methods: An application to lunch payment station at university of Salerno. International Journal of Applied Engineering Research. 11(10), 7114-7118.
17. Annarumma, M., Pappalardo, M., Naddeo, A. Methodology development of human task simulation as PLM solution related to OCRA ergonomics analysis. In IFIP 2008 Int. Fed. Inf. Process. 277, 19-29, doi:10.1007/978-0-387-09697-1.
18. Naddeo, A., Barba, S., Ferrero, Francia I.F., 2013. Propuesta de un nuevo método no invasivo para el análisis postural con aplicaciones de fotogrametría 4d. XI Congreso Ibero-Americano de Ingegnieria Mecanica (CIBIM2013), 11-14, La Plata, Argentina.
19. Naddeo, A., Cappetti, N., Califano, R., Vallone, M., 2013. Manual assembly workstation redesign based on a new quantitative method for postural comfort evaluation. Applied Mechanics and Materials. 459, 368-379.
20. Apostolico, A., Cappetti, N., D’Oria, C., Naddeo, A., Sestri, M., 2013. Postural Comfort Evaluation: Experimental Identification of Range of Rest Posture for human articular joints. Int J Interact Des Manuf. pp.1-14, doi: 10.1007/s12008-013-0186-z.
21. Naddeo, A., Apicella, M., Galluzzi, D., 2015. Comfort-¬Driven Design of Car Interiors: A Method to Trace Iso¬Comfort Surfaces for Positioning the Dashboard Commands. SAE Technical Papers. DOI: 10.4271/2015-01-1394.
22. Naddeo, A., Cappetti, N., Ippolito, O., 2014. Dashboard reachability and usability tests: A cheap and effective method for drivers' comfort rating. SAE Technical Papers. DOI: 10.4271/2014-01-0455.
23. Naddeo, A., Memoli, S., 2009. Postural comfort inside a car: Development of an innovative model to evaluate the discomfort level. SAE International Journal of Passenger Cars - Mechanical Systems.2,1065-1070.

A new approach for measuring the seat comfort

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Abstract

In this paper a measurement tool is developed and tested to check the effects in the interaction between the human and a seat. Many studies report a relationship between discomfort and pressure distribution, but the exact effect in the interaction are still unknown. The purpose of the study to develop a measuring device which learns more on the shear forces in a seat pan of separate elements in a seat, but also of the combinations. The device is developed and tested. The test shows that the reproducibility and repeatability of the stamp sensors are appropriate for our purpose very high. The results show that the layout structure of the sensors could be optimized as well as the re-clamping procedure of the cover materials to reach a better reliability.

Keywords: objective measurement concept, pressure distribution, shear forces, comfort

1 Introduction

The European Union and the European Free Trading Association-States together have a population of 520.582.413 (*Eurostat*, 2017 and *European Free Trading Association*, 2015) people and about 259.834.000 (*Jurado*, 2014) vehicles in use. Statistically nearly one out two persons owns a vehicle irrespective of whether they have a driver's license or not. Therefore, it is obvious that the automobile is an essential part of our everyday life. The results of the market research institute Consumer Science & Analytics with the Title "OUR LIVES INSIDE CARS" underlines the rising importance of vehicles as a daily companion. In average a person spends four years and one month in a vehicle during their lifetime (*CSA Research*, 2017), most of the time sitting causing a static load of the musculoskeletal system. In the future autonomous driving opens opportunities to use this travel time in a more efficient way and facilitate variations in postures. Hence, it is important for the car manufacturers to emphasize the role of a comfortable, adaptable and pleasant car interior, with a special focus on the seats as the main interface between the human and the vehicle. Depending on the boundary conditions the challenge for the seat design is to develop an ergonomic and comfortable product, avoiding any discomfort in the seat interaction zone.

The interaction between the human and the seat results from the indentation process. There is much literature on the subjective experience of this interaction zone. For the objective seat comfort evaluation of this interaction zone there is a need for more knowledge. However, this is complex. The complexity is caused by the seat characteristics and the individual properties of the sitting person and this interaction changes in time. For this reason, it is common to divide the evaluation of the seat design in three time dependent subcategories: the initial, the short-term and the long-term comfort. *Mergl* (2006) defined the initial comfort as the first three minutes, the short-term-comfort lasts up to 30 min and long-term comfort starts after 30 minutes. Furthermore various researcher studied the influence of the time influence. *Sammonds* (2017) showed that in 140 minutes the number of seat-movements rise as well as the discomfort scores. *Adler* (2007) found that long-term seating comfort is directly related to system stress. *Hartung* (2006) investigated the time-dependency of the subjective seat comfort evaluation. The discomfort feeling was significantly higher ($p<0.05$) after 135 minutes compared to an

evaluation after 15 minutes. Other authors also illustrated the time-dependency of the interaction zone (e.g. *Smulders et al.*, 2016).

The seat usually consists of different components influencing the interaction zone. It is assumed that car manufacturers usually specify the components separately, but an overall specification of the seat, describing the interaction of the component, is mostly not considered in the automotive industry. A seat can consist of the seat-frame, the adjustment systems of the seat, the foam hardness and dimensions, the cover materials with different tensions and friction coefficients as well as the different layers, the lamination, the heating system, the resistant layers and the seat-suspension. These systems are often well tested individually, but a factor making it complex is the non-linear behavior of certain components, like the viscoelasticity of the foam *(Gibson and Ashby*, 2001) and the combinations of those.

The human body, influences the seat by its individual weight, shape, height, percentile, gender and sitting position (*Kilincsoy et al.*, 2014, *van Veen*, 2014, *Vink* , 2012). The reaction of the seat components during the indentation deforms the human skin and the underlying tissue, also effecting the blood flow, musculoskeletal system and tissues. Many systems in the human body react and amongst these the mechanoreceptors in the skin record the changes in the stressed surface and send the information to the brain (*Diesing*, 2006) for interpretation and evaluation of the seat comfort. Other systems, like propriocepsis influence this as well. The skin has four receptors, the Merkel disks for the pressure, the Ruffini corpuscles for the stretch and shear stresses, the Pacinian corpuscles for vibration and the Meissner's corpuscles, primarily providing information about tactile and sensitive changes. The Merkel disks and the Ruffini corpuscles are slowly adapting cutaneous mechanoreceptors. The Meissner corpuscles and the Pacinian corpuscles adapt comparatively slowly (*Schmidt and Thews*, 1980). The sensors in ligaments and muscles gather information as well and form the proprioceptive input. For the comfort evaluation the slowly adapting mechanoreceptors are probably more critical than the fast adapting mechanoreceptors (*Goossens et al.*, 2005). Therefore, the parameters in the interaction zone that might be very relevant are the pressure, the elongation, the shear stress and the friction coefficient. Depending on the age or gender the sensitivity and the signal power changes. *Hartung* (2006) described that the gender has a big influence on the comfort evaluation and *Venkatesan et al.* (2015) mentioned that the physical structure in the skin changes with age effecting the skin sensitivity.

Most seat comfort studies focus on the seat pressure distribution (probably related to Meissner corpuscles) and the correlation to the subjective seat discomfort evaluation. *De* Looze *et al.* (2003) discussed different studies and pointed out that most of them described a correlation between the pressure and the discomfort, predominantly with a limitation on special body parts. *Gyi and Porter* (1999) described a correlation between the pressure under the ischial tuberosites and discomfort for very tall males. The study of *Ebe* and *Griffin* (2001) showed a high correlation between pressure (load) under the ischial tuberosity and seat comfort. The purpose of the most seat pressure studies is a design recommendation. *Kyung* and *Nussbaum* (2008) recommended a lower pressure ratio at the buttock and higher pressure ratio at the upper and lower back. *Franz et al.* (2012) suggested that the foam for the neck support should be softer than the foam contacting the head. *Hartung* (2006), *Zenk* (2006) and *Mergl* (2006) worked out general guidelines for an ideal seat pressure distribution. *Hartung* (2006) describes a correlation between the pressure distribution and the subjective seat comfort evaluation. *Mergl* (2006) presented a pressure distribution in the cushion of 49%-57% in the buttock, <28% in femur area next to the buttock and < 6% on the front femur area. *Zenk* (2006) reports nearly the same results, 49%-54% of the load in the buttock, <28% in femur area next to the buttock and < 6% of the front femur area. *Kilinscoy et al.* (2016) investigated the ideal pressure distribution for the rear seats in an upright and relaxed position. He concluded that 54%-60% of the load should be in the buttock area and depending on the sitting position a load of 4%-10% in the front of the seat. Statistically the significance in the correlation between the pressure distribution and the comfort evaluation in the seat cushion is higher than in the backrest of the seat. *Zenk* (2006)] and *Mergl* (2006) mentioned that the pressure distribution in the cushion influence the pressure distribution in the backrest and vice versa. *Vink* and *Lips* (2017) confirmed the results of the previous studies by studying sensitivity and described a higher sensitivity in the shoulders and at the front of the seat cushion. Less sensitivity was found in the lumbar area.

Most of the studies mentioned use a small variety of seats and have no connection to the different seat components on the comfort evaluation. To advise on the seat components or test the effect in this paper it is assumed that the elongation (shear stress and friction coefficient) could be useful to make linkages with the seat components, It is a parameter for the comfort evaluation and has potential to supplement the previous studies. While sitting in a car seat the elongation and the shear stresses might influence seat comfort.

In the field of Dekubitus (*Diesing*, 2006), especially in the wheelchair development (*Goossens*, 2001), the research studies investigated a significant elongation/shear stress influence on the human body and the seat comfort. In the past the effects of pressure and shear stress on the human body were studied in-depth. *Bennet*

and Worthen (1980) investigated in the palm of the hand that it is only half of the initial pressure necessary to stop the blood flow if high shear forces are included. In his study *Goossens* (1994) has measured a cut-off pressure of 11.6 kPa in the absence of shear stress. With a shear stress of 3.1 kPa he has shown that the cut-off pressure was significantly reduced to 8.7 kPa.

Previous studies have shown that both stresses, the shear force and the pressure, have influence on the deformation of the anatomical structure, like the tissue and skin on a sitting person. *Chow* and *Odell* (1978) described that the interface shear force has a significant effect on pressure distribution. It is underlined by the statement that the frictionless interface produces much lower pressure. *Zhang* and *Roberts* (1994) mentioned that the externally applied stresses to the skin alter the internal stress distribution. The shear forces externally applied to skin surface roughly have the same effects on underlying tissues as normal forces (pressure). Also, the skin blood flow reduces with the increase of shear force.

Therefore, the elongation (shear force, friction coefficient) could be an important part in the evaluation of the seat comfort worthwhile studying further. This gap could be closed by the presented method. The objective of this paper is to describe a measurement method which records human relevant parameters during the indentation process related to the human mechanoreceptors. This work outlines the advantages and the limitations of the applied method.

2 Methods

2.1 Measurement method

To explore the effects in the interaction zone between human and seat a measurement method is developed. Figure 1 shows the measurement method consisting of a material testing machine with a controllable spindle, a stamp with sensors and a measurement setup, consisting of four degrees of freedom. The stamp is connected to the material testing machine a Z005 from the Zwick/Roell Company. The spindle of the machine allows an upward and downward movement of the stamp. A Zwick/Roell Software named testXpert II allows to define sequences of the test cycles. Typical parameters are the indentation velocity, the rest time, the force control and time control. The stamp simulates the initiated stress of the human body and the associated sensors simulate the

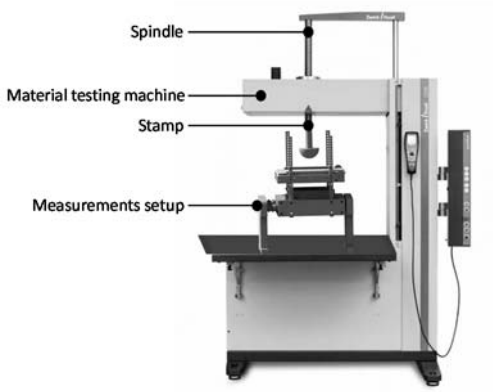


Fig. 1. Schematically setup of the new measurement method

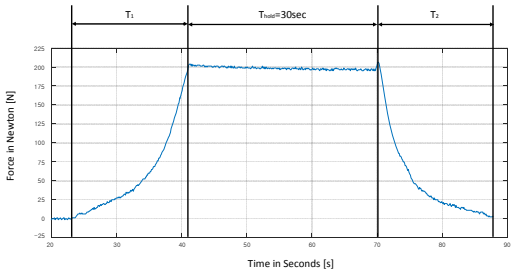


Fig.2. Measurement curve without pre-cycles

recording of the skin-mechanoreceptors. On the fixing plate of the testing machine a measurement setup is mounted. The measurement setup represents various seat structures with common seat components such as different foams, covers or suspensions. The testXpert II Software controls the specified testing procedure getting information from the force sensor and the position of the spindle. During the increase of the load the stamp records the pressure and elongation signals whereas the testing machine records the applied force and distance of the indentation.

2.1.1 Stamp

The shape of the stamp is a half sphere with a diameter of 75 mm. It follows the requirements of the Standard *DIN 53579* (2005), which measures the foam hardness. The Stamp is equipped with four elongation sensors and four pressure sensors. For the analysis of the sensor signals the cable capacity is also considered. A microcontroller processes the recorded sensor signals and LabView visualizes these signals. For the synchronization of the sensor signals the microcontroller processes as well as the signals of the Zwick/Roell force sensor and the position information of the spindle via an I/0-module.

2.1.2 Measurement setup

The measurement setup represents the various combinations of the seat structure. The setup allows to use various foams with different degrees of hardness and heights, different cover materials with adjustable cover tensions as well as the various seat suspensions. Furthermore, it is possible to integrate different laminations, layers or interfering contours. The seat suspension is replaceable by a plate which follows the requirements of the *DIN EN ISO3386-1* (2009). The holes of the plate have a diameter of 6 mm and a distance of 20 mm.

2.1.3 Measurement procedure

The measurement procedure is based on the *DIN 53579* (2005) and *DIN EN ISO3386-1* (2009). The validity of the DIN requirements are restricted to foams and not to the overall seat structure. Therefore some parameters of the DIN requirements have to be adapted. The environmental conditions of the specifications are unchanged with a humidity of (50±5) % and the temperature of (20±2) C°. Other process parameter of the DINs, like the indentation velocity, the number of pre-cycles, the time of the holding phase and the maximum force have to be investigated and adjusted to ensure a suitable process reliability. The original measurement procedure (*DIN 53579* (2005) and *DIN EN ISO3386-1* (2009)) has three pre-cycles and one measurement cycle. Figure 2 shows an exemplary curve of an applied measurement cycle. It is divided in three sectors: T_1=stress-phase, T_{hold}=holding phase (30 seconds) and T_2=relief-phase. The indentation velocity for the pre-cycle is for the stress-phase as well as for the relief-phase 300 mm/min. For the measurement cycle the stress- and relief-velocity is 100 mm/min. Preliminary investigations with a pressure mat (XSensor X3 LX210) have shown that the stamp reaches the maximum measurable pressure of 10,34 N/cm^2 at a force of 350 N. Therefore the predefined measurement range is 0 N - 350 N and 0 N/cm^2 – 10.34 N/cm^2. To avoid lasting damages in the cover materials the maximum force for this research is defined to 200 N. The amount of the pre-cycles is an investigated test parameter of this measurement method.

2.2 Technical protection on the base of quality factors

For an evaluation of the measurement method it is essential to assess the method based on the quality factors: Objectivity, Reliability and Validity. For the verification of the quality factors the measurement setup includes a commercial seat suspension, a commercial fabric- and leather-cover and a foam with the height of 100 mm and the hardness of 4 kPa.

2.2.1 Objectivity

The objectivity is in this case defined as the operator independency of the measurement method. The focus is on the execution of the measurement procedure. The most influential factors for the measurement execution

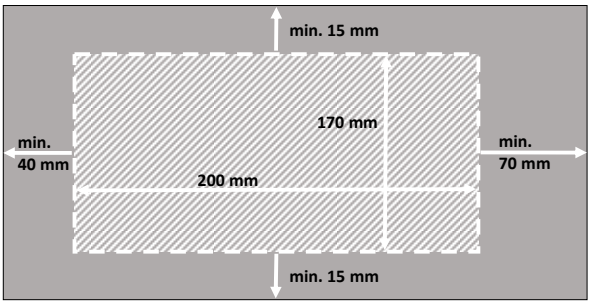


Fig. 3. Geometrical guidelines for the cover sample

are the stamp including the sensors, the measurement setup and the material testing machine. The position of the stamps is aligned to the material testing machine The measurement setup is made in such a way that it is able to simulate the various structures of the seats. The seat suspension and the foam is adjusted by a mechanical end stop. The fixation of the cover is critical because the initial tension of the same cover type (same material, new fixation) has to be equal for each clamp. During the increase of the load the fixation has to avoid any cover-movements. Figure 3 shows the guidelines for each cover sample. The cover has a marked field to align the right position in the measurement setup. The surfaces of the cover clamp device have a high roughness in order to be able to keep the fixation pressure constant. The cover is connected to a crankshaft to adjust the tension in 20° steps, up to 240° maximum. The Zwick/Roell machine is proved by a technical institute to guarantee the specified tolerances.

2.2.2 Reliability

The reliability is tested and defined in this case as the reproducibility and repeatability of the measurements. The comparison of the data is done during the holding phase (T_{hold}, Figure 2). For each measurement the raw data of the sensor was analyzed among the following aspects: internal error, average value and variance. These statistical parameters are the base for verification of the reliability tests. With regrades to the statistical significance these parameters are calculated with 815 to 850 sensor values. To evaluate the reproducibility of the measurement method it is essential to determine the amount of pre-cycles to ensure meaningful results. Simultaneously these tests can be used to prove the reproducibility of the measurement. Additional attempts are made to guarantee a minimal deviation of the measurements results for re-clamping the same cover samples. The above mentioned effects will be studied for each sensor. Table 1 shows the procedure of the reliability tests conducted.

Table 1. Overview of the reliability test.

No.	Measurement setup	Pre-cycles	Measurement Repetitions	Focused Parameter
1	commercial suspension, foam (100mm, 4kPa) and max. fabric tension (240°)	**10**	3	Def. of the pre-cycles amount / repeatability
2	commercial suspension, foam (100mm, 4kPa) and max. fabric tension (240°)	**5**	3	Def. of the pre-cycles amount / repeatability
3	commercial suspension, foam (100mm, 4kPa) and max. fabric tension (240°)	**3**	3	Def. of the pre-cycles amount / repeatability
4	commercial suspension, foam (100mm, 4kPa) and max. fabric tension (240°)	**0**	3	Def. of the pre-cycles amount / repeatability
5	commercial suspension, foam (100mm, 4kPa) and max. fabric tension 240° (**Re-clamping the cover**)	5	3	Accuracy of re-clamping
6	commercial suspension, foam (100mm, 4kPa) and max. fabric tension 240° (**Re-clamping the cover**)	5	3	Accuracy of re-clamping

2.2.3 Validity

The technical protection of the measurement method was evaluated by the criterion validity. This quality factor assesses how well the results of a measurement refers to the expected measurement results. The test parameters were: cover tension, foam hardness and the isotropy of the cover material. Table 2 contains an overview of the tests for the technical protection of the conducted measurement.

Table 2. Overview of the validity test.

No.	Measurement setup	Pre-cycles	Measurement Repetitions	Focused Parameter
1	commercial suspension, foam (100mm, 4kPa) and max. fabric tension (240°)	5	3	Reference measurement
2	commercial suspension, foam (100mm, 4kPa) and **lower fabric tension (l00°)**	5	3	Recording of changes in the cover tension
3	commercial suspension**, foam (100mm, 4kPa)** and **max. leather tension (240°)**	5	3	Recording of anisotropy of the leather material

3 Results and Discussion

3.1 Analysis of the Reliability

Table 3 shows the average values of the unstressed and stressed capacity of each Elongation-Sensor. These values are the base for the determination of the elongation by calculating the percentage increase of the capacity. All sensors show in an unstressed position nearly the same magnitude. Only Sensor 4 shows a smaller variance. In the stressed position Sensor 1 and Sensor 2 (same axes) have nearly the same value with a nine hundredth deviation in the variance. The measurement axes of sensor 3 and 4 is 90° rotated to the axes of Sensor 1 and 2. Because of the cover tension this sensors recognize a deviation of the elongation. Still, the variance of the signals are the same. The conclusion of this comparison is that the signals are stable enough for our purpose.

Table 3. Results of the unstressed and stressed elongation sensor. The capacity changes during the stress.

	Elongation-Sensor 1	**Elongation-Sensor 2**	**Elongation-Sensor 3**	**Elongations-Sensor 4**
Average value (un-stressed)	240.24 pF	240.24 pF	240.24 pF	240.23 pF
Variance (unstressed)	0.022 pF	0.022 pF	0.022 pF	0.013 pF
Average value (stressed)	257.42 pF	257.08 pF	260.35 pF	256.18 pF
Variance (stressed)	0.021 pF	0.012 pF	0.021 pF	0.021 pF

The following section shows the results of the pre-cycle tests specified in Table 1 (Test 1 to 4). The pressure signals are independent of the pre-cycles. No measurable deviation was recorded. Table 4 shows the results of the Elongation-Sensors, exemplary for Elongation-Sensor 1. With decreasing pre cycles the deviation of the elongation values decreases. Therefore, no pre-cycles are needed. With regards to realistic circumstances (pre-cycles for foams), a minimum of three pre-cycles for the measurements has to be set.

Table 4. Comparison of the pre-cycle influence

	10 pre-cycles	**5 pre-cycles**	**3 pre-cycles**	**non pre-cycles**
Elongation	7.13 %-7.53 %	6.95 %-7.21 %	7.10 % - 7.19 %	7.14%-7.20%
Max. Elongation Deviation	5.6 %	3.8 %	1.35%	0.83%

Table 5 contrasts the reproducibility of the stressed sensor signals based on 12 measurements. The pressure sensors have no measurable deviations. The Elongation-Sensors 1 and 2 have the same maximum deviation of 0.24 % (symmetric elongation). The sensor-signals 3 and 4 (symmetric elongation) have a higher max. deviation up to 0.77 %. The higher deviation in sensor 3 and 4 is most likely to be justified in the sensor layout structure of the stamp. In general the max. deviation of the signal is less than 1% with regards to the tolerance of the various seat components.

Table 5. Investigation of a reproducible sensor signal

	Elongation-Sensor 1	**Elongation-Sensor 2**	**Elongation-Sensor 3**	**Elongations-Sensor 4**
Max. Deviation	0.24 %	0.24 %	0.77 %	0.41 %
Absolut Deviation	0.61 pF	0.61 pF	2 pF	1.05 pF

Table 6 shows the measurement results of the test series 5 and the test series 6. These were done under the same conditions with the difference that the identical cover material was re-clamped. The maximum deviation of the elongation within the test series 5 is 1.26 % and for the test series 6 0.70 %. An analysis of both test series together yield in the worst case to a maximum elongation deviation of 4.03 %, caused by the re-clamping procedure of the cover material. More marks for the cover clamping would decrease the deviation of the results significantly. The deviation of the other parameter shown in Table 6 are influenced by the deviation of the cover re-clamping. Additionally Table 6 illustrates the accuracy of the control parameter (Force-Sensor of the Zwick /Roell) with a maximum error of 0.47 %.

Table 6. Influence of the re-clamping on the measurement accuracy and reproducibility.

Test-No.	Elongation in ΔpF	Pressure equivalent in ΔpF	s in mm	F in N	Max. Deviation of Elongation in %	Max. Deviation of Pressure in %	Max. Deviation of s in %	Max. Deviation of F in %
	16.63	168	26.48	199.04				
5	16.79	169	26.22	199.04	1.26	0.60	1.65	0.45
	16.84	169	26.05	198.94				
	17.19	165	27.09	198.96				
6	17.31	166	26.77	198.96	0.70	1.21	1.69	0.01
	17.30	167	26.64	198.98				
Total parameter for Test 5 and 6					**4.03**	2.42	3.99	0.47

3.2 Analysis of the Validity

Table 7 shows that the measurement system recognizes the changes in the cover tension and the cover material. The pressure and the elongation were measured by the stamp. The indentation depth and the indentation force were recorded by the material testing machine. Furthermore the measurement method recognizes the anisotropy of the surface materials. For the fabric the sensors measure for one axis only a very similar elongation, for leather the elongation for the same axes deviates noticeable. The stamp records surface and volume effects in the seat structure, not shown in Table 7.

Table 7. Recordings of changes in the cover tension and the cover materials

Test-No.	Elongation in ΔpF	Pressure equivalent in ΔpF	s in mm	F in N	average Elongation in ΔpF	average Pressure in ΔpF	average s in mm	average Force in N
	17.42	163	26.68	199.07				
high cover tension (fabric)	17.08	163	26.88	199.13	17.04	163	26.82	199.11
	16.76	163	26.90	198.12				
	25.05	169	30.00	198.54				
low cover tension (fabric)	24.25	180	28.35	198.67	24.42	174.34	29.26	198.67
	23.95	174	29.43	198.80				
	18.44	176	28.03	198.77				
high cover tension (leather)	18.39	174	27.65	198.78	18.72	174	27.75	198.78
	19.31	172	27.52	198.79				

4 Conclusion

Overall it can be said that the reproducibility and repeatability of the stamp sensors are appropriate for our purpose. The results (Table 5) illustrate also that the layout structure of the sensors could be optimized as well as the re-clamping procedure of the cover materials to reach a better reliability. The new measurement procedure is able to break down the effects of the surface (cover materials and layer) and the volume effects (foam) in a very granular way up to the anisotropy of the cover materials.

This measurement approach is suitable for an investigation of the various seat components affecting the seat comfort. In order to be able to rank the objective measurements relative to the subjective seat comfort evaluation a study with subjects has to be conducted.

References

1. Adler, S., 2007. Zusammenhang von Langzeitsitzkomfort und Fahrerbewegungen. Dissertation. Friedrich-Schiller-Universität Jena.
2. Bennet, T. and Worthen, E. F., 1980. Shear vs. pressure as causative factors in skin blood flow occlusion. Plastic and Reconstructive Surgery 66, 1, 180.
3. Chow W. W. and Odell, E. I., 1978, Deformations and Stresses in Soft Body Tissues of a Sitting Person, 1978.
4. CSA Research. 2017. OUR LIVES INSIDE OUR CARS. EUROPEAN SURVEY.
5. De Looze, M. P. de, Kuijt-Evers, L. F. M., and van Dieen, J., 2003. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics 46, 10, 985–997.
6. Diesing, P., 2006. Prüf- und Bewertungsmethoden für Antidekubitus-Systeme. Dissertation, Technische Universität Berlin.
7. DIN 53579. 2005. Testing of flexible cellular materials –Indentation test on finished parts. DIN-Normenausschuss Materialprüfung (NMP).
8. DIN EN ISO 3386-1. 2009. Polymeric materials, cellular flexible –Determination of stress-strain characteristics in compression –Part 1: Low-density materials. DIN-Normenausschuss Materialprüfung (NMP).
9. Ebe, K. and Griffin, M. J., 2001, Factors affecting static seat cushion comfort. Ergonomics 44, 10, 901–921.
10. EUROPEAN FREE TRADE ASSOCIATION. 2015. This is EFTA.
11. Eurostat, 2017. Population of the European Union 2014, http://ec.europa.eu/eurostat (accessed 03.04.2017).
12. Franz, M., Durt, A., Zenk, R., and Desmet, P. M. A., 2012. Comfort effects of a new car headrest with neck support. Applied Ergonomics 43, 2, 336–343.
13. Gibson, L. J. and Ashby, M. F., 2001, Cellular solids. Structure and properties. Cambridge solid state science series. Cambridge Univ. Press, Cambridge u.a..
14. Goossens, R. H. M., 1994. BIOMECHANICS OF BODY SUPPORT. A study of load distribution, shear, decubitus riskand form of the spine.
15. Goossens, R.H.M., 2001, Shear stress measured on three different cushioning materials, Delft University of Technology.
16. Goossens, R. H. M., Teeuw, R., and Snijders, C. J., 2005. Sensitivity for pressure difference on the ischial tuberosity. Ergonomics 48, 7, 895–902.
17. Gyi, D. E. and Porter, J., 1999. Interface pressure and the prediction of car seat discomfort. Applied Ergonomics 30, 2, 99–107.
18. Hartung, J., 2006. Objektivierung des statischen Sitzkomforts auf Fahrzeugsitzen durch die Kontaktkräfte zwischen Mensch und Sitz. Dissertation, Technischen Universität München.
19. Jurado, A., 2014, EUROPEAN MOTOR VEHICLE PARC. VEHICLES IN USE(2009-2014). Anfac.
20. Kilincsoy, Ü., Wagner, A.-S., Bengler, K., Bubb H., and Vink, P., 2014. Comfortable rear seat postures preferred by car passengers. Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014.
21. Kilincsoy, Ü., Wagner, A.-S., Vink, P., and Bubb H., 2016. The Ideal Pressure Distribution for SUV and Sedan Rear Seats.
22. Kyung, G. and Nussbaum, M. A., 2008. Driver sitting comfort and discomfort (part II). Relationships with and prediction from interface pressure. International Journal of Industrial Ergonomics 38, 5-6, 526–538.
23. Mergl, C., 2006. Entwicklung eines Verfahrens zur Optimierung des Sitzkomforts auf Automobilsitzen. Dissertation, Technischen Universität München.
24. Sammonds, G. M., Fray, M., and Mansfield, N. J., 2017. Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs). Applied Ergonomics 58, 119–127.
25. Schmidt, R.F. und Thews, G., 1980. Physiologie des Menschen. Springer Verlag; Springer, Berlin u.a..
26. van Veen, S. A. T., Hiemstra-van Mastrigt, S., Kamp, I., and Vink, P., 2014, Improving car passengers' comfort and experience by supporting the use of handheld devices. Work (Reading, Mass.) 49, 2, 215–223.
27. Venkatesan, L., Barlow, S. M., and Kieweg, D., 2015 Age- and sex-related changes in vibrotactile sensitivity of hand and face in neurotypical adults. Somatosensory & motor research 32, 1, 44–50.
28. Vink, P., 2012. Advances in Social and Organizational Factors. Advances in Human Factors and Ergonomics Series. CRC Press, Hoboken.
29. Vink, P. and Lips, D., 2017. Sensitivity of the human back and buttocks: The missing link in comfort seat design. Applied Ergonomics 58, 287–292.
30. Zenk, R., Mergl, C., Hartung, J., Sabbah, O., Bubb H., 2006. Objectifying the Comfort of Car Seats, SAE International.
31. Zhang, M. and Roberts, V. C., 1993. The effect of shear forces externally applied to skin surface on underlying tissues. Journal of Biomedical Engineering 15, 6, 451–456.

Ranking of human senses that contribute to passengers' aircraft interior comfort experience

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Abstract: There are many factors influencing passengers' comfort, such as expectations and environment. When experiencing comfort, the different human senses all play a role. According to Bubb (2008) [1], six factors determine discomfort: Smell, Light, Vibrations, Sound, Climate and Anthropometry. Bubb [1] presented these factors in a discomfort pyramid, with Smell as most important factor and Anthropometry as least important. The goal of this study is to investigate whether the expectations of aircraft passengers are comparable to the hierarchy of the human senses as proposed by Bubb's discomfort pyramid [1]. A survey has been conducted among aircraft passengers (respondents with flight experience in the last year). In total 183 respondents between 19 and 64 years old (mean: 30.5, SD: 12.8) were asked to rank six different factors: Smell, Light, Vibrations, Sound, Climate and Anthropometry. These factors were presented to the respondents as 15 different pairs (e.g. Smell-Sound), and respondents were asked to indicate for each pair, which is most important according to them in order to experience comfort. The results of this study suggest that the expectations of aircraft passengers differ from the hierarchy of senses suggested by Bubb [1]. In this study, respondents indicated 'anthropometry' as most important, whereas this was the least important factor according to Bubb [1]. The other factors, in reducing order of importance according to the respondents of this study, were 'noise, smell and climate', 'vibration' and, lastly, 'light'. However, according to the remarks made by the participants, some factors could be interpreted in different ways. For example, climate does not only refer to temperature, but also to humidity and atmospheric pressure. Therefore, these factors and their influence on comfort and discomfort experience should be studied in more detail.

Keywords: comfort, expectations, human senses

1 Introduction

When booking a flight, passengers are looking for comfort and are willing to pay more to get better seat comfort [2]. Since a good and comfortable experience is an indication to return to an airline, most airlines invest in the design of a comfortable airplane interior. There are many factors that influence passengers' perception of comfort and discomfort, such as expectations and environment [3,4]. Linked to the human senses, according to Krist [5] and Bubb [1], discomfort is influenced by six factors: anthropometry, climate, noise, vibrations, light and smell.

Anthropometry

Anthropometry is the scientific study of measurements of the human body. When designing products such as aircraft seats, anthropometric data can be a valuable source of information. A study by Hiemstra-van Mastrigt [6], comparing the dimensions of economy class aircraft seats to anthropometric measurements from a database, showed that current economy class aircraft seats exclude up to 21% of passengers due to the distance between armrests, which is too narrow for the hip width of passengers. If the dimensions of the aircraft seat, such as width of the seat or the seat pitch (distance between two seats) are not well fitted to the passenger, this will have an effect on the perceived discomfort.

Climate

With a range from 20°C to 27°C on intercontinental flights and 21°C to 31.7°C on continental flights, it can be concluded that the temperature in an airplane cabin varies strongly [7]. Therefore, Kuijer & De Jong [8] suggest that indoor climate conditions can only work when occupants are offered sufficient means for creating their own comfort. Personal thermal systems are integrated in car seats for many years now. Oi et al. [9] found that heated seats effectively improve the occupants' initial comfort when the air temperature is lower than 15°C, and that heated seats can prevent decreases in toe skin temperature. Pasut et al. [10] found that self-controlled heated and cooled seats enables participants to remain a neutral thermal sensation (neither too hot nor too cold), with an environmental temperature between 16°C and 29°C. However, when the temperature is 25°C, the use of the cooling or heating system will not result in improved comfort. Next to improved thermal experience, air quality is perceived better by participants using the heating and cooling system [10].

Noise and vibrations

Aircraft interior sound levels depend on different factors, such as flying speed and altitude, and seat position [11]. The average noise level in an aircraft on cruise flight altitude is 75 dB [12], mainly originating from the aircraft engines. These current sound levels in airplane cabins do not reach the discomfort threshold [13] and highly unlikely cause permanent hearing loss [15], but may result in annoyance among airplane passengers [16], although Quehl states that annoyance caused by sound is based on individual preferences [11]. Mellert et al. [16] found that lower noise levels result in less symptoms of tiredness, difficulty in concentration, swollen feet and headache for flight crew and passengers. Current sound design in an airplane cabin is mainly focused on reducing this noise; however, the use of sound also offers opportunities in terms of positively influencing passenger behaviour. Tasks that require creativity prosper with moderate ambient noise of 50 – 70 dB [17], so the sound of a coffee bar for example can stimulate creativity. Music can also affect comfort and emotion [18]. Classical music is a sound that could calm the passenger. Harmat et al. [19] indicate that this intervention can even help to reduce sleeping problems.

As long as there is no heavy turbulence, the experienced accelerations of an aircraft in cruise are not notably heavier than, for example, when travelling by car. This is different than for example trains, where passengers experience a lot of lateral movement which affects their activities such as writing, eating and drinking [20-25].

Light

The effects of light (colour) on people's mood and comfort has also been studied extensively. For example, Schauss [26] suggests that pink should be used in any situation where sudden or uncontrollable aggression is likely, since this colour has a sedative effect on people. According to Sokolova & Fernández-Caballero [27] the colour green, followed by yellow and blue attain the most positive emotions, although this is strongly dependent on the mood and personality (introvert or extrovert), the demographics and age of the person. Also, the use of coloured light could be applied to treat jetlegs [28].

Smell

The factor scent is rather complex. People do react on scents; odours can affect mood, physiology and behaviour [29], but they are unable to communicate about smell experiences through words [30], which makes it difficult to research. Nevertheless, it is suggested that scent can support cooperation and interaction [31], peppermint scented questionnaires resulted in more compliance and increased willingness to volunteer [32], whereas citrus scented all-purpose cleaner smell made people clean their spilled breadcrumbs from eating more often [33].

Although a lot of studies have been conducted on the individual factors, the relationship and hierarchy between the different human senses remains underexposed in scientific literature. Research by Quehl [11] on effects of aircraft interior sound and vibration on passenger comfort, shows that the sound pressure level contributed approximately 70 % and the vibration magnitude about 30 % to the comfort evaluation, in accordance with the commonly reported dominance of noise regarding subjective annoyance responses [11].

Krist [5] and Bubb [1] propose a hierarchical model of six discomfort sensations based on Maslow's hierarchy of human needs, to indicate their relative significance (Fig. 1); anthropometry, climate, sound, vibrations, light and smell. The base layer smell ('geruch') is most important, followed by other factors such as vibrations and climate. Improvements on a better fit of the seat by involving anthropometric data seems to be the final concern in the development process of a comfortable seat, according to Bubb's pyramid.

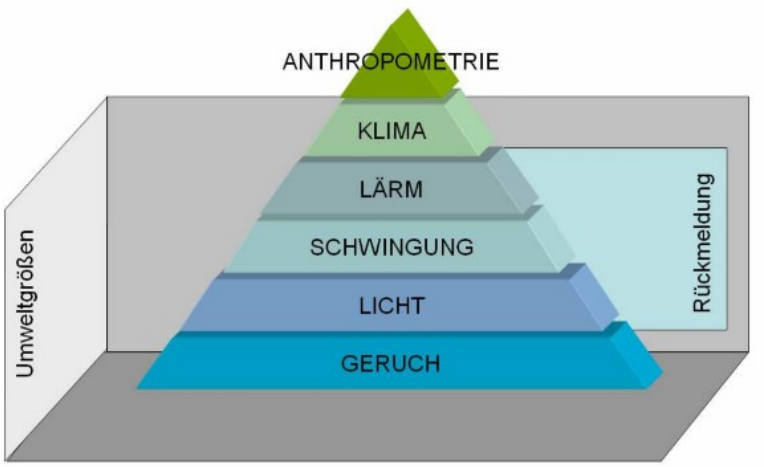


Fig. 1. Discomfort pyramid (Bubb, 2008) [1]

Assuming that the factors mentioned in the discomfort pyramid give a representative and more or less complete overview of factors to take into account while designing an airplane seat, influences such as expectations are not taken into account in this discomfort pyramid. Therefore, the research question of this study is:

What is the order of importance of the factors as contributors to aircraft interior comfort experience based on passenger expectations?

2 Method

In a questionnaire, respondents were asked to rank six different human senses: climate, vibrations, light, noise, anthropometry and smell. These senses are presented to respondents as 15 different 'word pairs', and respondents were asked which element, according to their expectations, is the most important in experiencing a comfortable aircraft interior. They had to indicate for each of the element pairs (Table 1), which one is more valuable to them by drawing a circle around the most important one. In total 183 respondents between 19 and 64 years old (mean: 30.5, SD: 12.8) with flight experience completed the questionnaire. The number of times each element is indicated as most important is counted (with a maximum of 5 times per element). The scores per human sense are analysed with a Wilcoxon signed rank test, and significance was accepted at $p<0.05$. Additionally, respondents were allowed to give comments on the questionnaire.

Table 1. Fifteen different word pairs of the human senses; for each pair, respondents had to indicate which of the two elements is, according to their expectations, most important to experience a comfortable aircraft interior.

Element 1	*Element 2*
Climate	Noise

Vibrations	Light
Light	Climate
Noise	Light
Anthropometry	Smell
Smell	Climate
Vibrations	Anthropometry
Light	Anthropometry
Noise	Vibrations
Vibrations	Smell
Noise	Smell
Anthropometry	Noise
Climate	Vibrations
Smell	Light
Anthropometry	Climate

3 Results

The ranking of the human senses based on the expectations of aircraft passengers is presented in Fig. 2. The element Anthropometry is on average 3.5 times indicated as most important to experience aircraft interior comfort. For the three elements Noise, Smell and Climate this is almost 3 times, element Vibration almost 2 times and Light 1 time. Three significant differences were found ($p<0.05$): between Anthropometry and Noise, Smell and Climate, between Climate and Vibrations, and between Vibration and Light.

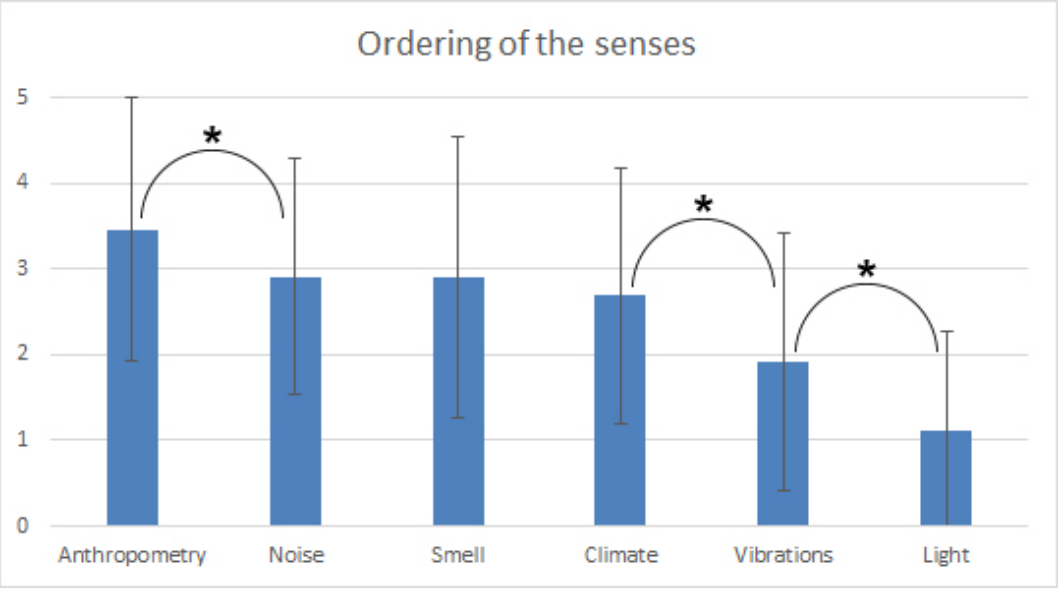


Fig. 2. Ordering of the human senses from most important (5) to least important (0) to experience aircraft interior comfort. (n=183, the asterisk * indicates significance $p<0.05$)

In 16% of the comments by respondents it was mentioned that it is dependent on the situation how you would rate the importance between both senses. For example, one of the comments on climate: '*does climate refer to warm or cold air?*' and on smell: '*hate a bad smell more than love a nice smell*'.

4 Discussion

The results of this study show that respondents rate the six elements differently in importance to contribute to a comfortable aircraft interior experience. Based on this outcome, an order of senses appears, with 'Anthropometry' as most important, followed by 'Noise, smell and climate', 'Vibration' and, lastly, 'Light'. This order is different from the discomfort pyramid as proposed by Krist [5] and Bubb [1] (Fig. 3). One main difference with the discomfort pyramid is that in this study, respondents were asked about their comfort experience, and specifically for the aircraft environment. Comfort and discomfort are two separate entities, with different underlying factors [34]. Since comfort can only occur when discomfort is low or absent, appreciation for nice smell might not occur when the environment is too cold.

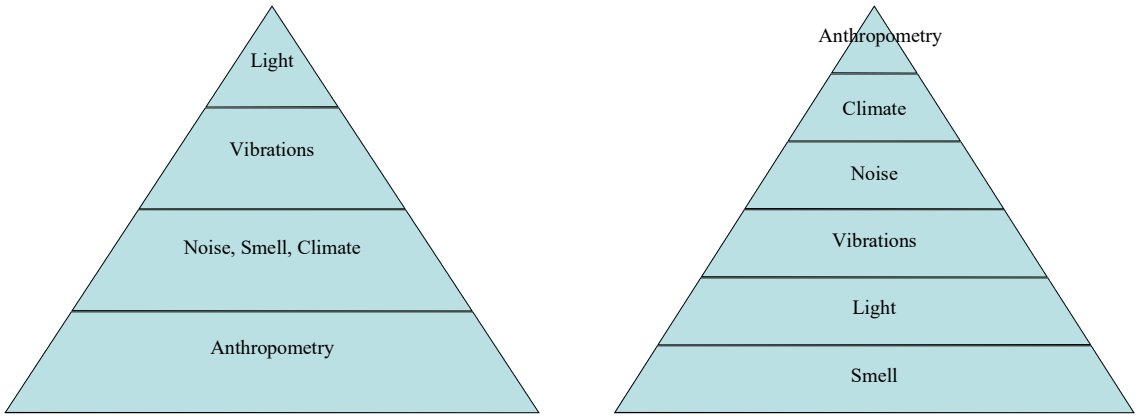


Fig. 3. Pyramid for aircraft interior comfort experience based on expectations from passengers (left), in comparison with Bubb's discomfort pyramid (right).

However, also confirmed by the remarks from the respondents, some factors could be interpreted in different ways. For example, 'climate' does not only refer to temperature, but also to humidity and atmospheric pressure. Smell is highly dependent on personal preferences, since odour is often related to memories.

In this study, respondents were asked about their expectations, but some factors also influence the perception of comfort and discomfort unconsciously. A study by Mellert et al. [16] showed for example that more physical complaints were reported in a noisy airplane cabin, although the flight crew and passengers were unaware of the difference in sound levels. Similarly, a study by McMullin [35] showed that for the new Boeing 737 Sky Interior, passenger satisfaction of seat comfort was 78% higher compared to a standard interior. The Sky Interior even affected passengers' perceptions of air quality (+41%) and temperature during the flight (+40%). It seems that the Sky Interior, consisting of a different ceiling lighting system and different overhead bins, created a positive 'halo'-effect on the unchanged cabin features [35].

Although the outcomes of this research suggest a hierarchical order in the factors, that might give a direction to prioritizing design efforts, Vink et al. [36] discuss that optimizing every single element in the environment in order to optimize comfort is neither possible nor wise. Lewis et al. [37] suggested that people can be distracted from sources of discomfort with a virtual environment. This technique seems to be more effective for distracting people from discomfort caused by restricted space than noise disturbances (such as a crying baby). Contradictory, negative associations people might have with some factors, such as noise, can also have positive side effects. For example, the presence of a background noise is considered positive by train passengers, as it masks other sounds such as conversations between other passengers [38].

5 Conclusion

Based on expectations of 183 respondents ranking six factors (light, vibrations, noise, smell, climate and anthropometry) an order of importance has been identified that slightly differs from the order suggested in the discomfort pyramid of Bubb [1]. Since comfort is also influenced by passenger's expectations and emotions [3,4,39], the model should be extended. The relationships between the different factors should be quantified on the basis of experimental studies and will reveal whether or not the factors can be ordered as a pyramid or that a more complex, networked model is more appropriate.

References

1. Bubb, R. (2008). *Sitting comfort*. Paper presented at the IQPC aircraft interior innovation, Hamburg.
2. Airbus. (2013). Passengers willing to invest time and money in search of comfort. Retrieved from http://www.airbus.com/presscentre/pressreleases/press-release-detail/detail/passengers-willing-to-invest-time-and-money-in-search-of-comfort/
3. De Looze, M. P., Kuijt-Evers, L. F. M., & Van Dieën, J. (2010). Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics, 46*(10), 985-997.
4. Vink, P., & Hallbeck, S. (2012). Editorial: Comfort and discomfort studies demonstrate the need for a new model. *Applied Ergonomics, 43*(2), 271-276. doi:http://dx.doi.org/10.1016/j.apergo.2011.06.001
5. Krist, R. (1993). *Modellierung des Sitzkomforts–eine experimentelle Studie, Katholische Universität Eichstätt, Philosophisch-Pädagogische Fakultät.* Dissertation.
6. Hiemstra-van Mastrigt, S., 2015. Comfortable passenger seats: Recommendations for design and research. PhD thesis, Technische Universiteit Delft, Delft.
7. Pang, L., Qin, Y., Liu, D., & Liu, M. (2014). Thermal comfort assessment in civil aircraft cabins. *Chinese Journal of Aeronautics, 27*(2), 210-216.
8. Kuijer, L., & de Jong, A. (2012). Identifying design opportunities for reduced household resource consumption: exploring practices of thermal comfort. *Journal of Design Research 14, 10*(1-2), 67-85.
9. Oi, H., Tabata, K., Naka, Y., Takeda, A., & Tochihara, Y. (2012). Effects of heated seats in vehicles on thermal comfort during the initial warm-up period. *Applied Ergonomics, 43*(2), 360-367. doi:http://dx.doi.org/10.1016/j.apergo.2011.05.013
10. Pasut, W., Zhang, H., Arens, E., & Zhai, Y. (2015). Energy-efficient comfort with a heated/cooled chair: Results from human subject tests. *Building and Environment, 84*, 10-21.
11. Quehl, J., 2001. *Comfort studies on aircraft interior sound and vibration.* PhD thesis, Universität Oldenburg.
12. Ozcan, H. K., & Nemlioglu, S. (2006). In-cabin noise levels during commercial aircraft flights. *Canadian Acoustics, 34*(4), 31-35.
13. Slater, K. (1985). *Human comfort* (Vol. 1): Springfield, Ill., USA: CC Thomas.
14. Passchier-Vermeer, W. (1997). *Hoe ongezond is geluid?: Gehoorschade, hinder, slaapverstoring en stress door geluid*: TNO.
15. Mixson, J. S., & Powell, C. A. (1985). Review of recent research on interior noise of propeller aircraft. *Journal of aircraft, 22*(11), 931-949.
16. Mellert, V., Baumann, I., Freese, N., & Weber, R. (2008). Impact of sound and vibration on health, travel comfort and performance of flight attendants and pilots. *Aerospace Science and Technology, 12*(1), 18-25.
17. Mehta, R., Zhu, R., & Cheema, A. (2012). Is Noise Always Bad? Exploring the Effects of Ambient Noise on Creative Cognition. *Journal of Consumer Research, 39*(4), 784-799. doi:10.1086/665048
18. Kruithof , A.R., 2012. Effects of Music and Activity on Comfort and Emotion: An Empirical Study. MSc thesis, Delft University of Technology.
19. Harmat, L., Takács, J., & Bodizs, R. (2008). Music improves sleep quality in students. *Journal of advanced nursing, 62*(3), 327-335.
20. Krishna Kant, P. V. 2007. "Evaluation of Ride and Activity Comfort for the Passengers While Travelling by Rail Vehicles." Thesis (Master of Technology in Mechanical Engineering). India: Indian Institute of Technology Roorkee.
21. Khan, S., and J. Sundström. 2004. "Vibration Comfort in Swedish Inter-City Trains – A Survey on Passenger Posture and Activities." In Proceedings of the 17th International Conference in Acoustics (ICA), Kyoto, Japan, 3733–3736.
22. Khan, S. M., and J. Sundström. 2007. "Effects on Vibration on Sedentary Activities in Passenger Trains." Journal of Low Frequency Noise, Vibration and Active Control 26 (1): 43–55.
23. Nassiri, P., Koohpaei, A.R., Zeraati, H., Jafari Shalkouhi, P., 2011. Train passengers comfort with regard to whole-body vibration. Journal of Low Frequency Noise Vibration and Active Control 30(2): 125-136.
24. Bhiwapurkar, M.K., Saran, V.H., Harsha, S. P., 2010. Effect of Multi-Axis Whole Body Vibration Exposures and Subject Postures on Typing Performance. International Journal of Engineering Science and Technology 2(8): 3614–3620.
25. Corbridge, C., and M. J. Griffin. 1991. "Effects of Vertical Vibration on Passenger Activities: Writing and Drinking." Ergonomics 34 (10): 1313–1332.

26. Schauss, A. G. (1979). Tranquilizing effect of color reduces aggressive behavior and potential violence. *Journal of Orthomolecular Psychiatry, 8*(4), 218-221.
27. Sokolova, M. V., & Fernández-Caballero, A. (2015). A review on the role of color and light in affective computing. *Applied Sciences, 5*(3), 275-293.
28. Zee, P. C., & Goldstein, C. A. (2010). Treatment of shift work disorder and jet lag. *Current treatment options in neurology, 12*(5), 396-411.
29. Herz, R. S. (2009). Aromatherapy facts and fictions: a scientific analysis of olfactory effects on mood, physiology and behavior. *International Journal of Neuroscience, 119*(2), 263-290.
30. Engen, T. (1982). The perception of odors. *New York: Academic*.
31. Cardello, A., & Wise, P. (2011). Taste, smell and chemesthesis in product experience. In H. N. Schifferstein & P. Hekkert (Eds.), *Product experience* (pp. 91-131): Elsevier.
32. James, A. L. (2006). The effects of odor on compliance and willingness to volunteer. *Journal of Undergraduate Psychological Research, 1*(1), 13-17.
33. Holland, R. W., Hendriks, M., & Aarts, H. (2005). Smells Like Clean Spirit Nonconscious Effects of Scent on Cognition and Behavior. *Psychological Science, 16*(9), 689-693.
34. Zhang, L., Helander, M.G., Drury, C.G., 1996. Identifying factors of comfort and discomfort in sitting. Human Factors 38(3): 377–389.
35. McMullin, D. (2013). Aircraft seating comfort in the context of passenger comfort *IQPC Innovative Aircraft Seating conference*. Hamburg, Germany.
36. Vink, P., Bazley, C., & Jacobs, K. (2016). Modeling the relationship between the environment and human experiences. *Work, 54*(4), 765-771.
37. Lewis, L., Patel, H., Cobb, S., D'Cruz, M., Bues, M., Stefani, O., & Grobler, T. (2016). Distracting people from sources of discomfort in a simulated aircraft environment. *Work, 54*(4), 963-979.
38. Khan, S. M. (2003). Effects of masking sound on train passenger aboard activities and on other interior annoying noises. *Acta Acustica united with Acustica, 89*(4), 711-717.
39. Ahmadpour, N., Lindgaard, G., Robert, J.-M., Pownall, B., 2014. The thematic structure of passenger comfort experience and its relationship to the context features in the aircraft cabin. Ergonomics 57(6): 801-815.
40. Pasut, W., Zhang, H., Arens, E., Kaam, S., & Zhai, Y. (2013). Effect of a heated and cooled office chair on thermal comfort. *HVAC&R Research, 19*(5), 574-583.

Aircraft Seat Discomfort Scale Using Item Response Theory

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Abstract The comfort and discomfort in the aircraft seat are phenomena experienced daily by thousands of passengers, especially those who travel long distances. The interaction process of the passenger with the aircraft seat can generate a high level of comfort, associated with the sensation of pleasure and well-being, or, on the other hand, it may lead to discomforts that can be accompanied by pain. This article aims to evaluate the psychometric properties of a scale to measure aircraft seat discomfort. In this study a set of items were developed to compose a questionnaire about aircraft seat discomfort. It was based on the existing literature about the theme and also on the psychometric theory. A discomfort scale using Item Response Theory (IRT) was created and the validity and reliability criteria of this instrument were verified. The study was conducted in three steps: 1) the questionnaire creation; 2) data collection; and 3) data analysis, including in this last step the factor analysis, the item analysis, and the creation of the measuring scale for aircraft seat discomfort using IRT. The sample consisted of 1,500 passengers who completed a questionnaire at a Brazilian airport. Full information factor analysis showed the presence of one dominant factor explaining thus 30% of data variance. The generated scale covered all levels of discomfort data, from 'no discomfort' to 'maximum discomfort'. The results pointed out that when the discomfort feeling is minimal, the passenger is disappointed with what was to be the expectation of comfort. The passenger also presents pain, tension, difficulties in supporting the spine and thighs in the aircraft seat, and perceives the aircraft seat tight and of poor quality, representing constraints that hamper desired activities. The discomfort tends to increase when the aircraft seat quality is worse (hard seat and no backrest) and when passengers are unable to perform the desired activities (e.g., reading, using the notebook, sleeping etc.). At this level of discomfort the passenger gets annoyed and disappointment. The Maximum Discomfort level occurs when the noise disrupts the activities and the aircraft seat is considered hard. This study proved to be valid to identify that discomfort in the aircraft seat is influenced by some aspects such as: physical, psychic, object, environment and context. This study advances in the theory of discomfort and contributes to the aeronautical industry identifying the requirements for aircraft seats design by interpreting the discomfort levels in the generated scale. Further research is advised to compare the outcome of this questionnaire with other research methods, to check if the questionnaire is sensitive enough and whether its conclusions are useful in practice.

Keywords: Discomfort, Aircraft Seat, Scale, Item Response Theory.

1 Introduction

To meet an increasingly competitive market, the industry has been striving to develop aircraft seat designs with an emphasis on comfort and minimization of discomfort (Vink and Brauer, 2011; Baumann and Trimmel, 2013). In the dictionary, discomfort is defined as the absence of comfort and of convenience; it's something that slaughter the spirit and provokes discouragement, disconsolation and malaise (Houaiss, 2009).

But in the field of ergonomics, discomfort is generally associated with pain and with the feeling of body heaviness (Zhang et al., 1996), which arises when man and his physiological, psychological, or well-being homeostasis or even both, are affected in a negative way (Shen and Parsons, 1997). The studies developed by Vink et al. (2004) and Straker (2003), consider discomfort as a risk factor for musculoskeletal disorders.

Although Hertzberg (1972) has postulated comfort as the absence of discomfort, some studies from the last decades have shown that comfort and discomfort are different phenomena, since the absence of discomfort does not necessarily imply the presence of comfort (Zhang et al., 1996; Vink et al., 2004; Sauter et al., 2005; Menegon et al., 2016).

It seems that the perception of armchair discomfort is affected by the following aspects: physical, psychological, object, environment and context contexto (Zhang et al., 1996; Crane et al., 2003; Looze et al., 2003; Sauter et al., 2005; Vink et al., 2004; Vink and Brauer, 2011; Kolich, 2008; Silva et al., 2012; Menegon et al., 2016). However, most measures and instruments of discomfort do not consider this full range of aspects. Some instruments measure the discomfort level starting from a single item and they have the advantage to ease the administration and its comprehension by the respondents, but on the other hand, they are considered limited instruments, since they have low sensitivity (Corlett and Bishop, 1976; Shen and Parsons, 1997; Coelho and Dahlman, 2000; Straker, 2003). It's also available the traditional discomfort maps, which evaluate only the physical component of discomfort, through body regions where the person presents pain (Smith, Andrews and Wawrow, 2006). There are as well some discomfort questionnaires (Pinheiro et al., 2002; Franzblau et al., 1997).

Some instruments of discomfort present items related only to physical aspects which interfere with comfort (Borg, 1982), others are related only to psychic aspects (Shen and Parsons, 1997; Straker, 2003; Corlett and Bishop, 1976; Sauter et al., 2005). There are yet other items that investigate physical and psychological aspects in the same instrument (Grabisch et al., 2002; Pinheiro et al., 2002).

We did not find any instrument of discomfort in aircraft seat with items to measure aspects related to the object (seat), environment and context. In this sense, the main goal of this study is to develop and to validate an aircraft seat discomfort scale with the use of Item Response Theory (TRI) in order to develop a knowledge about the different aspects that influence the discomfort of the passenger in the aircraft.

2 Methods

2.1 Questionnaire Creation

The questionnaire was developed following the procedures described by Wilson (2005). The creation of the questionnaire used the following steps: a) literature review; b) the drawing up of discomfort map; c) creation of a set of items, d) expert analysis, e) semantic analysis, f) pilot test. The final questionnaire consisted of 37 items. Each item has six categories of response, ie: 0 = I strongly disagree; 1 = I disagree; 2 = I disagree a little bit; 3 = I agree a little bit; 4 = I agree; 5 = I strongly agree. The items 4 (I was satisfied with the aircraft seat), 5 (the seat was good), 7 (I liked the seat) and 12 (I easily reached the individual lighting control) had the response categories inverted, since they are related to the opposite descriptors of discomfort.

2.2 Data collection

The data were collected at an International Airport in Brazil were 1,500 passengers were interviewed. The main characteristics of the sample are: sex: 57% are male and 43% are female; weight (kg): 74 ± 15.6; height (m): 1.71 ± 9.3; age: 39 ± 13.2; average ± standard deviation). The passengers answered a questionnaire based on their last flight. Out of these 1,500 passengers, 74.4% answered based on a flight lasting less than 2 hours, 17.4% between 2-5 hours and 7.9% between 5-24 hours.

2.3 Data analysis

Data analysis involved factor analysis, estimation of item parameters and the creation of discomfort scale in aircraft seat.

A complete information factorial analysis was performed to verify the dimensionality of the instrument which means, to identify the number of factors involved in the construction (De Ayala, 2009). This analysis was performed by using software R version 15.1, 'mirt' package, The Multidimensional Items Theory of Response (Chalmers, 2012). The aircraft seat discomfort items were analyzed through Graduate Response Model (GRM) of the TRI Samejima (Samejima, 1997; Menegon et al., 2017).

The TRI has emerged as a way of considering each item in particular, therefore, the conclusions do not depend on the test or questionnaire as a whole, but rather on each item that composes it (Araujo et al., 2009). The TRI comprises of a set of probabilistic models that represent the probability of an individual giving a certain response to an item according to his/her latent trait and his/her characteristics (item parameters) (Bortolotti et al., 2013). For GRM parameter estimates, MULTILOG software was used (Thissen, 1991). All parameters of the items and of the discomfort levels were obtained by using the metric (0,1). However, for the construction of the measurement scale, it was performed a linear transformation for the metric (50, 10), but respecting the existing order of relation between points (Andrade et al., 2000; Menegon et al., 2017). The aircraft seat discomfort scale is constructed by anchored levels and anchored items (Beaton and Allen, 1992).

During data analysis it was observed that some items overlapped the various categories of response. Therefore, a grouping was made as it follows: the response categories 0 (I strongly disagree) and 1 (I disagree) were grouped and coded as 0. The response categories 2 (I slightly disagree) and 3 (I slightly agree) were grouped and coded as 1. The response categories 4 (agree) and 5 (strongly agree) were grouped and coded as 2. The overlapping between response categories 0, 1 and 2 was also observed (I strongly disagree, I disagree and I slightly disagree). These items were then coded as 0. The response categories 3, 4 and 5 (I agree a little bit, I agree and I strongly agree), were coded as 1. These codifications occurred in items: 1, 3, 6, 8, 9, 10, 11, 12, 14, 15, 16, 18, 21, 22, 24, 25, 26, 29, 31 and 33.

2.4 Research Protocol

Passengers who met the criteria selection were invited to read and to sign the informed consent document. This study was approved by the Research Ethics Committee of the Federal University of Santa Catarina under code 01615812.6.0000.0121 for technical procedures that preserve the confidentiality and the well-being of passengers, in accordance with the CNS 196/96 Resolution criteria.

3 Results

3.1 Dimensionality

In the dimensionality analysis, the presence of a dominant factor was observed, explaining thus 30% of the data variance. Being so, it's allowed then the use of a one-dimensional IRT model (Reckase, 1980). In this analysis, it was observed that out of the 37 analyzed items, 12 items had a low factorial load (<0.30) and they were eliminated from the instrument.

3.2 Estimates of item parameters and Information Function

The estimated parameters of the items retained in the instrument are shown in table 1. The discrimination parameters ranged from 0.61 to 3.95. This indicates that all the items have a reasonable discriminatory power.

Table 1. Estimate of discomfort items parameters in aircraft seat

Items	a	b1	EP b1	b2	EP b2	b3	EP b3	b4	EP b4	b5	EP b5
Item 1	0,61	0,31	0,17	2,92	0,58						
Item 3	1,94	0,05	0,06	1,48	0,12						
Item 4	3,48	-2,34	0,16	-1,19	0,08	-0,46	0,05	0	0,05	0,98	0,06
Item 5	1,97	-2,7	0,22	-1,24	0,1	-0,42	0,07	0,35	0,07	1,61	0,12
Item 6	1,18	-0,38	0,1	1,45	0,17						
Item 7	3,95	-2,21	0,12	-1,28	0,07	-0,44	0,05	0,03	0,04	1	0,06
Item 8	1,49	-0,82	0,11	0,48	0,1						
Item 9	0,96	-0,21	0,11	1,9	0,26						
Item 10	1,26	-0,26	0,11	1,11	0,14						
Item 11	1,16	-0,6	0,11								
Item 12	0,64	0,12	0,17	2,49	0,48						
Item 14	0,75	-0,22	0,13								
Item 15	1,68	-0,46	0,08	0,9	0,11						
Item 16	1,15	0,76	0,13								
Item 17	1,81	-2,15	0,14	-0,9	0,1	-0,26	0,08	0,47	0,08	1,7	0,13
Item 18	1,66	-0,24	0,07	0,95	0,11						
Item 19	1,68	-2,35	0,21	-1	0,11	-0,21	0,07	0,59	0,09	2,05	0,18
Item 21	0,79	-0,06	0,12	2,39	0,37						
Item 22	1,14	-1,27	0,18								
Item 24	1,83	-1,37	0,11	-0,3	0,09						
Item 25	1,35	-1,42	0,17	-0,1	0,09						
Item 26	0,75	-0,77	0,18								
Item 29	0,7	1,13	0,25								
Item 31	1,47	-0,98	0,12	0,44	0,09						
Item 33	0,86	0,01	0,14	2	0,25						

3.3 Aircraft Seat Discomfort Scale

The discomfort scale was constructed using the estimates of the items parameters by the IRT and it presents the distribution of the items in the different discomfort levels (30, 40, 50, 60, 70, 80.) of the items, with their respective aspects and indicators (Table 2).

The scale created allows to interpret the scores of the respondents in each level of the scale, from “without comfort" to "maximum discomfort". Because it is a cumulative scale, it is expected that a passenger with a high level of discomfort has agreed to items at this level as well as at lower levels. For example, for a passenger to be at level 80, he should have agreed to the items of density and noise, as well as all aspects of the items contained in the lower levels. The generated scale of aircraft seat discomfort allows us to state that at level 30 there is no perceived discomfort as "Without discomfort". At this level, passengers agree with the positive emotions items, satisfaction (item 4), good seat (item 5) and affection (item 7) and they disagree that the seat was hard (item 19). At level 40, "Minimum discomfort", the passenger begins to notice the discomfort, but at that level it is only remarkable. From level 50 on, "Little discomfort", the discomfort tends to increase, and the physical facet, contemplated by indicators such as pain (item 11) and muscular contracture (item 15), is only perceived from this level of discomfort. It is also from this level of discomfort that the passenger tends to feel negative emotions such as considering the aircraft seat ugly (item 6) and is disappointed with the seat for expecting it to be comfortable (item 8); in addition to having difficulty of supporting parts of the body in the seat (spine and thighs) (items 17 and 18). At level 60 the passenger perceives "Moderate discomfort", feeling irritated (item 3), difficulties in carrying out activities (item 31) and annoyance with the noise (item 33). From level 70, "Much Discomfort", the passenger tends to become restless (item 10) and tense (item 15), besides bothering with the neighbor beside him (item 29). At level 80, Maximum Discomfort, the passenger perceives the hard seat (item 19) and has difficulty performing activities due to the noise (item 33).

Table 2. Distribution of the items according to the facets and the respective indicators of aircraft seat discomfort and their levels on the generated scale

Aspects	**Indicators**	**NÍVEIS DE DESCONFORTO EM POLTRONA DE AERONAVE**					
		30 Discomfort	**40 Minimum Discomfort**	**50 Little Discomfort**	**60 Moderate Discomfort**	**70 Much Discomfort**	**80 Maximum Discomfort**
Psychic	Emotion				Item 3 (DP or CP)	Item 3 (C)	
		Item 4 (C)	Item 4 (CP)	Item 4 (DP)	Item 4 (D)	Item 4 (DF)	
		Item 7 (C)	Item 7 (CP)	Item 7 (DP)	Item 7 (D)	Item 7(DF)	
				Item 8 (DP or CP)	Item 8 (CF)		
Physical	Pain			Item 11 (C)			
	Movement					Item 10 (C)	
	Muscle spasm			Item 15 (DP or CP)		Item 15 (C)	
Object	Quality	Item 5 (C)	Item 5 (CP)	Item 5 (DP)	Item 5 (D)	Item 5 (DF)	
Object	Aesthetics			Item 6 (DP or CP)		Item 6 (C)	
	Support			Item 17 (CP)	Item 17 (C)	Item 17 CF)	
				Item 18 (DP and CP)		Item 18 (C)	
	Density	Item 19 (D)		Item 19 (DP)	Item 19 (C)		Item 19 (CF)
	Width		Item 24 (DP or CP)	Item 24 (C)			
	Space		Item 25 (DP or CP)				
Context	Neighbor					Item 29 (C)	
	Activity			Item 31 (DP or CP)	Item 31 (DF)		
Environment	Noise				Item 33 (DP or CP)		Item 33 (C)

The response categories were represented as it follows: D = I disagree, DP = I disagree a little, DF = I strongly disagree, C= I agree, CP= I agree a little, CF= I strongly agree.

Table 3 presents the description of the items of the validity version of the questionnaire. The response categories are represented as follows: D = disagree, DP (DL) = disagree little, DF (SD) = strongly disagree, C (A) = agree, CP (AL) = agree a little, CF (SA) = strongly agree.

Table 3. Aircraft Seat Discomfort Questionnaire Validated by TRI

Items
Item 1. I was anxious during the flight.
Item 3. I was annoyed when sitting in the aircraft seat.
Item 4. I was pleased with the aircraft seat.
Item 5. The seat was good.
Item 6. The seat was ugly.
Item 7. I liked the seat.
Item 8. I expected the seat to be comfortable, but I was disappointed.
Item 9. I felt pressure points on the buttocks and it bothered me.
Item 10. I got restless in the seat.
Item 11. I felt pain in some part of my body when I was in the airplane seat.
Item 12. I easily reached the individual lighting control.
Item 14.My knees touched the seat in front of me.
Item 15. I felt tension on my body.
Item 16. I felt tingling in one or more parts of my body during the flight.
Item 17. I had difficulty on supporting my back in the seat backrest.
Item 18. The seat did not fit my thighs well.
Item 19. The seat was hard.
Item 21. The seat was old.
Item 22. The backrest did not recline as I wanted it to.
Item 24. The seat was tight.
Item 25. I had difficulty on getting in and out of the seat because there was so little space.
Item 26. I was unpleased with the food served during the flight.
Item 29. I was bothered by the neighbor next to me.
Item 31. I was able to successfully carry out the activity I most wanted.
Item 33. The noise disrupted the performance of some activities.

4 Discussion

The main goal of this study was to develop and to validate an aircraft seat discomfort scale using TRI. The results show that the scale is valid and accurate to estimate the different levels of an aircraft seat discomfort, from "without discomfort" to "maximum discomfort" according to the psychometric criteria (Wilson, 2005; Wilson et al., 2006a, 2006b; Urbina, 2004).

The developed questionnaire included items of all identified facets in the literature: psychic (4 items), physical (3 items), object (7 items), context (2 items) and environment (1 item). The psychic facet was contemplated by the indicators: emotion and affection. The physical facet reached the indicators: pain, movement and muscle contraction. The facet of the object covered the indicators: good, support, aesthetics, density, width and space. The context facet aggregated the indicators: neighbor and activity. In environment facet it was considered only the indicator of noise.

It can be observed that the indicators related to the object facet were those that most participated in the scale of discomfort (from level 30 to 80). In sequence, the psychic facet (emotions and affection towards the seat) included a discomfort scale of level 30 to 80. The physical facet and context indicators only participated in the scale from level 50 (moderate discomfort). The environment facet was only contemplated by the noise indicator and from level 60 (much discomfort) going to level 90 (maximum discomfort).

Level 30 is considered "without discomfort". Passengers at this level do not agree with the aspects associated with discomfort. At this level they have positive emotions about the seat. Level 40, "Minimal Discomfort", is especially characterized by the spatial aspect. For Hinninghofen and Enck (2006), the obstruction of

the free space constitutes an aggravating factor for the discomfort and health of the passenger, since the limitation of space to enter and to leave the seat represents less space for the legs. Regarding the width of the seat, Vink and Brauer (2011) point out that it not only causes discomfort but it disturbs breathing, restricts gastrointestinal transit and the normal blood circulation, besides contributing to the edema accumulation in the lower limbs.

Level 50, "Little discomfort", is marked by the presence of pain, which according to several researchers is considered one of the main characteristics of discomfort (Zhang et al., 1996; Shen and Parsons, 1997; Sauter et al., 2005; Tan et al., 2010). Since the scale of discomfort is cumulative, the presence of pain at this level indicates a high probability that the passengers, in the above-50 levels, agree they feel pain when they are sitting on the aircraft seat.

Level 60, "Moderate Discomfort" refers to those who can't accomplish the desired activities, which is a differential in this level of discomfort scale, because the constraints are so many that the passengers do not find forms of regulation to carry out the activities, implying in moderate discomfort. The constraints to the activities during the flight, and the strategies adopted by passengers, were evidenced in the study of Rossi et al. (2012). This level also highlights problems related with support or backrest, also considered as one of the main indicators of discomfort by Lusted et al. (1994), Huet and Moraes (2002) and Vink and Brauer (2011).

Level 70, "Much discomfort", highlights aspects related to the need for body movement, it's also associated with discomfort in the study of Crane, Holm and Hobson (2004) and Huet and Moraes (2002). In this level there is also presence of tension in the body, also described as muscle contracture in the study of Grabisch et al., (2002) and rigidity (Crane et al., 2004; Sauter et al., 2005; Straker, 2003). A lot of discomfort is also associated with the presence of a neighbor in the aircraft, possibly due to the dispute over the arms support during the handling of food or during rest and /or for odor reasons, since the neighbor is very close to the passenger. According to Bubb (2008) cited by Vink and Brauer (2011), the presence of the neighbor interferes in the discomfort due to the bad smell, which makes the passenger to move the body aside inducing discomforts.

Level 80 is characterized by the seat hardness and the presence of noise. The foam density and softness were also associated with discomfort by Kolich and Taboun (2004). The only environmental indicator that was retained in the discomfort scale was the noise, possibly due to its interference to accomplish the activities. Considering that the scale was estimated by means of a cumulative model, passengers with this level of discomfort are also in agreement with the items of the lower levels.

5 Conclusion

This study built and validated an instrument to measure aircraft seat discomfort, covering all levels, from "Without Discomfort" to "Maximum Discomfort". The study shows that aircraft seat discomfort is a multifaceted phenomenon, being affected by indicators, such as: emotions, aesthetics, pressure distribution in the seat, movements, pain, anthropometry, available space, muscle tension, tingling, support, foam density, reclining, seat width, food, neighbor, noise and activity.

These scales can contribute to the industry in the development of aircraft seat designs. With these scales, it will be possible to make comparisons between the discomfort of passengers from different countries when they are submitted to questionnaires that have common items, and also to compare passengers from the same country in different situations. This is possible because the fundamental elements of TRI are the items, not the questionnaire as a whole.

To eliminate discomfort in practice, it is important to offer a soft and a beautiful seat with adequate support for the back (adequate backrest) and for the thighs, in an environment where both noise and seat conditions do not create constraints on the activities that passengers wish to accomplish during the flight. In addition, the airlines companies can enable, as far as possible, the absence of neighbors which can impact on reducing discomfort.

The scales developed through this study can also be useful to civil aviation regulators departments, since they make it possible to measure the passengers discomfort through a set of items. Besides, the interpretation of the scales provides information regarding the indicators that effectively impact on passengers' perception of discomfort, and which could be used to elaborate regulations regarding the levels of "acceptable" discomfort for Brazilian aircraft.

References

1. Andrade, D.F., Tavares, H.R., Valle, R.C., 2000. Item Response Theory: concepts and applications [Item Response Theory: Concepts and Applications]. Brazilian Association of Statistics (ABE), 4◦ SINAPE.
2. Araújo, E.A.C., Andrade, D.F., Bortolotti, S.L.V., 2009. Teoria da Resposta ao Item. Revista da Escola de Enfermagem 43, 1000-1008.
3. Baumann, I., Trimmel, M., 2011. Distribution of subjective assessments in a controlled aircraft environment. Aerospace Science and Technology 25(1):93-101.
4. Beaton, A.E., Allen, N.L., 1992. Interpreting scales through scale anchoring. J. Educ. Stat, 17, 191–204.
5. Bortolotti, S.L.V., Tezza, R., Andrade, D.F., Bornia, A.C. Sousa Junior, A.F., 2013. Relevance and advantages of using the Item Response Theory. Qual. Quant. 47, 2341–2360.
6. Chalmers, P., 2012. Multidimensional Item Response Theory: Package "mirt". Available in: http://cran.r-project.org/web/packages/mirt/mirt.pdf . Access in: 24 Oct. 2012.
7. Coelho, D.A. Dalhman, S., 2002. Comfort and Pleasure, in: Jordan, P.W., Green, S.W., and Green, W.S. (Eds.), Pleasure With Products: Beyond Usability, CRC Press, 25, 321–330.
8. Corlett, E.N., Bishop, R.P.A., 1976. Technique for measuring postural discomfort. Ergonomics 9, 175-182.
9. Crane, B.A. et al., 2004. Development of a consumer-driven wheelchair seating discomfort assessment tool. International Journal of Rehabilitation Research 27(1), 85-90.
10. De Ayala, R.J., 2009. The Theory and Practice of Item Response Theory, New York: The Guilford Press.
11. Embretson, S., Reise, S., 2000. Item Response Theory for Psychologists. Mahwah, NJ: Lawrence Erlbaum.
12. Franzblau, A. et al., 1997. Test-retest reliability of an upper-extremity discomfort questionnaire in an industrial population. Scand J Work Environ Health 23, 299-307.
13. Grabisch, M. et al., 2002. Subjective Evaluation of Discomfort in Sitting Positions. Fuzzy optimization and Decision Making 1, 287-312.
14. Hambleton, R.K., Swaminathan, H., Rogers, H.J., 1991. Fundamentals of Item Response Theory. Newbury Park: Sage.
15. Hertzberg, H.T.E., 1972. The Human Buttocks in Sitting: Pressures, Patterns, and Palliatives (Technical Paper no. 72005). New York: Society of Automobile Engineers.
16. Hinninghofen, H, Enck, P., 2006. Passenger well-being in airplanes. Autonomic Neuroscience: Basic and Clinical 129, 80-85.
17. Houaiss, A. 2009. Dicionário Houaiss da língua portuguesa. Rio de Janeiro: Instituto Antônio Houaiss de lexicografia e banco de dados da língua portuguesa.
18. Huet, M., Moraes, A., 2002. Apoio ergonômico para a região sacro-ílio-lombar na posição sentada em viagens de longa distância. Fisioterapia Brasil 3(5).
19. Kolich, M., Taboun, S., 2004. Ergonomics modelling and evaluation of automobile seat comfort. Ergonomics 47(8), 841-863.
20. Kolich, M.A., 2008. Conceptual framework proposed to formalize the scientific investigation of automobile seat comfort. Appl. Ergon. 39, 15–27.
21. Looze, M. P., Kuijt-Evers, L.F.M., Dieen, J.V., 2003. Sitting comfort and discomfort and the relationship with objective measures. Ergonomics 46(1), 985–997.
22. Lusted, M., Healey, S., Mandryk, J.A., 1994. Evaluation of the seating of Qantas flight deck crew. Applied Ergonomics 25(5), 275-282.
23. Menegon L. da S., Vincenzi S.L., Merino E.A.D., Barbetta P.A., Andrade D.F. de, 2016. Interaction levels between comfort and discomfort in aircraft seats. Work 54, 905-912. DOI:10.3233/WOR-162354.
24. Menegon L. da S., Vincenzi S.L., Andrade D.F. de, Barbetta P.A., Merino E.A.D., Vink P., 2017. Design and validation of an aircraft seat comfort scale using item response theory. Appl. Ergon. 62, 216-226. http://dx.doi.org/10.1016/j.apergo.2017.03.005.
25. Pinheiro, F.A., Tróccoli, B.T., Carvalho, C.V., 2002. Validation of the Nordic Osteomuscular Symptoms Questionnaire as a measure of morbidity. Rev. Public Health 36(3), 307-312.
26. Rossi, N.T. et al., 2012. Activity analysis: contributions to the innovation of projects for aircraft cabins. Work: A Journal of Prevention, Assessment and Rehabilitation 41, 5288-5295.
27. Reckase, M.D., 1979. Unifactor latent trait models applied to multifactor tests: Results and implications. Journal of Educational Statistics 4, 207-230.
28. Samejima, F., 1997. Graded response model, in: Van Der Linden, W. J.; Hambleton, R. K. (Eds.), Handbook of modern item response theory, New York: Springer, 85–100.
29. Sauter, S.L. et al., 2005. Musculoskeletal Discomfort Surveys Used at NIOSH. In: Handbook of Human Factors and Ergonomics Methods. London: CRC Press, 2005.
30. Shen, W., Parsons, K.C., 1997. Validity and reliability of rating scales for seated pressure distribution. International Journal of Industrial Ergonomics 20, 441-461.

31. Silva, L., Bortolotti, S.L.V., Campos, I.C.M., Merino, E.A.D., 2012. Comfort model for automobile seat. Work 41, 295–302.
32. Smith, D.R, Andrews, D.M., Wawrow, P.T., 2006. Development and evaluation of the Automotive Seating Discomfort Questionnaire. International Journal of Industrial Ergonomics 36, 141–149.
33. Straker, L.M., 2003. Body Discomfort Assessment Tools, in: Karwowski, W. S. Marras. Occupational Ergonomics: Engineering and Administrative Controls. London, CRC Press, 26.1–26.14.
34. Tan, C.F., Chen, W., Rauterberg, M., 2010. An approach to study the sitting position and neck discomfort of economy class aircraft passenger during air travel. In: International Conference on Applied Human Factors and Ergonomics. Miame, Florida, USA. Chapter 40, 2010, 376-382.
35. Thissen, D., 1991. MULTILOG user's guide: Multiple categorical item analysis and test scoring using item response theory. Chicago: Scientific Software.
36. Vink, P., Looze, M.P., Kuijt-Evers, L.F.M., 2004. Theory of Comfort, in: Vink, P. Comfort and Design: Principles and Good Practice, London, CRC Press, 13–32.
37. Vink, P., Brauer, K., 2011. Aircraft interior comfort and design, EUA: CRC Press, 121.
38. Zhang, L., Helander, M.G., Drury, C.G., 1996. Identifying factors of comfort and discomfort in sitting. Hum Factors. 38, 377–389.
39. Wilson, M., 2005. Constructing Measures: An Item Response Modeling approach. London: LEA.
40. Wilson, M., Allen, D. D. Li, J. C., 2006. Improving measurement in health education and health behavior research using item response modeling: comparison with the classical test theory approach. Health Educ Res. 21(1), 9–32a.
41. Wilson, M., Allen, D.D. Li, J.C., 2006. Improving measurement in health education and health behavior research using item response modeling: introducing item response modeling. Health Educ Res. 21(1), 4–18b.
42. Urbina, S., 2004. Essentials of Psychological Testing. New York: John Wiley & Sons, Inc.

Designing for Comfort in Shared and Automated Vehicles (SAV): a Conceptual Framework

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Abstract To date, automotive design and research is heavily biased towards the driver. However, with the rapid advance of vehicle automation, the driving task will increasingly being taken over by a machine. Automation by itself, however, will not be able to tackle the transport challenges we are facing and the need for shared mobility is now widely recognized. Future mobility solutions are therefore expected to consist of Shared and Automated Vehicles (SAV). This means that the passenger experience will take center stage in the design of future road vehicles. Whereas at first sight this may not appear to be different to the experience in other modes of transport, automation and shared mobility introduce different psychological, physical and physiological challenges. These are related to the fact that the occupant is no longer in control, has to put his or her life in the hands of a computer, while at the same time expects such future vehicles to render travel time more efficient or pleasurable and engage in so-called non-driving related tasks. Taking inspiration from work conducted in the field of aircraft passenger comfort experience, we discuss major comfort factors in the context of SAV and highlight both similarities and differences between transport modes. We present a human centered design framework to assist both the research agenda and the development of safe, usable, comfortable, and desirable future mobility solutions.

Keywords: vehicle automation, shared mobility, user requirements, human centered design

1 Introduction

The transport sector is witnessing unprecedented changes, if not revolutions, which are best summarized and memorized by the acronym CASE: Connected, Automated, Shared, and Electric vehicles. The expectation is that the convergence of these developments will transform transport, improving road safety, traffic efficiency, pollution, productivity, and accessibility, while also creating new business models and industries [1]. Each of these developments have also implications for comfort. For instance, electrification allows for a smoother and quieter ride, whereas anxiety may occur when the driver is unsure the battery has sufficient juice to make it to the next charging station. Connectivity allows for internet in-vehicle internet services and for vehicles to communicate with each other (vehicle to vehicle, or V2V) or infrastructure (vehicle to infra-

structure, or V2I) to inform you of the most appropriate speed to safely and comfortably merge with the motorway traffic (i.e. lane merge assist), for example. Badly designed user interfaces, on the other hand, may lead to distraction, confusion, frustration, and ultimately disuse [2]. Connectivity is often also considered a prerequisite for full-scale deployment of vehicle automation. In essence, automation refers to the transfer of vehicle control from the driver to the car. Not only has this the potential to avoid the causes of human error (e.g. distraction, inattention, inebriation, fatigue) and suboptimal behavior (e.g. inappropriate time headways and speeds), it also provides the ultimate comfort in that it allows the driver to do something other than driving, whether this involves simply relaxing, catching up on emails, conversing with other passengers, or reading the news.

Perhaps surprisingly, however, comfort is a double edged sword in this context. The increased level of comfort is likely to make the journey more productive or enjoyable and lead individuals to accept longer commuting times, potentially leading to increased urban sprawl and vehicle kilometers. Ultimately, this may negate the potential benefits of automation, or, in fact, lead to even worse outcomes compared to our current situation [3]. The only way we are able to achieve the benefits these technologies may bring is to ensure that the largely non-technological aspect of shared mobility is realized. As a society, we will have to come to accept that private car ownership can no longer remain the norm. Whether it is in the form of ride-hailing, ride-sharing, carsharing, or any combination thereof, shared mobility is increasingly being considered the essential ingredient for any sustainable future transport solution [3,4,5]. As such, it therefore seems most unfortunate that today nearly every university, research institute, Government, or car manufacturer has a dedicated CAV (Connected and Automated Vehicle) as opposed to SAV (Shared and Automated Vehicle) unit.

In light of the above discussion, the main aim of this paper is to facilitate the research and development, design, and, ultimately, the introduction and acceptance of Shared and Automated Vehicles. In recent years, we have seen several concept SAVs presented at motor shows by various design houses, automotive manufacturers and suppliers. Whereas these present evocative, and sometimes provocative, future visions, they tend to be designed around technologies rather than humans. Unintentionally, these concept cars provide perfect case studies for the human factors researcher and highlight the perhaps unexpected difficulty in making such vehicles work.

There are at least four major challenging factors that affect not only physical, but also psychological and physiological aspects of comfort. These include: 1) the loss of vehicle control, 2) the coexistence of automated and conventional vehicles, 3) the fact that these vehicles are moving, and 4) people's expectations of these technologies. As a consequence, we cannot simply think of such vehicles as living rooms, offices, or entertainment venues on wheels [6]. Furthermore, analogies with other modes of transport, including taxis, trains, and buses, only partially hold true as will be discussed in more detail below. For clarity, however, we first introduce a brief overview of what we mean by vehicle automation and shared mobility.

1.1 Defining Shared and Automated Vehicles (SAV)

Vehicle automation refers to the transfer of the driving task (vehicle control and monitoring of the environment) from driver to car. Currently, the automotive industry is adopting an evolutionary approach. Level 2 or partially-automated driving [7] has already been commercialized. Level 2 does not require the driver to physically operate the vehicle in terms of longitudinal and lateral control, but does require the driver to supervise the system to be able to resume manual control at any time. As such, the drivers is not replaced but assisted. From Level 3 upwards, the driver is no longer required to monitor the environment and is thus able to engage in non-driving tasks under certain conditions. Level 3 (Conditional automation) would still require the driver to regain manual control if required within a certain time buffer, e.g. within 30 s following a warning signal. The necessity to regain control in levels 0-3, and the difficulty humans have monitoring and safely intervening when automation fails [8], has led others, such as Google, to follow a revolutionary approach and jump to Level 4 and 5. Level 4 (High automation) no longer requires the driver to intervene, but the autonomous mode may not be available on all types of roads. Finally, at level 5 (Full automation), the vehicle can perform all driving functions and monitor roadway conditions for an entire trip. The SAE categorization has received the necessary criticism due to its largely technology and feature driven nature. In the current context, the essential dichotomy in vehicle automation is between supervised (Levels 0-2) and unsupervised automation (Levels 3-5). Further, it should be pointed out that automation is not restricted to passenger (M1) vehicles but also so-

called first and last mile mobility vehicles, or autonomous pods, operating at Level 4 but at relatively low speeds and restricted areas are expected to provide valuable contributions to future transport systems (e.g. Alessandrini et al. 2014).
As pointed out by Fulton et al. [3], the term shared mobility is often incorrectly used. Ride sharing (or trip sharing or shared mobility) refers to rides or trips that are actually shared between different individuals or different parties and paid separately. Ride hailing (or ride booking) refers to any app-based system to secure a ride from a taxi or other "on-demand" ride service provider such as GrabTaxi, Uber, Lyft, Ola, or Easy Taxi. These rides may or may not be shared. Strictly speaking, on-demand ride-hailing services are not ride-sharing services unless they exclusively offer shared rides as may be the case with the first and last mile mobility solutions discussed above. For the current discussion, however, we here also define "robot taxis" as shared mobility in that the vehicle is shared across individuals.

1.3 Major factors challenging the comfort experience in SAV

The overall comfort experience is here modelled as a point on a fragmented continuum between comfort and discomfort whereby comfort can be defined as "a pleasant state of well-being, ease, and physical, physiological and psychological harmony between a person and the environment", while discomfort refers to "a state where one experiences hardship of some sort which could be physical, physiological or psychological" [9]. Whilst it is easy to argue that comfort and discomfort can occur simultaneously and are not polar opposites, the concept is kept uncomplicated here.
As mentioned earlier, there are at least four major factors that challenge the comfort experience of occupants in SAVs. The implications of the different factors will be discussed in more detail in the next section in which it will become apparent that these factors are not independent but interrelated instead.

- **Loss of control**: The transfer of control lies at the heart of any automation. In the context of SAV, this refers to the (partial) transfer of vehicle control to the car or system. Automation renders occupants system monitors and, ultimately, passive passengers.
- **Coexistence**: The introduction of automation will not happen overnight. As a consequence, automated vehicles will be sharing the space with conventional vehicles but also vulnerable road users (pedestrians, cyclists, horses). Segregation of SAV may be envisaged but will limit the operational envelope of the technology and is unlikely to be accepted by society.
- **Moving environment**: The vehicle dynamics will be heavily dependent on the actual SAV implementation, e.g. low speed urban traffic versus high speed motorway traffic. Furthermore, vehicle dynamics can be expected to differ considerably from most public road transport (bus, train, metro) which largely involves relatively long distances at constant speeds. This has inevitable knock-ons to the biomechanical response of the vehicle occupant and could influence comfortable postures and tasks.
- **User expectations**: Vehicle automation is marketed and presented as enabling users to engage in various non-driving related tasks ranging such as sleeping, reading, or conversing. The technology promise and expectations may not necessarily match, in particular during the critical introductory phase.

The fundamental underlying aspect related to the above factors is that both vehicle automation and shared mobility is entirely focused on the passenger experience. The traditional driver-focused design approach is no longer valid and requires an entire recalibration of products and processes, whereby the relative importance of vehicle attributes is also likely to shift [10]. Despite the fact we have had passengers for as long as we had cars, i.e. for over a century, the passenger experience is not prioritized for road vehicles. The passengers have been largely neglected by the automotive industry as illustrated by the vast differences in trim levels and budgets between front and rear compartments, the absence of any car reviews *not* focusing on the driver, and the inability for anyone above the 80th percentile in stature to comfortably travel in the rear of virtually any vehicle. However, given the extremely low occupancy rates of cars (e.g. rates barely exceed 1 during commuting), the automotive industry is not to blame and only higher car occupancy rates will be able to shift this focus.

In the meantime, SAV may benefit from looking at other industries that traditionally have focused on the passenger experience. When considering expectations and the conditions under which SAV are considered to operate, it becomes apparent that the aviation industry may provide a suitable inspiration. Here, the passenger experience has long been recognized as a commercial differentiator. For example, 35% of passengers on intercontinental flights base their choice of airline on comfort, placing it after flight schedules [11]. Recently, Ahmadpour et al. [12] conducted a large scale survey amongst long-haul flight passengers to identify key factors associated with the passenger comfort experience. A factor analysis of 60 comfort descriptors revealed eight main factors. From most to least important these included: peace of mind, physical wellbeing, proxemics, satisfaction, pleasure, social, aesthetics, and association. They provide a useful starting point to think about the different factors that may also be of relevance in the context of the passenger comfort experience in SAV while acknowledging fundamental differences between the two transport modes.

First, with the exception of occasional periods of air turbulence, the motion profile of an aircraft largely consists of constant velocity motion. Due to the fact that our organs of balance only sense changes in velocity [13], we sense no motion and experience the in-flight environment as stationary. In contrast, the motion profile of road transport involves extensive lateral and longitudinal accelerations (e.g. start-stop traffic, cornering, and lane changes), as well as high frequency vibration [14]. Secondly, compared to air travel, the road environment is an extremely high risk environment where miscalculations, measured in centimeters and milliseconds, can be fatal. Air travel, on the other hand, enjoys a high level of slack as also reflected in being the safest mode of transport. Third, lower levels of road vehicle automation require shared vehicle control between the driver and the car. Semi-automation will expect the driver to regain vehicle control when the vehicle has reached the limits of its operational envelope (e.g. no road markings available on road). Bringing the driver back in the loop is a classic human factors problem and also one of the main concerns in road vehicle automation [15]. Whereas this automation issue of course also exists, and in fact originated from the field of aviation, a fourth difference is that we can rely on professional trained pilots to deal with this problem. New driver training requirements for an automated future are being discussed, however, it may be unrealistic to expect the same level of skills, capabilities, and behaviors from the general driving population.

Reflecting on these differences, it becomes apparent that the user and subsequent design requirements for the passenger experience in road vehicles may differ considerably. In the below, we provide an initial framework with the aim of guiding the design of future vehicles while identifying gaps in knowledge and areas of future research. Please note that at this stage, the framework is not intended to be exhaustive nor, for obvious reasons, validated.

2 Conceptual framework for the comfort experience in SAV

Figure 1 shows eight preliminary factors that are expected to be of particular relevance for the passenger comfort experience in SAV. For reasons of brevity, we will only provide an initial overview of each of the factors and refer to some example research studies for illustration purposes.

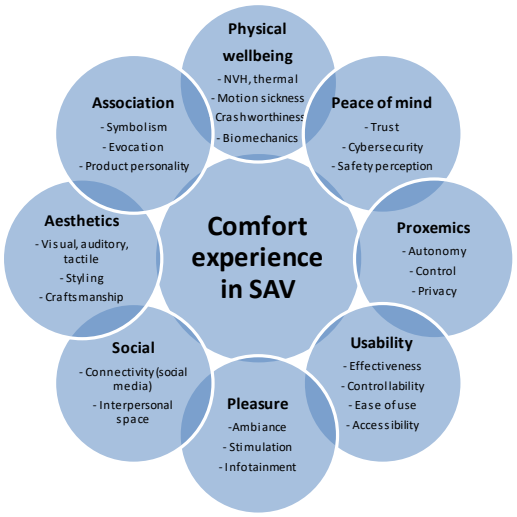


Fig. 1. Conceptual framework for the design of the passenger experience in Shared and Automated Vehicles (SAV).

Physical wellbeing

Arguably, together with peace of mind, physical wellbeing is the most critical aspect to enable the perception of comfort. Referring back to the major factors challenging the comfort experience in SAV, coexistence of automated and conventional vehicles means that occupant safety and related vehicle crashworthiness will remain largely unchanged at least until we have achieved sufficiently high penetration rates of automated vehicles, or segregate them from conventional traffic. Whereas the automated vehicle may be smart and safe, there is no guarantee that other vehicles may collide with it. This fact alone has considerable ramifications in terms of the design of user interactions and render visions of rotating seating arrangements or the use of nomadic devices (i.e. tablets, laptops) problematic unless passive safety systems (e.g. airbags) are being developed accordingly. Similarly, the need to retain current interior layouts and associated confined spaces makes it extremely challenging to develop HMI concepts that allow us to comfortably (i.e. postural comfort) and productively (i.e. efficient input devices) engage in so-called Non Driving Related Tasks (NDRT). We can also expect that users will become increasingly perceptive of the vehicle performance in terms of noise, vibration, and harshness, as well as thermal comfort, simply due to the fact that he or she is no longer engaged in an meaningful task, i.e. driving [16,17]. With energy management being a major concern in the context of electrification and HVAC use for example, this raises the question whether we ought to consider the concept of acceptable versus optimal comfort perception [18]. This discussion will also become relevant when considering the fact that comfortable vehicles tend to be large and heavy, contradicting the trend towards lightweight and efficient vehicles. Finally, the impact of a moving environment and no longer being in control of a vehicle affects comfort in a number of ways. First, biomechanically, we can expect the passive passenger not holding on to a steering wheel to be shaken around significantly more which opens up the opportunities for novel seating design solutions. Secondly, we can expect significantly higher levels of carsickness in SAV compared to conventional vehicles due to the fact that the passenger is less able to predict the oncoming motion profile while also sensing conflicting motion cues when engaged in NDRT such as reading in the vehicle [6,19,20]. On-road studies suggest that under such conditions carsickness may be experienced by as much as 50%-75% of the population [21,22].

Peace of mind

On par with physical wellbeing, peace of mind will be essential for the successful introduction and uptake of SAV. The major challenge for automated and shared vehicles is to instill a sufficient and appropriate, or calibrated, level of trust [24]. Trust develops over time, but can be facilitated by providing the right type of information. Research thus far seems to suggest a holy trinity of mode awareness (i.e. who is in control of the vehicle), situation awareness (i.e. what does the vehicle see), and behavioural awareness (i.e. what is the vehicle going to do next) [23]. Future research will be required to understand how best to represent this infor-

mation although initial studies already point towards the intricate and interrelated nature of comfort as illustrated by the role of HMI aesthetics in instilling system trust [25]. Interestingly, trust in fellow passengers may appear to be less challenging than one would expect. A study by BlaBla car ride-sharing company revealed that, rather surprisingly, fellow users enjoyed higher levels of trust than work colleagues or neighbors [26]. Another challenge pertains to the concerns around cybersecurity [27]. Recent reports about hacked vehicles have raised awareness around the vulnerability of current automotive systems and will have to be addressed to ensure customer confidence.

Proxemics and Social

Proxemics, as interpreted in Ahmadpour et al's [12] study, refers to the experience of privacy and control over one's environment. This factor appears to show considerable overlap with the social aspect of the comfort experience and, for brevity, is discussed jointly. Whether it is for business or for pleasure, using our time more constructively as enabled via SAV can be regarded as a game-changing proposition. How we want to use this time will dependent on several factors but in the extreme we can make a distinction between a "stagecoach" or "shared space" model which facilitates social interactions, for example by positioning seats towards each other, versus a "cocoon" or "individual space" model which emphasizes the independence and isolation of the individual. We can observe a similar dichotomy in the digital realm where we can see user interaction concepts facilitating individual connectedness (i.e. social media) to the outside world versus a shared digital experience within the vehicle. Here we can imagine different types of vehicles depending on an individual or shared experience, but of particular interest may be the ability to swap between these two experiences.

Usability

We here refer to usability as the effectiveness, efficiency and satisfaction with which users achieve their goals. As mentioned, the ability to engage in leisurely or economically productive non-driving related tasks, is at the heart of the proposition put forward by vehicle automation, and by extension shared mobility. However, as already discussed in the above section on physical wellbeing, the ability to do so in a confined and moving environment is far from trivial [20]. The use of existing interaction paradigms, e.g. mouse and keyboard, in an automotive environment is cumbersome and particularly difficult to implement in semi-automated vehicles requiring the driver to regain control within set time limits. User expectations play an important role here too. The ability to free up our time to engage in more useful or enjoyable activities is pertinent to vehicle automation. Whereas we may elect not to use public transport or accept that we won't be able to use our laptop sitting in the passenger seat as it makes us feel queasy, the proposition of vehicle automation differs. The benefits of automation may not be perceived significant unless we can actually engage in other activities. In fact, the inability to do so, and in the worst case, having to constantly monitor the system and environment, may well be perceived as less comfortable and acceptable than manual driving [21].

Pleasure

SAV will provide unprecedented opportunities to enhance the experience within the vehicle. This can be trip related (e.g. geo-specific information), an entirely decoupled immersive experience, or a wellbeing spa on wheels. We have seen several concept vehicles indulging in variations of such future scenarios. However, to date, these concepts may not have sufficiently appreciated some of the other challenges associated with SAV in particular with reference to the factors of physical wellbeing and peace of mind. The future challenge lies in enabling such new experiences while ensuring that more basic requirements are respected. Conversely, we also need to take into account the effect of time and experience and we may need to balance system trust and the ability to comfortably engage in non-driving tasks in favor of the latter, for example [28].

Aesthetics

Aesthetics is sometimes mistakenly referred to as "styling". As with any product, the appearance is of utmost importance, referring to not just the visual but also the haptic, tactile, auditory, and olfactory sensations. Material and trim options form a particular challenge given the hygiene, durability and maintenance requirements in SAVs. To date, the aesthetics of the experience have largely been neglected and, understandably, the focus has been on demonstrating the technological capabilities and feasibilities of SAVs. However, when only considering the visual appearance of SAVs, we can expect it to play a vital role in public perception and acceptance since it signals a wide range of attributes [29]. As an example of the impact the visual appearance

can have in the context of comfort, changes in the visual appearance of otherwise identical seats dramatically affects the perception of seating comfort [30].

Association
Following on from the above, the associations related to a product, including its appearance, can have considerable implications. Vehicles are considered "avatars", or extensions of oneself [31], and psycho-social aspects have to be taken into account when introducing a new type of transport. This is illustrated by the social stigma attached to bus and coach travel in the United States. Efforts to provide more upmarket interior designs for long distance coach services have been successful in making customers feel comfortable in using these services. Similarly, in particular last mile mobility solutions providers and operators need to be mindful of the effects association and exterior design can have on future use [32].

3 Conclusion

Shared and automated vehicles (SAV) have the potential to provide a positive contribution to today's transportation challenges. As yet, most of the development has focused on the technological feasibility of such vehicles without sufficiently taking into account the human factor, particularly in the context of the anticipated vehicle-user interactions. Future vehicles will be entirely focused on the passenger experience and understanding the passenger requirements in a future of shared and automated vehicles is expected to become an important line of research. We here presented an initial framework around major factors influencing the passenger experience to guide the vehicle design process and highlight gaps of knowledge and areas for future research.

References

1. Alessandrini, A., Cattivera, A., Holguin, C., & Stam, D. CityMobil2: Challenges 37 and Opportunities of Fully Automated Mobility. In Road Vehicle Automation: 38 Lecture Notes In Mobility. Springer International Publishing Switzerland, 2014, 39 pp. 169-184.
2. Payre, W., Diels, C., 2017. Human-Machine Interface Design Development for Connected and Cooperative Vehicle Features. 8th International Conference on Applied Human Factors and Ergonomics (AHFE 2017), 17-21 July, Los Angeles, CA, US.
3. Fulton, L., Mason, J., Meroux, D., 2017. Three Revolutions in Urban Transportation. Institute of Transportation and Development Studies, UC Davies. Accessed 9 May 2017: https://www.itdp.org/3rs/
4. McKinsey, 2016. Automotive revolution – perspective towards 2030. How the convergence of disruptive technology-driven trends could transform the auto industry. Accessed 9 May 2017: http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry
5. National Association of City Transportation Officials, 2016. NACTO Policy Statement on Automated Vehicles. Accessed 9 May 2017: https://nacto.org/wp-content/uploads/2016/06/NACTO-Policy-Automated-Vehicles-201606.pdf
6. Diels, C., 2014. Will autonomous vehicles make us sick? In S. Sharples & S. Shorrock (Eds.), Contemporary Ergonomics and Human Factors (pp. 301-307). Taylor & Francis.
7. SAE J3016, International, 2014. SAE International's Draft Levels of Automation for On-Road Vehicles.
8. Bainbridge, L., 1983. Ironies of automation. Automatica, 19, 775-780.
9. Vink, P., 2005. Comfort and design principles and good practice. Boca Raton, FL: CRC Press.
10. Kukova, M., Diels, C. Jordan, P., Franco-Jorge, M., Anderson, J., Kharouf, H. (2016). Do we really know which vehicle attributes are important for customers? Proceedings of the 10th Design and Emotion conference, Amsterdam, 27-30 October 2016.
11. Brauer, K., 2006. What is it worth? In: Aircraft Interior EXPO' 06, April 4, 2006, Hamburg, Germany.
12. Ahmadpour, N., Robert, J.-M., & Lindgaard, G., 2016. Aircraft passenger comfort experience: Underlying factors and differentiation from discomfort. Applied Ergonomics, 52, 301–308.

13. Howard, I.P., 1982. Human Visual Orientation. Wiley, Chichester.
14. Mansfield, N.J., 2004. Human Response to Vibration. CRC Press.
15. Stanton, N.A., Young, M.S., Walker, G.H., 2007. The psychology of driving automation: a discussion with professor Don Norman. Int. J. Veh. Des, 45 (3), p. 289.
16. Bennett, C.A., Rey, P., 1972. What's so hot about red? Hum. Factors 14 (2),149–154.
17. Berry, P.C., 1961. Effects of colored illumination upon perceived temperature, J. Appl.Psychol. 45 (4), 248–250.
18. Hodder, S.G., 2017. Acceptable versus optimal comfort perception. Personal Communication.
19. Diels, C., Bos, J.E., 2015. User interface considerations to prevent self-driving carsickness. Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications; 09/2015.
20. Diels, C. Bos, J.E., 2016. Self-Driving Carsickness. Applied Ergonomics, (53) Part B, pp. 374-382. DOI information: 10.1016/j.apergo.2015.09.009
21. Diels, C., Bos, J.E. Hottelart, K., Reilhac, P., 2016. Motion Sickness in Automated Vehicles: The Elephant in the Room. Road Vehicle Automation 3 (Eds. Gereon Meyer, Sven Beiker), Springer Verlag, Berlin.
22. Krause, M., Henel, J., & Bengler, K., 2016. Performance and Behavior of a Codriver When Using a Mobile Device. In 62. Kongress der Gesellschaft für Arbeitswissenschaft, Germany, Aachen.
23. Diels, C. Thompson, S., 2017. Information expectations in highly and fully automated vehicles. 8th International Conference on Applied Human Factors and Ergonomics (AHFE 2017), 17-21 July, Los Angeles, CA, US.
24. Payre, W., Cestac, J., Delhomme, P., 2017. Impact of training and in-vehicle task perfor-mance on manual control recovery in an automated car. Transportation Research Part F: Psychology and Behaviour. doi: 10.1016/j.trf.2017.02.001
25. Ekman F., Johansson M., Sochor J., 2016. Creating appropriate trust for autonomous vehicle systems: A framework for HMI Design. In Proceedings of the 95th Annual Meeting of the Transportation Research Board.
26. Benamran, D., 2015. Creating Positive Disruption. MRS Automotive Research Conference, London, July 2015.
27. Cheah, M., Shaikh, S. A., Haas, O. & Ruddle, A., 2017. Towards a systematic security evaluation of the automotive Bluetooth interface. Vehicular Communications. 9, p. 8-18.
28. Miglani, A., Diels, C., Terken, J.A.M., 2016. Compatibility between Trust and Non Driving Related Tasks in UI Design for Highly and Fully Automated Driving. Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.
29. Creusen, M. E. H., Schoormans, J. P. L., 2005. The different roles of product appearance in consumer choice. Journal of Product Innovation Management, 22(1), 63-81.
30. Erol, T., Diels, C., Shippen, J., Richards, D., Johnson, C., 2014. Effects of Appearance on the Perceived Comfort of Automotive Seats. Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014, Kraków, Poland 19-23 July 2014.
31. Benson, R., MacRury, I., Marsh, P., 2007. The secret life of cars and what they reveal about us. Accessed 9 May 2017: https://www.dezeen.com/2007/07/22/the-secret-life-of-cars-by-bmw/
32. Wasser, J., Diels, C., Baxendale, A., Tovey, M., 2017. Driverless Pods: from Technology Demonstrators to Desirable Mobility Solutions. 8th International Conference on Applied Human Factors and Ergonomics (AHFE 2017), 17-21 July, Los Angeles, CA, US.

Two-level representation for passengers' appreciation of comfort in urban public transport

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Abstract Comfort is an ill-defined and little controlled concept. It cannot be measured directly as it is a complex response from an individual to a specific situation. However, it can be studied and analyzed to a certain extent through contextualized "comfort models". This paper will propose a new representation based on a review of literature, an anthropocentric approach and observations in situ. For a long time, comfort was not a priority in urban public transport. Passengers spend a little time in those places, compared to bigger transports like high-speed trains or planes, and they are not necessarily seated. Thus, in urban public transport, comfort is mostly considered linked to the frequency or easy access of the trains, and the availability of free seats. Now, how can the interior design of a rolling stock improve passenger comfort? Observations led around the world showed that every passenger develops a strategy to be seated in metros or tramways, and in the most "uncomfortable" situations, the majority is still standing on their feet. Many papers deal with seats at an individual and almost isolated scale, but almost none deal with what really happens in such transports. This work proposes a holistic approach to help answering this question, based on an anthropocentric point of view that wants to go beyond ergonomics. Comfort is set here as the valenced appreciation resulting of the dynamic relationship between the passenger (who has individual characteristics and motivations) and the space (e.g. the seat, the different kinds of supports such as bars or handles) in a specific context (cultural, social, spatial and temporal). Even if comfort is an individual and subjective feeling, it is also a product of socialization, which is not clearly stated in current comfort models. On a global level, it depends on various parameters along the different steps of the ride, surrounding the experience of the passenger. A sensory approach is also introduced in order to understand the local interactions between the passenger and the space. The combination of these global and local levels gives a dynamic comfort model, representative of the situations encountered in urban public transport, and can be the basis for a further design reflection.

Keywords: Anthropocentrism, Comfort representation, Sensory, Spatial organization, Urban public transport

1 Introduction

In the middle of the 20th century, only 30% of the humans were city-dwellers. Today, they represent more than 50% of the world's population. This galloping urbanization is intrinsically linked to the mobility needs, each forming the other [1]. Daily mobility is an integral part of this modern phenomenon, and it concerns many people: planners, researchers, industrials, and obviously lots of people in their daily life. This paper presents an

overview of the results of two PhD theses that are in the frame of a global project sponsored by the French railway manufacturer Alstom, entitled "Global Approach of Perceptible Differentiation Aspects of Rolling Stocks". More than 20 years ago, Le Goff demonstrated how the concept of comfort reached public space, including urban public transports [2]. Nowadays, this concept is key for designing interiors of such vehicles because it impacts the quality of the interaction between passengers and transportation environment, for most of them in a daily routine. The literature about comfort in the context of urban public transport is rather rare, as most papers mainly focus on comfort in working environments or long-distance transports, spotlighting predominantly the seated position. It is also discussed on a local and individual level, lacking the influence of social interactions. Furthermore, most of the studies are based on surveys, declarative data, not on observations in situ on how people are interacting together and with the space. Human factors and ergonomics is the discipline devoted to understand, measure or improve the comfort of products, but the context of urban public transport requires additional data, coming for example from human and social sciences. In light of this, observations were conducted in buses, metros and tramways all around the world to complete the current knowledge. Finally, the confrontation of those observations with the existing models of comfort (that needed contextualization) resulted in a two-level representation of passengers' appreciation of comfort.

2 The pursuit of comfort

Comfort is an ancient word, but its meaning has evolved across the ages. More than a word, it is a concept that evolved following the development of modern society, and it is now a guarantee of quality for a product. Unfortunately, comfort cannot be measured or assessed directly as it depends on a large number of parameters and conditions. However, it can be studied under certain limitations. This first part will demonstrate the complexity of comfort, how it became a modern necessity, and how it is represented today.

2.1 The evolution of comfort: from private to public sphere

Le Goff offered an excellent genealogy of comfort based on the history of the French modern society [2]. From as far as the Industrial Revolution to this day, he demonstrated how comfort was forged by the changes in society. Nowadays, comfort does not refer only to luxury or material welfare, as it used to in the past. When basic needs were fulfilled in France by new laws providing a minimum of comfort for the middle classes, Taylorism and the post-war prosperity led to new needs of performance and gain of time. A new threshold was then crossed: people had to respond to secondary "needs", to better themselves, to make life easier by purchasing technical prostheses. This step forward, symbol of modernity, implied that comfort became a new individual necessity. Afterwards, the development of capitalism led to a major crisis post-1973. The social damages engendered by the large industrialization and the changes of the society could not be neglected anymore. Traffic jam, pollution, noise, infernal paces, new forms of social inequality, environmental destruction were the price of progress. This society of quantitative comfort, returning to luxury, could not last any longer as such. In fact, the more society gains comfort, the more discomfort becomes unbearable. Hegel already noted this tendency in 1820 when he wrote in *Elements of the Philosophy of Right*: "What the English call "comfortable" is something endless and inexhaustible. Every condition of comfort reveals in turn its discomfort, and these discoveries go on for ever. Hence the new want is not so much a want of those who have it directly, but is created by those who hope to make profit from it" (§191). The discomfort met in public space came into conflict with the comfort met in private space. Thus, comfort, which was mostly restricted to the private sphere, extended to community life and to public space, developing what Le Goff called the "being-together". In fact, today's occidental modern society relies upon this founding paradox of the contradiction between individual and material comfort and collective and harmonious comfort. This resulted in new territories for comfort: besides the private space (the house or the car), it reached the public space, like hospitals, administrations, or public transports.

Nowadays, comfort is used as an added value to products, it became a stake per se. Comfort sells. In the case of private products, it is obvious, but for public goods, there is still a long way to go. Urban public transports are no exception: as access to the city became a political and economic issue, a solution was necessary to reduce traffic jam and car pollution, while increasing mobility. As Le Goff noted, they were still a virgin territory in

terms of comfort. It was not the primary objective of those transports because of the small amount of time passengers spent in them. Since around two decades, a new way of thinking emerged for the design of both railway networks and urban rolling stocks. Today's main goals are to attract more passengers by improving passenger experience, which go inevitably through a better understanding of comfort on behalf of rail manufacturers and operators.

2.2 Towards a modern definition of comfort

The previous part showed that comfort can adopt various shapes and meanings. Le Goff gave it this global definition: "[The] relationship built between an individual and his environment, which can be either material or spiritual". This relationship can be of two sorts. First, he mentions the idea of a "comfort of ephemerality", related to hedonism. It is basically the pursuit of immediate pleasure or well-being: comfort is here an end in itself. This "comfortable quest" is somewhat common between the cultures, each and every one developing his own "needs". The second relationship is the "comfort of the social body", related to a certain "neo-Taylorism". It refers to a rationalization of pleasure, what Le Goff calls a "social chain of comfort". It is not the ultimate goal anymore, but a way to better achieve one's objectives. Those two inherent parts of comfort show that it is not only related to one's body, but also to one's practice. It is built through experience in a particular context. To resume, comfort is relative to history and a particular period of time, to the subject feeling it, to his own culture and to the circumstances [3]. Therefore, it is a feeling really subjective and individual, besides being contextual. Suffice it to say it is not a physical quantity that can be measured directly, it is way more complex to study. It is also really important to keep in mind that when it comes to think about comfort, or to study it, it is done through an unintentional ethnocentric point of view: it has to be thought according to one's culture, one's history, one's geography, one's situation. There just cannot be a universal definition for it, but only a contextual definition.

In general terms, for the previous reasons, comfort is not really what is studied, but discomfort is. In fact, they are not opposites on a one dimension scale, but two separate dimensions. The first is rather linked to aesthetics and psychological factors, whereas the second is rather linked to biomechanical and physiological factors, easier to assess [4]. Human factors and ergonomics uses various tools to measure the different parameters impacting discomfort: pressure distribution, muscular efforts, biomechanical charges, or even questionnaires to ask directly the subjects about their feelings. Several authors attempted to develop "comfort models" to sum up the causes of comfort or discomfort.

2.3 Nowadays comfort representations

Comfort representations are an interesting issue as they can help designers, operators or even managers to understand how this relationship between a person and his environment work. In 1996, Zhang et al. envisioned the first representation thanks to a questionnaire survey study in which employees had to assess the comfort or discomfort on their work environment [4]. This was a milestone in the comfort research, as it broke off the common belief that comfort and discomfort were the two extremes of a unique scale, as considered before [5]. Then, in 2003, De Looze et al. proposed a pioneering theoretical model, based on a review of several studies in which subjective (dis)comfort ratings and objective measures were simultaneously obtained [6]. Two years later, Moes went further on the explanation of the discomfort feeling by establishing five stages in the process to feel discomfort: interaction, effects in the internal body, perceived effects, appreciation of the effects, then finally the feeling of discomfort [7]. So far, those models were useful to the etiology of work-related physical complaints, as they were focused on discomfort. However, when it comes to develop innovative products, comfort is more appealing, as seen previously. It was reincluded in a new representation by Vink [8]. He added psychosocial factors, such as the history or the state of mind of the user.

The last comfort model was published in 2012 by Vink and Hallbeck (see figure 1) [9]. It says that basically, when a person uses a product in a specific environment, the interaction (I) of the person's body (whether there is a physical contact or not) with the product or environment results in internal human body effects (E), for example muscle activation. These effects are perceived (P) and influenced by expectations (E), then they are

interpreted as either feelings of comfort (C), discomfort (D) or nothing particular is felt (N). Discomfort can lead to pain, such as musculoskeletal complaints (M). If discomfort it too high or comfort not good enough, the person will try to improve the situation by moving, adapting, or adjusting the product, hence the feedback loop. Finally, the ellipse including expectations and comfort illustrates that expectations are believed to have a bigger influence on comfort: "comfort will be felt when more is experienced than expected". Now, it appears the context of urban public transport doesn't really match with this model, as the next part will explain.

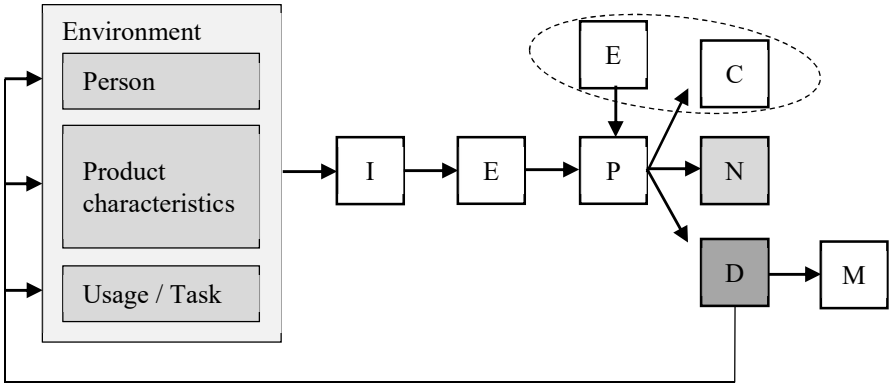


Fig. 1. Comfort model proposed by Vink & Hallbeck (2012)

3 The context of urban public transports

Designing comfortable rolling stocks for urban public transports is a real challenge for manufacturers, as they are highly constrained by technical and safety standards. Moreover, the number of passengers is impossible to control, unlike long-distance transports, containing only seats. Thus, designers have to balance contradictory elements in order to satisfy the main objective of railway operators. How to transport a maximum of passengers in a minimum amount of time, with a maximum of individual comfort? Some studies showed that the passengers didn't essentially care of the comfort of seating, but rather of the possibility of seating, of the waiting time on the station platforms or of the crowding [10, 11, 12]. Besides, as everyone cannot be seated and has to interact with strangers, strategies emerge to "mark one's personal space" for the time of the ride. This part will develop the crowding parameter and a part of this strategy, called here "anchoring".

3.1 The crowding parameter

As Le Goff said, crowding is conflicting with individual happiness. Unfortunately, it is the lot of the passengers of the urban public transport to deal with the crowd. This trademark parameter is worth a deepening. To start from the beginning, a crowd is a social structure, organized or non-organized, with a certain density [13]. In public transport, the crowd is non-organized. What about density? It is globally the ratio of the « number of social units per space units » [14]. This definition has to be clarified, because these two elements are not specified. A review of the definitions of density in public transports made by Li and Henscher illustrated how difficult this task was, especially in this context [15]. They demonstrated that there are many ways to define density and the accepted density threshold. This complexity comes from the fact that there are standing and sitting areas in most of the interiors and that the ratio between those two types of areas can differ between the rolling stock models. Also, a sitting person takes more space than a standing person. Sometimes, even a time factor is added. Besides, density is often used as an objective tool to assess the subjective perception of it, in the form of a percentage of occupation of the vehicle, in relation to a standard occupancy rate (usually four people per square meter). This is here believed to be an error, because of the nature of the subjective feeling called « crowding » that can't be rated. Eventually, interpersonal distances can be measured and assessed in relation to proxemics [16]. Indeed, proxemic activity allows a person to adapt to the presence of others, by setting a certain distance

between them. It is for example the reason why passengers leave an empty seat between them if they can. The width of the seats has then a special role in this "unconscious" behavior.

Crowding is defined as "the psychological state created by being in a space with an amount of people exceeding the attended or needed amount" [14]. It is a perception based on spatial and social factors. If the space can be the origin of discomfort because of its size or its organization, the social conditions caused by the crowd, however, impose to interact visually or verbally with the other passengers. Yet, passengers need to keep control on their mobility as much as on their social interactions. They then try to ignore each other while taking care of the physical presence of others [17]. Goffman theorized it as the « civil inattention » [18]. Finally, Morval noted that density was necessary but not sufficient to create this feeling [19]. It means that other factors have to be taken into account: the size of the crowd, the groups, if the persons know each other or not, the age of the person and the ages of the people surrounding him, the culture, the expectations, the frequency of the situation, etc. Thus, passengers deal with a pretty uninviting space, leading them to adopt specific strategies.

3.2 The need to anchor

This research led to understand the interactions between two spatial features: the passenger compartment and the passenger's body. Personal experience of public transports and exploratory observations helped to build an observation grid that was then applied to twelve cities in seven different countries (France, Switzerland, Germany, Estonia, Morocco, Hong Kong and United Arab Emirates). The spatial behavior of people in tramways, metros, buses, one trolley-bus and one monorail were observed. The analysis of the data was based on an approach combining the systemic paradigm of Le Moigne [20] and a geographical approach of space, resulting in different scales of observation (from the body to the environment) and different axes (from side to side or from nose to tail).

The general result is rather obvious: people prefer to sit rather than to stand. The percentage of occupied seats is always superior to the percentage of occupation of the standing room, and the percentage of occupation of the standing room increases only when almost all the seats are taken. It is important to note that the percentage of occupied seat cannot exceed 100% (passengers do not generally sit on other people's lap), but the percentage of occupation of the standing room can exceed it, depending on the initial density setting (usually four people per square meter is considered 100%). Incidentally, it is another example why defining density is difficult. Furthermore, the lone passengers tend to stay on the sides of the vehicle more than the groups. On average, more than 60% of the passengers are sitting. It depends on the seats available, but also on the global density. Nonetheless, the density is changing over time, which leads to observe more people sitting. Yet, during rush hours, more people are standing in vehicles that offer fewer opportunities to sit. If another part of the interior furniture allows it, people will sit on it. The standing passengers always try to lean against something by staying on the sides of the vehicle, but if it is not possible, they lean against whatever they can (like the vertical bar). Indeed, every type of furniture is used as a support, depending on the crowd. Everyone standing is at least holding onto a bar, whether it is to stabilize themselves, to stand so as to mark his personal space, or to move through the vehicle. Passengers holding onto nothing are rare. Finally, the fact that people tend to lean against something seems to indicate that they try to stabilize the top of their body (when they are sitting, most of them are leaning de facto). The stability offered by simply holding onto a bar seems not enough. Only one exception was observed: the Palm Jumeirah monorail in Dubai. In this vehicle, people are moving a lot, which disturbed the observations (the grid was built to observe a rather static space). This hustle is probably simply due to the fact that the monorail is mostly used by tourists looking everywhere around. Another explanation could be that the vehicle is very stable, accelerations and decelerations are really smooth, and so the passengers don't really need to hold onto something. As a matter of fact, there is a relative absence of supports in the monorail, whereas vehicles shaking a lot like buses offer a lot of supports.

All these observations help to understand two different things, related to each other. Firstly, the need of stability is noticeable by the way the passengers organize themselves in the vehicle. Holding onto a bar is the smallest link between the body and the vehicle. Most of the people try to find back support, and if possible to sit down. This is why it is believed there is a need to "anchor" in the transport. Most of the passengers need more than just standing there holding onto something or not. Therefore, the expression "anchoring" is proposed to define the tendency for the passengers to look for a support for at least their pelvis and at best their whole upper body. Looking for an anchoring spot can be considered as the expression of a search of security, perhaps

a search of comfort, especially for standing persons during rush hours. Secondly, the case of Dubai, going against the observations, shows that the motion of the transport influences this need to anchor (its acceleration, deceleration, etc.). The more stable a vehicle is, the less required supports are. Finally, it is acceptable to say that this body anchoring is the link between comfort and security, as anchoring allows the passengers to secure their position, physically but also psychologically, by creating their "own spot". In conclusion, taking place in a vehicle relies upon two activities: anchorage, by using the supports to keep balance, and proxemics, by setting social distances towards others. In the light of the above, proposals for a new representation are made in the final part of this paper in order to summarize these results.

4 Proposal for a two-level representation of passengers' appreciation of comfort

Two levels of representations are proposed to illustrate the two relationships defined by Le Goff. First, the comfort of the body is described with a local model of sensory interaction between the passenger and the support (see figure 2), inspired from the previous comfort models. The process of perception described in neurosciences gives stages similar to the Moes model. Very briefly, once human sensory receptors are stimulated by an energy in the environment (interaction), they will emit an action potential that will diffuse through the sensory fibers to the central nervous system. Then the information will be processed in the cortical and subcortical areas, resulting in the sensation. From this point, several inputs can alter the perception of this sensation, such as emotions (or mood), attention or memory [21]. Then, a valenced appreciation of the perception will give the sought feeling of (dis)comfort. As expectations result from the memory of previous experiences, they have a clear impact on the appreciation of the perception. Travel conditions are the context of the travel. As seen previously, the crowding is an example among others that influence the passenger's appreciation of comfort. Modalities of interaction include the accessibility of the support, the intention and its use. The accessibility echoes the idea of anchoring.

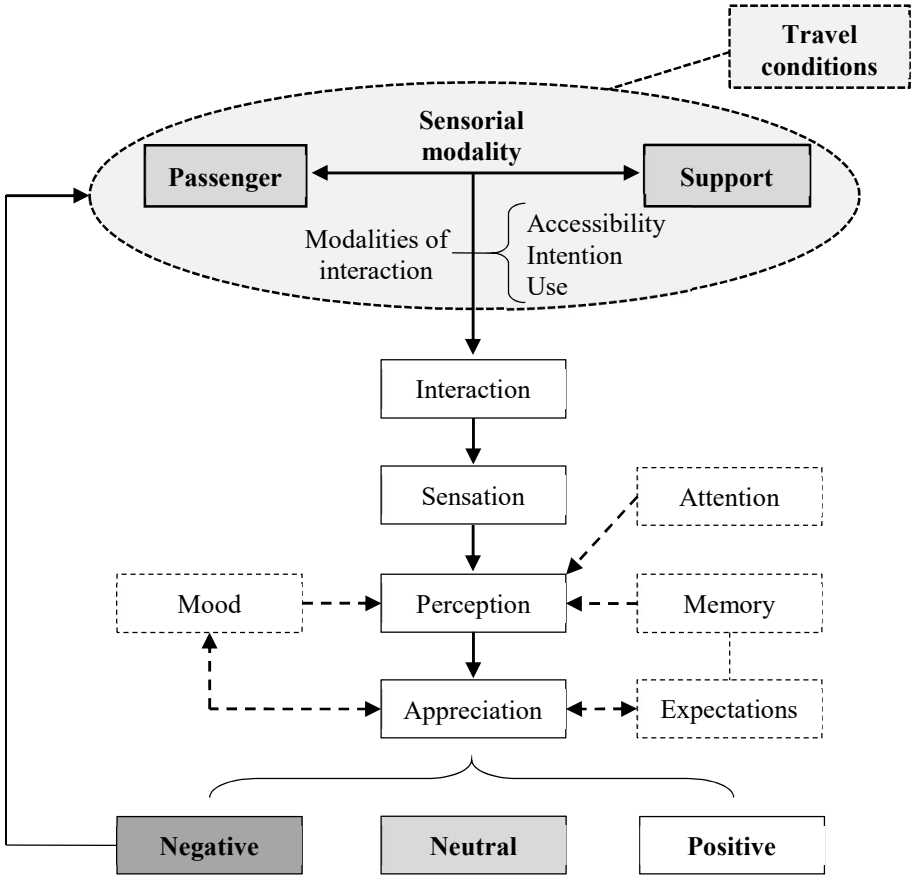


Fig. 2. Comfort of the body: representation of the local sensory interaction between the passenger and his environment

Now, another representation can be depicted: the comfort of the social body. It is based on the fact that the transport is only a mean to go somewhere, it is not the destination itself (except when they are used as a tourist attraction). The ride is only a step in the travel of the passenger, more or less prepared and ordinary, filled with impacting or neglecting events. As expectations influence the appreciation of (dis)comfort, it is interesting to consider the whole picture. The appreciation of comfort occurs in a global situation, declined in a lot of complex and dynamic factors of any sorts, physiological or psychological, sometimes totally out of control. However, uncontrollable elements for designers can be controlled by other actors of the railway service: the operators, but also the designers of the railway infrastructures. This new approach, that we called in French "*approche 5A*" (for *avant – accueil – ancrage – activités – après*), translated into the five stages "before, welcoming, anchorage, activities and after", wants to lead up to a holistic design of rolling stocks (see figure 3). It is inspired from the micropsychology analysis developed by Moles [22]. This approach decomposes a situation in elementary actions, on the limit of consciousness, in order to dress the most complete and acute list of all the possible scenarios during the execution of the analyzed task. This method allows to identify the different stages and sensory modalities involved in an action, but also to identify the most important elements to study and to assess the various types of costs of each step (financial, energetic, psychological, temporal, etc.). Here are selected the five main steps of an urban ride, that can be then declined in smaller steps. First, the "before" step includes the preparation of the travel: is the transport service free or not, is it accessible, is there a lot of people waiting for the train, is the train late, etc.? Then comes the "welcoming" time, when the individual enters the vehicle: is there a lot of people inside it, is there a seat available, etc.? Once the doors close and the vehicle starts, the person will look for an "anchoring spot", as seen previously. Next, if the person is sufficiently anchored, it can perform various "activities": reading a book, listening to music, chatting with his neighbor, etc. There is a loop between the stages of welcoming, anchorage and activities, echoing the loop induced by discomfort seen previously. Indeed, during a ride, the passenger can change his position, for example if a seat is available after a stop and he wants to sit, or if he wants to catch up with an acquaintance. Finally, at the end of the ride, the "afterwards" step refers to the easiness of leaving the vehicle and continuing the travel.

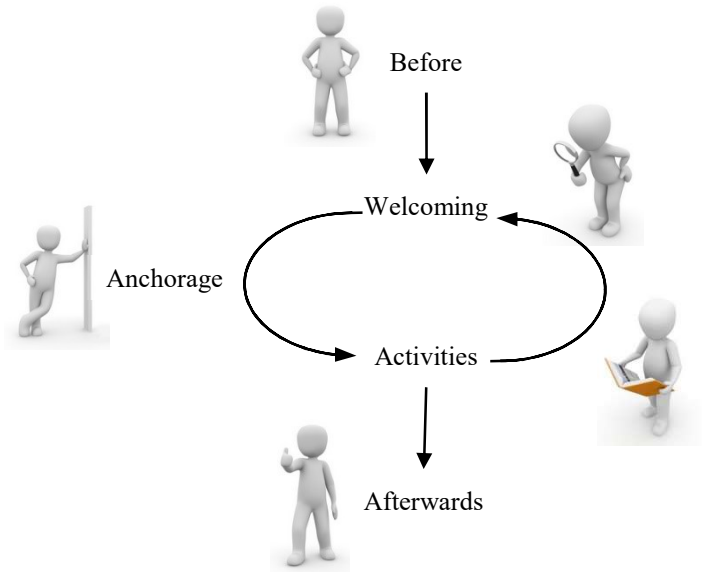


Fig. 3. Comfort of the social body: holistic approach of the ride

This two-level representation does not pretend to give the answer to the assessment of comfort, but rather to build a knowledge basis to help designers to understand the underlying factors of (dis)comfort. It requires further studies as to which factor impacts it the most, but it shows that a rolling stock cannot be designed without taking into account the entire transport service.

5 Conclusion

It exists as many ways to represent comfort as there are situations. It is always necessary to redefine it and to adapt the study to the context, by confronting it with experience. Actually, comfort is felt through practice and differs from one individual to another, from one culture to another, from one society to another, and so on. As difficult as it seems to assess, it is however possible to study the parameters that come into play in its appreciation. The aim of the representations proposed in this paper is to help designers understand better this notion and give them the tools they can "play" with. For now, they only are guidelines for further case-by-case work.

For the specific situation of urban public transports, comfort can be resumed as "the ease to take place, or to find one's own spot". The social dimension introduced by crowding cannot really be controlled by the sole design of rolling stocks, as it is a very fluctuating and erratic parameter. First recommendations could then be to design urban transport under a holistic approach, through a dialogue between the different actors of the urban transport. Another recommendation could be to study how passengers perceive the motion of the vehicle in regard to their psychosocial, physiological and physical characteristics (e.g. their age, if they travel with luggage, etc.). Ecological situations should be studied in order to assess the impact of the vehicle dynamic behavior on the passengers and on the crowd.

References

1. Lussault M. L'avènement du monde. Essais sur l'habitation humaine de la Terre (*The advent of the world. Essays on the human habitation of Earth*), 2003 (Éditions du Seuil, Paris).
2. Le Goff O. L'invention du confort : naissance d'une forme sociale (*Invention of comfort: birth of a social form*), 1994 (Presses universitaires de Lyon, Lyon).
3. Sèze C. Confort moderne. Une nouvelle culture du bien-être (*Modern comfort. A new culture of the well-being*), 1994 (Autrement, Paris)
4. Zhang L., Helander M.G. and Drury C.G. Identifying factors of comfort and discomfort in sitting. Human Factors, 1996, 38(3), 377-389.
5. Shackel B., Chidsey K.D. and Shipley P. The assessment of chair comfort. Ergonomics, 1969, 12(2), 269-306.
6. De Looze M.P., Kuijt-Evers L.F.M. and Van Dieën J. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics, 2003, 46(10), 985-997.
7. Moes N.C.C.M. Analysis of sitting discomfort, a review. Contemporary Ergonomics, 2005, pp.200-204 (Taylor & Francis, London).
8. Vink P. Comfort and design. Principles and good practice, 2005 (CRC Press, Boca Raton).
9. Vink P. and Hallbeck S. Editorial: Comfort and discomfort studies demonstrate the need for a new model. Applied Ergonomics, 2012, 43(2), 271-276.
10. Kroes E., Kouwenhoven M., Debrincat L. and Pauget N. Crowding on public transport for Île-de-France. In : Valuing Convenience in Public Transport, 2014 (Éditions OCDE, Paris). URL : http://dx.doi.org/10.1787/9789282107683-en
11. Kogi K. Passenger requirements and ergonomics in public transport. Ergonomics, 1979, 22(6), 631-639.
12. Haywood L. and Koning M., translated by Waine O. In the Paris metro, hell is other people. Métropolitiques, 2015. URL : http://www.metropolitiques.eu/In-the-Paris-metro-hell-is-other.html
13. Moscovici S. L'âge des foules (*The age of crowds*), 1981 (Fayard, Paris).
14. Dion-Le Mee D. La foule dans un contexte commercial : concept, mesure, effets sur les comportements (*The crowd in a commercial context : concept, measure, effects on the behaviors*), PhD thesis, 1999 (Université de Rennes 1, Rennes).
15. Li Z. and Hensher D. Crowding in public transport: a review of objective and subjective measures. Journal of public transportation, 2013, 16(2), 107-134.
16. Hall E.T. The hidden dimension, 1966 (Anchor Books, New York).
17. Aranguren M. and Tonnelat S., translated by Waine O. Coping with crowdedness in mass transportation. The role of emotions in the Paris metro. Metropolitiques, 2014. URL : http://www.metropolitiques.eu/Coping-with-crowdedness-in-mass.html
18. Goffman E. Relations in public. Microstudies of the public order, 1971 (Harper and Row, New York).
19. Morval J. Introduction à la psychologie de l'environnement (*Introduction to the psychology of the environment*), 1981 (Mardaga, Bruxelles).
20. Le Moigne J.-L. La théorie du système général. Théorie de la modélisation (*Theory of the general system. Theory of the modelization*), 1994 (Presses universitaires de France, Paris).
21. Calas A., Perrin J.-F., Plas, C. Vanneste P., and Figarella P., Précis de physiologie (*Physiology precis*), 2016 (Douin, Paris).
22. Moles A. and Rohmer E. Micropsychologie et vie quotidienne (*Micropsychology and daily life*), 1976 (Denoël, Paris).

The effect of spine discomfort on the overall postural (dis)comfort: the case of vending machines

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Abstract Currently, the word 'comfort' is often used in relation to the marketing of products such as chairs, cars, clothing, hand tools and even airplane tickets. The aim of this study is to investigate the influence of spinal posture on postural comfort perception while using a vending machine for purchasing food or beverages. A statistical sample of 20 healthy students performed the required tests, with each participant asked to take a product from three different vending machines (snacks, drinks and coffee). The subjects' postures were acquired non-invasively using cameras. Angular detection was performed directly on photographs, using Kinovea® software. Joint positions were used for the virtual-postural analysis, using DELMIA®. Digital Human Modelling (DHM) software. Postural comfort was evaluated in two ways: CaMAN® software, by University of Salerno (Italy), was used to calculate the objective comfort indexes, while a questionnaire was used to evaluate subjective comfort indexes. The results obtained from these simulations and questionnaires were compared, and a method to weigh the effect of the perceived spinal discomfort on overall postural comfort was proposed. These results reveal a good correlation between subjective perception and objective evaluation obtained through simulations, confirming the validity of the proposed method.

Keywords: Comfort Evaluation, Non-invasive Postural Analysis, Vending machines, spine discomfort, Information fusion.

1 Introduction

During the last two decades, the market has been impacted by several standards (e.g. EN ISO 14738, 2002 [1], ISO 11226/2000 [2] and EN 1005-3/2009 [3]) that set geometric parameters for machine design whose aim is to improve the workers' safety. Meanwhile, the three parts of ISO Normative series 11228 [4,5,6] deal with ergonomics in the manual handling of objects. In ergonomics-driven product analysis, ISO 11228-3 is the most frequently applied standard, as it deals with risk evaluation for repetitive movements while using a particular product. Risk evaluation is based on two procedures: first, an initial screening of the checklist proposed by the ISO Standards; second, a detailed evaluation procedure based on International standard ergonomic analysis methods, such as RULA [7], REBA [8], LUBA [9], STRAIN INDEX [10], OCRA [11], OREGE [12], NIOSH [13, 14] and others, with a preference given to OCRA [11,15]. These standards have been used as reference point for developing an ergonomics-driven design/redesign method for processes and plant-layouts. The focus of this paper is on users' postures while using a vending machine. A posture is defined by the human body's joints, positions and movements. Several studies [16,17] cite the need to understand the behaviour of human joints in terms of Range of Motion (ROM) [17,18], neutral (zero) positions

(those which allow the maximum state of comfort) and Comfort Range of Motion (CROM) [19, 20]. In the present study, postural analysis was carried out using a cheap and effective method based on 4D photogrammetry, as suggested in [21,22], which did not affect the efficiency of the job/task. Wide-reaching research of papers dealing with ergonomic/comfort-related problems for vending machines did not provide any results. Generally, machine comfort studies are able to identify design evaluation parameters that help designers, buyers and users to improve products and develop new solutions. For product analysis and optimisation, we used a method [21, 23, 24, 25, 26, 27, 28] based on the following four steps: 1) Direct and indirect (pictures) observations of users and vending machines; 2) information collection about vending machines and the actions involved in retrieving the product and collecting the change; 3) data analysis; 4) comfort-index synthesis. Photogrammetry 4D and the use of Kinovea® software allowed us to acquire the subjects' movements and postures, while digital human models allowed us to simulate the way that customers pick up the product and retrieve their change. These models were also used to simulate the acquired posture during the use of the vending machines, according to the subjects' anthropometric characteristics. CaMAN® software [29] was used to evaluate comfort for subjects using three different vending machines, and to compare the results with those obtained from the comfort questionnaires. All these steps allowed us to perform comfort analyses that were efficient both in terms of design effort and development time. The good results in terms of simulation and postural comfort prediction provided by the use of DELMIA/CaMAN® allowed us to perform a sensitivity analysis, and fine-tune it using numerical/experimental correlation. One of the main aims of the study was to understand which types of perception affected the perceived (dis)comfort and, in particular, to determine the influence of spinal (back and lumbar) discomfort on overall postural comfort. To achieve this, a hypothesis of the 'fusion rule' for (dis)comfort perception in the upper limbs and spine was tested and correlated to 'quantify' the influence of both in contributing to overall postural comfort.

2 Modelling the work environment

The comfort evaluation was focused on three different vending machines (snack, drinks and a coffee machine) located in the University of Salerno, Italy. The machines were measured, and human/machine interfaces and interactive mechanisms (e.g. movable doors or buttons) were analysed. The modelling phase was carried out to simulate the interaction between subjects and machines. CATIA® CAD modelling software was used for the three-dimensional design of the analysed machines (Figure 1).

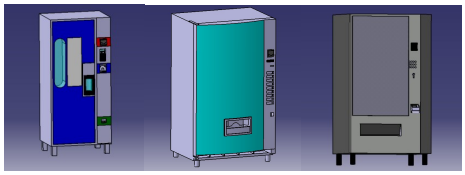


Fig. 1. Virtual vending machines.

3 Methods and Tools

The test protocol was based on the following five steps:

1. Three cameras were positioned to acquire the postures assumed by each student for each vending machine. The cameras were positioned to acquire photos from three points of view: side (Camera C), behind (Camera B), and above (Camera A). The setup for the central vending machine is shown in the Figure 2.

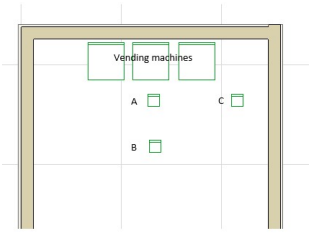


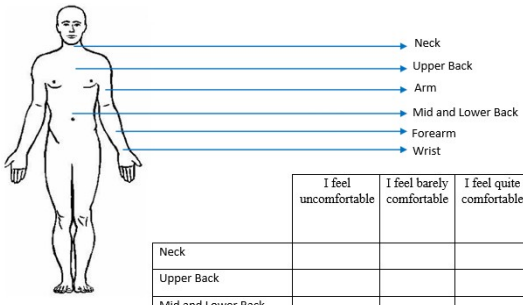
Fig. 2. Setup.

2. Eighteen master's students, all volunteers, participated in the experiment. None had a history of musculo-skeletal disease. All the subjects were informed of the nature of the tests, and written consent was obtained. All the subjects were measured and classified, and their anthropometric measurements are given in Table 1 below.

Table 1. Students measures.

	Age (years)	*Mass (Kg)*	*Height (mm)*	*Sleeve outseam (mm)*	*Armpit height (mm)*	*Waist height (mm)*
Mean	24.22	70.67	1720.56	563.44	1333	1067.38
Std. Deviation	2.21	13.63	92.96	48.74	68.65	55.57
Minimum	21	46	1550	470	1193	981
Maximum	28	93	1870	640	1465	1180

3. Subjects were asked to take a drink or snack from each of the three vending machines. For each task, three photos were taken simultaneously. The subjects were free to assume any posture they wanted.
4. At the end of each task, the perception of (dis)comfort was recorded using a questionnaire. For each region of the upper limbs, perceived (dis)comfort was rated on a 5-point scale. For each action, both overall comfort and spinal (back and lumbar) comfort were assessed. The questionnaire is shown in Figure 3.



	I feel uncomfortable	I feel barely comfortable	I feel quite comfortable	I feel perfectly comfortable	I feel completely comfortable
Neck					
Upper Back					
Mid and Lower Back					
Arm					
Forearm					
Wrist					

Fig. 3. Comfort questionnaire.

5. To acquire the postural angles, the photos for each action made by the participants (inserting coins, collecting change, and picking up the product) for each machine were processed using KINOVEA® software. Analysis was made of the following upper limbs: shoulder flexion, shoulder abduction, elbow flexion, wrist radio-ulnar deviation, and neck frontal flexion.
An example of the postural angle acquisition is shown in the Figure 4. Here, to reach the drink, the student has her right arm and forearm extended, with the left arm in a free position.



Fig. 4. Angular detection for picking up the coffee.

4 Digital Human Modelling

A virtual manikin is a realistic model of the human body designed with a real skeleton and several articular joints. It can be used to represent the kinematic, dynamic and anthropometric characteristics and behaviours of a real person. The present study used DELMIA® (by Dassault Systems) software's DHM manikin, which has all the necessary characteristics in terms of flexibility, scalability and movements of body parts for our purposes here. Detected and measured angles were used in the DELMIA® simulation to replicate real postures as closely as possible by applying small corrections to the 'free' joints. All of the analysed postures (inserting coins, collecting change, and picking up the drink) were processed using this method. This phase was also used to verify that there was a good correlation between the real user in the workplace and the model of the human/workplace interaction analysed by photographic acquisition and photogrammetry (Kinovea®). The under-positioning of photos and simulation screenshots was sufficient for tuning the simulation and obtaining very good correlation results.

5 Simulation

After measuring the angles of the joints involved in all the activities, we carried out the simulation using DELMIA® software for each of the activities described above (Figure 5). The numerical-experimental correlation between the real and virtual working environments revealed very small differences between the real operator's posture and angles acquired by photogrammetric analysis. In some cases, a slight modification of angle values was needed to guarantee that the manikin was able to reach and touch the object/commands. The fact that these changes were very small demonstrated the validity of the photogrammetric acquisition method, previously verified in [21] and [25]. Some angles were not recognizable from the photos due to the relative position of the human and the machine. In these instances, we manually adjusted the manikin's posture to appear as natural as possible. We then performed an analysis of visibility and over-positioning of software images and video.

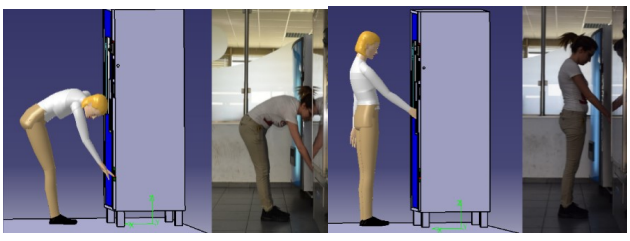


Fig. 5. Virtual interaction between a student and a vending machine.

6 Comfort analysis

The last phase of the analysis involved determining the comfort indexes for each posture assumed by the participants and, due to the cost of simulation, by their digital human models, in order to verify that these postures were more or less 'comfortable'. Based on the angular measurements performed for each tested object, the set of angles helped us to determine the indexes of postural comfort (ICP). Comfort evaluation was performed using CaMAN® [29] - a MatLab application developed by Cappetti and Naddeo. The application takes the angles describing operator posture as input, and provides an index of overall postural comfort (ICP overall) as output, using a value range of 1 to 10.

7 Results

Table 2 gives the comfort values obtained from CaMAN® (C) and the questionnaires (Q) for the three vending machines analysed.

Table 2. Score Comfort, by questionnaire (Q) and by CaMAN®(C), for each vending machines and each participant.

	Comfort snack: picking up the product		Comfort snack: collecting the change		Comfort coffee: picking up the product		Comfort coffee: collecting the change		Comfort drink: picking up the product		Comfort drink: collecting the change	
	Q	C	Q	C	Q	C	Q	C	Q	C	Q	C
Mean	2.89	8.11	3.56	7.08	5.67	7.59	3.89	7.08	4.56	7.34	4.56	6.61
Std. Deviation	1.21	0.37	1.41	0.90	1.61	0.81	1.19	0.90	1.33	0.71	1.67	0.86
Minimum	2	6.90	2	4.94	4	5.66	2	4.94	2	5.35	2	5.41
Maximum	6	8.41	6	8.24	10	8.56	6	8.24	6	8.03	6	7.57

The comfort analysis highlighted a substantial difference between the two methods used to evaluate the comfort indices.
To understand the correlation between acquired data and variables for each vending machine, a large multivariate analysis was performed. SPSS rel.13 statistical analysis software was used to perform these analyses. Spearman correlation coefficients were calculated to determine the strength of the relationships between all the variables.
The correlation analysis highlighted two important results:
1. an absence of correlation between height and total subjective comfort (questionnaire) and between height and total objective comfort (CaMAN® comfort);
2. total subjective comfort in some cases was not correlated with CaMAN® global comfort. However, in other cases, such as collecting change for coffee, the correlation between the two comfort indexes was opposite (Table 3). Our thought is that this contradiction was due to the strong influence of the back and lumbar posture on total subjective comfort. This hypothesis was confirmed by the strong correlation between overall subjective comfort and subjective back and lumbar comfort.

Table 3. An extract of the correlation matrices for collecting change from the coffee vending machine.

	Age (years)	*Mass (Kg)*	*Comfort Questionnaire*	*Comfort neck*	*Comfort back*	*Comfort arm*	*Global CaMAN® Comfort Index*
Age	1	0.399	-0.258	-.544(*)	-0.349	0.054	0.003
Mass	0.399	1	-0.366	-0.078	-0.333	0.157	0.158
Comfort Questionnaire	-0.258	-0.366	1	.529(*)	.772(**)	.625(**)	-.485(*)
Comfort neck	-.544(*)	-0.078	.529(*)	1	.709(**)	.480(*)	-0.035
Comfort back	-0.349	-0.333	.772(**)	.709(**)	1	.699(**)	-0.141

Comfort arm	0.054	0.157	.625(**)	.480(*)	.699(**)	1	-0.34
Comfort lumbar	0.083	0.019	.662(**)	.610(**)	.688(**)	.834(**)	-0.174
Comfort forearm	0.009	0.124	.587(*)	.486(*)	.589(*)	.875(**)	-.555(*)
Comfort wrist	0.009	0.124	.587(*)	.486(*)	.589(*)	.875(**)	-.555(*)
Flexion/extension neck	0.156	0.111	-0.381	0.088	-0.095	-0.16	
Lateral extension neck	0.121	0.269	-.483(*)	-0.171	-0.199	-0.314	.833(**)
Flexion/extension elbow	-0.049	0.29	0.012	0.027	-0.066	0.043	-0.31
Flexion shoulder	-0.022	0.124	-0.344	0.143	0.057	-0.052	.798(**)
Abduction/adduction shoulder	0.082	0.113	-.472(*)	-0.224	-0.196	-0.307	.897(**)
Flexion/extension wrist	0.042	0.225	0.393	0.195	0.182	0.206	-0.041
Radial/ulnar deviation wrist	0.072	0.198	-.575(*)	-0.169	-0.348	-0.401	0.326
Global Caman Comfort Index	0.003	0.158	-.485(*)	-0.035	-0.141	-0.34	1
Height	0.152	.718(**)	-0.253	0.059	-0.171	0.055	0.428

8 Sensitivity analysis for tuning a fusion rule

To understand the influence of perceived lumbar comfort on overall postural comfort, we created a new global comfort index to include the subjective comfort of the back and lumbar. The new global comfort index is defined by the following formula (1):

$$Global\ Comfort\ Index = A * Index\ (Caman) + B * Index\ (Questionnaire\ Back\ \&\ Lumbar) \quad (1)$$

In which (2):

$$A + B = 1 \quad (2)$$

The subjective back and lumbar index was obtained by taking the arithmetic average between these two subjective indexes. The overall comfort index was calculated for each subject as the combination of two perceptions, as per Table 4 below:

Table 4. Combination of A and B.

A	*B*
0.2	0.8
0.4	0.6
0.6	0.4
0.8	0.2

A new statistical analysis was performed to verify a possible correlation between the new calculated index and the global subjective comfort index.

This new analysis revealed some extremely interesting results. For the drinks and coffee vending machines, as the subjective back and lumbar comfort (B) increased, the new comfort index showed a stronger correlation with the initial subjective comfort index. This result indicates that subjects felt discomfort in the back and lumbar area, which strongly influenced their total subjective comfort (Figure 6).

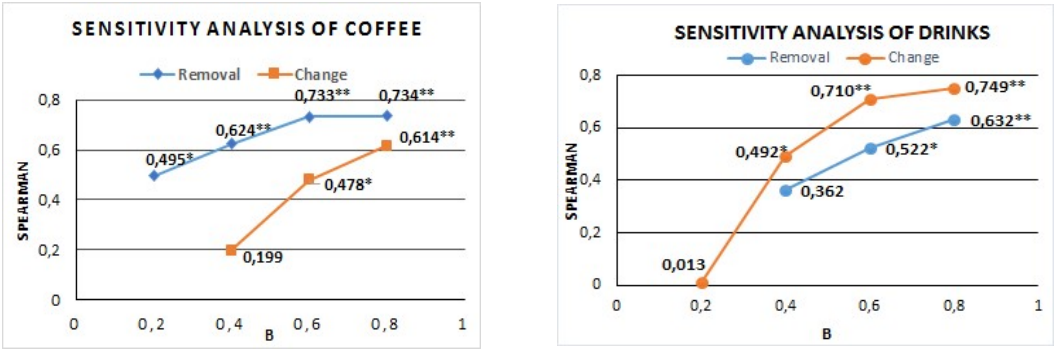


Fig. 6. Sensitivity analysis for the coffee and drinks machines.

However, results differed for the snack vending machine. For each value of B, there was no correlation between the new index and the global subjective index. This lack of correlation was probably due to the subjective discomfort of students also relating to the lower limbs, as the removal of snacks entailed a bending of the legs. To improve the general posture, the geometry of the virtual vending machine was altered. In particular, the height of the 'change box' of the coffee vending machine was raised (Figure 7). The altered vending machine model was used to perform new simulations using DELMIA® and to acquire new virtual postures. Two new configurations were tested, with change box heights of 515mm and a 615 mm. The height of the original was 415mm.



Fig. 7. Three steps of simulation with change-box located in higher positions.

Simulation outputs were elaborated using CaMAN® software and the relative index of comfort is given in Table 5 below.

Table 5. CaMAN comfort index for three different change-box heights.

High change box	*Global CaMAN® Index*
415 mm	6.55
515 mm	6.88
615 mm	6.91

The improvement of the comfort index is evident. By increasing the height of the change box, both back flexion and arm flexion decreased. It was only possible to perform a simulation correlation thanks to the alignment between simulated and real processes.

8 Conclusion

Our analysis of the vending machines used an experimental method based on photo/video recording and photogrammetry, coupled with the use of DHM commercial software and comfort rating software developed by the authors. The importance of posture and task analysis was highlighted by centering this method on pictures captured by cameras and video, and by photogrammetry and image processing using Kinovea software. All these acquisition methods are very cheap and easy to use. The precision of the acquisition method, as well

as the fact that by not using complicated, expensive acquisition methods we were still able to reach a very good level of numerical/experimental correlation (angle errors less than 5% in the first simulation run) are important results revealed by this paper. The analysis tools used were CATIA® for modelling, DELMIA® for simulation, CaMAN® for the evaluation of non-subjective comfort, and a questionnaire for the evaluation of subjective comfort. The results obtained by the two analysis (questionnaire and CaMAN) demonstrate that the CaMAN® comfort index is not sufficient for the evaluation of comfort. The problem is that CaMAN® does not consider back and lumbar comfort, which are accounted for in the questionnaire. Via a sensitivity analysis, it was possible to weigh the effect of perceived spinal discomfort on overall postural comfort. Finally, a new comfort index was developed. This new global index is the combination of the CaMAN® comfort index and spinal comfort information acquired from the questionnaire. The new global comfort index was utilized to suggest an easy solution for re-designing the coffee vending machine (the machine with the highest level of discomfort) by changing the height of the change box. The solution was validated in a completely virtual environment, and the comfort index was calculated virtually using CaMAN® software to verify the impact of the improvements on overall comfort.

References

1. UNI EN ISO 14738:2009, Safety of machinery – anthropometric requirements for the design of workstations at machinery.
2. ISO 11226:2000, Ergonomics - Evaluation of static working postures.
3. UNI EN 1005-3:2009, Safety of machinery – Human physical performance – part3
4. ISO 11228-1, Ergonomics - Manual handling - 1: Lifting and carrying.
5. ISO 11228-2, Ergonomics - Manual handling - 2: Pushing and pulling.
6. ISO 11228-3, Ergonomics - Manual handling - 3: Handling of low loads at high frequency
7. McAtamney, L., Corlett, E.N., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Applied Ergonomics, 24(2).
8. Hignett, S., McAtamney, L., 2000. Rapid Entire Body Assessment (REBA). Applied Ergonomics. 31, Issue 2, 201-205.
9. Kee, D., Karwowski, W., 2001. LUBA: an assessment technique for postural loading on the upper body based on joint motion discomfort and maximum holding time. Applied Ergonomics. 32.
10. Moore, J.S., Garg, A., 1995. The strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am Ind Hyg Assoc J. 56(5), 443-58.
11. Occhipinti, E., Colombini, D., 1996. Proposta di un indice sintetico per la valutazione dell'esposizione a movimenti ripetitivi degli arti superiori (Ocra index). Medicina del Lavoro. 87, 526-548.
12. Valentin, L., Gerling, A., Aptel, M., 2004. Validité opérationnelle d'OREGE (Outil de Repérage et d'Evaluation des Gestes). Laboratoire de Biomécanique et d'Ergonomie: Département Homme au Travail, Université Henri Poincaré Nancy(FR).
13. Konz, S., 1982. NIOSH lifting guidelines. American Industrial Hygiene Association Journal. 43 (12), 931-933. doi: 10.1080/152986682914108.
14. Waters, T.R., Putz-Anderson, V., Garg, A., Fine, L.J. 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics. 36(7), 749-776. doi:10.1080/00140139308967940.
15. D'Oria, C., Naddeo, A., Cappetti, N., Pappalardo, M., 2010. Postural analysis in HMI design: an extension of OCRA standard to evaluate discomfort level. Journal of Achievements in Materials and Manufacturing Engineering. 39, 60-70. ISSN 1734-8412.
16. Thompson Jon, C., 2001. Netter's Concise Atlas of Orthopaedic Anatomy. Publisher: Saunders; 1st edition.
17. Apostolico, A., Cappetti, N., D'Oria, C., Naddeo, A., Sestri, M., 2013. Postural Comfort Evaluation: Experimental Identification of Range of Rest Posture for human articular joints. Int J Interact Des Manuf. 1-14. doi: 10.1007/s12008-013-0186-z.
18. Naddeo, A., Apicella, M., Galluzzi, D., 2015. Comfort-¬Driven Design of Car Interiors: A Method to Trace IsoComfort Surfaces for Positioning the Dashboard Commands. SAE Technical Papers. DOI: 10.4271/2015-01-1394.
19. Fagarasanu, M., Kumar, S., Narayan, Y., 2004. Measurement of angular wrist neutral zone and forearm muscle activity. Clinical Biomechanics. 19, 671-677.

20. Christensen, H.W., Nilsson, N., 1999. The ability to Reproduce the Neutral Zero Position of the Head. Journal of Manipulative and Physiological Therapeutics. 22(1), 26-28.
21. Naddeo, A., Barba, S., Ferrero, Francia I.F., 2013. Propuesta de un nuevo método no invasivo para el análisis postural con aplicaciones de fotogrametría 4d. XI Congreso Ibero-Americano de Ingegnieria Mecanica (CIBIM2013), 11-14, La Plata, Argentina.
22. Naddeo, A., Cappetti, N., Ippolito, O., 2014. Dashboard reachability and usability tests: A cheap and effective method for drivers' comfort rating. SAE Technical Papers. DOI: 10.4271/2014-01-0455.
23. Vallone, M., Naddeo, A., Cappetti, N., Califano, R., 2015. Comfort Driven Redesign Methods: An Application to Mattresses Production Systems. The Open Mechanical Engineering Journal. 9, 492-507.
24. Di Pardo, M., Riccio, A., Sessa, F., Naddeo, A., Talamo, L., 2008. Methodology development for ergonomic analysis of work-cells in virtual environment. SAE Technical Papers. doi: 10.4271/2008-01-1481.
25. Naddeo, A., Cappetti, N., Califano, R., Vallone, M., 2013. Manual assembly workstation redesign based on a new quantitative method for postural comfort evaluation. Applied Mechanics and Materials. 459, 368-379.
26. Naddeo, A., Vallone, M., Cappetti, N., Califano, R., Di Napoli, F., 2017. Ergonomic-driven redesign of existing work cells: The “Oerlikon friction system” case. DOI:10.1007/978-3-319-45781-9_120.
27. Bassi, C., Naddeo, F., Pulignano, C., Senatore, B., Tarantino, D., 2016. How to analyze and improve a super-market cashier’s work cycle. International Journal of Applied Engineering Research. 11(20), 10358-10366.
28. Califano, R., Cozzitorto, P., Delmastro, M., de Vito, C., Sellitto, G., Vallone, M., 2016. Virtual ergonomic analysis and redesign methods: An application to lunch payment station at university of Salerno. International Journal of Applied Engineering Research. 11(10), 7114-7118.
29. Naddeo, A., Cappetti, N., D'Oria, C., 2015. Proposal of a New Quantitative Method for Postural Comfort Evaluation. International Journal of Industrial Ergonomics. 48, 25-35.

Comfort in clothing – Determining the critical factors

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Abstract Comfort is often considered in relation to a single factor causing discomfort, be it environmental, physical, physiological or perceptual. But rarely does one factor actually fully influence how comfortable an individual feels. Even within the clothing system numerous factors; fit, material, design, etc, can affect an individual's comfort perception. Currently the understanding of the impact of individual fabric properties on wear comfort is limited. This paper will consider the various interactions that occur within the clothing system that contribute to wearer comfort. The dynamic interaction of the clothing material with large areas of the skin surface changes the perception of wetness felt by the user. To understand how sensation of wetness perception is influenced by textile parameters, a number of textile samples with different thickness, fiber type, and surface texture, were tested. They were evaluated in Static (upper back) and Dynamic (inner forearm) contact with the skin, under both low and high application pressure. Wetness perception and stickiness sensation (tactile cue) were measured with ordinal perception scales and local skin temperature (thermal cue) by thermocouples. Under Static contact, wetness perception in fabrics containing the same amount of moisture per volume was positively related to fabric thickness ($r^2 = 0.87$). Under Dynamic, higher wetness perception was associated with greater stickiness sensation ($r^2 = 0.68$), occurring from differences in fabric surface texture. Under Dynamic fabric thickness did not correlate with wetness perception directly, however when combined with stickiness sensation it provided a strong predictive power ($r^2 = 0.86$). In both Static and Dynamic conditions, greater wetness perception ($p < 0.05$) was observed in High compared with Low pressure condition; interestingly when matching for thickness, fiber type (cotton, polyester) did not affect wetness perception ($p > 0.05$). Fabric thickness and surface texture properties trigger thermal and tactile inputs, respectively, underpinning skin wetness perception in static and dynamic clothing applications. Additionally, fabric weight and clothing fit could cause changes in fabric-to-skin pressure, which represents another tactile sensory modality contributing to skin wetness perception. Consideration of these factors could aid the design of clothing and fabric products, particularly office and vehicle seating, towards optimising comfort.

Keywords: Clothing, Comfort, wetness perception.

1. Introduction

Comfort is often considered in relation to a single factor causing discomfort, be it environmental, physical, physiological or perceptual. But rarely does one factor actually fully influence how comfortable an individual feels. The clothing system can be considered to be a combination of components between which there are interactions which build to a final overall performance, from the basic fibre used to make the fabric to the end use of the product. Currently the understanding of the impact of individual textile and fabric parameters on wear perception is limited. This paper will consider the various interactions that occur within the clothing system that contribute to wearer comfort.

Within the clothing system numerous factors; fit, material, design, etc, can affect an individual's comfort perception. Clothing is not a passive cover for the skin, it interacts with the body changing the level of thermoregulation required accordingly. This interaction and effect varying with physical properties of the clothing (1). The properties of textile fabrics and garment embrace both mechanical and heat moisture/transfer properties, the complex effect of these properties characterise the comfort of the fabric consistency with reference format (2). This highlights the need for multiple factors to be considered during the evaluation of clothing.

Manufacturers can evaluate the physical properties of fabrics and materials through a number of test methods. These give a comparison between materials but do not link easily through into measures of wearer comfort. A particular factor influencing wearer comfort is skin wettedness, the sensation of moisture on the skins surface leading to discomfort (3,4). During activity, the production of sweat causes moisture build-up at the skin surface - clothing interface. This results in a perception of wetness leading to thermal and sensorial discomfort. In absence of skin hygro-receptors (5), wetness perception occurs through the central integration of thermal and tactile stimulations. The dynamic interaction of the clothing material with large areas of the skin surface changes the perception of wetness felt by the user.

This recent work aims to link the physical properties of fabrics to perception felt by the user both under static and dynamic conditions.

2. Method

To understand the textile parameters that contribute to the sensation of wetness perception, a number of textile samples with different thickness, fiber type, and surface texture, were tested. They were evaluated in Static (upper back) and Dynamic (inner forearm) contact with the skin, under both low and high application pressure. Wetness perception and stickiness sensation (tactile cue) were measured with ordinal perception scales and local skin temperature (thermal cue) by thermocouples.

Study 1- static interaction

Twenty-four knitted fabric samples (100 x 100 mm) selected for different structure, thickness and fibre type were evaluated.

Twelve 7 male / 5 female participants (23.4 yrs. ± 2.4), (Western European origin), participated in this study.

Fabrics were assessed in four separated trials which differed in the amount of water applied: 100REL – 100% absorption capacity (µL)/fabric volume (mm^3); 50REL - 50% absorption capacity (µL)/fabric volume (mm^3); ABS – same absolute water content 2400 µL, DRY – control. Fabrics were assessed by using a quantitative sensory test, which consisted of placing, 24 fabrics with different wetness levels on the upper back of each participant. Participants reported their local wetness perception, thermal sensation and thermal comfort on ordinal scales. The trials were completed in a counter balanced order and all experiments were performed in a climate controlled room, air temperature 25°C, relative humidity 50% and air velocity < 0.05 m/s.

In the experimental trials, participants entered the controlled climatic room and lied prone on a bench wearing underwear only. After a stabilization period in the room, each experimental fabric was applied on the participants' upper back for a period of 20 seconds. At the end of the 20 seconds stimulation period, participants were encouraged to verbally report their wetness perception, thermal sensation and thermal comfort for the stimulated area, using the three interval scales Fig 1. Additionally, since the continuous application of wet stimuli may decreases one's sensitivity, 1 min of rest, before the subsequent fabric application also allowed the recovery of the sensory system. The same protocol was repeated for each of the 24 fabrics.

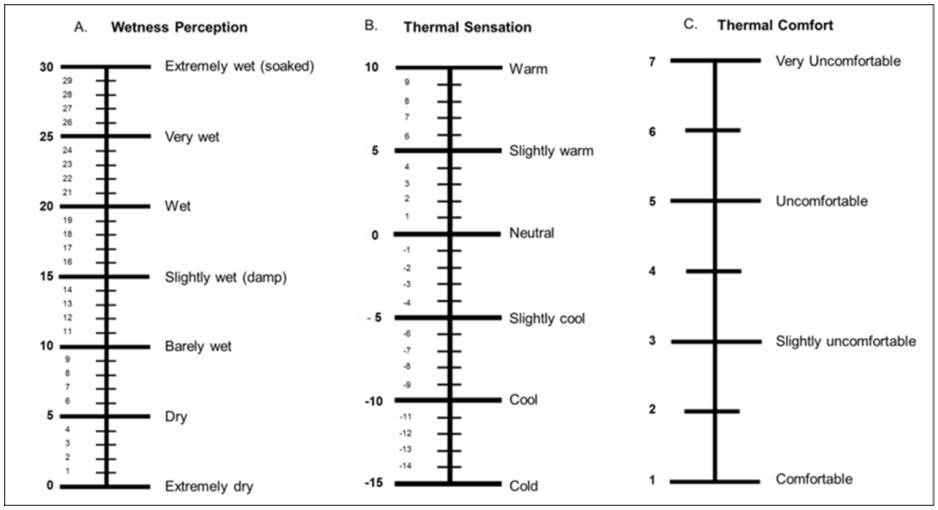


Fig. 1. Subjective scales – Study 1

Study 2 – dynamic interaction

Eight knitted fabrics (120 x 100 mm) selected for different structure, fibre type, surface texture properties, thickness, and treatments were included in this experiment.

Sixteen male (8) and female (8) (yrs. 22.4 ± 2.5), participants, of (Western European & North American origin), participated in this study. They were exposed to 8 fabrics under four experimental conditions DRY – control, WET - 50% absorption capacity (µL)/fabric volume (mm^3), WET LOW-P (Low pressure application - 127 Pa) and WET HI-P (High pressure application - 236 Pa).

Each fabric sample was placed in a custom made linear motion rig. The sample was connected to a motor drive on one side and to a counterweight on the other side. The fabric sample could run over two free running rollers, creating a horizontal area of stimulation. Under this area, the right forearm of each participant was placed such that the fabric touched the ventral forearm. The latter's setting was adjustable vertically to ensure equal pressure/ contact area in different size arms. The ventral forearm presents the same sensitivity to cold stimuli as the upper back (6), therefore the results can be compared with the static application (study 1). Participants were screened from the experimental textile samples before, during and after the application process, therefore any visual influence on the perceptual responses was prevented.

Each fabric sample was pulled bi-directionally across the skin at a velocity of 0.02 $m.s^{-1}$. Two fixed levels of pressure were applied, 127 Pa (LOW-P) and 236 Pa (HI-P) and the order of this two pressure conditions was counterbalanced. The the range of travel of each fabric was of 5 cm per stroke, with a total of 8 strokes per fabric. At the end of the exposure, participants were encouraged to verbally report their wetness perception, texture – roughness/smoothness, stickiness and pleasantness sensations for the stimulated area, using the four interval scales, Fig 2.

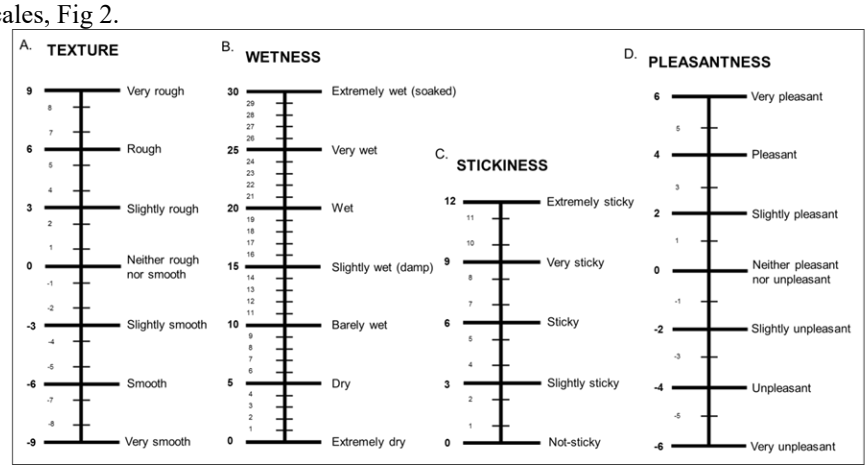


Fig. 2. Subjective scales – study 2

3. Results

The static study showed that wetness perception in fabrics containing the same amount of moisture per volume was positively related to fabric thickness ($r^2 = 0.87$), Fig 3.

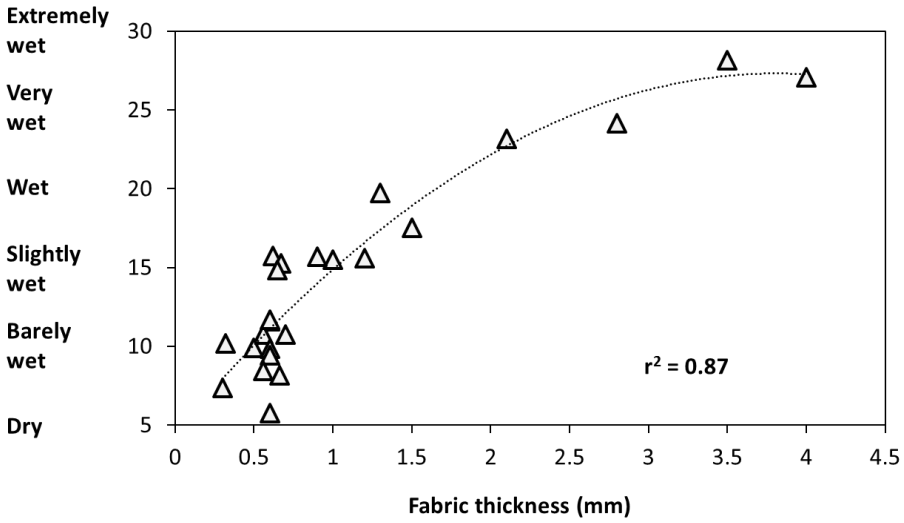


Fig. 3. Relationship between wetness perception and fabric thickness.

However, Under Dynamic conditions, higher wetness perception was associated with greater stickiness sensation ($r^2 = 0.68$), occurring from differences in fabric surface texture; additionally, fabric thickness did not correlate with wetness perception directly, however when combined with stickiness sensation it provided a strong predictive power ($r^2 = 0.86$) Fig 4.

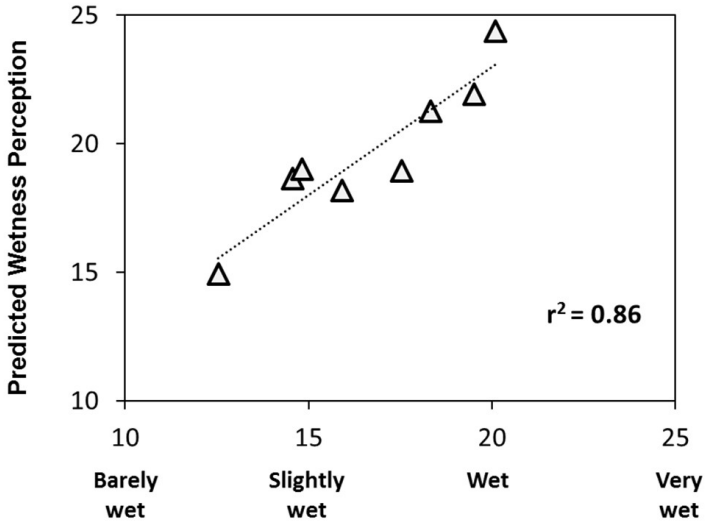


Fig. 4. Relationship between wetness perception and predicted wetness perception (stickiness + thickness)

In both Static and Dynamic conditions, greater wetness perception responses ($p < 0.05$) were observed in High pressure application compared with Low pressure application; interestingly when matching for thickness, fiber type (cotton, polyester) did not affect wetness perception ($p > 0.05$).

In the static condition, the strong impact of wetness perception on comfort was indicated by a linear positive relation between thermal comfort and wetness perception ($r^2 = 0.86$), Fig 5.

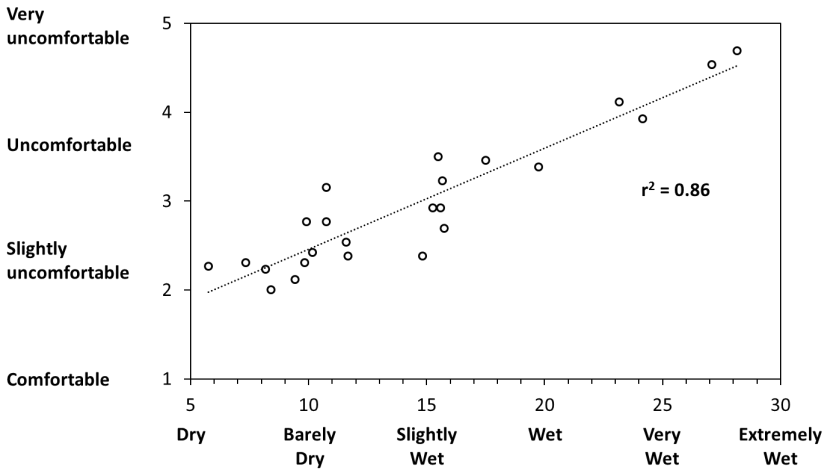


Fig. 5. Relationship between thermal comfort and wetness perception.

4. Conclusions

Fabric thickness and surface texture properties trigger thermal and tactile inputs, respectively, underpinning skin wetness perception in static and dynamic clothing applications. Which leads to perceptions of thermal comfort are also driven strongly by the moisture trapped in the wearers clothing Additionally, fabric weight and clothing fit could cause changes in fabric-to-skin pressure, which represents another tactile sensory modality contributing to skin wetness perception. It is important to note that single material factors, thickness, texture, etc, within the clothing system can have an interactive effect when combined into the finished product. This indicates that simple material testing and evaluation is not enough to ensure wearer comfort.

Consideration of multifactorial interactions could aid the design of clothing and fabric products, particularly between fabric systems, i.e., clothing and office or vehicle seating, towards optimising comfort.

5. References

1. Gavin TP. Clothing and Thermoregulation During Exercise. Sport Med [Internet]. 2003;33(13):941–7. Available from: http://dx.doi.org/10.2165/00007256-200333130-00001
2. Hes L. Recent developments in the field of user friendly testing of mechanical and comfort properties of textile fabrics and garments. In: World congress of the Textile Institute, Cario. 2002.
3. Fukazawa T, Havenith G. Differences in comfort perception in relation to local and whole body skin wettedness. Eur J Appl Physiol [Internet]. 2009;106(1):15–24. Available from: http://dx.doi.org/10.1007/s00421-009-0983-z
4. Filingeri D, Fournet D, Hodder S, Havenith G. Why wet feels wet? A neurophysiological model of human cutaneous wetness sensitivity. J Neurophysiol. American Physiological Society; 2014;112(6):1457–69.
5. Clark, R., Edholm O. Man and His Thermal Environment. London: E. Arnold.; 1985.
6. Parsons KC. Human Thermal Environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance. Vol. 2nd. London: Taylor and Francis; 2003.

Characterisation of PCM textiles by means of heat release tester WATson and subject trials

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Abstract: In the 1980ies, NASA developed clothing with incorporated phase change materials (PCM) for use in space. Nowadays, such textiles are used in huge variety of clothing systems here on earth, too. Manufacturers promise fast absorbance and release of heat respectively, resulting in high thermal comfort. On the other hand, there is no accepted standard to test thermal properties of textiles incorporating PCM (phase change materials). European standardization process for testing of fabrics is still ongoing. Several manufactured textiles incorporating PCM as well as textiles, which were especially coated in the laboratory, were tested. Heat uptake of pre-acclimatized PCM textiles was characterised by means of the heat release tester WATson. Trials were performed in a climatic chamber at T_a=10°C. Pre-acclimatized samples (T=10°C) were put a heat release tester (T_{WATson}=32°C) and heating power to maintain set skin temperature was measured. Furthermore, subject trials were performed to look on human perception of thermal properties of the same textiles. Four subjects wore different arm sleeves and judged temperature differences. Trials were performed in a climatic chamber at T_a=23°C. In each trial a pair of pre-acclimatized samples was put on right and left arm, respectively, for ten minutes. Subjected feedback was given on temperature perception and perceived temperature difference between a pair of samples. Additionally, skin temperature was measured. WATson test design is able to show differences in heat storage between PCM and control sample as well as between different PCM samples. Furthermore, results show that the amount of stored heat is related to the amount of incorporated PCM and the effect is just a temporary one. The higher the amount of PCM in the textile, the bigger the effect. These results are proven by subject trials. Depending on the amount of incorporated PCM subjects could perceive differences between samples with and without PCM. This effect was time dependent and lasted less than ten minutes. By means of the heat release tester and subject trials, it could be proven, that PCM textiles can cool/heat the skin just for short durations. Furthermore, the thicker the PCM coating the higher the cooling, but the less the textile appearance. It can be concluded, that PCM is not appropriate for lightweight clothing worn close to skin (1st and 2nd layer).

Keywords: PCM, heat loss, heat release tester WATson, thermal comfort

1 Introduction

In the 1980ies, NASA developed clothing with incorporated phase change materials (PCM) for use in space [1]. Nowadays, such textiles are used in huge variety of clothing systems here on earth, too. Furthermore, there is a growing number of further applications, e.g., medical and technical textiles [2]. Manufacturers promise fast absorbance and release of heat respectively, resulting in high thermal comfort. On the other hand, there is no accepted standard to test thermal properties of textiles incorporating PCM (phase change materials). European standardization process for testing of these fabrics is still ongoing [3].

2 Materials & Methods

Several manufactured textiles incorporating PCM as well as textiles, which were especially coated in the laboratory, were tested.
The sample selection from the market contained different kinds of fabrics – non-woven, woven and knitted fabrics -, different kinds of fibres – e.g. cotton and polyester – as well as different kinds of PCM incorporation – coating and fibre incorporation (table 1). Furthermore, the melting point of the used PCM differed slightly. The samples were tested in pairs of treated and untreated fabrics.

Table 1. Sample description of non-woven (N), woven (W) and knitted fabrics (K).

Sample No.	*Category*	*Fibre content*	*Description of PCM*
N1	non-woven	100% PES	coating with acrylat binder melting point 27-33°C
N2	non-woven	100% PES	no PCM
K1	knitted fabric	47.5% CO, 47.5% MD, 5% EL	MIC coating with silicon binder, melting point 26-30°C
K2	knitted fabric	47.5% CO, 47.5% MD, 5% EL	no PCM
K3	knitted fabric	100% PES	coating with acrylat binder melting point 26-30°C
K4	knitted fabric	100% PES	no PCM
W1	woven	70% CO, 30% CV with PCM	fibre incorporated PCM melting point 26-33°C
W2	woven	100% CO	no PCM

To have a closer look on the influence of the amount of PCM in the coating on the heat storage capacity of the textile, a non-woven was coated in the laboratory with different amounts of PCM (table 2). The coating contained encapsulated PCM. The amount of pure PCM in the coating was 50%. In addition, a thickener was used for better coating properties and to securely achieve coating thicknesses up to 1 mm. The usage of this thickener was minimal (less than 1% of coating mass).

Table 2. Sample description of self-coated non-woven fabrics (S).

Sample no.	*Thickness [mm]*	*Sample weight [g]*	*Description of PCM*
S1	0.258	5.10	control without PCM
S2	0.556	14.51	self-coated PCM
S3	0.606	14.99	self-coated PCM
S4	1.023	36.03	self-coated PCM

To characterise heat storage capacity of the samples the heat release tester WATson was used. It is a 20x20 cm hot plate with low heat capacity and electric heating system. The set temperature is controlled electronically and heat loss is measured (f=1 Hz).
Measurements were performed in a climatic chamber at T_a=10°C and RH_a=50% rh. Samples were pre-acclimatised for 24 hours inside the chamber. The set temperature was T_s=32°C. Measurements started with putting on the sample and lasted 30 minutes. Within this duration, all samples reached steady state of heat loss. Average heating power of every minute was calculated.

To determine influence of PCM textiles on human thermoregulation and temperature perception wear trials with subjects were performed. Four male subjects (27.5±5 years, 180±5 cm, BMI 24.4±0.5) performed a standardised activity protocol in a climatic chamber (temperature T_a=23°C, relative humidity RH_a=50% rh). Subjects were sitting in a car chair performing a test in a driving simulator wearing standard clothing (pants, socks, short sleeved short and trousers, shoes).
Trial duration was 190 minutes. At different points of time(t=30 min, 60 min, 90 min, 120 min, 150 min and 180 min) pairs of samples were put on the right and left forearm for ten minutes, respectively. Samples were

chosen by results of the heat release tester and included pairs of PCM textiles and references (table 3). Pairs were tested in randomized order; usage of right/left arm for a part of a pair was decided randomized, too. Every subject performed three of these trials, resulting in two test with each pair. Samples were pre-acclimatized for at least two hours.

Table 3. Description of sample pairs for wear trials.

Pair	*Description*	
N1-N2	pair of non-woven	PCM-non
K1-K2	pair of knitted fabrics	PCM-non
K3-K4	pair of knitted fabrics	PCM-non
K3-K3	"blind" pair with PCM	PCM-PCM
K1-K3	pair of knitted fabrics both with PCM	PCM-PCM
K3-N1	pair of knitted fabric and non-woven both wit PCM	PCM-PCM
S1-S4	pair of self-coated non-woven	PCM-non
S1-S3	pair of self-coated non-woven	PCM-non
S3-S4	pair of self-coated non-woven	PCM-PCM

Temperature at the forearm was measured by means of MSR 145 data loggers and associated sensors. Change of temperature was calculated and analysed. Additionally subjects rated perceived temperature using a modified Bedford scale[4] and perceived temperature difference on a four-point scale (table 4).

Table 4. Scales to rate perceived temperature (left; modified Bedford scale) and temperature difference (right).

Modified Bedford scale		*Perceived temperature difference*	
7	much too warm	3	distinct
6	too warm	2	small
5	comfortable warm	1	minimal
4	neutral	0	non
3	comfortable cold		
2	too cold		
1	much too cold		

Tests were performed under double-blind conditions. Additionally, subjects wore a sleep mask during the 10 minutes of the test. Test design followed ethical rules and written informed consent was obtained from all participants.

3 Results & Discussion

To maintain set temperature of the heat release tester WATson (T_{WATson}=32°C) electrical heating power $P_{heating}$ increases after putting on the sample (T_{sample}=10°C; figure 1). During first minutes, this heat loss is mainly to heat up the sample and therefore related to its heat capacity. After a few minutes heating up the sample ends, heat loss decreases and becomes more related to heat loss to the ambience. The slower the decrease of heating power, the higher the heat capacity/heat storage and the better efficiency of the PCM.
Within the groups of knitted fabrics (K; figure 1 - right), non-wovens (N) and self-coated non-wovens (S; figure 1 – left) differences in heat loss between samples with and without PCM could be found. There are no differences within the group of woven fabrics (W).

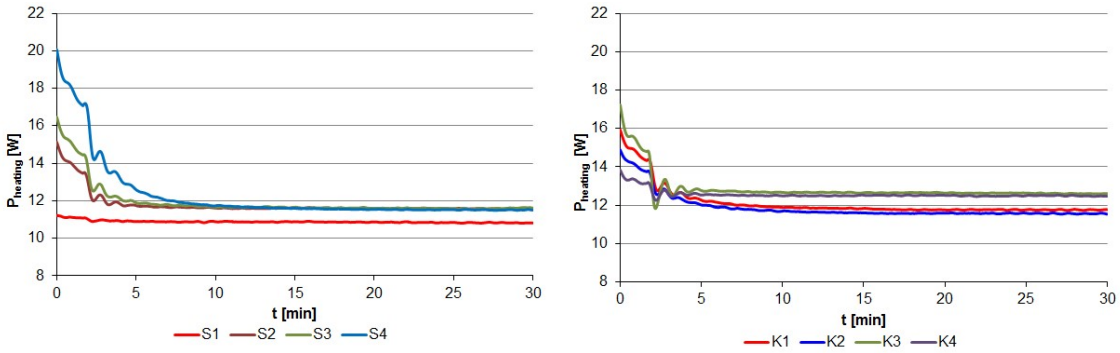


Fig. 1. Course of time of heating power $P_{heating}$ of self-coated non-wovens (S; right) and knitted fabrics (K; left).

Self-coated non-woven fabrics with PCM (S2; S3; S4) show higher heat loss in comparison to sample S1 (non-coated reference; figure 1 - left). Furthermore, there are differences between samples with PCM, e.g. sample S4 (1.02 mm) shows a higher cooling for a longer duration than sample S2 (0.56 mm). The thicker the sample/the higher the amount of PCM, the higher the heating power and the longer the cooling.
All knitted fabrics show high heating power during first seconds and a significant decrease ($\Delta P_{heating}$>2 W) during first ten minutes of the test (figure 1 – right). This finding is for samples with and without PCM, but within sample pairs K1 vs. K2 and K3 vs. K4 differences due to PCM can be found, too. Samples K1 and K3 with PCM show higher heating power and longer cooling duration in comparison to their references K2 and K4, respectively.
It can be concluded, that differences between fabrics with and without PCM could be found by means of the heat release tester WATson. The measured effect is time dependent and does not last longer than ten minutes. Differences between samples with altered amount of PCM can be shown, too, although even with very high amounts of PCM the effect of elevated heating power does not exceed ten minutes.

In the wear trials putting on the sample onto the forearm leads to a decrease in skin temperature (figure 2). Like with the heat release tester, this decrease is related to heat up the sample (T_{sample}=23°C) to the level of skin temperature (T_{sk}>30°C) during the first minutes of the test. After a short time, skin temperature rises due to thermal insulation of the samples. This leads with all samples to higher skin temperatures at the end of the test in comparison before putting on the sample.

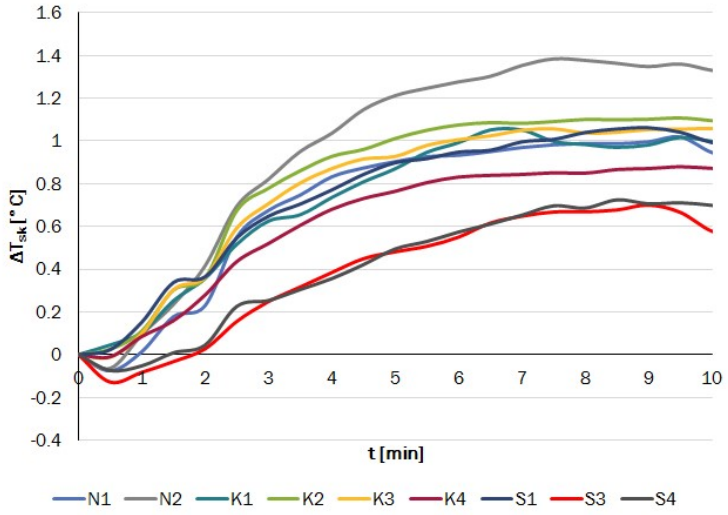


Fig. 2. Change of skin temperature after putting on a sample.

Before putting on the samples subjects perceive their skin temperature of the forearm as neutral (figure 3; T_{subj}(t=-1 min)=3.8 to 3.9). After putting on (t=0 min) perception of skin temperature decreases with samples

N1, K3, S3 and S4, while it increases right away with samples N2, K1, K2, K4 and S1. Best and longest cooling is achieved by samples S3 and S4. Subjective temperature of sample S3 decreases from T_{subj}(t=-1 min)=3.8 to T_{subj}(t=0 min)=2.8 and reaches start values after eight minutes. Sample S4 starts with T_{subj}(t=-1min)=3.9 decreases to T_{subj}(t=1min)=2.5 and is after ten minutes still perceived as cooler (T_{subj}(t=10 min)=3.5).

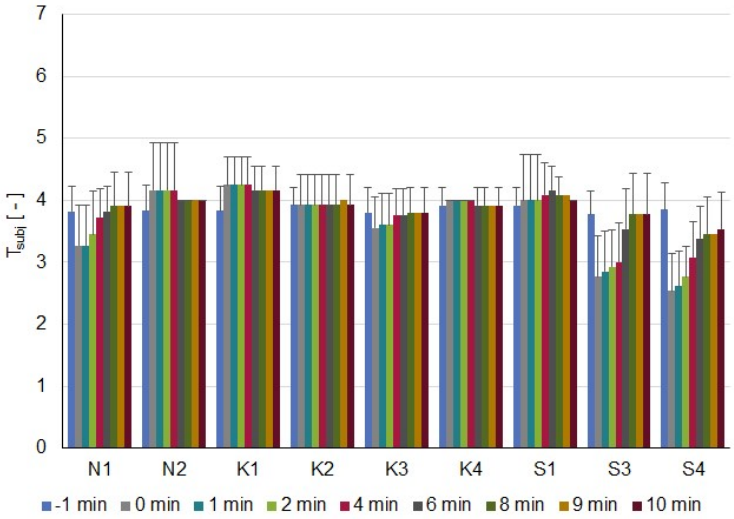


Fig. 3. Subjective temperature T_{subj} (Bedford scale; 1 much too cold, 4 neutral, 7 much too warm).

In direct comparison of pairs, there are perceivable differences ΔT_{subj} between N1-N2, K3-K4, S3-S1, S4-S1, S4-S3 and N1-K1 (figure 4). Taking into account standard deviation, just the pair S4-S1 shows significant differences (difference T_{subj}>2.5). Furthermore, perceived differences decline very fast and after about six minutes there are just minimal once. With sample pairs K1-K2, K3-K3 and K4-K2 subjects do not perceive temperature differences.

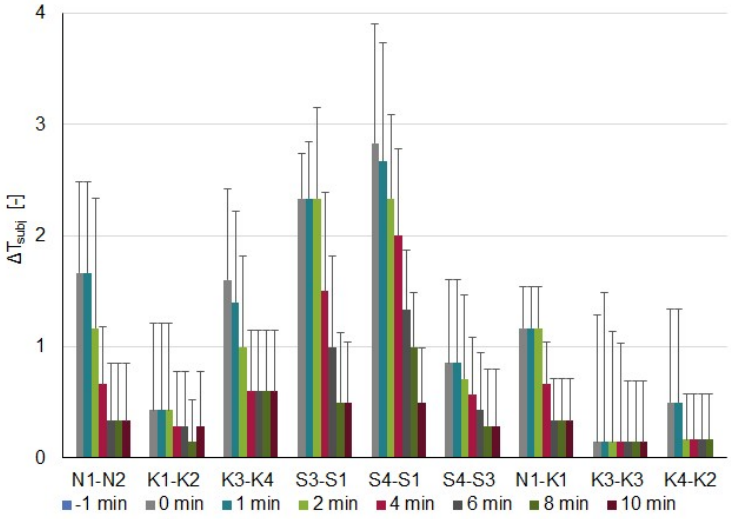


Fig. 4. Paired subjective temperature difference ΔT_{subj} (first named sample perceived as cooler; 0 non, 2 small, 3 distinct).

In conclusion, cooling effects by PCM can be shown by the used protocol of the wear trials. Subjects could perceive differences between PCM samples and their reference, but perceived cooling is short lasting. Just sample S4 with maximum PCM load and stiff non-textile properties can give cooling for approximately 10 minutes. Furthermore, decrease of skin temperature is at maximum 0.13°C and of short duration.

4 Conclusion

In overall conclusion differences between PCM samples and their control could be shown by means of heat release tester WATson and wear trials, although these differences are small and of short duration.
WATson test design is able to show differences in heat storage between PCM and control sample as well as between different PCM samples. Furthermore, results show that the amount of stored heat is related to the amount of incorporated PCM and the effect is just a temporary one. The higher the amount of PCM in the textile, the bigger the effect. These results are proven by subject trials. Depending on the amount of incorporated PCM subjects could perceive differences between samples with and without PCM. This effect was time dependent and lasted less than ten minutes. By means of the heat release tester and subject trials, it could be proven, that PCM textiles can cool/heat the skin for short durations. Furthermore, the thicker the PCM coating the higher the cooling, but the less the textile appearance.
With physical testing by e.g. DSC (differential scanning calorimetry) or POM (polarized optical microscopy) heat storage properties of PCM can be shown [5]. Furthermore there are several publications showing positive effects of PCM in textiles on clothing comfort [6]. On the other hand, clothing worn next to the skin should be light weight, e.g. a sports shirt weighs about 150 g. Therefore, the amount of PCM and its heat storage capacity is limited. Due to physics, the effect of a sports shirt with incorporated PCM on thermoregulation is limited, too, what is in consistence with our findings. It can be concluded, that PCM is not appropriate for lightweight clothing worn close to skin (1st and 2nd layer).

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References

1. Nelson G. Microencapsulation in textile finishing. Rev. Prog. Color, 2001, 31 (1), 57-64.
2. Ghosh, S. K. Functional Coatings by Polymer Microencapsulation. WILEY-VCH Weinheim, 2006.
3. ISO/TC 248/SC /WG31 working draft Textiles and textile products - Smart textiles - Definitions, categorisation, applications and standardization needs. 2010.
4. Ellis, A., Bertolini, A. and Thompson, L. The Thermal Comfort of bicycle helmets. In The Engineering of sport, Blackwell Sciences, London, 2000, pp. 75-81.
5. Onofrei, E., Maria Rocha, A. and Catarino, A. Investigating the effect of moisture on the thermal comfort properties of functional elastic fabrics. Journal of Industrial Textiles 2012, 42, 1, 34-51.
6. Mondal, S. Phase change materials for smart textiles - An overview. Applied Thermal Engineering 2008, 28 (11-12), 1536-1550.

Heat transport within car seats

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Abstract: Pleasant interior conditions within cars as well as a comfortable feeling while seating were achieved in conventional manner by active, energy-using systems nowadays. As well for seating furniture in the outdoor and (winter)garden area comfort which is not influenced by ambient conditions is expected. The issue of heat up and cool down processes within seating is relevant for different industries.
The project "heat transport within car seats" was performed between Forschungsinstitut für Leder und Kunststoffbahnen gGmbH (FILK), Institut für Institut für Holztechnologie Dresden gGmbH (IHD) and Hohenstein Institut für Textilinnovation gGmbH. Aim was a deeper understanding of heat transport mechanisms in complex upholstery under realistic ambient conditions having regard to the influence of a sitting human.
Common materials for car seats (cover material: leather, artificial leather, textiles; plus pad: foam, nonwoven, spacer fabric; upholstery: foam) as well as exotic materials out of steel wool, gel matt and latex were used for the investigations. First the thermal insulation, thermal conductivity and water vapour permeability of single layers were characterized by Hohenstein Skin Model (sweating guarded hot plate) according to ISO 11092. Then these single layers were combined to build a whole car seat combination, which was characterized the same way. In the next step a sitting human was simulated by the sweating buttocks model. So the heat flow density from the human in the upholstery combination could be measured for different ambient conditions. Finally controlled human sitting trials were performed to get a subjective evaluation of the upholstery combinations.
The results show that the cover material has main influence on the thermal feeling of a sitting human. Therefore a low maximum heat flux density (initial temperature perception of a sitting human) is desirable. During the wearer trails the cover materials out of textile showed the best performance followed by leather and artificial leather. The influence of the upholstery is visible during long term use of an upholstery system. Final the heat up and cool down processes within upholstery was optimized by passive systems.

Keywords: heat transport, car seats, seat comfort

1 Introduction

The heating and cooling behaviour as well as the energy balance of car seat upholstery in unused and used state is relevant to optimize energy consumption within vehicle interior and active car seat climatisation. Car interior is exposed to temperature fluctuations because of: small inner volume with small thermal capacity of used materials; seclusion which restricts the heat transfer with the ambient; high proportion of glass (greenhouse effect) and no specific measures for heat insulation.

Conventional methods to realize pleasant interior conditions as well as comfortable seat sensation use active, energy consumptive systems, which cause additional space, mass, production and energy cost. In other segments like public transports and outdoor/garden furniture's a pleasant seat comfort independent from the

ambient is desirable, too. The problem of heating and cooling behaviour of seat upholstery is interdisciplinary. This emphasizes the relevance of investigations of heating and cooling processes of car seat upholstery.

Within the project “heat transport within car seats” the Forschungsinstitut für Leder und Kunststoffbahnen gGmbH (FILK), Institut für Institut für Holztechnologie Dresden gGmbH (IHD) and Hohenstein Institut für Textilinnovation gGmbH wanted to gain a deeper knowledge of heat transport processes within complex upholstery in consideration of a sitting person. Further the heating and cooling behaviour of car seat upholstery should optimized.

2 Materials &Methods

2.1 Materials

Several common materials of car seat upholstery as well as unusual materials were used within the investigations (table 1). As cover material artificial leather based on polyvinylchloride (PVC) and polyurethane (PUR), leather tanned with and without chrome (Cr) and textile fabrics e.g. based on polyester (PES) or cotton (CO) as well as their mixtures were used. In case of the artificial leather and textiles some samples had a 2- or 3- layer laminated structure, consisting an additional laminated plus pad. All other cover materials were single face fabrics. As second layer, the plus pad, foams based on polyurethaneesters and –ethers, non-woven materials based on polyester (PES) or cotton (CO) and spacer fabrics, which were commonly used in car seat upholstery, were characterized within the investigations. Further exotic materials e. g. steel wool, gel matt or polyvinylchloride films, which are unusual for car seat upholstery, were investigated as plus pad. As support layer various foam types with different compression harnesses or exotic alternatives like latex, spacer fabric or coconut fibre were used.

Table 1. Sample description of cover material O, plus pad Z and support layer U

Sample	*Material*	*Layer*
O-K	artificial leather based on PVC, PUR	cover material
O-L	leather tanned with and without Cr	cover material
O-T	textile fabrics based on e.g. PES, CO	cover material
Z-S	foam (PU-ester and –ether)	plus pad
Z-V	non-woven material based on e.g. PES, CO	plus pad
Z-AG	spacer fabric	plus pad
Z-E	exotics: steel wool, gel matt, PVC	plus pad
U-S	foam (different compression harnesses)	support layer
U-E	exotics: latex, spacer fabric, coconut fibre	support layer

2.2 Methods

For characterization of the different materials as single layer and combinations three scenarios were used (table 2). Within scenario 1 there are no external influences on the car seat upholstery. Scenario 2 represents a parked car in summer, when the car seat upholstery is heated up. In contrast scenario 3 represents a parked car in winter, when the car seat upholstery is cooled down. Consequently the heat transfer in scenario 1 and 2 is from the sitting person to the car seat upholstery and with scenario 3 from the heated car seat upholstery to the sitting person.

To characterize the single layers as well as the 2-layer and 3-layer combinations by thermo-physiological aspects (e.g. water vapour resistance R_{et} and thermal resistance R_{ct}) sweating guarded hotplates were used according to DIN EN ISO 11092 [1]. The thermal conductivity was calculated from the data of thermal resistance. Considering scenario 2 and 3 measurements with a sweating buttocks model were performed at an ambient temperature of 23°C 50%rh (air-conditioned car) and heated up to 70°C or rather cooled down to -10°C car seat upholstery. The sweating buttocks model simulated a human being of 70 kg sitting in the car

seat. While measurement the heat floe density from the sweating buttocks model to the 3-layer combination of the upholstery was measured. Further temperature and humidity sensors (MSR Electronics GmbH), were placed between the single layers of the upholstery combination.

Table 2. Scenarios used for the investigations of heat transfer in car seat upholstery

Scenario	*Influences*	*Heat transfer*
scenario 1	no external influence	from sitting person to car seat upholstery
scenario 2 (winter scenario)	cooled upholstery	from sitting person to cooled car seat upholstery
scenario 3 (summer scenario)	heated upholstery	from heated car seat upholstery to sitting person

To validate the data subject trials with five male test subjects were executed in a driving simulator to rate the subjective thermo-physiological sensation while driving. To find correlations between the perception of the test subjects and the measured data of the sweating buttocks model similar, controlled ambient conditions (23°C, 50%rh) were used. The display the summer scenario 2 the car seat upholstery was heated up to 70°C for the subject trials. In the subject trials temperature and humidity sensors (MSR Electronics GmbH), were placed on the back, buttocks and thighs of the test subject as well as a forehead sensor (3M Deutschland GmbH) and heart rate sensor (Polar Electro GmbH Deutschland) to record physiological data like skin temperature and humidity, core temperature and heart rate. The seat was also prepared with temperature and humidity sensors on and under the cover. The test subject entered the climate chamber and got used to the climate conditions prevailing there in sitting position (15 min). After installing the heated car seat cushion the test subject immediately seated and drove in the simulator for 60 min.

3 Results & Discussion

Below the results of the material characterization with the sweating guarded-hotplate are given for the material groups as single layer (Fig. 1). The thermal resistance Rct is a material characteristic. It could be shown that the thick foams of the upholstery have a higher thermal insulation than the thinner foams of the plus pad layer, because more air is stored with the upholstery foams. By combining the cover material with an additional plus pad the plus pad dominates the thermal resistance. The same effect is visible by combining the upholstery. Then the third layer (upholstery) dominates the R_{ct} value.

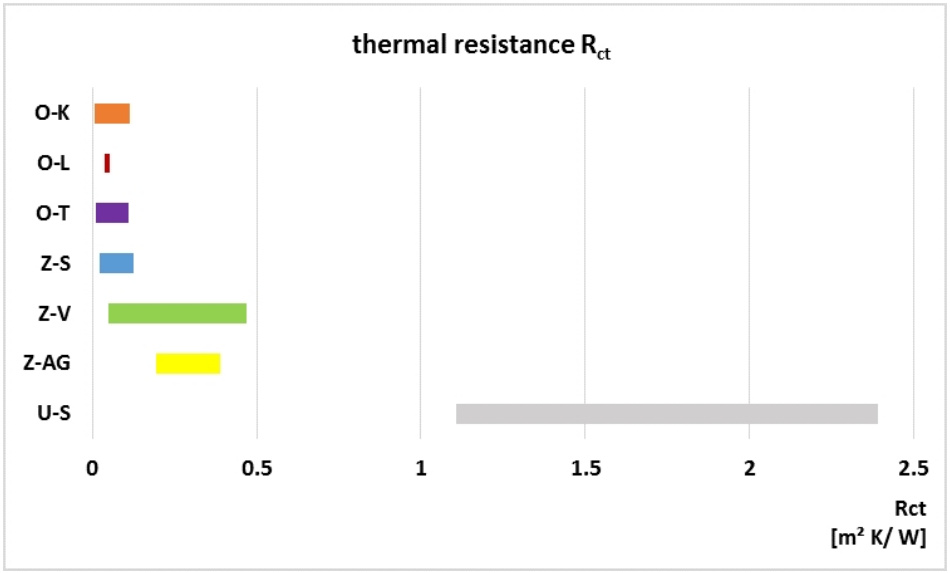


Fig. 1. Thermal resistance ranges of the material groups measured with the sweating guarded-hotplate

The calculated thermal conductivity values λ of the material groups as single layer are given in Figure 2. All textile material (non-exotic) have a thermal conductivity in the range of an isolator. Therefore additional materials Z-E and U-E to widen the material characteristics were used within the investigations. Furthermore it could be shown that the thermal conductivity correlates with the density of the materials.

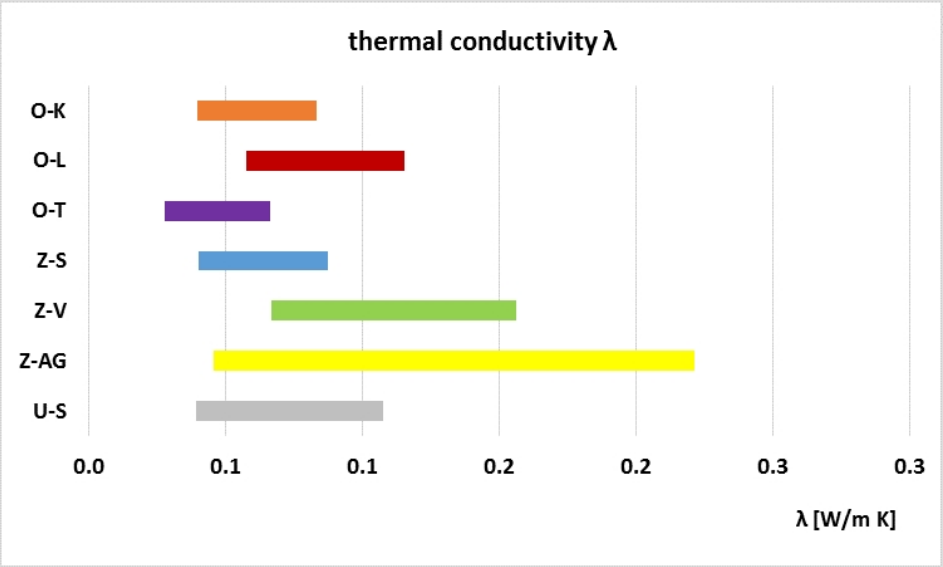


Fig. 2. Thermal conductivity ranges of the material groups

The water vapour resistance is an important thermo-physiological parameter to characterize the thermal comfort of car seats. The results of the R_{et} ranges of the material groups as single layers are given in Figure 3. Especially the differences for the cover materials are visible. The best water vapour resistance (breathability) show the textile cover materials O-T. Within the leather material group O-L there are a few samples with show R_{et} values in an acceptable range. But the artificial leathers O-K are rated as non-breathable. By combining these cover materials with plus pad or plus pad and upholstery, the results show that the water vapour resistance of a multi-layer car seat upholstery is mainly influenced by the cover material.

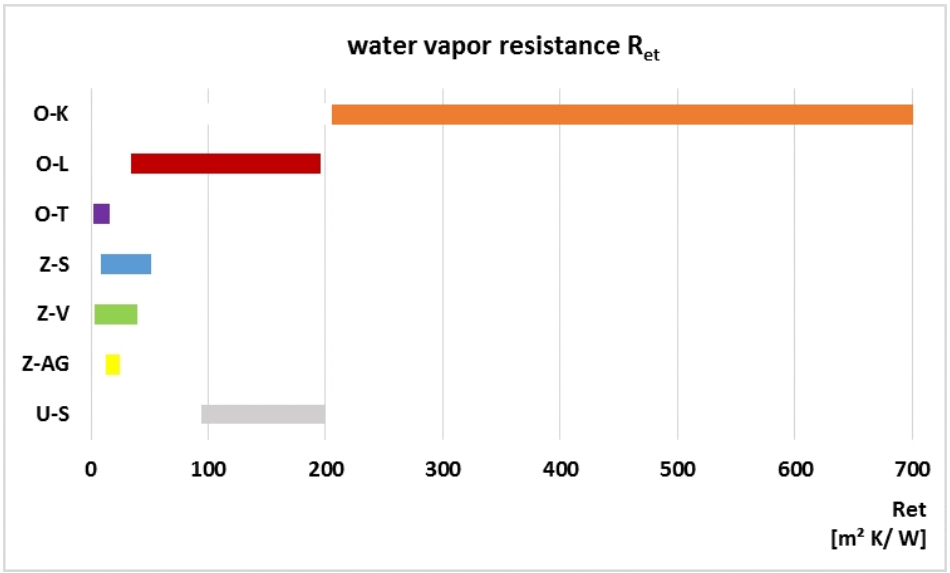


Fig. 3. Water vapour resistance ranges of the material groups measured with the sweating guarded-hotplate

The describe the thermo-physiological comfort of a sitting human on a car seat upholstery more in detail the sweating buttocks model is used. Figure 4 shows the heat flow density from the measurement device into the car seat upholstery with the temperature of 23°C. The initial heat flow density describes the initial heat sensation of a human by sitting on the cat seat. The results show, that textile (pink) is more comfortable than leather (red) and artificial leather (black). Furthermore the investigations could show, that the cover material has the main influence on the initial heat sensation. But the maximum heat flow density depends on the temperature of the car seat upholstery.

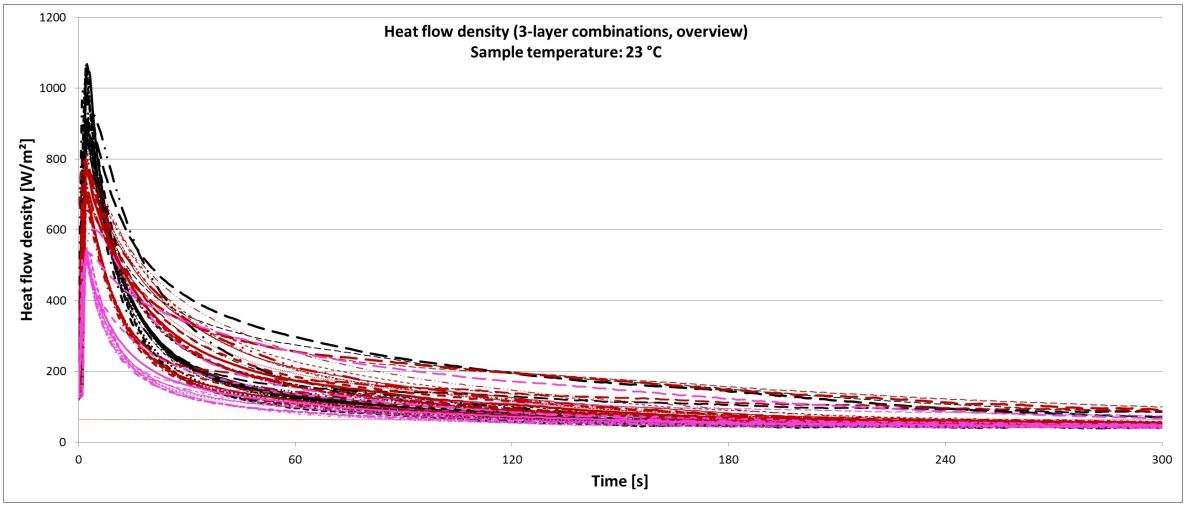


Fig. 4. Heat flow density of all material combinations measured with the sweating buttocks model

To validate the results of the measurements with the skin model and the sweating buttocks subject trials were executed in a driving simulator to rate the subjective thermo-physiological sensation while driving. Figure 5 shows the temperature between cover material and sitting human for textile (T, blue), leather (L, green) and artificial leather (K, orange) and the corresponding subjective temperature sensation of the test subjects (dashed lines). All car seat upholsteries have the same starting temperature of 70°C. Therefore the heat on the top of the cover materials show the same decay curve. After 45 minutes driving all upholstery combinations have reached the steady state. But there are differences in the subjective temperature sensation of the cover materials. The subjective sensation of artificial leather K is over a long time span (40 minutes) rated as unsatisfactory and warm. The textile cover material T is rated best. After 15 minutes driving the test subjects observed no subjective temperature sensation while sitting on the textile coved car seat upholstery. Thus the results of the sweating buttocks model could be validated.

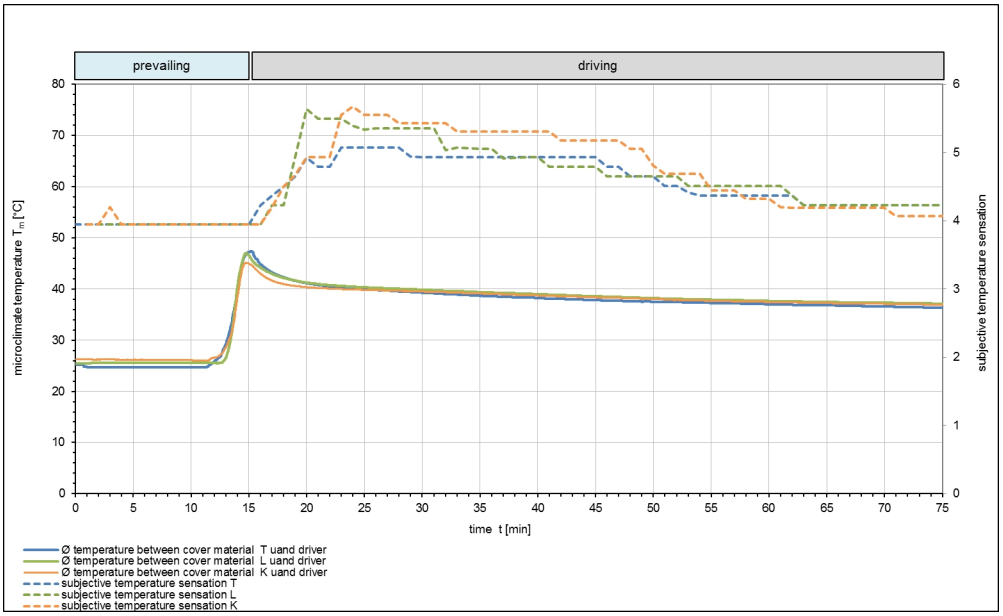


Fig. 5. Temperature between cover material and sitting human for textile and subjective temperature sensation

4 Conclusion

With the research project “heat transport within car seats” between Forschungsinstitut für Leder und Kunststoffbahnen gGmbH (FILK), Institut für Institut für Holztechnologie Dresden gGmbH (IHD) and Hohenstein Institut für Textilinnovation gGmbH the heat transport mechanisms of car seat upholsteries war investigated. It was possible to gain a deeper knowledge of heat transport processes within complex upholstery in consideration of a sitting person. Ambient or material temperature as well as the load of a sitting human has an influence on the thermal conductivity within car seat upholstery. Further the thermal resistance and water vapour permeability is important to characterise the thermos physiological characteristic of single layers and car sear upholsteries. Both parameters depend on the material. The initial heat sensation of human sitting in a cooled down or heated up car seat upholstery can be characterised by measurement with the sweating buttocks model. Further the heating and cooling behaviour of car seat upholstery could optimized by the use of exotic materials within the material combinations.

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References

1. DIN EN ISO 11092:2014-12 (E) Textiles - Physiological effects - Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test) (ISO 11092:2014)

Influence of radiative properties on the thermal comfort of passenger cars: a preliminary investigation for a design archetype

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Abstract Passenger cars are quickly evolving, and likely to switch to new types of powertrain, driving system, usage profile and mode of ownership in a few years. Nonetheless, their fundamental purpose of transporting people from place to place will remain, and this will must be done in the most comfortable way. In order to address this issue, the designer could benefit from the support of structured information and previous experience, as in the case of a Design Archetype for knowledge management. Moreover, the application of a user-centered approach in the automotive field aims to focus the designer's efforts on the specific needs of the car driver and the other occupants in terms of global comfort. With regard to thermal comfort, ensuring the well-being of passengers already requires a large fraction of the energy stored on board, especially for cooling. The more efficient and less energy demanding is the vehicle powertrain, the larger is the fraction of stored energy absorbed by the Heating, Ventilation and Air Conditioning (HVAC) system, with negative implications in terms of size and cost of the storage system, and range of the vehicle. In order to ensure the thermal comfort and thus help lowering the energy need of the HVAC system, this work starts an investigation on the impact that radiative properties of car surfaces such as solar absorption/reflectance and thermal emissivity may have on thermal comfort and the related energy consumption. The background to the investigation is provided by the experience of some authors on measurement and optimization of surface radiative properties and comfort of indoor environment, and it is aimed to build a complete CFD simulation of the car cabin, considering conductive and convective heat transfer processes, as well as radiative processes at different wavelengths. The ultimate aim is to integrate also the thermal comfort properties into a design archetype, through which the design knowledge can be stored and reused with a tool embedded in a CAD software.

Keywords: Design Archetype, CFD simulation, car cabin, thermal comfort, solar reflectance, thermal emittance

1 Introduction

Passenger cars are quickly evolving, and likely to switch to new types of powertrain, driving systems, usage profiles and mode of ownership in a few years. Electric cars with battery powered or fuel cells powertrains are approaching the market, and both those vehicles and the more conventional ones are being coupled with autonomous driving systems. Furthermore, car sharing approaches based on shared ownership or peer-to-peer rental schemes are more and more common. All this supports the expectations for a dramatic revolution of the car sector. Nevertheless, cars will keep their fundamental purpose of transporting people from place to place, and they must do it in the most comfortable way.

In the automotive field, a user-centered design approach focuses on gaining a deep understanding of the needs and perspectives of the car driver and the other passengers [1,2] since the early phases of the design process. As in many industrial fields, CAD-based methods are able to integrate, and sometimes to substitute, analytical methods in order to provide a more efficient and immediate response to specific problems [3].
In the design of a car cabin, we can distinguish two design levels, which correspond to the levels of a Design Archetype. A Design Archetype is developed to simply store and reuse the knowledge during the execution of a design task [4], generally by means of a tool embedded in a CAD environment. On the one hand, the design of a car cabin may be supported by the previous knowledge about the geometry and the morphology of its components (inner space, dashboard, seats, etc.), which can generate the first-level of a Design Archetype, in terms of ergonomics and perceived quality. On the other hand, a second-level Design Archetype may capture, store and formalize the characterization of the car cabin materials and their correlations with the thermal comfort, in terms of equations, analytical models, design criteria, and material properties.
With particular regard to thermal comfort, ensuring the well-being of passengers already requires a large fraction of the energy stored on board, especially for cooling. The more efficient and less energy demanding is the vehicle powertrain, the larger is the fraction of stored energy that is absorbed by the Heating, Ventilation and Air Conditioning (HVAC) system, with negative implications in terms of size and cost of the storage system, and range of the vehicle. Therefore, ensuring the thermal comfort and thus lowering the energy need has become a main priority of the car industry, favoring the start of numerous investigations. Comprehensive reviews on the topic, considering both theoretical and experimental means, can be find in [5,6,7].
The present work starts an investigation on the impact that radiative properties of car surfaces such as solar absorption/reflectance and thermal emissivity may have on thermal comfort and the related energy consumption. The background to the investigation has been provided by the experience of some authors [8,9] on measurement and optimization of radiative properties and indoor thermal comfort. In this regard, the potential of using solar reflective body elements can be easily understood and have stimulated in the last decades comprehensive investigation to innovate both glazing [10] and, more recently, the external surfaces of opaque body panels [11]. Improvements are also possible with regard to the inner surfaces of the car cabin with their radiative properties, on which this work is indeed focused.
The aim of the present investigation is to build a complete CFD simulation of the car cabin, achieving a proper level of detail not only for conductive and convective heat transfer processes, but also for radiative processes at all relevant wavelengths. Hence, this work represents a preliminary investigation for developing a design knowledge basis about thermal comfort of passenger cars: Section 2 introduces a brief introduction of Design Archetypes, Section 3 presents the applied method while Section 4 shows some selected results.

2 Design Archetype levels

Nowadays, the loss of information and knowledge in industries may be faced by the use of CAD-based methods and, in particular, of Design Archetypes. The experience coming from problems already solved, by the designer himself or by someone else, can be collected and stored in a model able to support the designer during the design process, especially in the earlier design phases. In the automotive field, and in particular in the design of car cabins, the architecture of the Design Archetype is multidisciplinary and may reflect a double levels structure.
In the first level, the design of the geometry and the space within the car cabin is focused on the ergonomics of seats and driving components [12,13], other than in the perceived quality [14], as in the assembly of the dashboard and door panels. Both aspects are strictly dependent on the mechanical properties of materials, which are commonly available into the CAD environment.
As an example, in the assembly of a dashboard (Figure 1), the use of a Computer Aided Tolerance (CAT) software may support the designer in investigating the final quality of the assembly itself, by assessing the gap conditions among rigid and flexible parts.

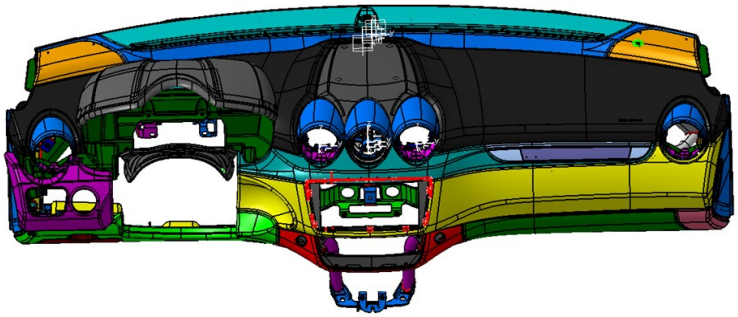


Fig. 1. Dashboard assembly

The second level of the Design Archetype of a car cabin is focused on the thermal comfort, which deals with material properties more than the geometry of the components. In the next section, a numerical model of the cabin is developed in order to achieved and collect knowledge on materials, their finishing and their correlations with the thermal comfort, in terms of equations, analytical models, design criteria, and material properties.

3 Numerical model

The cabin of a high performance sports car was simulated by means of the industrial CFD code ANSYS FLUENT R17.0. Inside the cabin, the driver body was also simulated. Figure 2 shows a sketch of the whole computational domain.

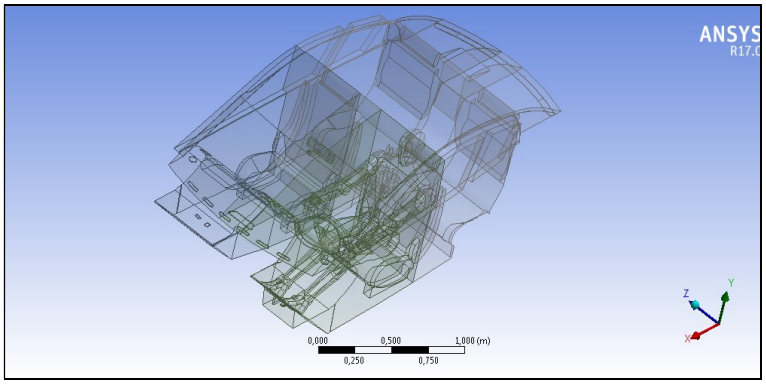


Fig. 2. Simulated car cabin and driver's body.

In order to simplify the operations of mesh construction, as well as to limit the number of final cells, minimal details such as edges, handles, buttons, etc. were simplified. The whole mesh and a vertical cross section on the driver side is shown in Figure 3 and Figure 4.
The mesh consists of about six million cells. The mesh was refined in order to achieve the best values of the mesh quality parameters commonly used in CFD simulation. More specifically, a very good aspect ratio of 1.88, excellent skewness of 0.24 and very good orthogonal quality of 0.85 were achieved.
The following computational models were used in the simulations:

- pressure-based resolution with energy equations;
- SIMPLE method for pressure;
- First-order upwind discretization for the other variables;
- SST (shear stress transport) k-ω turbulent model, which ensures a better treatment on wall boundaries;

- DO thermal radiation model, with 3 bands treatment (visible, near infrared and thermal infrared) and solar radiation;
- S2S and ray tracing thermal radiation model to generate the complex view factors between the numerous internal surfaces of the cabin.

In the preliminary set of simulation cases presented in this work, the car was assumed to be North facing while travelling or being parked in Modena (Italy), long. 10.92552°E lat. 44.64708°N. The worst environmental conditions for air conditioning where considered, using weather data for a midsummer day (August 15) one hour after noon (13:00). In particular, direct radiation was assumed equal to 869 W/m^2, vertical and horizontal diffuse radiation were assumed equal to 90 W/m^2 and 108 W/m^2, respectively, the sky temperature was set equal to 285 K.

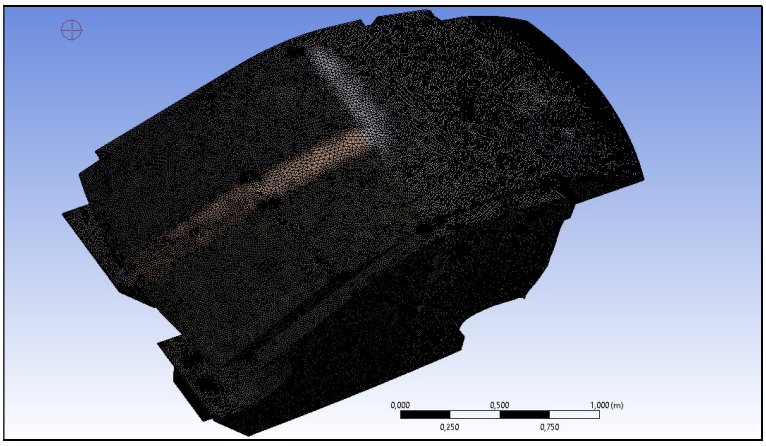


Fig. 3. Mesh of the simulated car cabin.

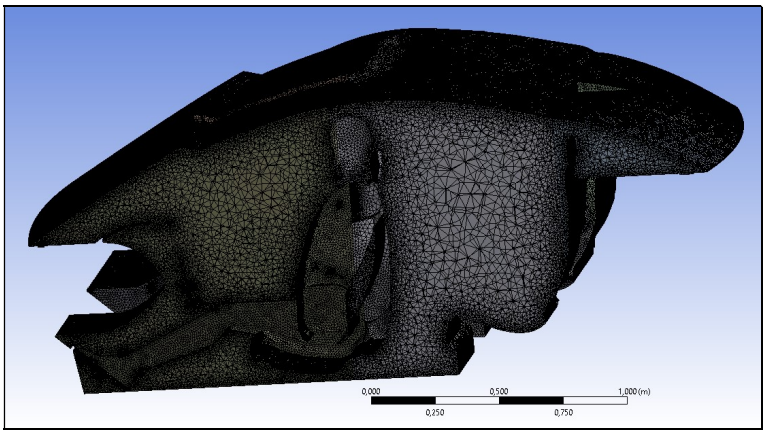


Fig. 4. Vertical cross section of the mesh.

Different material types were considered for the surfaces of the passenger cabin, distinguishing between glass (windshield, rear window and side windows), human skin, cotton fabric, leather, and plastics. High values were initially assumed for the emissivity/absorption coefficient of all opaque surfaces, i.e. close to unity as usual for standard materials.

The values of air velocity and temperature at the air conditioning vents (see Figure 5) were experimentally measured on a real car by means of a portable temperature sensor. The metabolic heat flow for an adult driving a car was imposed on the driver's body surface, equal to 80 W/m^2 (1.4 met).

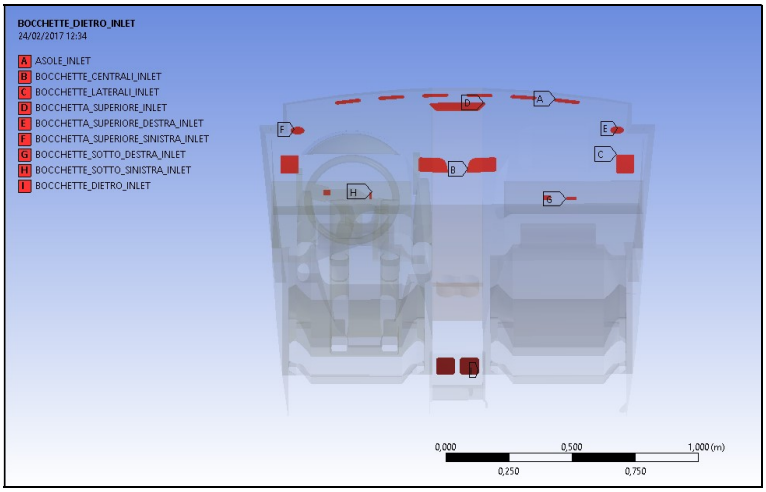


Fig. 5. Air conditioning inlet vents.

4 Results

Several operative conditions were tested, considering the car velocity (affecting heat transfer by convection on the external surfaces) and the radiative properties of the cabin outer and inner surfaces. Selected results, representative of the potentiality of CFD simulation, are presented in the following paragraphs.

4.1 Test case 1 – Car travelling at 130 km/h

The temperature maps calculated for a car travelling in a summer day with a velocity of 130 km/h are shown in Figure 6 and Figure 7. A dark body surface and standard glazing were considered. Air temperature of 16°C and maximum air velocity were assumed at the air conditioning vents.
As expected, the driver left arm was found to be warmer due to solar radiation from the side window (Figure 7), and the surface temperature is significantly higher on the dashboard under the windshield and on the luggage cover under the rear window.

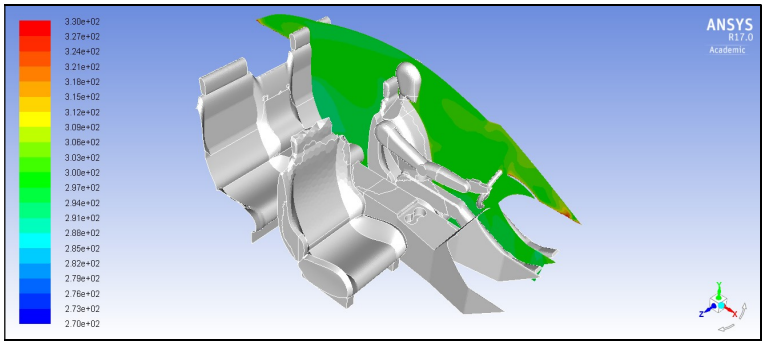


Fig. 6. Test case 1 – Air temperature around the driver's body.

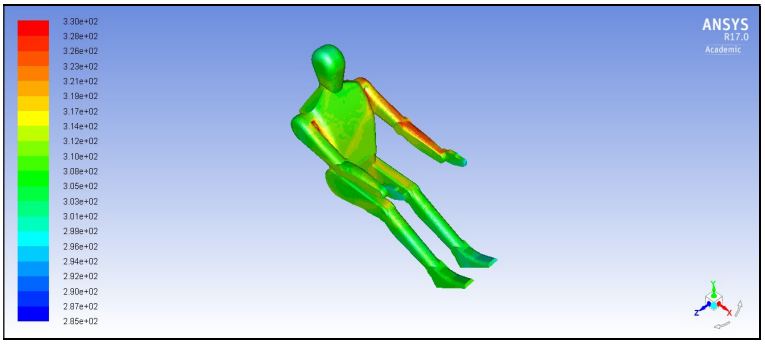


Fig. 7. Test case 1 – Surface temperature of the driver's body.

In order to assess the thermal comfort level, the PMV/PPD model was used. This was developed to assess thermal comfort in buildings and other enclosures by using heat balance equations and empirical studies about skin temperature [15]. More specifically, a predicted mean vote (PMV) of a large group of subjects can be calculated for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation, and a predicted percentage of dissatisfied (PPD) can be associated to the PMV. Zero is the ideal value for PMV, representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits of -0.5<PMV<+0.5.
In test case 1, a PMV value of 0.30 was calculated for Test case 1, with an associated PPD value of 7%, by extrapolating for the car cabin the approach proposed for buildings in EN 15251 [16].

4.2 Test case 2 – Solar reflective inner surfaces

Further analyses were performer to assess how the radiative properties of selected surfaces could affect the temperature and thermal comfort inside the car cabin. This preliminary study was aimed at verifying the sensitivity of the model to changes in the simulation parameters, so limit values of the radiative properties were considered as observed by the authors in their research activities on measurement and optimization of properties such as solar reflectance/absorption coefficient [8] and thermal emissivity [9].
In test case 2, a very low solar absorption coefficient of 0.1 in the wavelength range from 0.4 to 2.5 μm was set inside the car cabin for both the ceiling and the seats surfaces, leaving all other simulation parameters unchanged. The solar absorption coefficient is the ratio of absorbed and incident solar energy and, for an opaque surface, it is the complement to unity of solar reflectance. The wavelength range is that relevant to the visible and near infrared components of solar radiation, which include above 90% of total solar energy. Selective transmittance of the glazing may also alter the spectrum of solar radiation incident onto the inner surfaces.

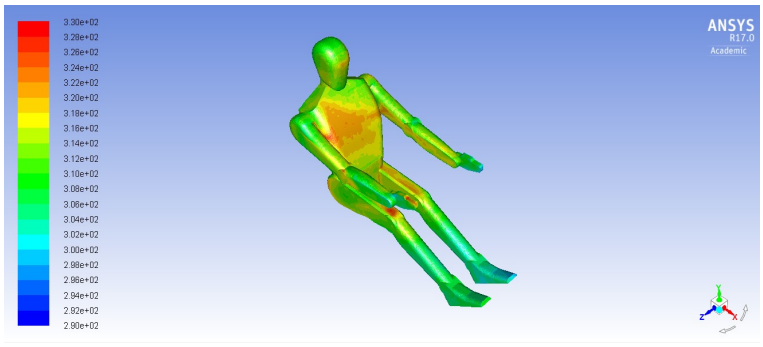


Fig. 8. Test case 2 – Surface temperature of the driver's body.

The considered values of the solar absorption coefficient are those typical of dazzling white surfaces, which could be expected to decrease solar absorption and thus improve thermal comfort. Instead, radiative interaction between surfaces inside the car cabin leads to a result opposite to expectations, providing a demonstration

of the complexity of the problem: the ceiling temperature rises significantly due to the greenhouse effect, and the average radiant temperature of inner surfaces calculated near the chest also rises. The head, chest, and thigh areas becomes hotter (Figure 8), and the PMV rises to 0.46, with PPD equal to 9%.

4.3 Test case 3 – Low-emissivity inner surfaces

Thermal emissivity is the ratio of radiation emitted by a surface and the maximum theoretical emission at the same temperature. In test case 3, an emissivity value of 0.1 was set in the wavelength range from 2.5 to 100 μm for the ceiling and seats surface, again leaving all other parameters unchanged. The wavelength range is that relevant to thermal radiation emitted by surfaces at near ambient temperature. The considered values of the emissivity are those typical of polished metal surfaces and can be approached by fabrics with fibres made of metal or coated with metal or even advanced nanostructured materials.
A low thermal emissivity could be expected to decrease the mean radiant temperature of inner surfaces and thus improve thermal comfort. Nonetheless, the comparison of the temperature maps with those obtained for cases 1 and 2 showed a further increase of the internal temperatures, especially in the front seats area (Figure 9), due to the lower release of heat towards the outer body panels by thermal radiation. The driver's surface temperatures increase further and become quite high with the exception of the feet area, where they benefit from the direct impact of cold air and the low exposure to solar radiation. The PMV values rises to 0.60, with associated PPD equal to 13%, indicating a higher feeling of warmth perceived by the driver.

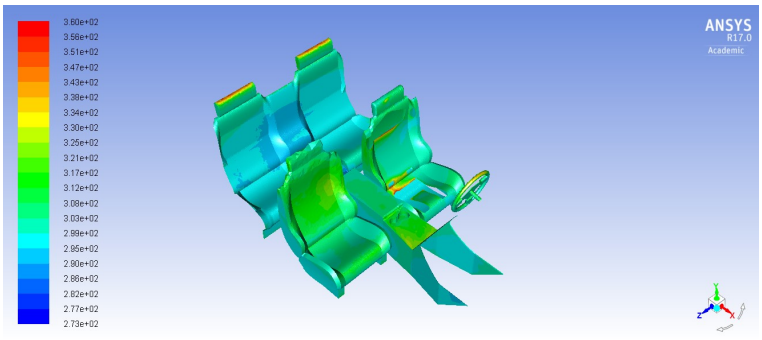


Fig. 9. Test case 3 – Surface temperature of the seats.

5 Concluding remarks

This work represents a preliminary investigation for developing a two-levels Design Archetype aimed to consider the global comfort of car driver and passengers. Beside the characterization of ergonomics and perceived quality (first level) in a car cabin, we investigate the thermal comfort of passenger cars by means of numerical models and the simulation of material properties and finishing.
The obtained results demonstrated the complexity of achieving an adequate thermal comfort in the car cabin, where one has to take contemporarily care of solar absorption, air convection and thermal radiation phenomena. The best thermal comfort is achieved by a combination of a well distributed airflow of the air conditioning system with properly selected radiative properties of the inners surface.
The use of solar reflective and/or low emissivity materials in the car cabin may generally be beneficial since they respectively lower absorption of solar radiation that passes through the car glazing and emission of infrared radiation from the inner cabin surfaces toward the occupants' bodies, but a thorough optimization of their properties and location inside the cabin is needed, otherwise it was shown that results opposite to the expectations can be achieved.
Future work will be aimed to develop and validate a comprehensive approach to optimize preventively the choice of radiative properties in the car cabin in the perspective of the thermal comfort, by completely integrating the material characterization within the second level of the Design Archetype we proposed in this

work. In particular, the thermal characterization of the investigated materials will be collected within a specific tool embedded in a CAD environment, able to support the designer in addressing the thermal comfort needs of the car driver and the passengers. Because those choices of materials will condition the global comfort of the car cabin, also in terms of ergonomics and perceived quality, the Design Archetype will act as an integrated design tool.

References

1. Gherardini, F., Renzi, C. & Leali, F., 2016. A systematic user-centred framework for engineering product design in small- and medium-sized enterprises (SMEs). International Journal of Advance Manufacturing Technology. In press, pp. 1-24. doi:10.1007/s00170-016-9857-9
2. Renzi, C., Leali, F., Di Angelo, L., 2017. A review on decision-making methods in engineering design for the automotive industry. Journal of Engineering Design, 28 (2), 118-143.
3. Gherardini, F., Zardin, B. & Leali, F., 2016. A parametric CAD-based method for modelling and simulation of positive displacement machines. Journal of Mechanical Science and Technology 30, 3253-3263
4. Xiaotao, H. A study on design archetypes based on "Without Thought Design" (2012) Applied Mechanics and Materials, 224, pp. 189-192.
5. Walgama, C., Fackrell, A., Karimi, M., Fartaj, and A. Rankin, G.W., 2006. Passenger Thermal Comfort in Vehicles – A Review. Proc. of the Institution of Mechanical Engineers 220, Part D: Journal of Automobile Engineering
6. Alahmer, A., Mayyas, A., Mayyas, A.A., Omar, M.A., and Shan, D., 2011. Vehicular thermal comfort models; a comprehensive review. Applied Thermal Engineering 31, 995-1002.
7. Croitoru, C., Nastase, I., Bode, F., Meslem, A., and Dogeanu, A., 2015. Thermal comfort models for indoor spaces and vehicles—Current capabilities and future perspectives. Renewable and Sustainable Energy Reviews 44, 304-318.
8. Ferrari, C., Libbra, A., Muscio, A., and Siligardi, C., 2013. Influence of the irradiance spectrum on solar reflectance measurements. Advances in Building Energy Research 7, 244-253.
9. Pini, F., Ferrari, C., Libbra, A., Leali, F., and Muscio, A, .2016. Robotic implementation of the slide method for measurement of the thermal emissivity of building elements. Energy and Buildings 114, 241-246.
10. Lynam, N., 1990. Smart Windows for Automobiles. SAE Technical Paper 900419.
11. Levinson, R., Pan, H., Ban-Weiss, G., Rosado, P., Paolini, R., and Akbari, H., 2011. Potential benefits of solar reflective car shells: Cooler cabins, fuel savings and emission reductions. Applied Energy 88, 4343-4357.
12. Naddeo, A., Apicella, M., and Galluzzi, D., 2015. "Comfort-Driven Design of Car Interiors: A Method to Trace Iso-Comfort Surfaces for P ositioning the Dashboard Commands," SAE Technical Paper 2015-01-1394, doi:10.4271/2015-01-1394.
13. Naddeo, A., Cappetti, N., and Ippolito, O., 2014. "Dashboard Reachability and Usability Tests: A Cheap and Effective Method for Drivers' Comfort Rating," SAE Technical Paper 2014-01-0455, doi:10.4271/2014-01-0455.
14. Panari, D., Renzi, C., Vergnano, A., Bonazzi, E., Leali, F., 2017. Integrated design method for optimal tolerance stack evaluation for top class automotive chassis. In: Advances on Mechanics, Design Engineering and Manufacturing, Part of the series Lecture Notes in Mechanical Engineering, pp 1013-1022.
15. Fanger, P.O. Thermal comfort: analysis and applications in environmental engineering. New York: McGraw-Hill 1970.
16. CEN. EN 15251:2007 – Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, 2007.

Development of a human thermal model to predict seat occupant thermal comfort

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Abstract While heated and cooled seats used to be integrated only in luxury cars, a wider range of carmakers proposes now such seats for their midrange market too. The design of heated or cooled seats, as well as their optimization to effectively increase the thermal comfort of the occupant, is very complex. Each of the interactions between the occupant, the seat cover, the cushion foam, and the heating or ventilation systems has to be taken into account, as the thermal comfort feeling of the occupant, which is highly subjective.

The use of virtual seat prototyping to predict the thermal comfort of a driver seating in a heated or cooled seat enables to answer effectively such a car interior design challenge. However such simulations require the use of digital human models including human body thermal behavior and objective thermal comfort criterion.

This paper presents the latest developments performed on Virtual Seat Solution Human Models to include human thermal modeling and thermal comfort criteria. The developed human model is then used with a virtual seat prototype equipped with heating pad to predict the thermal comfort of the occupant in various configurations.

Keywords: Thermal comfort, Human model, Virtual Seat Prototype, Heated, Ventilated, seat, Simulation

1 Introduction

This paper investigates how virtual seat prototyping and digital human thermal models can be used to find the right car interior design, optimizing both the energy consumption of an electrical vehicle and the comfort of the driver. After a brief description of ESI digital thermal human model and virtual seat model, it will be shown how to predict accurately the thermal comfort of a car seat occupant. Then a case study based on a car cabin temperature decrease, to improve an electrical car range, will be performed to investigate the effects on the thermal comfort of the seat occupant, with and without using seat heating system. The impact on the energy consumption and range of an electrical vehicle will be highlighted.
The paper will then show how digital human model combined with virtual testing can be used to optimize seat heating system to improve the thermal comfort of a seat occupant.

2 Thermal comfort of a seat occupant

2.1 Virtual seat and digital human model

2.1.1 Virtual Seat Prototype

A seat model is first created, with the objective of having a very realistic model, representing a behavior close to a real one: it contains all the seat components: frame, suspensions, foam blocks, heating pad, cover and padding with related attachment systems.

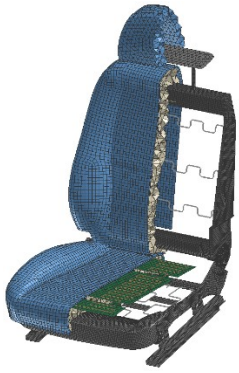


Figure 1. ESI's Virtual Seat Model

The frame is considered as rigid since the model will be used only for seating and thermal comfort simulation but all other components are deformable and connected the ones to the others through joints and contacts.
This modelling method has been extensively validated through comparison between simulations and real tests, regarding H-Point and pressure distribution measurements. [5] [6] [7] [8] [9].
Thermal material properties are added to the seat components, having a significant influence on the global thermal seat behavior, such as trim components (cover, foam and padding).
A heating system is incorporated inside the seat. The heating pad is modelled with beam elements representing the electrical wires, embedded in shell elements representing the unwoven fabric. A thermostat with sensors positioned on the cushion is added to the heating system.

2.1.2 Digital human model

Several human model anthropometries are available within the complete human model library of ESI's Virtual Seat Solution.



Figure 2. Examples of ESI's human models

For each finite element human model, an adapted thermal behavior has been integrated. It contains two main parts:

- A thermal passive system

The thermal passive system models the heat transfer conducted inside the body through conduction and blood circulation. It takes also into account the heat generation coming from the human basal metabolism or from the mechanical activity of muscle. Additionally the external heat exchanges through sweat evaporation, breath, convection, conduction and radiation are simulated, taken into account the clothes worn by the occupant.

- A thermal active system :

An active system representing the thermoregulation system of the human body (vasodilatation, vasoconstriction, shivering and sweating) is added to the human models. This thermoregulation is per nature transient and requires thus the direct coupling of the human model and the simulation of its environment: seat and air. The thermal behavior of the digital human models has been validated using data from independent experiments in literature (figure 3).

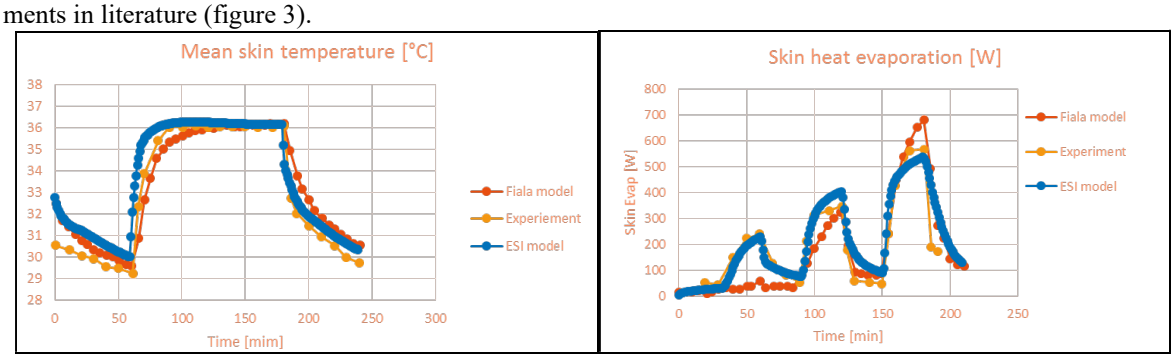


Figure 3. Example of comparison between thermal behavior of ESI's human models, Fiala model and experimental results.

The complete results comparison campaign showed good correlation with measured data.

2.2 – Virtual seating of human model

An exact prediction of the contact area between the seat and the occupant is important to calculate accurately the heat conduction between the seat and the human body (figure 4).



Figure 4. Seating of occupant and contact area Simulated with ESI Virtual Seat Solution

Similarly the simulation of the local pressure mapping and foam deformations under seated occupant (figure 5) enables a precise calculation of the heat conduction inside the seat, as it has been shown in previous paper [3].

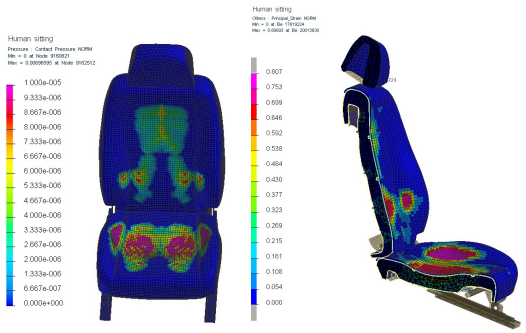


Figure 5. Seat pressure and foam deformation Simulated with ESI Virtual Seat Solution

2.3 - Thermal comfort criterion

The objective of defining a thermal comfort criterion is to have an objective criterion to support the design of seat heating and cooling system or global thermal management of the car cabin. The thermal comfort criterion which has been developed is partially based on the work of Zhang at UCB (University of California Berkeley). Based on experimental data, Dr. Zhang has established a direct relationship between objective values (skin temperature, skin temperature variation…) and the subjective feeling of comfort/discomfort.
The developed comfort criterion is not only adapted to transient environment, but also to non-uniform environments. This second point is very important in the car cabin environment, as for instance the seat introduces a high asymmetry between the heat transfer in the front of the occupant (convection) and the back of the occupant (conduction with seat). To take into account the asymmetry, the human body is divided into many parts, each part being divided into two to three sectors, having a local thermal value.
To calculate thermal comfort, Zhang has introduced the thermal sensation, which is easier to understand. In an environment where the temperature is far below (or above) the temperature needed for neutral sensation, one will feel cold (or hot) and in a discomfort situation.

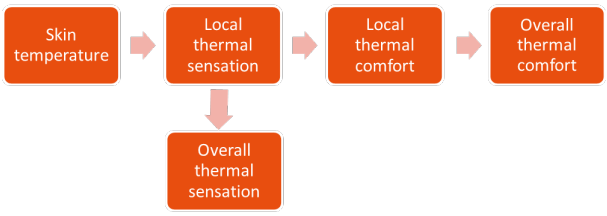
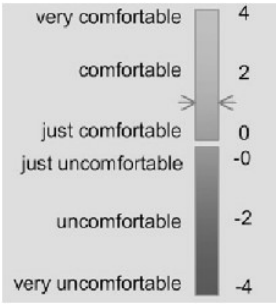


Figure 6- Model for prediction of Thermal Sensation and Comfort from physiological information e.g. skin temperature

Thermal comfort index and thermal sensation index are fixed by Zhang in a scale between -4 and 4. Figure 7 shows relation between each thermal sensation and its index value (from very hot to very cold sensation) and relation between thermal comfort and its index value.



Index value	Thermal sensation
4	Very hot
3	Hot
2	Warm
1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold
-4	Very cold

Figure 7. Thermal comfort and Thermal sensation indexes

3 Effect of cabin temperature decrease on seat occupant comfort

3.1 Weather temperature and electrical vehicles range

To study a concrete example, let's choose a standard electric vehicle with average range of 130 Km Nissan leaf 24kWh [4].
Information collected by society FleetCarma from Nissan Leaf users has shown that vehicle autonomy can decrease by over than 40% in cold weather (figure 8). The main reason of this, is energy consumption used on car cabin heating.

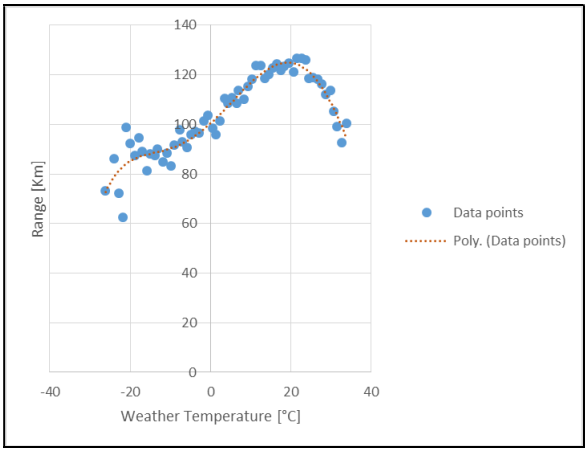


Figure 8. Nissan Leaf Energy consumption vs temperature

These results highlight the importance of optimizing the HVAC of electric vehicles, not only to optimize thermal comfort but also to minimize energy consumption and to increase electric vehicle's autonomy.
To minimize HVAC energy consumption in cold weather, it is possible to decrease the global car cabin temperature and add a seat heating system to compensate and maintain the thermal comfort of the occupant. Simulation can be used to test such scenario and find an optimum thermal management system.
Let's first investigate what happens on seat occupant when the car cabin temperature decreases from 18°C to 15°C.

2.2 Effect of a 3°C decrease in the cabin on seat occupant thermal comfort

To compare the influence of a decrease of 3°C in the car cabin on the thermal comfort of the seat occupant, the following scenario is simulated:

1. The human model is initially outside the car.

Outside temperature	-10 °C
Outside humidity	80 %
Outside Air velocity	10 m/s

He wears winter clothing, providing adapted insulation. He walks (from a building to the car) during 2 minutes with a moderated speed, which is equivalent to 2.5 met.

2. After he enters in the car, which is at -10°C, the HVAC is activated to reach 15°C or 18 °C after about 5 min.

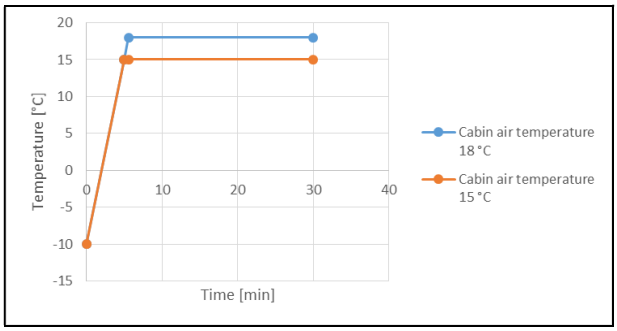


Figure 9. Car cabin air temperature vs time

Let's first compare overall thermal comfort and overall thermal sensation of the seat occupants in the two configurations (15°C and 18°C):

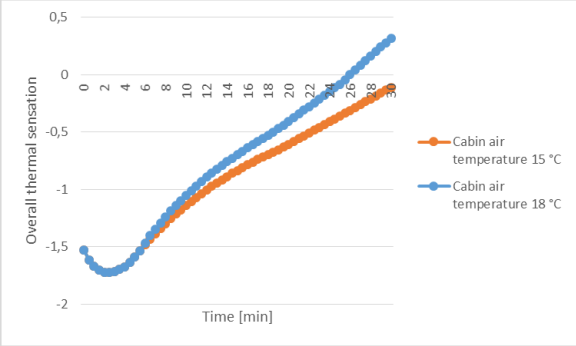


Figure 10 – Overall thermal sensation

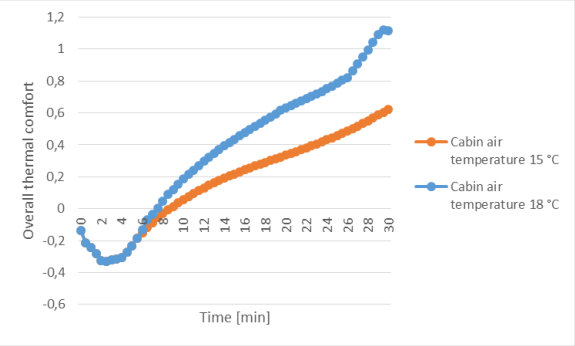


Figure 11 – Overall thermal comfort

The results for overall comfort & sensation (figures 10 and 11) are as expected: the occupant in the car cabin at 18°C feels more comfortable than the one in the car cabin at 15°C. To investigate if the difference is due to specific body parts or is the same in all body parts, it is interesting to analyze locally thermal comfort and sensation for all the body parts, focusing on those which show local comfort advantage at 18°C.
If we look at the local thermal comfort index, there are four parts having an index at 15°C below the index at 18°C: Arm, Foot, upper Abdomen and lower abdomen (figure 12).

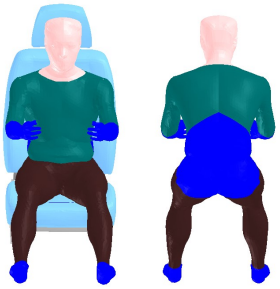


Figure 12. Highlighted in blue, parts where local comfort index at 15°C below the index at 18°C

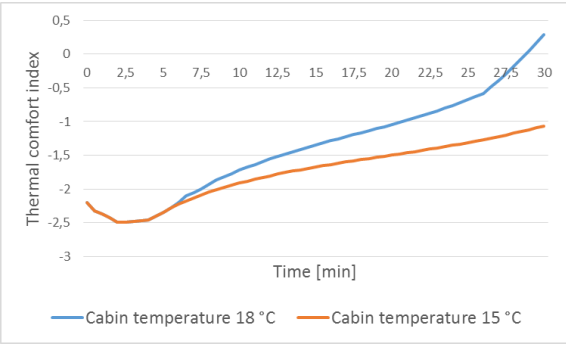


Figure 13a – Arm thermal comfort

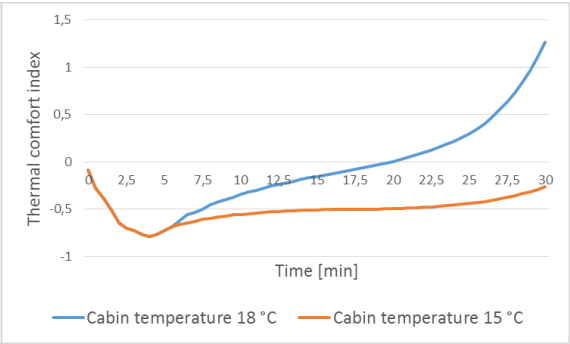


Figure 13b – Foot thermal comfort

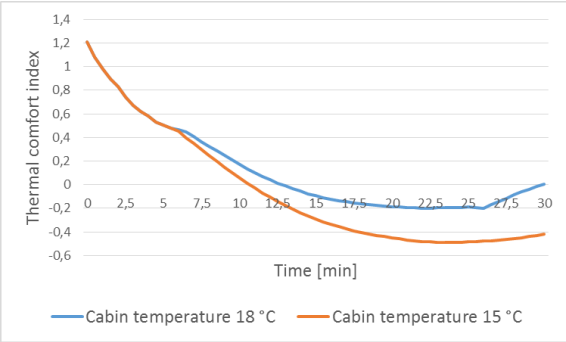


Figure 13c – Upper abdomen thermal comfort

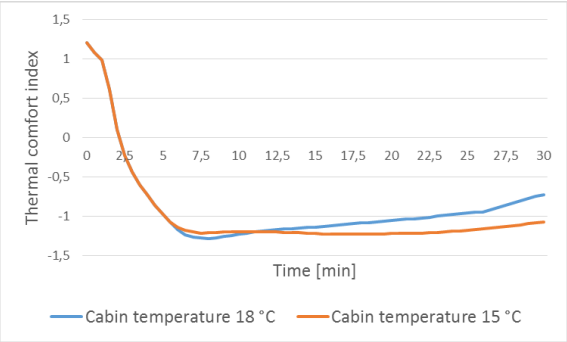


Figure 13d – Lower abdomen thermal comfort

The analysis of the simulation shows that in order to increase overall thermal comfort of the seat occupant in a car cabin at 15°C, local thermal comfort of these four body parts must be increased.
As the abdomen parts are in contact with the seat, it can be supposed that an active heating seat could impact positively the local and thus the overall comfort in a colder car cabin environment.

2.3 Use of heating system and effect on seat occupant thermal comfort

Based on the previous analysis, let's investigate how an active heating seat could contribute in keeping the same level of comfort for the occupant without increasing car cabin temperature. The study focuses on the improvement of local thermal comfort in the lower abdomen area, by activating a heating pad system in the virtual seat prototype.
The heating pad is piloted by a thermostat, used to control heating cycles (the on/off status) and maintain the temperature between two limit values. The heating pad stays ON until the seat has reached the maximum prescribed temperature and it is then turned off until the seat temperature is lower than the minimum temperature limit.
The same scenario than in previous paragraph is simulated, in a car cabin at 15°C with a heating pad, piloted by a thermostat with two temperature limits of 31°C and 33 °C measures by sensors on the seat cushion.

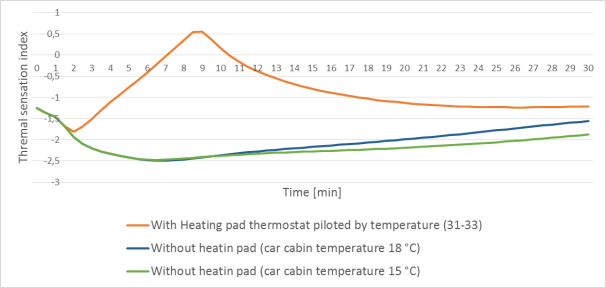


Figure 14a. Lower abdomen thermal sensation

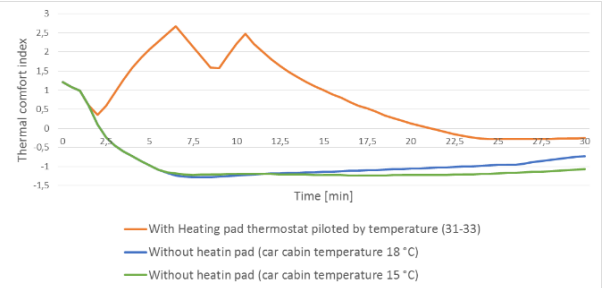


Figure 14b. Lower abdomen thermal comfort

The figure 14b shows that the thermal comfort in lower abdomen has increased and becomes even more comfortable than in a car cabin at 18°C. The same can be done for the upper abdomen part, by using a heating pad in the seat backrest.
The other body parts thermal comfort (arm and foot) could not be improved by seat heating system since there is no contact between them and the seat. Other local solution, such as radiation panels can be used.
The use of virtual seat prototyping with digital human model helps finding solution to reduce the cabin temperature (in this case of 3°C), without decreasing thermal comfort of the occupant. Such solution will contribute to reduce the car energy consumption and thus the range of electric car vehicle:
Applied on a car such as the one illustrated in paragraph 3, it can be calculated that:

- In cold weather, by activating the HVAC to maintain the car cabin temperature, the car loses more than 40 % of its autonomy, which is equivalent to 8 Kwh (in two hours if we suppose vehicle average speed is 45 Km/h).
- On the other hand heating pad with electric power of 40 W will consume 80 Wh in two hours, which represent 1% of the energy consumption of the global HVAC system. This value can even be reduced by half if we take into account the heating cycles of the heating pad (In two hours driving, heating pad will be on, only one hour).

This means that the car energy consumption by the HVAC system in electrical vehicles can be reduced by over than 10%, the vehicle range increased by 4%, all this without any thermal discomfort.

4 Heating system optimization

Let's now investigate how the simulation can help optimizing the heating system, described in the previous paragraph to maximize the thermal comfort of the occupant. A comparison of local comfort in the lower abdomen area will be performed between five different configurations:

- For four configurations, the heating system is piloted by a thermostat with a temperature sensor positioned placed on the seat cushion. Different intervals of temperature limits are defined for the thermostat, 31°C-33°C, 32°C-33°C, 32.5°C-33.5°C and 33.5°C-35.5°C.
- One configuration with a heating system piloted by the optimum occupant local thermal sensation index, close to zero.

The same scenario as in previous paragraph is used for the driver, the car and the outside conditions, with a car cabin warmed at 15°C.

The following results are obtained:

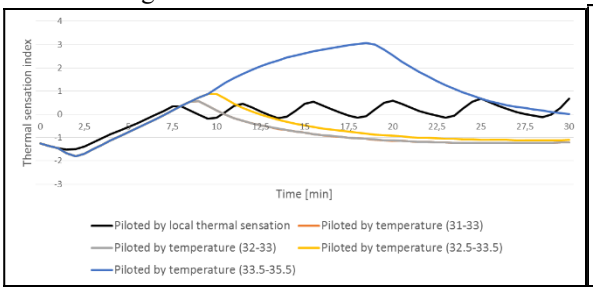


Figure 15a. Lower abdomen thermal sensation

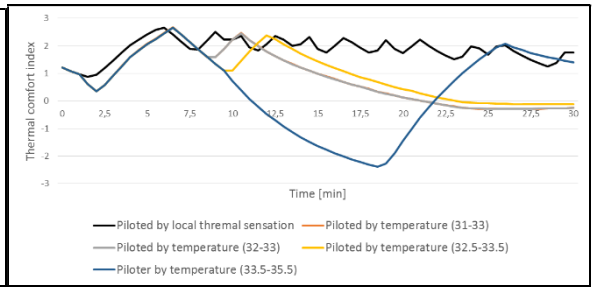


Figure 15b. Lower abdomen thermal comfort

Even if heating pads are supposed to improve thermal comfort, an incorrect definition of the heating cycle may lead to discomfort:

In figures 15, the heating pad piloted by temperatures interval does not enable to reach a good thermal comfort level:

- The temperature interval 33.5°C-35.5°C leads to over-heating, as shown by the sensation index superior to 1, until reaching the index 3
- The other temperature intervals lead to under-heating, with a sensation index close to -1, remaining at that level.

The piloting of the heating pad by sensation index, enables to reach a good thermal comfort level along time. We can then use its heating time cycle, to pilot the thermostat.

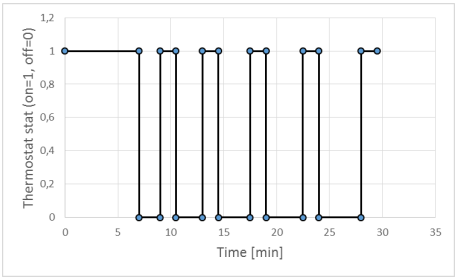


Figure 16. Heating cycle output form simulation with thermostat piloted by thermal sensation

The analysis of this heating time cycle shows that, after a heating period of 7 min, the heating system alternates between two states: off for 120 to 240 seconds and on for (90 seconds). An average heating cycle is then defined (figure 17).

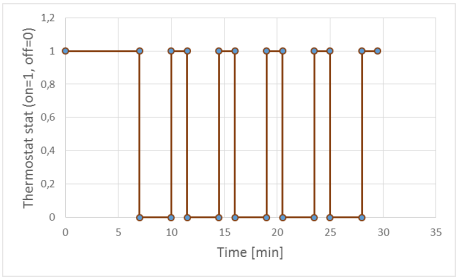


Figure 17. Heating cycle approximation of the heating deducted from thermal sensation

Figure 18.b, below, shows that with this new heating system a better level of comfort is reached. Such heating system definition and optimization by simulation could be performed for different scenarios (with different thermal conditions) and for different human anthropometries.

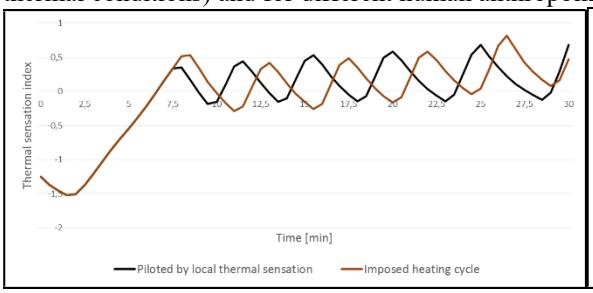


Figure 18a. Lower abdomen thermal sensation

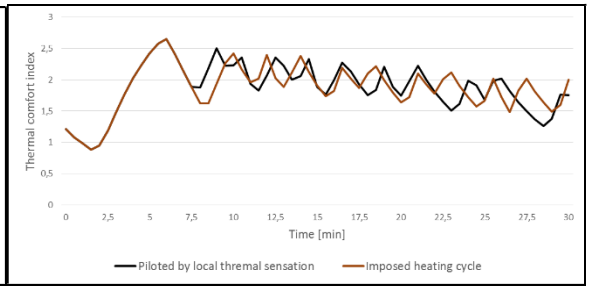


Figure 18.b Lower abdomen thermal comfort

Table 1 shows warm up duration, energy consumption and average thermal comfort, for the four heating thermostat piloted by temperature, the one piloted by thermal sensation, and the optimized heating system with imposed time cycle.

Heating system piloted by:	Warm up Duration [min]	Power consumption [Wh]	Mean Comfort
Thermal Sensation	15	5	1,87
Imposed	14.5	4.83	1.87
T [32,33]	9	3	0,82
T [32.5,33.5]	10	3,33	0,95
T [33.5,35.5]	19	6,33	0,42

Table 1. A comparasion between different heating systems

As mentioned previously, energy consumption of heating system embedded in car seat is negligible compared with energy consumption of the global HVAC system of an electric vehicle.

5 Conclusion

This paper shows with a simple example how the simulation coupling virtual seat prototype and human thermal model can support engineers in managing both the thermal comfort of the seat occupant and the electrical vehicle range. Next step is to add to this seat, human model and cabin environment coupling, the computation of fluid dynamics, both in seat-embedded ventilation systems and in the car cabin, as system management between the different possible heating systems (seat, HVAC…).

References:

1. D. Fiala, 1999 Dynamic Simulation of Human HeatTransfer and Thermal Comfort, Phd Thesis, Institute of Energy and Sustainable Development de Montfort University Leicester
2. H. Zhang 2003 Human thermal sensation and comfort in transient and non-uniform thermal environments, Phd Thesis, University of California, Berkeley
3. C. Marca, C. Borot, Thermal Comfort Prediction for Heated Seat, the 8th Seat R&D Symposium
4. https://www.nissan.fr/vehicules/neufs/leaf/autonomie-recharge.html
5. A. Savary, J. Makala, N. Montmayeur, C. Marca, “Virtual Seat Comfort Design”, IQPC Congress “Innovative Seating”,2007
6. N. Montmayeur, E. Haug, C. Marca, H.-Y Choi, S. Sah “Numerical and Experimental Analyses of Seating and Riding Comfort”, SAE Paper 04DHM-3, 2004.
7. N. Montmayeur, C. Marca, H.-Y Choi, S. Sah, “Experimental and Numerical Analyses of Seating Pressure Distribution Patterns”, SAE Paper 05DHM-16, 2005.
8. M. Kolich, S. Nunez, N. Montmayeur, R. Dwarampudi, C. Marca, “Virtual Seat Manufacturing and Testing for FMVSS202a Backset Prediction”, SAE Paper 07 DHM-11, 2007
9. M. Kolich, S. Nunez, N. Montmayeur, R. Dwarampudi, C. Cabane, C. Marca, “Virtual Seat Comfort Assessment through Effective Fore-Aft Lumbar Travel Prediction with a HPM-II Dummy Model”, 7th International CTI Forum On Automotive Seats, 2007

Virtual Testing Environment and Methodology for Thermal Comfort Models

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Abstract The electrification and automatization of vehicles increases the necessity to address human factors during the design process as well as the operation of those vehicles. Especially thermal comfort shows great influence both on energy demand as well as on the driver's performance. Studies show a decrease in range of more than 40 % of the electric range in cold heating scenarios, largely influenced by the additional power demand of the electric heater. Prototypic implementations of energy efficient climatization systems show a great potential for the reduction of energy demand, e.g. a prototypic implementation of radiation panels shows energy savings of approx. 30 % compared to the conventional electric heater. In order to further improve energy savings as well as thermal comfort, further development is necessary. Time and cost efficient development processes include detailed CAE (computer-aided engineering) tools, such as CFD (computational fluid dynamics) and objective thermal comfort models. Especially the latter are a vital part of the detailed design, both for the identification of feasible climatization components and their integration as well as the subsequent control algorithm. As a variety of thermal comfort models have been developed for different applications and under varying boundary conditions, a methodology for the comparison of these comfort models is needed. Thus, this paper describes a virtual testing environment and methodology for human thermal comfort models. The developed environment allows for fast comparisons between different thermal comfort models regarding their results in various boundary conditions. For this purpose, a CFD model with local resolution of the human body is introduced and a post-processing tool for the simultaneous implementation of different comfort models is developed. While the CFD model allows for the variation of the thermal boundaries, the calculation of the comfort states is carried out by the post processing environment. Especially this decoupling of simulation and comfort assessment allows for a flexible implementation, comparison and even development of new thermal comfort models. Results based on exemplary boundary conditions are presented for four different comfort models (Predicted Mean Vote, Equivalent Temperature, Local Mean Vote and Zhang's Model) and discussed. By the usage of an existing testing geometry, the possibility for comparative measurements and subjective studies has been included for further investigations.

Keywords: Thermal Comfort, Climatization, Simulation, Human Model, CAE

1 Motivation

The increasing electrification of passenger cars calls for changes regarding the climatization of the passenger cabin. Studies show a decrease in range of more than 40 % in cold heating scenarios [1], largely influenced by the additional power demand of the electric heater. Thus, the limited range of most EVs (electric vehicles) is

reduced further. In order to decrease the power demand of cabin heating and cooling, different measures are currently investigated in order to generate a comfortable climate in the passenger cabin. To assure customer acceptance, these systems are bound to generate an equally or more comfortable climate than conventional convective HVAC (heating, ventilation and air conditioning) systems. Prototypic implementations of such energy efficient climatization systems show a great potential for the reduction of energy demand, e.g. a prototypic implementation of radiation panels shows energy savings of approx. 30% compared to the conventional electric heater [2]. In order to further improve energy savings as well as thermal comfort, further development is necessary. Time and cost efficient development processes include detailed CAE tools, such as CFD and thermal comfort models. While a variety of comfort models have been described [3, 4, 5, 6], not all of these are equally suited for the boundary conditions of vehicle cabins or the heat transfer mechanisms of multimodal climatization systems. As accurate comfort prediction has to be considered crucial for the CAE process of innovative climatization concepts, a suitable comfort model has to be chosen in advance. Therefore, this paper will focus on a testing case for the comparison of different thermal comfort models for the use in an automotive passenger cabin. The resulting testing scenario can be used to compare different comfort models as well as to transfer results from studies based on different comfort models.

2 Thermal Comfort Models

A crucial part of comfort studies is the comfort model. As a variety of different thermal environments have been studied in the past, a plurality of comfort models [3, 4, 5, 6] suited for various purposes has been developed. The state of the art of thermal comfort models includes both local as well as global resolution models. Additional distinctions are the possibility to include active thermoregulation and the comfort basis (heat flow vs. temperature).
Thermal comfort models should account for all relevant heat transfer mechanisms in the respective environment, as shown in Figure 1. Parameters with influence on thermal comfort include air temperature (convection, sweating), air velocity (convection, sweating), air humidity (convection, sweating), radiation, metabolism (heat production), and clothing (insulation) [7].

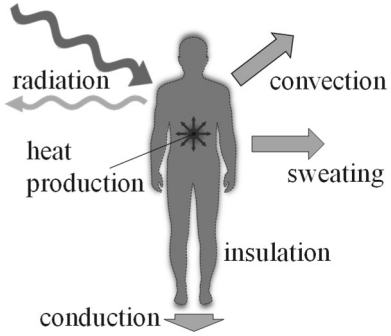


Fig. 1. Mechanisms influencing thermal comfort.

Additionally, the contact surface temperature will show major impact, especially in vehicle cabins, as many body parts are in contact with surfaces (e.g. steering wheel, seat). The corresponding components can either be considered in the comfort model itself (cf. Predicted Mean Vote) or solved externally, e.g. using a CFD simulation. The most commonly used or widely spread [8, 9, 10] thermal comfort models for comfort studies in vehicle cabins are described shortly in the following.

2.1 Heat Balance Based Comfort Models

In the following, comfort models based on the energy balance around the human body will be presented and discussed.

2.1.1 Predicted Mean Vote

The PMV (Predicted Mean Vote) was described by Fanger in [3] and describes a semi-empiric user rating on a scale from "-3" (too cold) to "+3" (too warm) and a neutral rating "0" (comfortable). The PMV is based on a heat balance around the human body, which is given in (1).

$$PMV = S \cdot [(M - W) - V - E - L - R - C] \tag{1}$$

The energy balance given in (1) is scaled to the PMV range with the scaling factor S and accounts for the metabolic heat production (M), the mechanical work (W), water vapor diffusion (V), evaporation on the surface of the skin (E), latent respiration (L), radiation (R), and convection (C) based on a skin temperature of 35.5 °C. Although the PMV is widely spread in the automotive industry, the definition only accounts for steady state and homogeneous environments, boundary conditions usually not present in the cabin environment. Additionally, thermal conductance is not addressed by its definition, which will yield inaccurate results for automotive cabins.

2.1.2 Equivalent Temperature

A common way to indicate comfort with local resolution is the ET (Equivalent Temperature) as described in [4]. Instead of a dedicated comfort scale, comfort is deducted by the temperature of a homogeneous environment with the same heat loss. The heat loss is determined in the actual, non-uniform environment and is assigned the same comfort as a uniform environment with the same local heat loss. Therefore, the combined boundary heat transfer coefficient h_{cal} (convective and radiative) is determined in calibration measurements or simulations for several sampling points. The resulting ET T_{eq} is then calculated based on the heat transfer coefficient h_{cal}, the boundary heat flux $\dot{q}_i''$ and the resulting surface temperature $T_{surface}$ as given in (3).

$$T_{eq,i} = T_{surface,i} - \frac{\dot{q}_i''}{h_{cal}} \tag{2}$$

In order to determine the comfort at various ETs, comfort rating studies are conducted in homogeneous environments, reducing the complexity of comfort clinics. Figure 2 shows the comfort temperatures for a clothing factor of 1 clo. The resulting areas are too cold (I), cold but comfortable (II), neutral (comfortable, III), warm but comfortable (IV), and too warm (V).

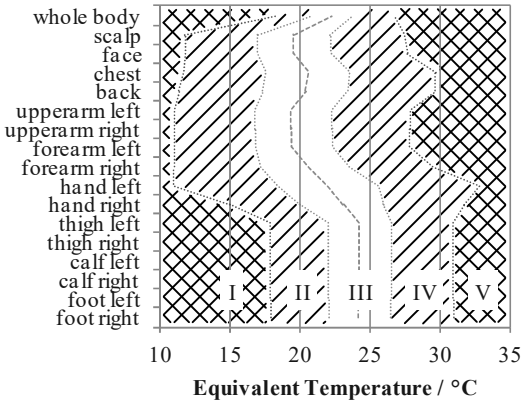


Fig. 2. Comfort temperatures for clothing factor 1 clo; Areas: I – too cold, II – cold but comfortable, III – neutral (comfortable), IV – warm but comfortable, V – too warm.

Additionally, the mean temperature for thermal comfort is marked in region III. Testing conditions for the homogeneous calibration prescribe that the mean radiative temperature equals the air temperature and an air velocity below 0.05 m/s. While the standard states a homogeneous chamber for calibration, the geometrical properties are not specified further.

Unlike the other comfort indices in this paper, the ET is not given on a rating scale but as the temperature of the equivalent environment and its comfort. While the possibility to conduct comfort clinics in thermally homogeneous environments reduces the complexity, interdependencies between different body parts in inhomogeneous environments cannot be considered.

2.2 Temperature Based Models

In the following, comfort models based on the temperature of the human body will be presented and discussed.

2.2.1 Local Mean Vote

The LMV (Local Mean Vote) was specifically developed for comfort studies in vehicle cabins to assess the impact of solar radiation [5]. Similar to the PMV, the LMV is based on a scale centered at "0" (comfortable). In contrast to the PMV it is not based on the resulting heat flows, but on the resulting surface temperature $T_{surface}$ of the respective body part. The thermal comfort is assumed to show a linear dependency from the RST, as indicated by (3).

$$LMV_i = a_i + b_i \cdot T_{surface,i} \tag{3}$$

The parameters have been determined empirically for each body part. The offset a_i shows results from different comfort temperatures for different body regions whereas the coefficient b_i describes the temperature sensitivity for the respective body part [5].

2.2.2 Thermal Comfort Scale by Zhang

In order to overcome shortcomings of previous models, e.g. the necessity for steady state or the limitation to a global comfort value, Zhang proposes a comfort model for both non-uniform and transient environments [6]. The comfort is defined by Zhang's temperature based local sensation values (S_l) as given in (4) [11].

$$S_{l,steady,i} = 4 \cdot \left(\frac{2}{1+e^{-C1_i \cdot (T_{skin,i}-T_{skin,set,i}) - K1_i \cdot [T_{skin,i}-T_{skin,set,i} - (\overline{T}_{skin}-\overline{T}_{skin,set})]}} - 1 \right) \tag{4}$$

The local sensation is based on the skin temperature of the individual body part $T_{skin,i}$ as well as the mean skin temperature $\overline{T}_{skin}$, both in reference to their temperatures in neutral and stable conditions ($T_{skin,set,i}$, $\overline{T}_{skin,set}$). The parameters $C1_i$ and $K1_i$ describe the temperature sensitivity and the influence of the overall thermal state on the local sensation respectively. Values for set temperatures have been described in [12], those for other parameters in [11]. The deduction of overall (global) sensation S_o from local sensation is described in [13]. Based on the local sensation in (4), the local comfort can be determined by (5) – (8). The coefficients *C31*, *C32*, *C6*, *C71*, *C72*, *C8*, and *n* are based on measurement data and are described in [6]. Similar to local sensation values, local comfort values also depend on the thermal state of the whole body, thus the overall sensations S_o^- and S_o^+ (cf. [13]). The resulting comfort values range from "-4" (very uncomfortable) to "+4" (very comfortable) with "0" representing the transition from "just uncomfortable" to "just comfortable".
Overall comfort is based on local comfort and determined by the two following criteria: The user has control over the thermal environment or transient thermal conditions are present. Due to the fact that at least the first criterion will be fulfilled in a passenger cabin, this is also assumed for the testing case described below. The overall comfort is then determined as the average of the two minimum local comfort votes and the maximum one (cf. [13]).

$$LC_i = \left[\frac{\frac{-4-A_{1,i}}{|(-4+A_{2,i})|^{n_i}} - \frac{-4-A_{1,i}}{|(4+A_{2,i})|^{n_i}}}{e^{25 \cdot A_{3,i} + 1}} + \frac{-4-A_{1,i}}{|(4+A_{2,i})|^{n_i}} \right] \cdot A_{3,i}{}^{n_i} + A_{1,i} \tag{5}$$

$$A_{1,i} = C6_i + C71_i \cdot |S_o^-| + C72_i \cdot |S_o^+| \tag{6}$$

$$A_{2,i} = C31_i \cdot |S_o^-| + C32_i \cdot |S_o^+| + C8_i \tag{7}$$

$$A_{3,i} = S_{l,i} + A_{2,i} \tag{8}$$

As the comfort definitions presented above show, the comfort ratings between these comfort models cannot be converted directly. While a variety of studies regarding passenger comfort have been conducted [14, 15, 16], the results cannot be compared directly as different models were chosen. On the other hand, different comparative simulations have been published for specific purposes, e.g. [8], but a generic environment for the comparison has not been proposed for the virtual comparison of thermal comfort models. A benchmark environment to compare measurements on thermal manikins to simulations is proposed in [17]. Thus, a testing scenario to virtually compare different comfort models is necessary and proposed in the following.

3 Testing Scenario

In order to provide a testing scenario for the comparison of different thermal comfort models, two aspects are needed: a testing environment providing a defined thermal environment and a human shaped thermal manikin to implement the resulting temperatures and heat fluxes.

3.1 Testing Environment

The testing environment should fulfill a variety of requirements, such as simple geometries and the possibility to include localized climatization (e.g. local nozzles) or different technologies (convective vs. radiative heating). Simple geometries reduce the effort necessary for meshing and may shorten calculation times, while also simplifying the realization of additional nozzles or radiative elements.
An existing test bench for the comparison between simulative models and test dummies is described in [17]. A test case has been set up in a rectangular wind tunnel with dimensions allowing to test standing and sitting dummies. The chamber offers dimensions of 2.44 m x 1.20 m x 2.46 m with a large inlet and two separate outlets (cf. Figure 3). The thermal dummy is positioned 0.70 m behind the inlet [17]. In order to improve the feasibility of actual comparative measurements, the testing environment of [17] has been replicated virtually and is used for the comparison in this paper.

3.2 Thermal Manikin

State of the art thermal models provide the possibility to take the human thermophysiology into account. Consequently, the heat flow between and the heat production in body parts is adjusted based on the respective thermal state in order to achieve thermal comfort. For the purpose of the benchmark environment to compare different comfort models, a fixed implementation of the heat fluxes is feasible and reduces the simulation effort. Thus, for the purpose of this paper, a uniform heat distribution of 58 W/m^2 is assumed [7], but can be easily changed to inhomogeneous heat distribution or active thermal models if necessary.
Regarding the physiology, a 50th percentile Caucasian male has been chosen as reference to compare the thermal comfort models described above and has been adjusted to a typical seating position for vehicular passenger cabins. The resulting thermal dummy shows a body height of 174.5 m with a weight of 70.64 kg.

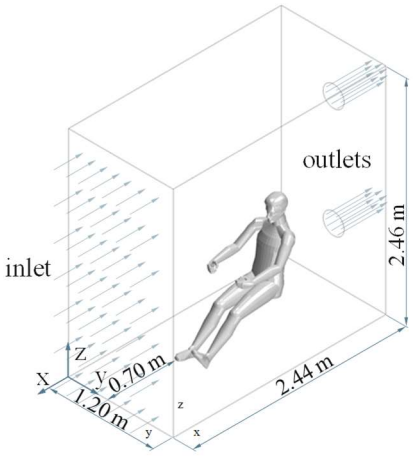


Fig. 3. Geometry and dimensions of testing environment.

3.3 Simulation Model

After the preparation of the geometries (manikin and testing environment), the model is set up using the commercial software STAR-CCM+ for pre- and post-processing as well as solving. In order to reduce computational times and effort for the purpose of comparison while maintaining an accurate solution, a mesh independency study has been conducted for inlet velocities of 0.25 m/s and 1 m/s. The profiles for the velocity magnitude and air temperature for a linear probe positioned centrally 150 mm behind the thermal dummy are shown in Figure 4 for mesh base sizes of 25 mm (approx. 7 Mio. cells), 50 mm (approx. 1.1 Mio. cells) and 100 mm (approx. 0.22 Mio. cells). The boundary prism layers remain unchanged to provide acceptable dimensionless wall distance (y+) values for all meshes.

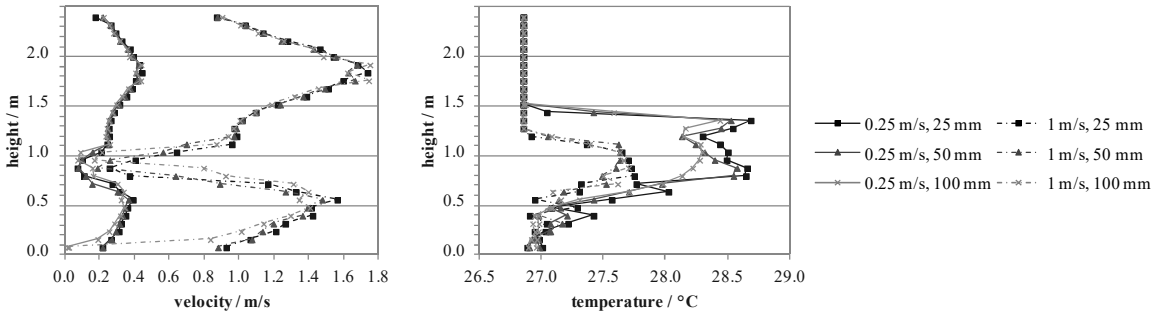


Fig. 4. Results from mesh independency study for different mesh sizes and boundary conditions: Velocity profile (left) and temperature profile (right).

As can be seen in Figure 4, the mesh can show significant impacts on velocity magnitude and temperature profiles. Solutions from the mesh with a base size of 100 mm differ notably from those with finer meshes, especially for higher air velocities. On the other hand, the differences between base sizes of 25 mm and 50 mm are negligible, especially for lower air velocities prevailing in this paper. Thus, a mesh base size of 50 mm is chosen in order to provide faster calculation times compared to the finer mesh. In case of increased air velocities above 1 m/s, further studies will be necessary.

Regarding the boundary conditions, the inlet is defined with a uniform velocity, as described in [17], while the outlet is used as pressure reference for the simulation. Furthermore, the Segregated Flow Solver has proven to be more robust for this simulation case. Other parameters are summarized in Table 1.

Convergence criteria are the drop of the residuals for continuity, X-, Y- and Z-momentum, turbulent kinetic energy and dissipation rate as well as energy by several orders of magnitude. Additionally, temperatures on the thermal dummy must have stabilized.

As a homogeneous heat distribution is assumed, the comfort does not have to be implemented during the simulation, but can be calculated during post-processing. Therefore, several comfort models can be considered simultaneously and additional comfort models can be easily added without the need for further iterations. The resulting temperatures for the thermal dummy by the CFD simulation are the resulting surface temperatures. While these temperatures are directly applicable for the LMV model, other comfort values, as shown above, are based on skin temperature.
For steady state simulations, the skin temperature can be calculated by the thermal conduction of the heat flux $\dot{q}_i''$ through the clothing (thermal conductance λ_i) as

$$T_{skin,i} = T_{surface,i} + \frac{\dot{q}_i''}{\lambda_i}. \tag{9}$$

Additionally, the overall heat transfer coefficient $h_{cal,i}$ for the ET [4] is determined by (10) based on the heat flux $\dot{q}_i''$, the RST and the homogeneous ambient temperature.

$$h_{cal,i} = \frac{\dot{q}_i''}{T_{surface,i} - T_{ambient}} \tag{10}$$

Table 1. Simulation parameters and values.

Domain	*Category*	*Parameter*	*Value*
Mesh	Polyhedral Volume Mesh	Base Size	50 mm
		Target Surface Size	25 mm
	Prism Layer Mesh	Number	2
		Total Tickness	5 mm
Physics Continuum	Gravity		-9.81 m/s^2
	Ideal Gas (Air)	Reference Density	1 kg/m^3
	k-ε Turbulence		
	Segregated Flow		
	Steady State		
	Surface-to-Surface Radiation	Gray Thermal Radiation	
Model Specific	Thermal Dummy	Heat Flux	58 W/m^2
		Surface emissivity	0.98

4 Exemplary Results

For the purpose of demonstration, exemplary simulations have been set up and are presented in the following. All cases were calculated and reached the convergence criteria described in section 3. Based on the results of the CFD simulation, the steady state global and local (where applicable) comfort values have been determined for the comfort models described in section 2. The boundary conditions are listed in Table 2.
The results are presented in Figure 5. All models show the same tendencies with changing boundary conditions, while the resulting comfort values differ greatly.
As expected, the most extreme comfort values are found for cases 1 and 2, as these show the lowest air velocities and thus the lowest mass flow rates of cooling air and additionally the lowest air inlet temperature (case 1). Cases 3 and 4 on the other hand provide additional cooling compared to case 2, as the inlet velocity is increased (case 3) or the mean radiative temperature decreased (case 4). The mean radiative temperature for case 4 has been adapted to the effect that cases 3 and 4 show the same resulting PMV with different inlet velocities. As shown in Figure 5, the remaining models with a global comfort indication (ET and the model by Zhang) also show the same global comfort indication, although the resulting comfort values differ.
Both the PMV and the ET indicate relatively good comfort for all cases, with the PMV indicating slightly warm and cool sensations and the ET remaining within moderate comfort boundaries. The LMV and model by Zhang on the other hand show the absence of comfort for several body parts in each case. For case 1, the LMV indicates

cold discomfort for both calfs, while cases 2 – 4 mainly suffer from warm discomfort on the arms, chest and head.
The model by Zhang on the other hand shows relatively good comfort for head, chest, forearms, pelvis and feet in case 1, while most other body parts do not reach "just comfortable" ("0"). For cases 2 – 4, almost no region reaches a state of comfort.
Large differences for local comfort indications can be observed especially for the calfs. While ET and LMV indicate good comfort for these regions, Zhang's model shows very strong discomfort, due to the large asymmetries and the influence of the overall sensation.

Table 2. Boundary conditions for simulations presented.

	v_{in}	$T_{air,in}$	$T_{radiation}$	*Annotation*
Case 1	0.025 m/s	20 °C	$T_{air,in}$	Also used as calibration case for ET.
Case 2	0.025 m/s	25 °C	$T_{air,in}$	Also used as calibration case for ET
Case 3	0.25 m/s	25 °C	$T_{air,in}$	Resulting PMV used for case 4
Case 4	0.025 m/s	25 °C	Lefthand wall 16 °C, others $T_{air,in}$	Asymmetric, same global PMV as case 3

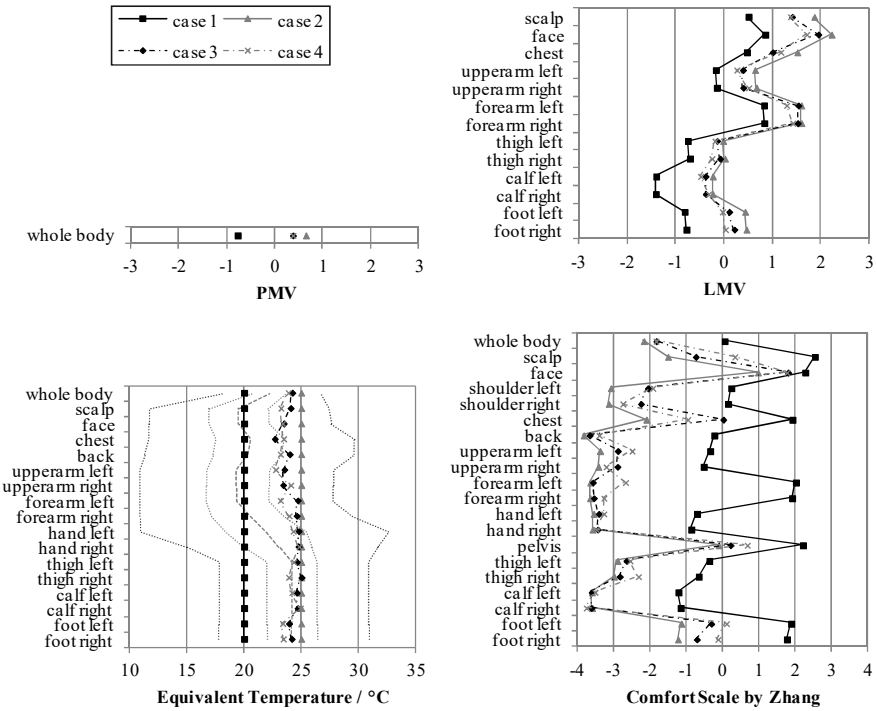


Fig. 5. Resulting comfort values from exemplary cases 1 – 4 for different comfort models: Predicted Mean Vote (top left), Equivalent Temperature (bottom left), Local Mean Vote (top right), and Comfort Scale by Zhang (bottom right).

5 Conclusion

This work presents a virtual testing environment that allows for fast comparisons between different thermal comfort models. By the usage of an existing geometry, the possibility for comparative measurements has been made possible. The usage of robust solver settings and mesh properties allow for the testing of a wide range of different boundary conditions. By the implementation of the comfort model in the post-processing, it is possible to include several comfort models simultaneously for direct comparison of their results. Additionally, further

comfort models can be added effectively to already existing simulation cases without the need of further iterations in the CFD solver.
As can be seen from the results of the exemplary cases, the comfort models show quite differentiating results regarding the comfort assessment. Further work is needed in order to identify strengths and weaknesses for the comfort models used above and identify suitable comfort models for the application in the design of automotive passenger cabins.
For these future works, the testing environment has to be evaluated including a wider range of boundary conditions, e.g. localized heating or cooling nozzles, and the effect of non-uniform heat distributions over the human body will be investigated. Additionally, the environment will be extended to allow for the simulation of transient boundary conditions and the respective comfort.

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References

1. Konz, M., Lemke, N. Försterling S., Eghtessad, M., 2011. Spezifische Anforderungen an das Heiz-Klimasystem elektromotorisch angetriebener Fahrzeuge. FAT-Schriftenreihe, no. 233.
2. Lichius, T., Backes, D., Dreyer, S., Pingel, M., Gissing, J., Baltzer, S., Schwalm, M., Eckstein, L., 2015. Textile Applications for Air-Conditoning of the Vehicle‘s Interior. 24. Aachener Kolloquium Fahrzeug- und Motorentechnik Proceedings, 429-441.
3. Fanger, P., 1972. Thermal comfort: analysis and applications in environmental engineering. McGraw-Hill, New York, NY, USA.
4. ISO 14505-2, 2006. Ergonomics of the thermal environment - Evaluation of thermal environments in vehicles - Part 2: Determination of equivalent temperature.
5. Schwab, R., 1994. Einfluß der Sonneneinstrahlung auf die thermische Behaglichkeit in Kraftfahrzeugen. FAT-Schriftenreihe, no. 109.
6. Zhang, H., Arens, E., Huizenga, C., Han, T., 2010. Thermal sensation and comfort models for non-uniform and transient environments, part II: Local comfort of individual body parts. Build Environ 45 (2), pp. 389-398.
7. Parsons, K., 2002. Human Thermal Environments. CRC Press, Boca Raton, FL, USA.
8. Cheng, Y., Niu, J., Gao, N., 2012. Thermal comfort models: A review and numerical investigation. Build Environ. 47, 13-22.
9. Alahmer, A., Mayyas, A., Mayyas, A., Omar, M., Shan, D., 2011. Vehicular thermal comfort models; a comprehensive review. Appl Therm Eng 31 (6 – 7), 995-1002.
10. Alahmer, A., Omar, M., 2013. Vehicular Cabins' Thermal Comfort Zones; Fanger and Berkley Modeling. Vehicle Engineering 1 (1), 19 – 32.
11. Zhang, H., Arens, E., Huizenga, C., Han, T., 2010. Thermal sensation and comfort models for non-uniform and transient environments: Part I: Local sensation of individual body parts. Build Environ 45 (2), 380-388.
12. Zhang, H., 2003. Human thermal sensation and comfort in transient and non-uniform thermal environments. University of California, Berkeley, CA, USA.
13. Zhang, H., Arens, E., Huizenga, C., Han, T., 2010. Thermal sensation and comfort models for non-uniform and transient environments, part III: Whole-body sensation and comfort. Build Environ 45 (2), 399-410.
14. Chen, K., Bozeman, J., Wang, M., Ghosh, D., Wolfe, E., Chowdhury, S., 2015. Energy Efficiency Impact of Localized Cooling/Heating for Electric Vehicle. SAE Technical Paper 2015-01-0352.
15. Chen, K., Kaushik, S., Han, T., Ghosh, D., Wang, M., 2012. Thermal Comfort Prediction and Validation in a Realistic Vehicle Thermal Environment. SAE Technical Paper 2012-01-0645.
16. Daithankar, N., Udawant, K., Karanth, N., 2015. Prediction of Thermal Comfort Inside a Midibus Passenger Cabin Using CFD and Its Experimental Validation. SAE Technical Paper 2015-26-0210.
17. Nilsson, H., Brohus, H., Nielsen, P., 2007. CFD Modeling of Thermal Manikin Heat Loss in a Comfort Evaluation Benchmark Test. Roomvent 2007 Proceedings.

Development of automobile seat for fatigue reduction focused on biomechanical loads

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Abstract Neutral posture which can be observed in the zero-gravity environment seems to be low-fatigue posture which minimizes biomechanical loads. It needs to recline backrest backward so that the neutral posture can be realized at seating condition in the gravity field. The purpose of this study is to develop an ideal driving posture which is fitted with ordinarily used seatback structure and a new seat which supports upper-body so that it may reduce physical fatigue during driving. The developed seat was tested by subjective evaluation and physiological measurement during long-term driving. The results showed the developed seat reduced physical fatigue compared with the conventional seat.

Keywords: Automotive seat, Fatigue reduction, Driving posture, Biomechanical loads.

1 Introduction

Physical fatigue during long-term driving is mainly caused by muscle loads that maintain posture, palsy or pain due to the concentration of contact pressure, decrease of blood flow due to muscle load and contact pressure concentration. In the past, for the purpose of restoring blood flow, research aimed at reducing the concentration of contact pressure by verifying the fatigue reduction effect using vibrator at the lumbar part in the seat [1], and studies have been reported in which fatigue of buttocks and thighs is reduced by distributing the contact load on the devised shape of the urethane surface [2].

The decrease of blood flow is not a direct factor of physical fatigue, but it is considered to be a secondary factor due to muscle loads and contact conditions. And, the effect of contact pressure reduction is mainly effective for a seat part where large loads concentrate. This study was focused on the reduction of muscle loads on the lumbar region considered as a direct cause of the physical fatigue.

As a research aimed at reducing the lumbar muscle loads, a seat that supports the pelvis and the lumbar has been proposed rather than intensively supporting the lumbar region. And, it has been shown that it is effective to be supported by a wide surface with a posture in which the muscle loads are small [3].

Also, not only the pelvis and the lumbar but also the entire trunk is suggested to support a driving posture with less biomechanical loads by supporting with an articulated two-piece backrest [4, 5, 6]. The proposed posture is a posture close to the neutral posture in the zero gravity [7] balanced in a state where the passive loads of the body are the minimum, which is considered to be an effective way of reducing the muscle loads. This posture is mainly supposed to be a highway, it will be a relaxed posture with reclined backrest. In addition, by making the seat back into two parts and making it possible to adjust the angle of the upper and the lower part, it is realized to provide optimum conditions individually.

2 Concept for development fatigue reduction seat

2.1 Physical fatigue reduction concept

The thoracic vertebrae located in the thorax in the human spine are closed by the ribs and can be regarded as a block structure with restricted movement. This thorax and pelvic area have a heavy weight and are connected by the lumbar spine with a high degree of freedom for movement. Also, in the sitting posture, the pelvic area rotate backward due to the activity of hamstrings.

Therefore, it is considered that the muscular loads on the spine that keep the posture can be reduced by supporting the pelvic part by lower-side of the backrest for preventing backward rotation, and by supporting the heavy thoracic part weight by the upper side of the backrest.

The author confirmed as a method of reasonably supporting the pelvis and the thorax that it is effective to support by articulated backrest at the optimum posture where the lower and the upper part of the backrest approaches near the body in the previous study [4, 5, 6].

In this research, regarding the concept written in above, we developed a seat with an articulated shape on backrest as to be in the optimum posture at the backrest angle suitable for ordinary driving. Because the optimum posture of previous study indicated reclined posture with articulated backrest, therefore it required much interior space and additional cost for seat structure, and also it is suitable for long cruising in highway but not for multipurpose driving at various scenes. We attempted to reduce the muscle loads on the lumbar region without any special adjustment mechanism by using this concept.

2.2 Pre-confirmation of concept

We confirmed the effect of fatigue reduction by using biomechanical simulation in advance.

In order to estimate fatigue reduction effect in normal usage of backrest angle, originally simulation system was used. The system was based on the estimation of fatigue evaluation result using biomechanical loads. Biomechanical loads were calculated by a 2-dimensional musculoskeletal model for sitting posture and seat reaction force estimation. The system was composed by 5 steps.

1) Input backrest angle.

2) Skeletal posture estimated using regression formulas constructed by measurement data of various subjects and postures.

3) Estimation of seat reaction forces acted to the body segments that balance of static equilibriums of the whole-body weight in the sitting posture using numerical optimization.

4) Estimations of biomechanical loads using 2-dimensional musculoskeletal model [8] shown in Figure 1.

5) Estimation of physical fatigue index using regression formula constructed by physical fatigue index calculated from subjective evaluations of fatigue on static long-term sitting and biomechanical loads that mainly concern the determination of sitting posture [9] in the various backrest angles.

Regarding whole paper purpose, methods were described briefly. Details of the methods will be written in upcoming papers [10].

Simulation results are shown in Figure 2. Regarding the simulation results, we confirmed we can get at least about 10 % fatigue reduction for ordinary driving typical backrest angle.

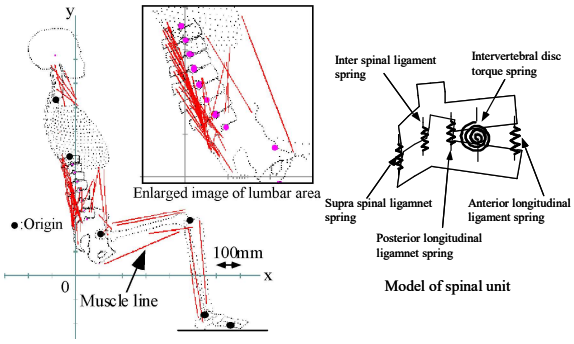


Fig. 1. 2-dimensional musculoskeletal model.

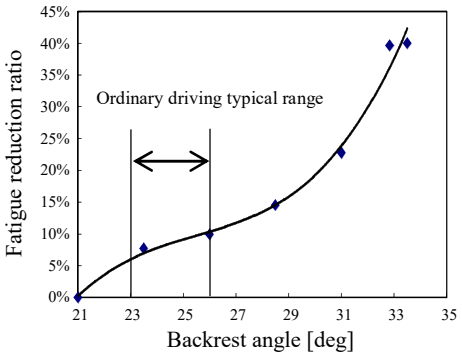


Fig. 2. Estimated fatigue index and backrest angle.

3 Optimizations of sitting posture and contours

3.1 Methods

The seat simulator [4] shown in Figure 3 developed with reference to the variable cushion chair [11] was used. The seat simulator has 8 plates on seat and 14 on backrest, each of which can be adjusted in position and can be changed into various seat shapes.

In the experiment, the initial shape of the seat simulator was set at 25 degrees on the premise of the backrest angle which is suitable for ordinary driving. The position of each of the lower 10 units located in the behind trunk were adjusted by the subjects, and the posture and the seat surface shape at that time were measured. The sitting posture was measured using a three-dimensional digitizer (FARO Technologies, Inc. FARO-ARM). Since T10 and S1 are hidden by backrest during sitting, the points were measured beforehand sitting in a chair without backrest, and geometrically estimated assuming the thorax and pelvis as rigid blocks. Twelve healthy subjects (male 10 and female 2, height 149-180 cm) were examined.



Fig. 3. The seat simulator.

3.2 Results

(1) Sitting posture

An example of the sitting posture measurement results and the angle definition of the measured posture are shown in Figure 4. Table 1 shows the average and standard deviation, and the comparison with the previous study results.

In the previous study, the measured posture was close to the neutral posture [4]. On the other hand, in this study, the optimum posture measured at the backrest angle suitable for ordinary driving was the posture that the lumbar and pelvis inclined forward in accordance with the backrest angle, and the thorax angle change was small. Therefore, the angle between the thorax and the lumbar became larger as the pelvis inclined, and the articulated angle became loose.

The result seems to be occurred by keeping the angle of the thorax for gazing forward and handling, and by changing the relationship between the torso weight and the passive resistance torque of the joints due to the backrest angle change. In other words, it is considered that the optimum angle between the thorax and lumbar tends to change according to the change of the backrest angle, but the thorax tries to keep the angle.

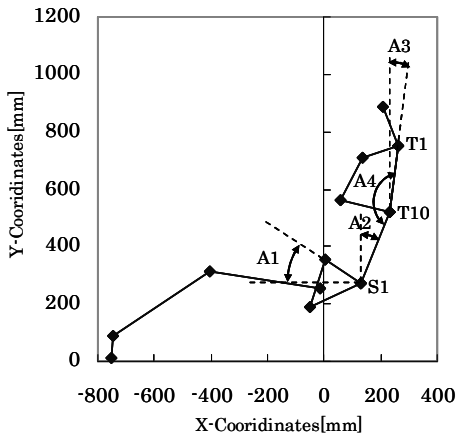


Fig. 4. Equation formatting.

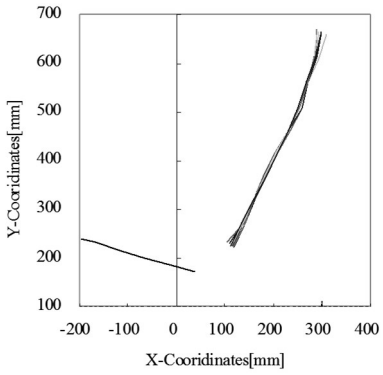
Table 1. Comparison of skeletal angle.

Skeletal angles		Previous study posture[4]	Measurement results of optimized posture		Difference of Ave.
		Ave.	Ave.	Std.	
A1	Pelvis angle	45.7	38.0	14.6	-7.7
A2	Lumbar angle (T10-S1)	35.0	25.6	7.4	-9.4
A3	Thorax angle (T1-T10)	9.2	7.6	6.6	-1.6
A4	Lumbar-Thorax angle (T1-T10-S1)	154.2	162.0	12.3	7.8

(2) Sitting contours

Figure 5 shows the backrest contour measurement results on the seat simulator of 12 subjects adjusted by themselves at the optimum sitting posture and Figure 6 shows the average shape. The contour that felt optimal is almost the same even if physique is different, and it shows an articulated shape that bends at the center part of the backrest. This seems to be the result of adjusting to being a constant optimum angle between the thorax and the lumbar suited to the backrest angle.

This result is the seat shape when sitting on a rigid seat. In the actual seat, we thought that it would be equivalent with the seat contour after the sitting deflection and we developed a seat prototype shown in Figure 7 with adjusted deflection characteristics so that the seat surface after sitting becomes the average shape of the measured results.



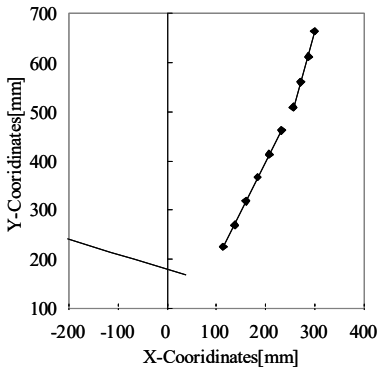




Fig. 5. Measurement results of optimized seat contours. **Fig. 6.** Average of optimized seat contours. **Fig. 7.** Developed seat.

(3) Confirmation of developed prototype seat

In order to check whether the developed seat was prototyped as intended, we compare the developed seat with the current seat using pressure distribution. For measurement of body pressure distribution, Tekscan Inc. BIGMAT system was used. The developed seat and the current seat had the same structure for the seat cushion part, and the evaluation was done with specifications that changed only the backrest.

Figure 8 shows the measurement result of the pressure distribution same when same subject (male, 171cm, 70kg) sitting on the current seat and the developed seat, and Figure 9 shows the comparison of the relationship between the sum of the pressure values of the cross sections of the two seats and the position in the longitudinal direction. The developed seat supports the pelvis and the thorax part and continuously supports from the bottom to the top of the backrest in contrast to showing the body pressure distribution strongly supporting the lumbar region in the current seat. Therefore, it was found that the seat having the articulated shape adjusted to keep the optimum posture made it possible to positively support the pelvis and the thorax according to the concept.

In addition, we confirmed reproducibility of the sitting postures.

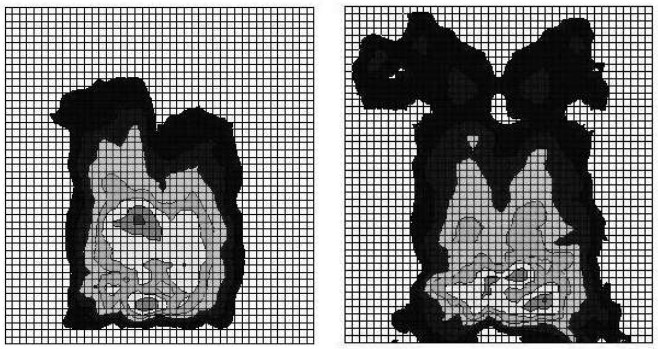


Fig. 8. Comparison of pressure distribution.

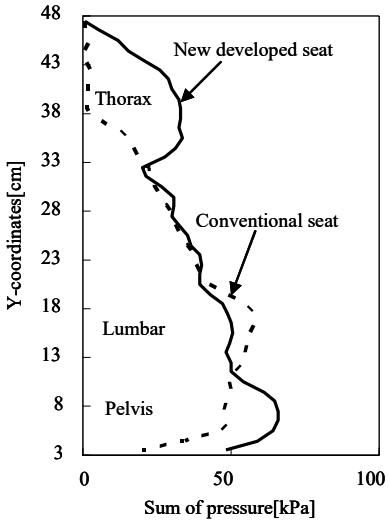


Fig. 9. Sum of pressure.

4 Dynamic evaluations of fatigue reduction effects

In order to verify the effect of the developed seat, we conducted a fatigue evaluation experiment during long-term driving using the current and the developed seat.

4.1 Experimental conditions

The developed seat and the current seat were attached to the same L class sedan vehicle (2500 cc), and 120 minutes continuous driving experiments were done on the condition of 100 km/h steady driving on an oval circuit of the test course (1 round 6.5 km). The driver's posture can be adjusted to an easy to drive position by using the seat slide, lifter, reclining, and steering position. Subjective evaluations were done on 14 male subjects (156-190cm), and electromyography measurements were performed on 3 subjects. The experiments of for the same subjects were conducted once a day to reduce the influence of accumulation of fatigue, and the second experiment was conducted at the same time on another day.

4.2 Methods

(1) Subjective evaluations of fatigue

Subjective evaluation of fatigue was measured as a rating of fatigue of each body part.
Ratings - 0: None 1: Felt slightly 2: Felt a little 3: Felt 4: Felt considerably 5: Unendurable
Body part - Neck, shoulder, back, lumbar, arm, buttock, thigh, knee, calf, and ankle
Evaluation time - 0, 5, 15, 30, 45, 60, 90, 120 minutes

Physical fatigue index was defined as the weighted sum of each rating. Weighting factors considering the relative importance fatigue of body part during long-term driving determined by Sheridan [12] were used. Weighting factors were as follows.

Neck, Back, Lumbar: 0.5
Shoulder, Buttock, Knee, Thigh: 0.4
Arm, Calf, Ankle: 0.3

(2) Electromyography

In order to measure the muscle loads in the driving posture, back muscle activity was measured using electromyography with an active electrode (Biometrics Ltd. Active SX230 Surface EMG System). The measurement was done in every 15 minutes in 20 seconds during running on the straight part of the test course. The electrode was attached to the surface of the back muscle on L2 level. In order to normalize the magnitude of the myoelectric potential between the subjects, the average amplitude of the myoelectric potential measured during 20 seconds at 196N lifting at the posture trunk tilted forward 30 degrees before driving. The measured myoelectric potential divided by the average was used as the normalized muscle activity during driving. The integrated myoelectric potential value was used as an index of the muscle activity.

4.3 Results

(1) Subjective evaluations

Fig. 10 shows the physical fatigue index of the current and the developed seat with an average and standard deviation. Figures 11 and 12 show the local fatigue index of the lumbar and buttocks, especially where fatigue reduction was large. The physical fatigue of the developed seat reduced since 45 minutes driving and maintained its effect by comparing those of the current seat. Also at the lumbar and buttocks, fatigue showed a tendency to decrease after running for 45 minutes as well. This result seems to be the effect of the supports at the pelvis and thorax which reduce the back muscle activity for maintaining the posture, and the reduction of fatigue on the buttock brought by the load movement from the seat cushion to the backrest in the developed seat.

(2) Electromyography

Fig. 13 shows the integrated electromyography during driving. The muscle activity in the developed seat was lower than in the current seat from the start of driving, and it maintained until the end of driving. Especially, the difference became large from 45 minutes, which also coincides with the tendency of subjective evaluation results. Therefore, it was found that the back muscle activity of the developed seat is smaller than that of the current seat.

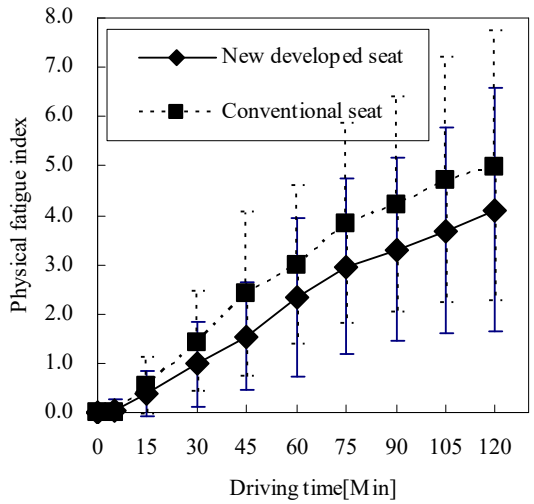


Fig. 10. Subjective evaluation of physical fatigue.

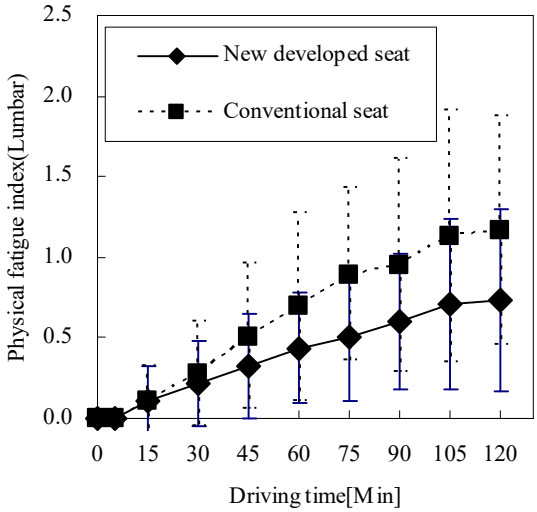


Fig. 11. Subjective evaluation of lumbar fatigue.

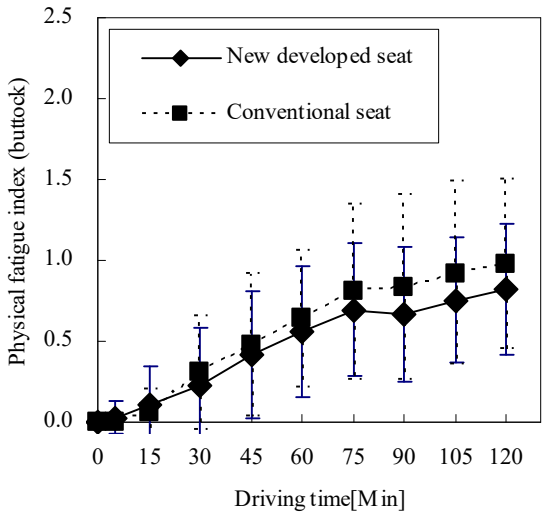


Fig. 12. Subjective evaluation of buttock fatigue.

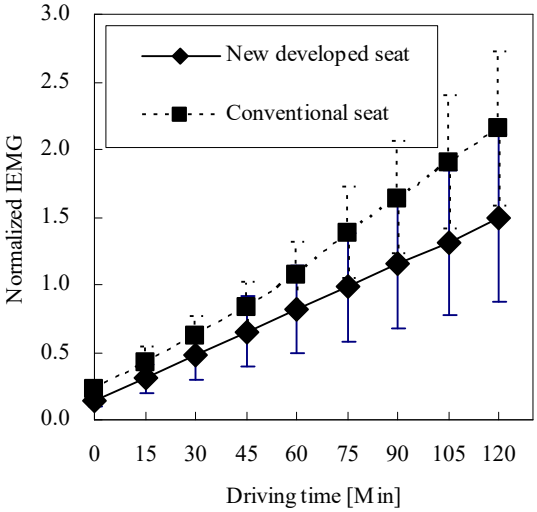


Fig. 13. Normalized IEMG.

5 Conclusions

In this study, a method of applying the idea indicated by the previous study, to reduce fatigue by supporting a trunk with an articulated backrest with a posture close to a neutral posture, was examined with a backrest angle suitable for ordinary vehicle with the current vehicle layout. As a result, it was found that the angle between the thorax and the lumbar becomes small at the optimum posture under the condition where the backrest angle upright. It was also found that the seat supporting this posture had an articulated contour shape after sitting, and developed a seat that achieves the shape with modifications of deflection characteristics.

It was confirmed that the developed seat strongly supported the pelvis and the thorax against the current seat and realized continuous support from the bottom to the top of the backrest.

In the dynamic evaluation for long-term driving, we confirmed fatigue reduction qualitatively by the subjective evaluations and quantitatively by the physiological measurements of muscle activity.

Therefore, as described in the concept, a seat having articulated shape optimum for a backrest angle suitable for current vehicles efficiently supports the pelvis and thorax, reduces the muscle loads on the spine column between them, and then physical fatigue can be reduced. For this reason, fatigue reduction could be realized

without additional cost by adjusting the deflection characteristics of the backrest instead of having a special adjusting mechanism such as articulation on the backrest.

In conducting all the experiments of this research, the informed consent for an experiment involving human subjects was obtained from the experiment participants with in advance explanations of the experiment.

Acknowledgments The authors would like to thank Professor Nobutoshi Yamazaki of Keio University for kind advice and Tachi-S Co., Ltd. for seat prototyping.

References

1. Iwata, Y., Hayashi, Y., Morita, Y., Ukai, H., Yokoyama, K., Fujimaki, G., Ando, T., Shiratori, A., Tanase, M., Verification of effectiveness of reducing fatigue of waist by vibration seat, Proceedings of JSME Tokai branch 58th Conference, 2009, 58, 161-162 (In Japanese).
2. Ishikawa, H., Moto, A., Nishimura, H., Imai, K., Kondo, S., The Evaluation of the Seat Pad for the Car in Consideration of the Ergonomic Technique, Fukuoka Industry Technology Center Research Report, 2009, No.19, 77-80 (In Japanese).
3. Katsuraki, M., Hanai, T., Takatsuji, K., Suwa, A., H. Nagashima., Development of the New Generation Ergonomic Seat Based on Occupant Posture Analysis, SAE Paper, 1995, 950140.
4. Hirao, A, Kitazaki, S., Yamazaki, N, Development of a new driving posture focused on biomechanical loads, SAE Paper, 2006, 2006-01-1302.
5. Hirao, A., Kato, K., Kitazaki, S., Yamazaki, N., Evaluations of physical fatigue during long-term driving with a new driving posture, SAE Transactions Journal of Passenger Cars: Mechanical Systems, 2008, V116-6, 69-76.
6. Hirao, A., Kato, K., Kitazaki, S., Yamazaki, N., Proposal of a Driving Posture for Fatigue Reduction Based on Manysided Evaluations, Biomechiansms, 2008, 19,125-135 (In Japanese).
7. George C. Marshall Space Flight Center: Man / System Requirements for Weightless Environments, 1976, MSFC-STD-512A, Chap.2.2.
8. Hirao, A., Yamazaki, N., Biomechanical estimation method of internal loads on sitting posture using a two-dimensional musculo-skeletal model, Transactions of the Japan Society of Mechanical Engineers. C , 2001, 67(661), 2921-2927 (In Japa-nese).
9. Hirao, A., Yamazaki, N., Biomechanical criteria for determination of sitting posture, 2017, In preparation.
10. Hirao, A., A driving posture comfort simulation tool based on physical fatigue estimation by musculo-skeletal model, 2017, In preparation.
11. Yamazaki, N., Sasaki, T., Aizawa, J., Development of cushion-adjustable chair for analysing individual sitting condition, The Japanese Journal of Ergonomics, 1997, 33(4), 211-218 (In Japanese).
12. Sheridan, T. B., Meyer, J. E., Roy, S. H., Decker, K. S., Yanagishima, T., Kishi, Y., Physiological and Psychological Evaluations of Driver Fatigue during Long Term Driving, SAE Paper, 1991, 910116.

Development of a method for rating thermal and moisture seat comfort

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Abstract The comfort aspect in the vehicle interior is becoming increasingly important. A high comfort level offers the driver a good and secure feeling and has a strong influence on passive traffic safety. One important part of comfort is the climate aspect, especially the microclimate that emerges between passenger and seat. The heat and moisture management between different assembled materials and their layer construction can influence the passengers comfort feeling. For seat systems, it is accordingly important to understand how moisture and heat are transferred and accumulated through the different layers of a seat. So far, there is no unified measurement scenario to determine the thermo-physiological behaviour of car seats. It shall investigate whether standardised methods for measuring thermo-physiological comfort of clothing can be adapted for investigations on vehicle seats. The aim of this project is to discover indicators for quantifying the quality of thermo-physiological behaviour of vehicle seats by a reliable measuring method. In this investigation, different combinations of typical seat materials were used. Woven and knitted fabrics, leathers and its substitutes for the face fabric layer, foam, non-woven and 3D spacer for the plus pad layer and for the support layer diverse foam types with variations in structure and raw material and a rubber hair structure were investigated. To characterise this sample set by thermo-physiological aspects (e.g. water vapour resistance R_{et}, thermal resistance R_{ct}, buffering capacity of water vapour F_d) regular and modified sweating guarded hotplates were used according to DIN EN ISO 11092. Subject trials in a driving simulator were executed to rate the subjective thermo-physiological sensation while driving. Physiological data like skin and core temperature, heart rate etc. were recorded, too. For objective thermo-physiological product measurements of the materials on the complete seat the thermal, sweating manikin (Newton Type by Thermetrics) was used. The manikin is able to measure the R_c and R_e values on the contact area to the seat. The results of the material characterization confirm the common knowledge that seat covers out of textiles have better water vapour resistance values than leathers and its substitutes. The results of the subject trials approve that the test subjects are able to distinguish between different materials and indicate that the support layer also has a great influence. It shows that every test subject has his or her own subjective perception concerning the climate comfort. This is one aspect why it is necessary to establish an objective, reliable and repeatable measuring method. It is necessary to identify correlations between manikin measurements and subject trials to hand out thresholds for R_e and R_c values. The challenge in this research is to derive the parameters for the manikin measurements out of the subject trials. Sweating rate and surface temperature adjustments for the manikin have to be realistic and repeatable. Such a measuring method can be used as a basic system to characterise seats by thermo-physiological aspects and to develop standards in the future. The Authors are grateful for the encouragement and for the financial support from Adient Components Ltd. & Co. KG.

Keywords: Thermal sweating manikin, seat comfort, clothing physiology, heat and moisture transport.

1 Background

Vehicle seats have to meet and fulfil many requirements and customer needs. The safety aspect is of prime importance, especially in case of a crash. To operate a vehicle without restrictions it is necessary to be able to access all control instances. The seat position is also responsible for a sufficient visibility field. Last but not least a high comfort level offers the driver a good and secure feeling and has a strong influence on passive traffic safety [1]. One important part of comfort is the climate aspect, especially the microclimate that is generated between passenger and seat [2]. The heat and moisture management between different assembled materials and their layer construction can influence the passengers comfort feeling. Accordingly, for seat systems it is important to understand how moisture and heat will be transferred and accumulated through the different layers of a seat. So far, there is no unified measurement scenario to determine the thermo-physiological behaviour of vehicle seats.

1.1 Aim of the research

This research shall investigate whether standardised methods for measuring thermo-physiological comfort of clothing can be adapted for a characterisation of vehicle seats. By using a thermal sweating manikin it should be possible to ascertain thermo-physiological parameters of seat systems. The aim of the research is to develop a measuring method that provides information about how to determine indicators, which can be used to quantify the quality of the thermo-physiological behaviour of vehicle seats. In the end, it should be possible to understand the comfort perception of vehicle passengers at the interface with the seat.

1.2 Microclimate seating comfort

There are numerous research projects in the area of seating comfort, which are trying to clarify the factors that influence the seating comfort. In order to approach this question, it is first necessary to clarify what comfort means at all. Michiel P. De Looze et al assess in 2003 that the concepts of comfort and discomfort in sitting are under debate. There is no widely accepted definition, although it is beyond dispute that comfort and discomfort are feelings or emotions that are subjective in nature, comfort is affected by physical, physiological and psychological factors and comfort is a reaction to the environment. Yet, beside several subjective methodologies, several objective methods […] are in use to assess sitting comfort or discomfort. [4] The microclimate aspect of seating comfort describes the interaction of the passenger on the interface with the vehicle seat. A well-composed seat provides a successful support of the passengers' temperature regulation over a wide range of different climatic conditions (summer and winter).

1.3 Human heat balance

The human heat balance equation describes how the body can maintain an internal body temperature near 37 °C in terms of heat generation and heat exchange with the environment. In practice, what is achieved is not a steady state (constant temperature) but a dynamic equilibrium: as external conditions continually change, so the body responds to regulate internal body temperature [5]. Equation (1) describes the mathematical equation for the human heat balance [6].

$$M - P_{ex} = H_{res} + H_c + H_e + \frac{\Delta S}{\Delta t} \tag{1}$$

M = metabolic rate
P_{ex} = external physical work

H_{res} = respiratory heat loss because of breathing
H_c = dry heat loss comprising radiation, conduction and convection
H_e = evaporative heat loss
ΔS = heat storage
Δt = time

The literature shows that there are many formulations for the human heat balance equation [5, 6, 7, 8, 9, etc.]. However, Parsons concludes there is ever the same underlying concept of these equations, which takes into account three categories of terms: Heat production, heat transfer and heat storage. For Equation (1) $M - P_{ex}$ is the generated heat, heat transfer mechanisms are described by the variables H_{res}, H_c and H_e and $\frac{\Delta S}{\Delta t}$ is the storage of heat per time. For a comfortable thermo physiological feeling, the human energy balance must be levelled. This means that the produced heat, as a result from the metabolism in the body, has to be dissipated in exactly the same amount. Arithmetically ΔS should be zero when the body is heat balanced. The same applies for microclimate seating comfort. The seat generates a per se resistance against heat or moisture to be dispensed from the passengers´ body. It is therefore sensible to keep the thermal and water vapour resistance of the used materials as low as possible.

2 Materials and methods

Vehicle seats consist of various components and individual materials. A seating system is usually made of the headrest, the backrest, the actual seating area (cushion) and the frame, plus additional equipment like various adjustment options, heating or cooling systems. The material specifications of these components are versatile and depend on the respective requirements. Textiles, leathers and its substitutes, plastics, metals and other materials are used. A distinction is made between material tests on the sweating guarded hotplate and product tests with complete seats measured by Newton and rated by test subjects.

2.1 Materials

The seat cover is mostly a 2- or 3-layer laminated structure, consisting of face fabric, plus pad and if necessary a scrim layer. For face fabrics textiles and/or leathers and its substitutes are used. There are three kinds of common plus pad categories: foam, non-woven and 3D spacer. The scrim is a very thin and lightweight textile. It is used as the bottom layer of the seat cover to reduce the friction between the seat cover and the support layer. The support layer is made out of various foam types or alternatives like rubber hair out of natural or man-made fibres.

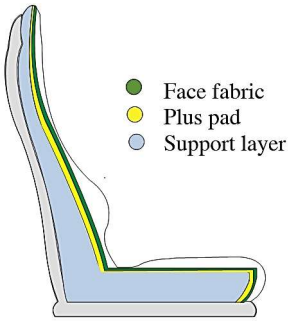


Fig. 1. Schematic seat construction with face fabric, plus pad and support layer

In this investigation, different combinations of typical materials were used without any additional equipment. Fourteen woven and knitted fabrics, eight leathers and its substitutes were used for the face fabric layer, one foam, one non-woven and one 3D spacer were used for the plus pad layer and for the support layer three foam

types with variations in structure and raw material and one rubber hair structure were investigated. Table 1 lists a selection of samples characterised on the sweating guarded-hotplate. The results were discussed in section 3.

Table 1. Samples M1-M6 as given examples for the layer combination of face fabrics with plus pads

Sample	*Face fabric*	*Plus pad*
M1	Perforated artificial leather	sewed with non-woven
M2	Lacquered leather	sewed with spacer
M3	Natural leather	sewed with non-woven
M4	Woven (PES tetralobal yarn construction)	laminated with spacer
M5	Woven (99 % PES/ 1 % PUR)	laminated with foam and scrim
M6	Woven (75 % PES/ 25 % WO)	laminated with non-woven

2.2 Methods

For the characterisation of the different seat materials, three different measuring methods were used and compared: sweating guarded-hotplate measurements for the characterisation of thermo-physiological parameters of the single and multilayer materials and human subject trials as well as manikin measurements for the characterisation of thermo-physiological parameters of the complete seat. To characterise seat cover materials by thermo-physiological aspects (e.g. water vapour resistance R_{et}, thermal resistance R_{ct}, buffering capacity of water vapour F_d) regular and modified sweating guarded hotplates were used according to DIN EN ISO 11092 [3], methods which are current state of technology. Subject trials with six (five male, one female) test subjects were executed in a driving simulator to rate the subjective thermo-physiological sensation while driving. To find correlations between the perception of the test subjects and the manikin output it is necessary to conduct the subject trials and the manikin measurements under controlled, similar conditions. Two climate scenarios, warm and cold conditions, were carried out. The results of the warm climate conditions 32 ± 0.2 °C, 40 ± 2 %rh and 0.4 ± 0.1 m/s deliver the parameters for the water vapour resistance measurements R_e with the sweating manikin under isothermal warm conditions e.g. in summer time. To investigate the driver's behaviour in cold climate conditions, trials were carried out under cold conditions 15 ± 0.2 °C, 50 ± 2 %rh and 0.4 ± 0.1 m/s. This scenario will be correlated with the thermal insulation R_c measurements of the non-sweating manikin. The manikin measurements can take place during the whole year but for the human beings it is important to take into account the acclimatisation for cold and warm environments, to get comparable results.
In the subject trials at first temperature and humidity sensors (MSR Electronics GmbH), were placed on the back, buttocks and thighs of the test subject as well as a forehead sensor (3M Deutschland GmbH) and heart rate sensor (Polar Electro GmbH Deutschland) to record physiological data like skin temperature and humidity, core temperature and heart rate. The seat was also prepared with temperature and humidity sensors on and under the cover. Then the test subject entered the climate chamber and got used to the climate conditions prevailing there in sitting position. To stimulate the metabolism heat production the test subject had to walk on a treadmill. Afterwards the test subject sat in the seat and started to drive in the simulator (see figure 2).



Fig. 2. Subject trial procedure: conditioning - walking – driving

For an objective product measurement the thermal, sweating manikin was used (Newton Type by Thermetrics) to measure the thermal insulation R_c and water vapour resistance R_e values of the seat. The thermal, sweating 34 segments Newton, corresponds in size and shape to the body of an adult, western standard man, clothing size 50. The manikins´ body height is 1.75 m with a weight of 30 kg. In order to simulate the real weight load of a sitting standard man the thighs were loaded with a weight of 15 kg. The manikin was dressed with the same clothing as the test subjects and the seat was prepared with the same sensor technique as in the subject trials. The R_c measurements were carried out in a climate chamber with 15 ± 0.2 °C, 50 ± 2 %rh and 0.4 ± 0.1 m/s and the manikin segments were adjusted to 32 °C. The R_e measurements were carried out under isothermal conditions of 32 ± 0.2 °C, 40 ± 2 %rh and 0.4 ± 0.1 m/s. The sweating rate for the R_e measurements were taken from the test subjects data und were realised in a work cycle, starting with an high sweating impulse and followed by a slighter sweating rate. The 34 segments of the manikin can be controlled independently. The manikin zone divisions are depicted below in Figure 3. All thermal zones are fitted with heaters to simulate metabolic heat output rates and use distributed wire sensors for measuring skin temperature. Additionally each thermal zone has sweat control through evenly distributed fluid ports on its surface. There is a fluid heater inside the manikin for pre-heating water before it is distributed to the ports on the manikin surface [10]. A wicking fabric skin layer distributes the water on the manikin surface. For the measuring method, the sweating system was adjusted for the back, buttocks and thigh segments 14, 16, 18, 20, 21, 23, 24, 26 and 28. The other segments did not sweat.

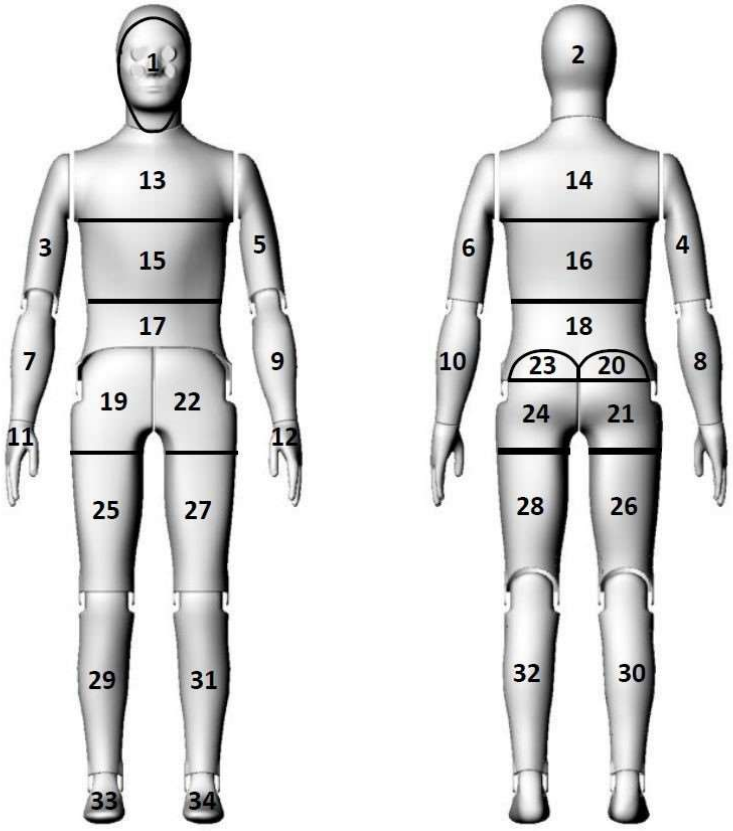


Fig. 3. Schematic illustration of the Newton manikin (Thermetrics)

3 Results and discussion

Below the results of the material characterisation with the sweating guarded-hotplate are given for the selected samples listed in Table 1. The results confirm textile seat covers have better water vapour resistance values than leathers and its substitutes (e.g. in Figure 4).

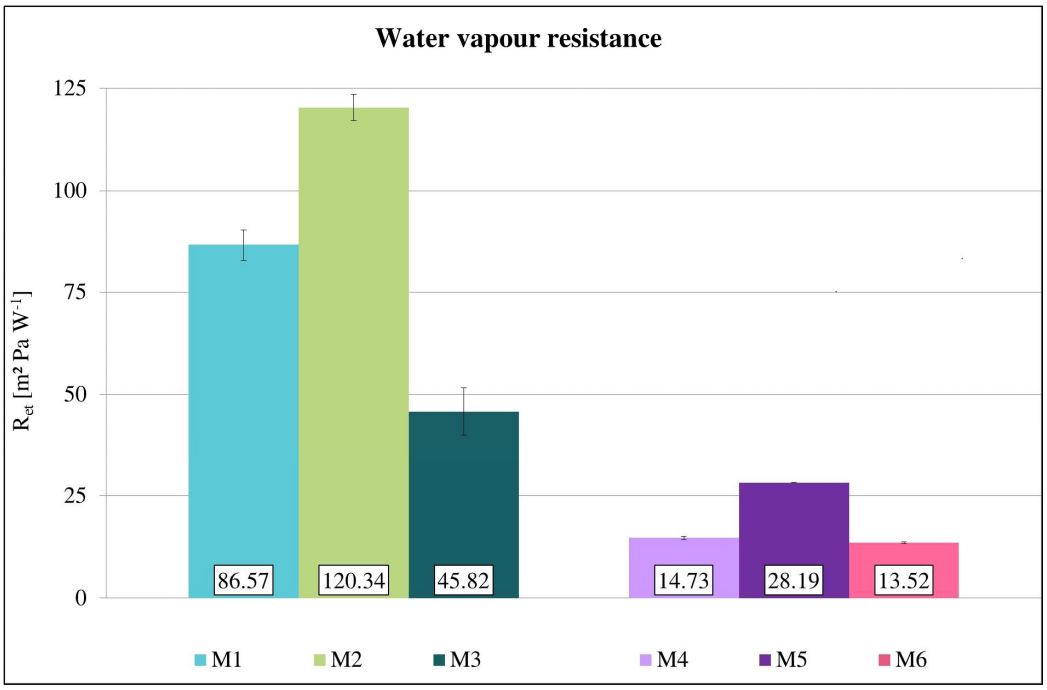


Fig. 4. R_{et} Water vapour resistance values measured with the sweating guarded-hotplate e.g. for sample M1-M6

In order to define the sweating rate set points for the measuring procedure with the manikin, all test subjects deliver the arithmetic mean values of the absolute humidity, measured on the seat cover. The aim was to receive the same absolute humidity values with the sweating manikin on the seat cover. One example is given in Figure 5. The two curves show that it is possible to receive the same absolute humidity values on the cushion cover measured by all test subjects and the Newton manikin. Therefore, the manikin must be pre-wetted in hanging position with a high sweating impulse. Then the manikin is placed in the seat, a slighter sweating rate is adjusted and the R_e is measured until a steady state value is reached over a time period of 30 minutes.

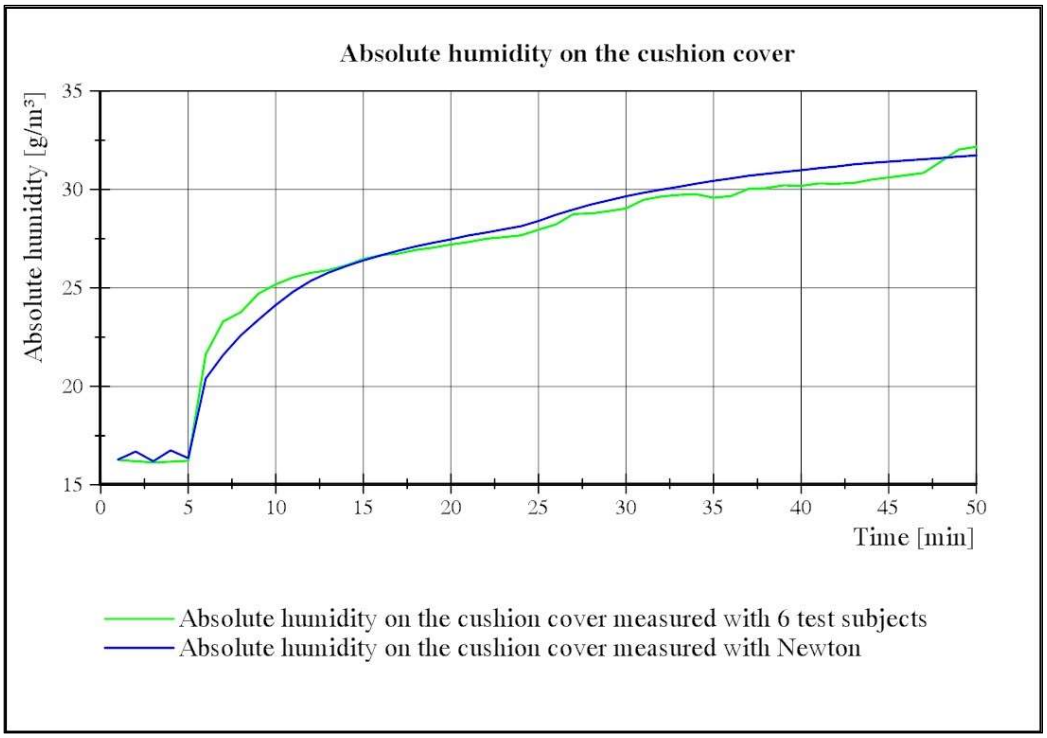


Fig. 5. Absolute humidity on the cushion cover measured by the test subjects and the manikin

The manikin measurements indicate that not only the seat cover (face fabric and plus pad) has an influence on the perception of temperature and humidity in the microclimate between passenger and seat. The support layer also has a great influence. The R_e values on the complete seat are higher when a standard foam is used (full coloured bars in Figure 6) in comparison to a structured foam with integrated holes and channels (hatched bars in figure 6). Figure 6 also shows that with M5 (foam is used for the plus pad layer) the influence of the support layer is not as significant as in comparison to M6 (non-woven is used for the plus pad layer).

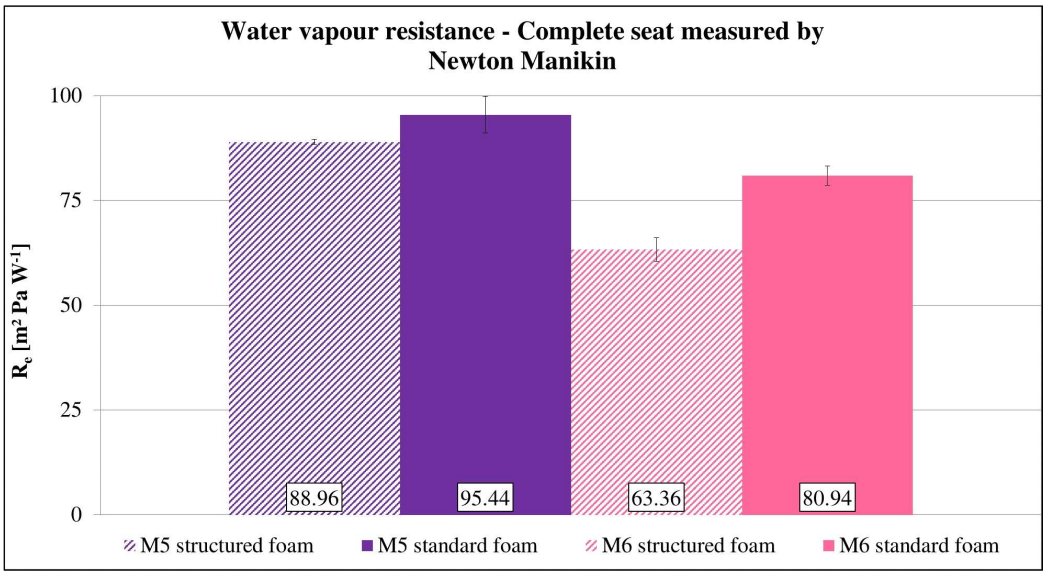


Fig. 6. R_e Water vapour resistance values measured with the Newton manikin on a complete seat e.g. for M5 with structured and standard foam and M6 with structured and standard foam4 Tables

4 Conclusions

It is possible to adapt standard measuring methods from the clothing physiology to determine the thermo-physiological behaviour of vehicle seats. This paper shows how the parameters from the subject trials deliver the parameters for the manikin water vapour resistance measurements. Influenceable parameters like ambient conditions, sensor position, clothing etc. have to be set as similar as possible in the subject trials and manikin measurements in order to get comparable results. The given example of the measuring procedure for the water vapour resistance measured by the manikin demonstrates that different material combinations provoke different water vapour resistance values for the complete seat. The next step is to define a classification system for rating the seats in accordance to the subjective feeling for temperature and humidity. To hand out recommendations for further developments of vehicle seats with optimized climate comfort, thresholds for R_e and R_c values have to be determined.

Acknowledgments The Authors are grateful for the encouragement and for the financial support from Adient Components Ltd. & Co. KG.

References

1. Walser S. and Thomas E. Mobile textiles between past and present Avr Allgemeiner Vliesstoff-Report Nonwovens in the car, 2012, pp. 7
2. Mergl C. Entwicklung eines Verfahrens zur Optimierung des Sitzkomforts auf Autositzen Dissertation am Lehrstuhl fuer Ergonomie der Technischen Universität München, 2006, p. 4
3. DIN EN ISO 11092:2014-12 (E) Textiles - Physiological effects - Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test) (ISO 11092:2014)
4. De Looze M. P., Kuijt-Evers L. F. M. and Van Dieen J. Sitting comfort and discomfort and the relationships with objective measures, ERGONOMICS, 2003, Vol. 46, No. 10, 985 – 997
5. Parson K. C. Human Thermal Environments – effect of hot, moderate and cold environments on human health, comfort and performance, 2003, p. 16
6. Shishoo R. Textile advances in the automotive industry – Bartels V. T. 8 Physiologically optimized car seats, 2008, pp. 150
7. Mecheels J. Körper- Klima- Kleidung, wie funktioniert unsere Kleidung?, 1998, pp. 21
8. DuBois E.F. Heat loss from the Human Body, New York Academy of Medicine, 1938, p.145
9. Hensel H. Temperatur und Leben - Menschen und warmblütige Tiere, 1955
10. Measurement technology Northwest, Newton Thermal Manikin Operator's Manual, 2015, p. 2

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Neural Correlates of Perceived Comfort in Human Strength Exertions

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ABSTRACT

The use of electroencephalography EEG frequency bands (including theta, alpha and beta waves) has a great potential for improving our understanding of brain signatures of physical work. The psychophysical approach has been used for decades to improve safe work practices by focusing on human abilities and limitations in various physical tasks. The main objective of this research was to study brain's EEG activity expressed by the power spectral density and corresponding levels of perceived comfort related to different levels of static arm exertions. The changes in EEG power spectral density were recorded during low (25%), medium (50%), high (75%), and maximum (100%=isometric strength) levels of static arm (elbow bending) exertions. Three replications of each tests were done. A total of ten healthy males participated in a laboratory study. The subjects were provided with written informed consent prior to the experiment. All procedures were approved by The Institutional Review Board at the University of Central Florida. EEG was recorded using a (Cognionics Data Acquisition Software Suite) and a Cognionics High-Density 64-channel Dry Headset 64-channel EEG (COGNIONICS, Inc. San Diego, CA). Electrodes were attached to the scalp using a custom subset of the 10-5 configuration. The artifacts correction in experimental EEG data was done using the Artifact Subspace Reconstruction method (ASR). The brain's areas of interest included the frontal part (attention, judgment, and motor planning); the central part (sensorimotor control); and the parietal part (cognitive processing). The results showed differences in EEG power spectral density between different levels of static arm (lifting) exertions and perceived comfort at three main brain areas, i.e. frontal, central and parietal. EEG activity was correlated with different levels of perceived comfort during static physical exertions. The results of this research are important for improving our understanding of the neural signatures of human physical activities and related levels of perceived comfort, and consequently, should have an impact on workplace design that considers brain activity in relation to human abilities and limitations for tasks with significant physical workload.

KEYWORDS: Static exertions, electroencephalography, brain, perceived comfort

Influence of passengers' anthropometry and tasks on posture and discomfort in an aircraft seat

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Abstract: Several studies have shown that performing different tasks or activities in work environments causes variations in user postures and movements. Therefore, it is likely that, also for an aircraft seat, different activities need different seat characteristics to accommodate the variety in postures and movements. The research question of this study therefore is: What are the effects of anthropometry on posture in aircraft seats while performing different activities (reading, relaxing and sleeping), and how does this influence the comfort and discomfort perception of aircraft passengers? In total 28 people (13 female, 15 male) of different nationalities were selected to participate in the research. Their average age was 34 (SD=12.9, range=22-65) years old. In a laboratory set-up, participants were asked to sit in an aircraft seat and to perform three tasks: reading, watching the in-flight entertainment system (IFE) and sideward sleeping. Three corresponding postures were prescribed for each of the three tasks: upright sitting and holding a book or magazine (reading); slouched position, relaxing (watching IFE); and turned to the right side of the body (sideward sleeping). If participants indicated they were sitting comfortably, measurements and pictures were taken and they were asked to complete a questionnaire. Posture was measured by determining the position of participants' head, torso, upper leg, lower leg, feet, upper arm and forearm with respect to the horizontal plane using stickers. Comfort experience was measured by asking participants to indicate whether they felt comfort or discomfort by marking different areas on a body map with a green (for comfort) and a red pen (for discomfort). Furthermore, anthropometric measurements were recorded of participants' stature, body mass (weight), and hip breadth. Results of this study show that passengers of different stature obtain different postures, and that their comfort and discomfort ratings differ. For example, taller participants reported more often discomfort in the head and neck region, while shorter participants more often reported discomfort in the feet and lower legs. Ideally, an aircraft seat facilitates these differences in postures and passengers' anthropometry.

Keywords: discomfort, sitting, passenger comfort, activities

1 Introduction

Today, people are constantly on the move, travelling for many reasons, such as business, leisure and family visits. Travelling by plane is growing and opportunistic for airlines. A study of Vink et al. [1] among 10,032 passengers shows that the interior of airplanes is significantly improved, but especially in the seat there is still

much possibility for improvement. Legroom and personal space (space for arms, shoulders and head and stowage close to the passenger) in particular result in lower comfort ratings. According to Brauer [2], an increase of 1% passenger revenue has an impact on profitability for the airline which is fourteen times greater than 1% reduction in maintenance costs. In order to attract more passengers, data are needed to determine the selection behaviour of passengers [2]. It appears that passengers first select on point-to-point transport, time and price, then on aspects like marketing (frequent flyer programmes), followed by comfort, past experiences and delays. For short distances the delay aspect is more important as opposed to long distance travel, where the comfort aspect plays a more important role.

Several studies showed that performing different tasks or activities in work environments causes variations in user postures and movements [3,4,5,6,7]. Therefore, it is likely that different activities need different seat characteristics to accommodate the variety in postures and movements. An indication was found that office workers performing a reading task preferred a larger backrest inclination range compared with a VDU task, in an experiment by Groenesteijn et al. [8] with a focus on activity support of the office chair.

Branton & Grayson [9] were the first with their observation of train passengers to report that tall persons sat longer than short persons in postures with knees crossed, particularly when slumped. Compared to the tall persons, the short persons sat more with two feet on the floor. In research about home furniture, Teraoka et al. [10] also found differences between tall and short persons. In comparison with tall persons, short persons had in this case less feet contact with the floor or less contact with the backrest in combination with a slumped posture. Ciaccia & Sznelwar [11] concluded based on an observational study with only five participants that these participants adopted very similar postures for both reading and resting in order to avoid discomfort, despite having different anthropometric characteristics.

It also appears that users' seat preferences in relation to function type differ in divergent functions [12]. It is assumed that this is related to a different mixture of activities with different relative duration of activities causing different body dynamics during seat use over the day. To build support for this assumption, firstly, more knowledge is needed on posture characteristics in different tasks and their corresponding comfort experience, leading to the research question:

What are the effects of anthropometry on posture in aircraft seats while performing different activities (reading and relaxing), and (how) does this influence the comfort and discomfort perception of the passenger?

2 Method

2.1 Research seat

For the research seat, dimensions were chosen to reflect the upcoming generation of aircrafts, such as the Boeing 787 and Airbus 350. Therefore, the angle of the seat pan was set at 7 degrees with respect to the horizontal plane (corresponding with 4 degrees to the inclined floor) and the backrest at 19 degrees with respect to the vertical, corresponding to a typical aircraft seat when partially reclined. A 3 degrees inclined floor was used for the tests to simulate the slope of an airplane at cruising altitude. The dimensions of the 2011 Pinnacle seat from B/E Aerospace were used to determine the dimensions of the wooden frame of the seat in the research set-up. The pitch was set at 30 inch (762 mm), which is comparable to an average economy class airplane. The depth, width and height of this seat were 480, 450 (between the armrests) and 336 mm, respectively (Fig. 1, left). A row of aircraft seats was placed in front of the seat to simulate legroom (Fig. 1, middle). In the seat, on top of the pressure mat, a free-formable mattress was used that could be moulded by the participants so that they were able to find the most comfortable position possible (Fig. 1, right).

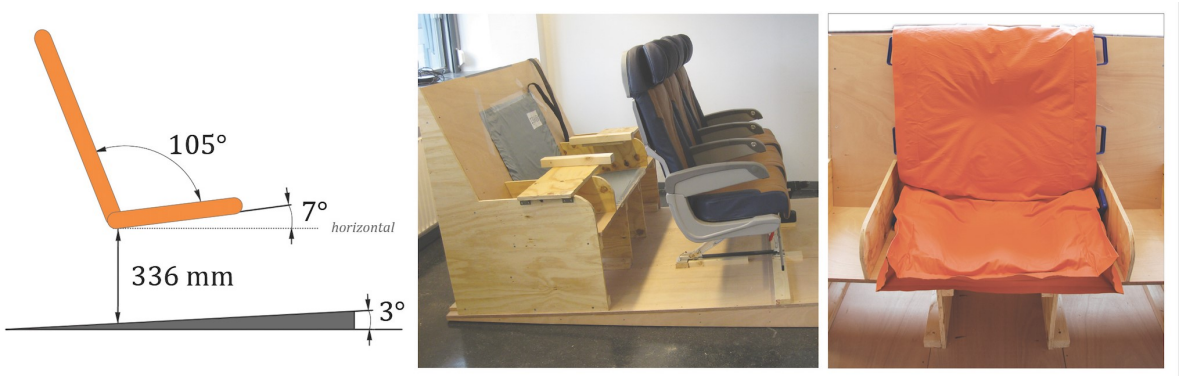


Fig. 1. Research seat, from left to right: dimensions; complete construction with row of seats in front and inclined floor; free-formable mattress.

2.2 Participants

A careful selection of people from Asia, America, Europe and Africa was made and care was taken that participants varied from 5th to 95th percentile (P5-P95) regarding stature and weight, and that enough people older than 40 years were involved. Therefore, we asked students and citizens of Delft to complete a list with their nationality, age and anthropometrics. We selected from this group and searched specifically for additional participants to include for missing representatives.

In total 28 people (13 female, 15 male) were selected to participate in the research. Their average age was 34 (SD=12.9) years in a range between 22 and 65 years old. Concerning nationalities, 6 of the participants were Asian, 3 were African, 17 were European and 2 were South-American. The mean stature of participants was 1.71 (SD=0.11) m with a minimum of 1.51 m and a maximum of 1.93 m. Their mean body mass was 73.7 (SD=19.9) kg with a minimum of 45 kg and a maximum of 116.8 kg.

2.3 Measurements

Body postures

The position of participants' head, torso, upper leg, lower leg, feet, upper arm and forearm with respect to the horizontal plane were determined. Stickers were positioned on participants' head (tempor), shoulder (acromion), elbow (lateral epicondylus), wrist (the palpable part of the posterior side of the semilunar bone), hip (greater trochanter), knee (lateral side of the patella), ankle (lateral malleolus) and toes (at the end of the fifth phalangus) and lateral pictures were made. On top of the pictures, lines were drawn between the stickers to estimate the angle between this line and the horizontal line. Mean angles, minima and maxima and standard deviation were calculated per activity.

Comfort experience

For each posture, participants had to indicate whether they felt comfort or discomfort by marking different areas on a body map with a green (for comfort) and a red pen (for discomfort). If they marked neither green nor red, it meant they noticed neither comfort nor discomfort. Additionally, the participants were asked to indicate the overall comfort experience after every task and to mention the most comfortable and least comfortable posture of the three in the end.

Anthropometric measurements

Besides stature and body mass (weight), hip breadth was also measured for every participant. Stature was recorded with an anthropometer from the floor to the highest point on the head while standing, having the head in the Frankfurt plane. Body mass (weight) was measured with a scale and hip breadth while seated was measured by putting the anthropometer on the most lateral point on the femur at hip level. Age, nationality and gender were also noted. The shoe height of the participants was measured as well and it was logged if participants were wearing their shoes during the performance of tasks. They were instructed to choose to wear their shoes like they would normally do during a flight.

2.4 Protocol

Three tasks were defined: reading, watching the in-flight entertainment system (IFE) and sideward sleeping. For each of these tasks, corresponding postures were defined (Fig. 2). For reading, this was upright sitting and holding a book or magazine. For watching IFE, this was a slouched position, relaxing. For sideward sleeping, this was turned to the right side of the body.

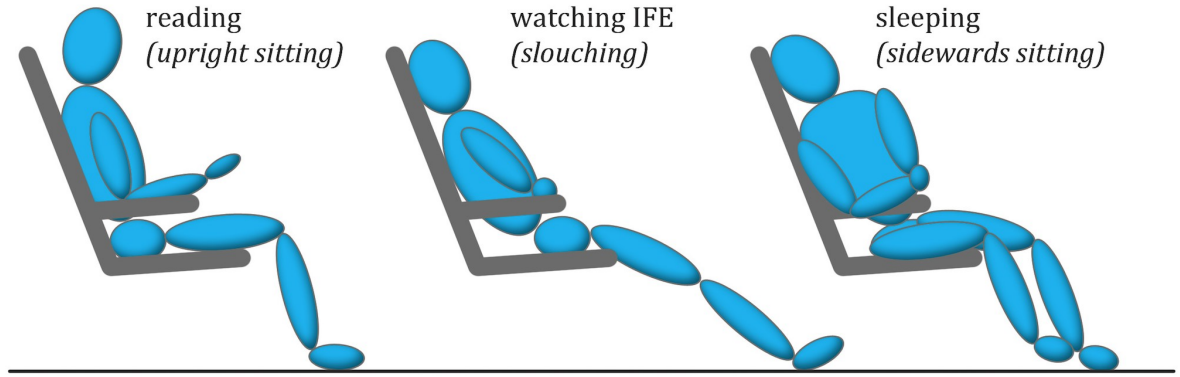


Fig. 2. Selected tasks (reading, watching IFE, sideward sleeping) with corresponding postures

Participants were instructed that they were going to perform three tasks in three different corresponding postures (pictures of the different postures had been shown) in the research seat. Every participant started with the reading activity (upright sitting), followed by watching IFE (slouching) and sideward sleeping. They were asked to take a seat in the research set-up and make themselves as comfortable as possible for the task. If they were, measurements and pictures were taken and they were asked to complete the questionnaire.

3 Results

Body postures

The stickers were difficult to observe as parts of the research seat or clothes of the participants interfered with the line of sight. Due to this and the asymmetrical posture of sideward sleeping, it was impossible for the third posture to position the angles in a 2D-plane. Therefore, only postures of reading and watching IFE are shown (Fig. 3). For the upright sitting condition (reading activity) compared with the slouched sitting condition (watching IFE), the head is more bent forward, the torso is more upright, the upper legs are more horizontal and the lower legs are more vertical.

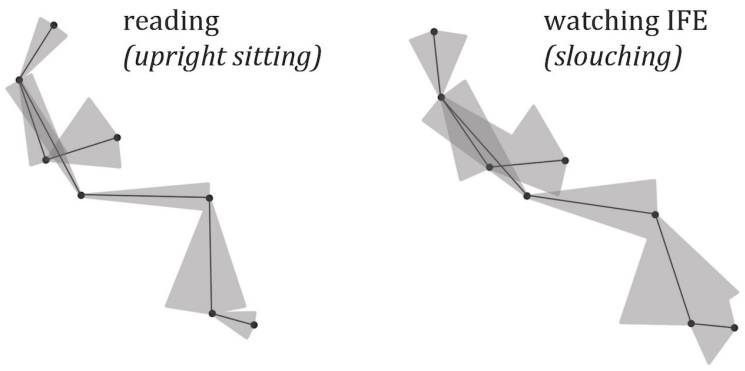


Fig. 3. Visual representation of the angles of the body observed for the postures corresponding with the tasks reading and watching IFE. The black lines represent the mean values; the grey areas represent the minimum and maximum observed angles.

5.3.3.2. Comfort experience

The number of areas that were marked green (comfort) by the participants is lowest in the sideward sleeping position (see also Fig. 4). Only the right side of the upper and lower back and the right shoulder were marked green by more than 10 participants. Reading and watching IFE had more green scores than the sideward sleeping position, particularly in the upper legs (14 and 13 out of 28, respectively), buttock (11 and 11) and upper (11 and 20) and lower back (10 and 13). The upper back region in the watching IFE position was rated most often green by the participants (20).

Discomfort (marked by a red pen) was rated most in the lower back area (11) while watching IFE (see also Fig. 5). So, 11 out of 28 rated discomfort in this lower back area while watching, while 13 out of 28 rated comfort (compare with Fig. 4). Discomfort was rated also in the right buttock by 12 out of 28 participants in the sideward sleeping position. The stature of the participants that rated discomfort in the feet for the reading position was below 1.65 m for all four participants.

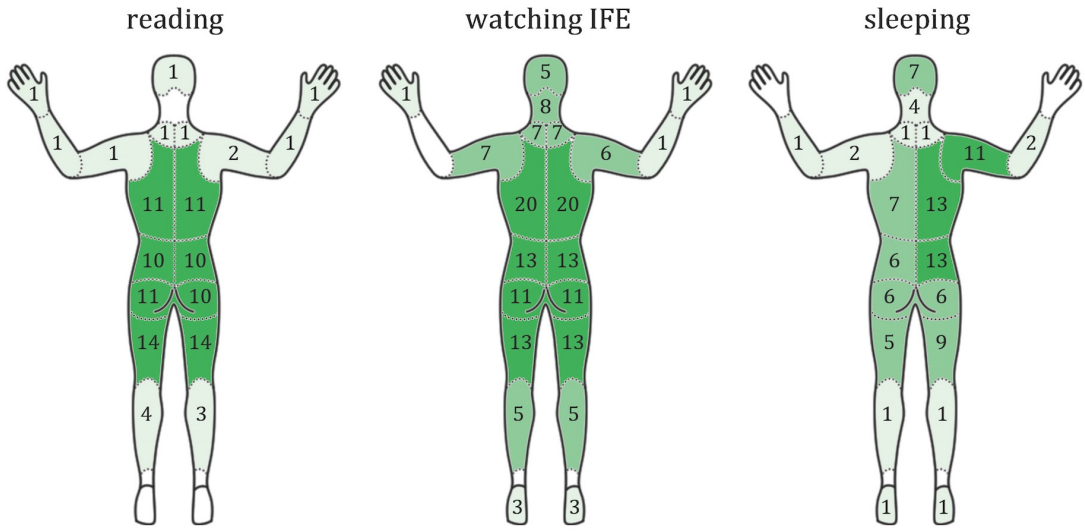


Fig. 4. Experienced comfort in the reading, watching IFE and sideward sleeping posture. The total number of participants reporting comfort in that specific body region is shown.

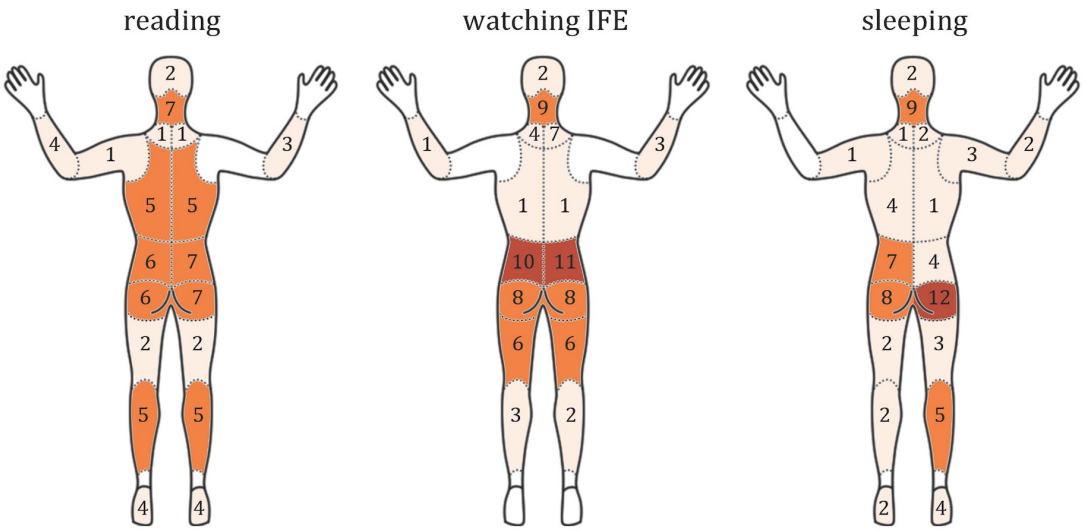


Fig. 5. Experienced discomfort in the reading, watching IFE and sideward sleeping posture. The total number of participants reporting discomfort in that specific body region is shown.

4 Discussion

This study has shown that the anthropometry of the passenger influences posture and comfort perception in aircraft seats while performing different activities.

Ideally, a seat facilitates these differences in postures in a comfortable way, which is a challenge for seat designers, but is becoming more feasible as new materials are becoming available. The fact that activities do influence the posture has been described before [8]. For watching television, it has been shown that a more backward rotated backrest is preferable [13], and if we follow the vision of Goossens & Snijders [14] that shear forces should be prevented, a tilted seat with the front of the seat upwards is a consequence of this posture. However, for smaller passengers this introduces another problem that the feet do not reach the floor anymore. This study indicates that there is discomfort for short people who cannot reach the floor. This phenomenon is seen before in a study among tram drivers [15], where height adjustable pedals were needed to create a comfortable tram driving posture for shorter persons.

One of the disadvantages of this study could be that the study is done in a laboratory environment and that participants were instructed on their activity and posture. However, real life observations also show much variation in posture. Van Rosmalen et al. [13] showed large differences while watching a screen, from an upright to a 30 degrees reclined trunk as well as various asymmetric postures. Kamp et al. [16] observed a large variety of postures in trains and lounge areas and found also differences in posture between reading and watching. Even within one task, differences in posture are found. Gscheidle & Reed [17] describe a variation in observed back rest angles between 20 to 40 degrees backwards at one task (office work). Park et al. [18] describe a variation between 103 and 131 degrees in observed trunk-thigh angle while driving in a car. The observations of Kamp et al., Gscheidle & Reed, and Park et al. [16,17,18] were done with seats that have a fixed shape and could restrict the freedom of posture choice. In this study, a free formable mattress was used which could be formed by the participants, allowing more freedom in posture. This could be unrealistic as in real life you are also not free to change your posture, but was chosen to make it possible to choose the ideal posture. On the other hand, the average variation in torso angle found in our study for the task reading (13 degrees) and watching (26 degrees) is comparable to the ranges found in the other studies described above. Several studies show the importance of varying your seated posture [e.g. 19,20].

Another difference of this study with real life studies is the focus on knee space. Two studies among passengers [1,21] showed that the main problem is knee space. That is not the outcome of this study, probably because the pitch in this study was 30 inch (762 mm), which is comparable to an average economy class airplane. However, due to the use of the free-formable mattress participants were able to sink deep into the mat-

tress, leaving a very thin (<20 mm) backrest, which is comparable to the more spacious economy class airplanes.

If we compare posture and comfort, it is remarkable that in all positions, participants can be appointed that feel themselves comfortable in this position. Ten participants experienced the reading (upright) position as most comfortable, 12 the watching (slouched) and 6 the sideward sleeping posture. Interesting is that for the watching situation, both many discomfort and comfort experiences are reported among the 28 participants around the lower back area. This is probably due to the fact that some people experience a convenient pressure in the lumbar region that follows their body contour, while others do experience too much or too little pressure. Other studies [22,23] have shown that there is a relationship between pressure distribution and comfort. The comfort in the neck/head region is often mentioned as an area of discomfort in this study; sometimes because of the lack of support, sometimes because the head is pushed forwards. The taller participants needed more head support, while the shorter participants preferred a situation where their head could be positioned more backwards.

5 Conclusion

This study has shown that passengers of different stature obtain different postures, and that their comfort and discomfort ratings differ. For example, taller participants reported more often discomfort in the head and neck region, while shorter participants more often reported discomfort in the feet and lower legs. It can be difficult for shorter passengers to reach the floor with their feet. Wearing high heels or changing posture (e.g. slouched) can sometimes be a solution for them, but the seat should also provide them with a footrest, for example integrated in the frame of the seat in front.

Acknowledgments ***removed for peer review***

References

1. Vink, P., Bazley, C., Kamp, I., Blok, M., 2012. Possibilities to improve the aircraft interior comfort experience. *Applied Ergonomics* 43(2): 354–359.
2. Brauer, K., 2006. What is it worth? Published as “Group Therapy” in *Aircraft Interiors International*, March 2006.
3. Babski-Reeves, K., Stanfield, J., Hughes, L., 2005. Assessment of video display workstation set up on risk factors associated with the development of low back and neck discomfort. International Journal of Industrial Ergonomics 35: 593–604.
4. Dowell, W.R., Yuan, F., Green, B.H., 2001. Office seating behaviors: An investigation of posture, task and job type. Proceedings of the Human Factors and Ergonomics Society, pp. 1245–1248.
5. Ellegast, R., Keller, K., Groenesteijn, L., Krause, F., Berger, H., Vink, P., 2011. Comparison of four specific dynamic office chairs with a conventional office chair: impact on muscle activation, physical activity and posture. Applied Ergonomics 43(2): 296–307.
6. Groenesteijn, L., Ellegast, R.P., Keller, K., Krause, F., Berger, H., De Looze, M.P., 2012. Office task effects on comfort and body dynamics in five dynamic office chairs. Applied Ergonomics 43(2): 320–328.
7. Van Dieën, J.H., De Looze, M.P., Hermans, V., 2001. Effects of dynamic office chairs on trunk kinematics, trunk extensor EMG and spinal shrinkage. Ergonomics 44(7): 739–750.
8. Groenesteijn, L., Vink, P., De Looze, M., Krause, F., 2009. Effects of differences in office chair controls, seat and backrest angle design in relation to tasks. Applied Ergonomics 40: 362–370.
9. Branton, P., Grayson, G., 1967. An evaluation of train seats by observation of sitting behaviour. *Ergonomics* 10(1): 35–51.
10. Teraoka, T., Mitsuya, R., Noro, K., 1994. Comfort in Furniture at Home. In: C*omfort and Design, Principles and Good Practice,* P. Vink (ed.). Boca Rotan: CRC Press, 137–145.
11. Ciaccia, F., Sznelwar, L., 2012. An approach to aircraft seat comfort using interface pressure mapping. *Work* 41 (1): 240–245.
12. Legg, S.J., Mackie, H.W., 2002. Milicich W. Evaluation of a Prototype Multi-Posture Office Chair. *Ergonomics* 45: 153–163.
13. Van Rosmalen D., Groenesteijn, L., Boess, S., Vink, P., 2009. Using both qualitative and quantitative types of research to design a comfortable television chair. *Journal of Design Research* 8(1): 87–100.
14. Goossens, R.H.M., Snijders, C.J. 1995. Design criteria for the reduction of shear forces in beds and seats. *Journal of Biomechanics* 28: 225–230.

15. Osinga, D.C., 2003. Participatory ergonomics: a mock-up study to determine the end user opinion on tram drivers' comfort. In: *Proceedings of the XVth Triennial Congress of the International Ergonomics Association and the 7th Joint Conference of Ergonomics Society of Korea* / Japan Ergonomics Society. Volume 6: Safety and Health Miscellaneous Topics. Seoul: The Ergonomics Society of Korea, 2003:425–428.
16. Kamp, I., Kilincsoy, Ü., Vink, P., 2011. Chosen postures during specific sitting activities. *Ergonomics* 54(11): 1029–1042.
17. Gscheidle, G.M., Reed, M.P., 2004. Sitter-selected postures of an office chair with minimal task constraints. In: *Proceedings of the Human Factors and Ergonomics Society (HFES)* 48th Annual Meeting, New Orleans, Louisiana, September 20-24, 2004. CD-ROM 1086–1090.
18. Park, S.J., Kim, C., Kim, C.J., Lee, J.W., 2000. Comfortable driving postures for Koreans. *International Journal of Industrial Ergonomics* 26: 489–497.
19. Lueder, R., 2004. Ergonomics of Sitting and Seating: The Case For and Against Movement For Its Own Sake. A Review of The Scientific Literature, April 4, 2004. Updated June 5, 2005. Humanics ErgoSystems, Encino (CA). www.humanics-es.com/movement-ergonomics.htm Viewed on 12/15/09.
20. Nordin, M., 2004. Zusammenhang zwischen Sitzen und arbeitsbedingten Rückenschmerzen. In: H.J.Wilke (ed.) Ergomechanics (pp. 10–35), Aachen: Shaker Verlag.
21. Blok, M., Vink, P., Kamp, I., 2007. Comfortable flying: comfort of the aircraft interior by the end user (in Dutch). *Tijdschrift voor Ergonomie* 32, 4, 4–11.
22. De Looze, M.P., Kuijt-Evers, L.F.M., Van Dieën, J.H., 2003. Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics* 46: 985–997.
23. Zenk, R., Franz, M., Bubb, H., Vink, P., 2011. Technical note: Spine loading in automotive seating. *Applied Ergonomics* 43(2012): 290–295.

A study on the correlation between the perceived comfort and the muscular activity, using virtual simulation techniques

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Abstract General comfort may be defined as the "level of well-being" perceived by humans in a working environment. The state-of-the-art about evaluation of comfort/discomfort shows the need for an objective method to evaluate the "effect in the internal body" and "perceived effects" in main systems of comfort perception. Some medical studies show that each human joint has its own natural Rest Posture (RP); in this Rest Posture human muscles are completely relaxed or at minimum strain level: when it happens the geometrical configuration corresponds to the natural position of resting for Arms/Legs/Neck etc.. From this starting point, authors developed and build, through a wide experimental campaign, the postural-comfort curves for each Degree of Freedom (DOF) of human upper-limbs' joints and a software, named CA-Man, that is able to analyse a general posture and calculate a postural comfort index for the entire upper body. In this paper, this postural comfort analysis has been compared with the virtual simulation results coming from ANYBODY Software. A detailed study has been conducted on the upper body muscular activation during upper limbs movement with and without any load. Postures have been analysed both by ANYBODY and by CA-Man in order to correlate the postural (dis)comfort perception with the calculated muscular activity. Interesting findings about the relation between perceived comfort and limits of Joints' Range of Motion (ROM) are shown.

Keywords: Postural Comfort, Anybody software, Muscle activity.

1. Introduction

Postural comfort feeling is strongly related to human body conditions during a task execution. As an example we can consider how temperature and loads modify physiological conditions when a subject makes a muscular effort. In addition other factor as environment or psychological conditions can raise or decrease comfort perception. An extended scheme of influencing parameters on postural comfort can be found in [1] based on Cappetti-Naddeo model [2].

Many scientific papers deal with the comfort feeling during movements with or without loads by means of electromyography (EMG) measures of muscular stresses and correlation of these measures with subjective judgements of comfort based on assessment questionnaires [3] [4] [5] [6].

The EMG-based analyses are limited by some basic aspects: it is impossible to measure all muscular stresses in order to make a complete analysis of the body; it is impossible to evaluate overlapping effects of different activities; it is impossible to clean comfort judgement from non-muscular aspects; it is impossible to generalise founded correlations to other activities so each product development requires new EMG acquisitions tests.

The availability of sophisticated numerical methods for multibody analysis and the deep knowledge of the human body recently allowed the development of software dedicated to human body simulations. In particular Anybody Technology developed a software that is specific for simulations of musculoskeletal systems. Many scientific works demonstrated the

capability of Anybody of correctly simulate the human body during task execution, by comparison with EMG results [7] [8] [9] [10].
In this paper, the authors intend to study the correlation between the muscular loads of all involved muscles and the postural comfort. Some simple upper limbs movements will be simulated in Anybody and the results will be compared with correspondent postural comfort curves experimentally developed in [11] and available in CA-MAN software.

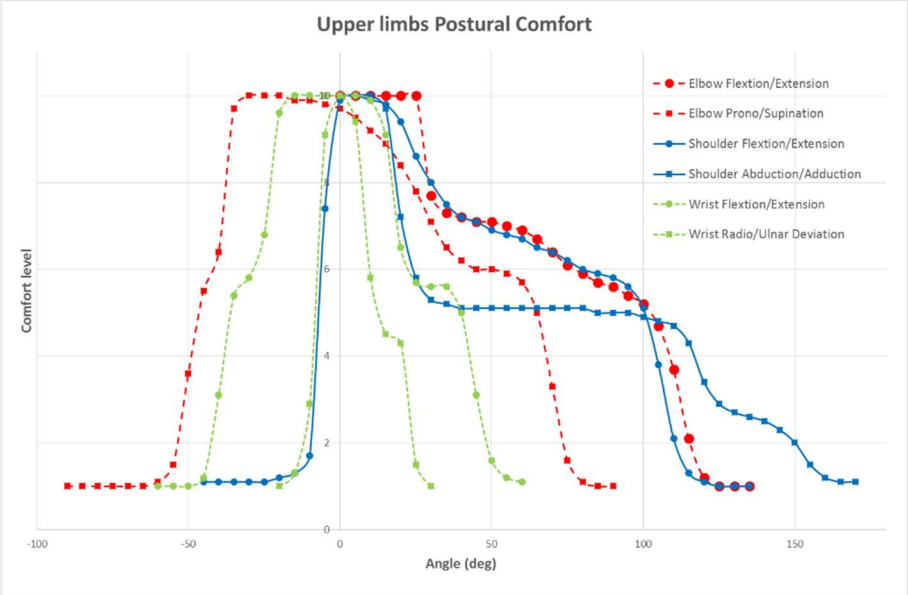


Fig. 1. Upper limbs postural comfort curves.

CA-MAN is a software where the upper limbs position of a standing human can be inputted in order to obtain a mean postural comfort value. It is based on the availability (**Fig. 1**), for each single movement type of upper limbs, of a comfort curve that averages the comfort judgement of a group of subjects.
With this software it is possible to know a Postural Comfort judgement for a standing human moving upper limbs for each combination of values in articular Range of motion angles. Considered movements are shoulder flexion/extension and abduction/adduction, elbow flexion/extension and pronation/supination and wrist flexion/extension and radio/ulnar deviation.

2. Human body simulation with Anybody

The evaluation of muscular stresses when a standing human assumes a posture is needed to analyse CA-MAN comfort curves from the physic point of view so we used the Anybody simulation software. The AnyBody Modeling System [12] is a multibody software that allows you to create detailed musculoskeletal models and run computer simulations that integrate the human body into a 3d environment to evaluate the human/product interaction. As results we can read individual muscle forces, joint contact-forces and moments, metabolism, elastic energy in tendons and antagonistic muscle action.
Anybody System provides also a Model Repository that is an open library of components and examples ready to be used in the AnyBody Modeling System™ with different detailed human parts or whole body models ready to make simulation examples of activities of daily living and validation studies.
In this study we used the Standing Human model (**Fig. 2**), that is a parametric model of a standing human configured for the 50th percentile European male 176cm tall and weighting 75kg. its feet are bounded to the ground and the posture of the body during simulations is re-evaluate and modified controlling the ankles in order to respect these bounds and to position the Centre of Gravity (CoG) vertically over the CoG of the ground contact. When the body is loaded by gravity and external forces and muscles will be recruited and feet repositioned to equilibrate them but in some cases the results are unreal because of the bounds.

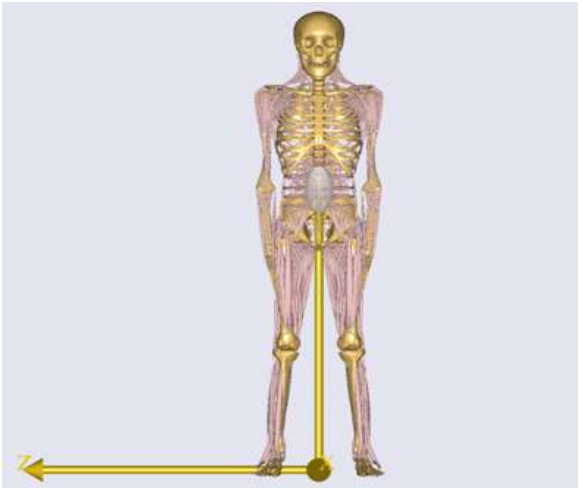


Fig. 2. Standing Human in Anybody

2.1 Muscle Activity and Muscle recruitment

In an Anybody model each muscle is characterised by points of connections with bones and by its maximum performable force that is ever a positive value because a muscle can only execute traction activities. The activity of a muscle is defined as the ratio between their instantaneous force and its maximum force.
In the human body the determination of muscular activities equilibrating a load is an undetermined problem because many combinations of activity can give the same result so a rule is needed. In a real body it is the brain that distribute load on muscles with unknown rules, depending on contest, such as optimising of performance, minimising muscular stresses or consumed energy, articulation protection, etc. In Anybody some rules called muscular Recruitment criteria, are available. From the mathematic point of view, the most important criteria are:
Linear Recruitment where loads are distributed in inversely linear proportion respect to muscle strength.
Quadratic Muscle Recruitment where loads are distributed in inversely proportion respect to quadratic muscle strength, so strong muscles are much involved. This is the most used criteria used in biomechanics and it agrees experimental tests with EMG, even if sometimes resulting activity appear not physiological.
Polynomial Muscle Recruitment where instead of quadratic one we can choice an exponent from 3 (default) to 5.
Min/Max Muscle Recruitment where all muscles can contribute become active muscles. It is a criteria of minimum fatigue but results are often not-physiological.
As you can see in **Fig. 3** for shoulder flexion, in upper limbs simple movements the mean activity tendency don't significantly change so, in our simulations, the default criteria will be used.

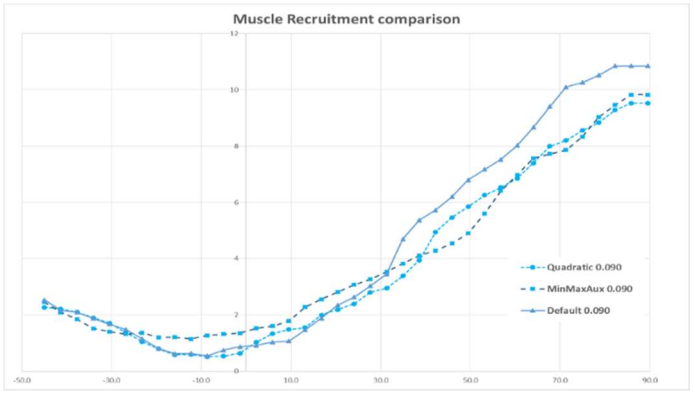


Fig. 3. Muscle recruitment comparison

3. Simulations and results

Based on Standing Human model with default percentile and default Muscle Recruitment Criteria a set of Anybody analysis was carried out where each one of upper limbs movements considered in CA-MAN was simulated and results was compared with the related Comfort curves. The starting posture of upper limbs of the Standing Human model was set to ideal Rest Posture [[[BIB]]] and one of them at a time was varied in time from minimum to maximum articular range listed in **Table 1**.

Table 1. Upper limbs joints range.

Joint	*movement*	*[min deg, max deg]*
Shoulder	Extension / Flexion	[-60, 180]
	Adduction / Abduction	[0, 180]
Elbow	Extension / Flexion	[-10, 150]
	Supination / Pronation	[-90, 90]
Wrist	Extension / Flexion	[-85, 80]
	Radio- Ulnar deviation	[-25, 45]

From Anybody simulation some results are pull out as Muscular Activities, elongation and forces. Graphs of figures from **Fig. 4** to **Fig. 6** shown Activities of the most active muscles during examined tasks.

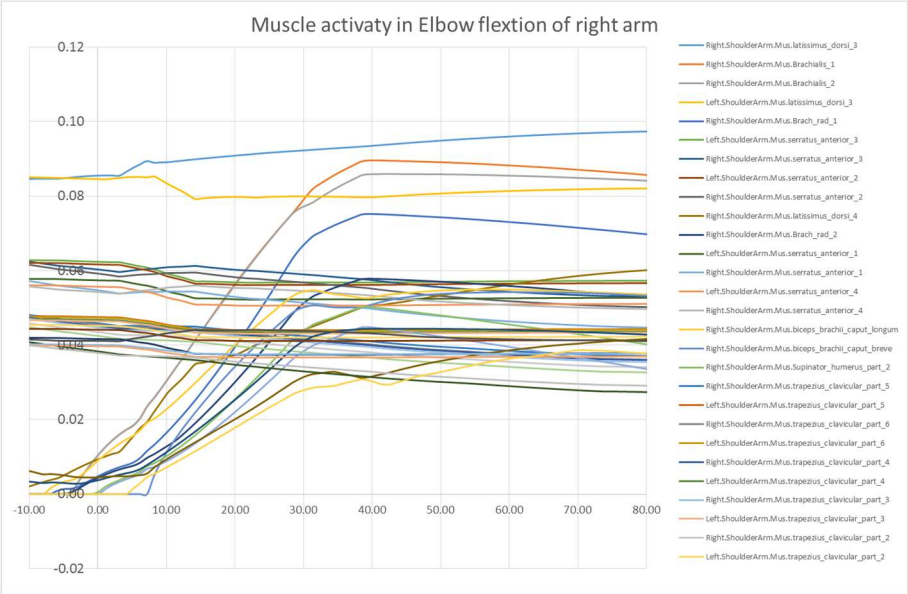


Fig. 4. Most active muscles in Elbow flexion of right arm

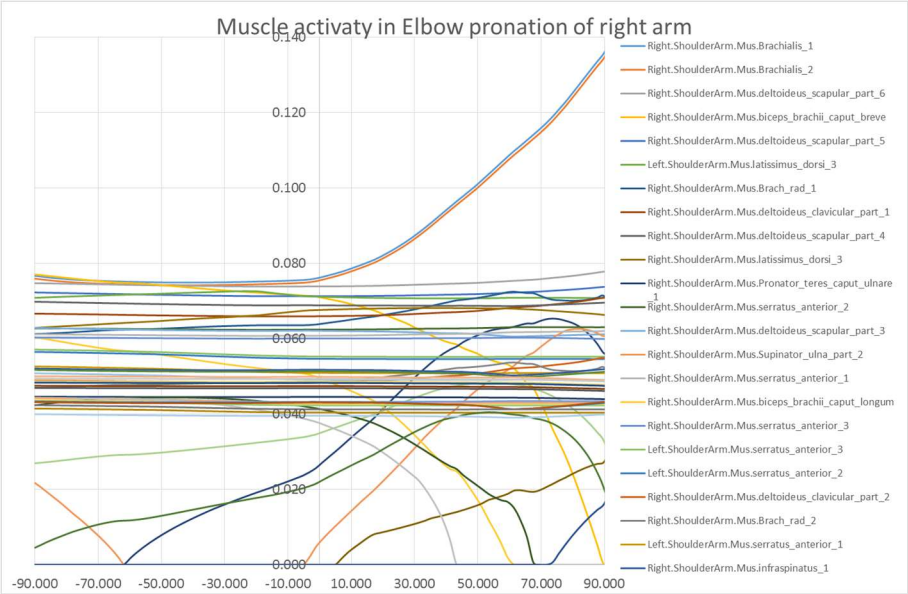


Fig. 5. Most active muscles in Elbow pronation of right arm.

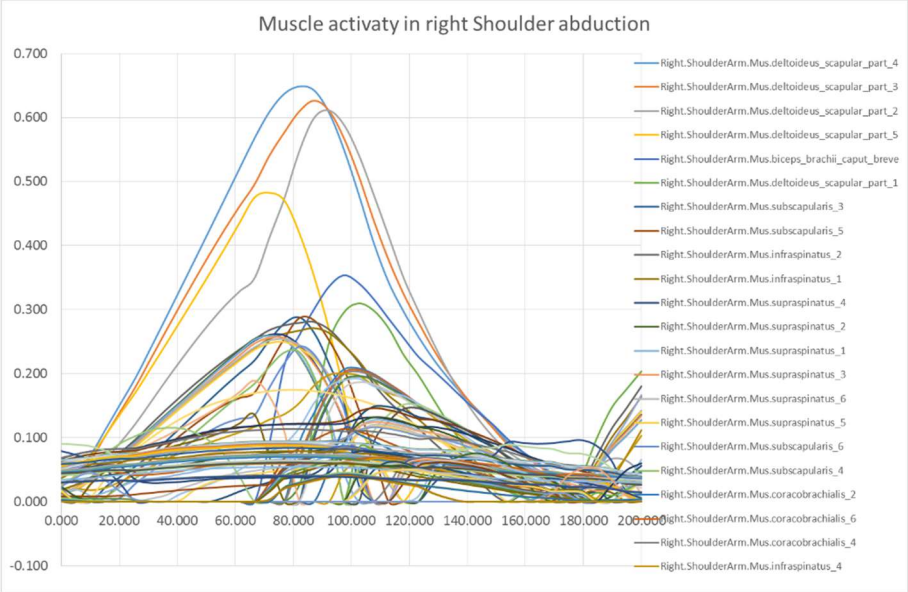


Fig. 6. Most active muscles in right Shoulder abduction.

4. Comfort-Muscle activity relationship

We can observe that is not useful to compare information about each muscle with Comfort curves because Postural Comfort score states a global subjective evaluation of Muscular condition. As a matter of fact, we can consider that a simple movement like elbow flexion produces a variation of Centre of Gravity that produce some compensation loads on muscles of abdomen and legs. So the comparison with Comfort curves will be performed by composition of muscular curves. The most interesting ones are *Mean Activity*, *Envelope* and *Number of Active Muscles*.

- *Mean Activity* is the curve Angle-Muscle Activity where for each Angle the mean Activity value of the body muscles is selected. Mean Activity was parametrized on a threshold value in order to ignore muscles not or not many loaded since they remarkably lower the Mean and we suppose the Comfort be caused by high muscular activity.
- *Envelope* is the curve Angle-Muscle Activity where for each Angle the biggest Activity value of the body muscles is selected. There is no parametrization because the max don't change cutting lower values.
- *Number of Active Muscles* count the muscles with a max activity value greater than the threshold.

In figures from **Fig. 8** to **Fig. 7** resulting curves for shoulder abduction are shown.

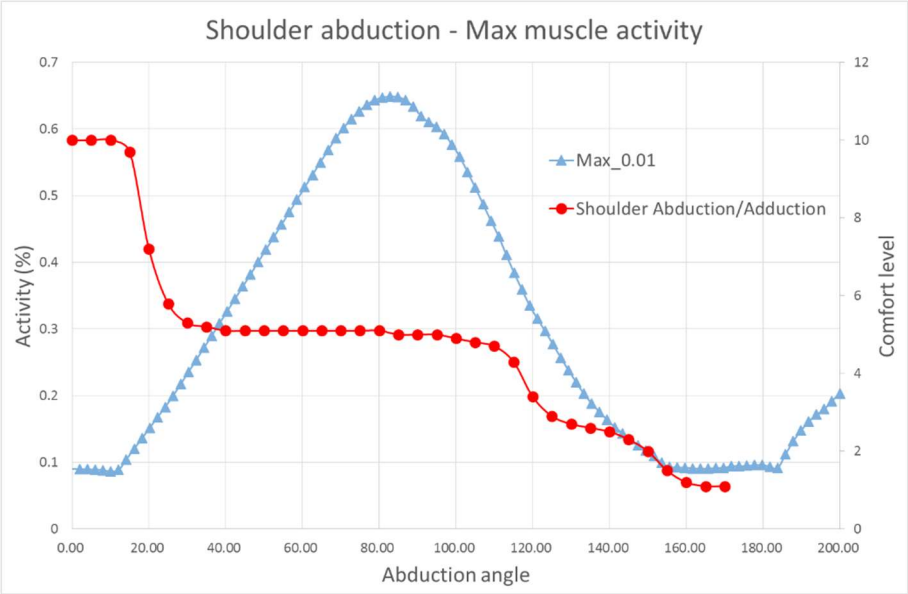


Fig. 7. Activity envelope in shoulder abduction movement.

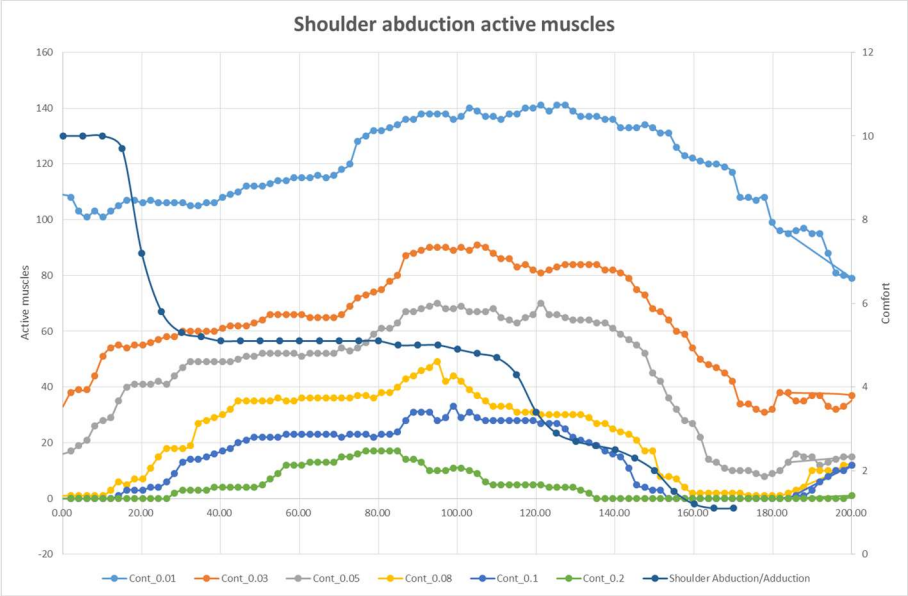


Fig. 8. Active muscles count in shoulder abduction movement.

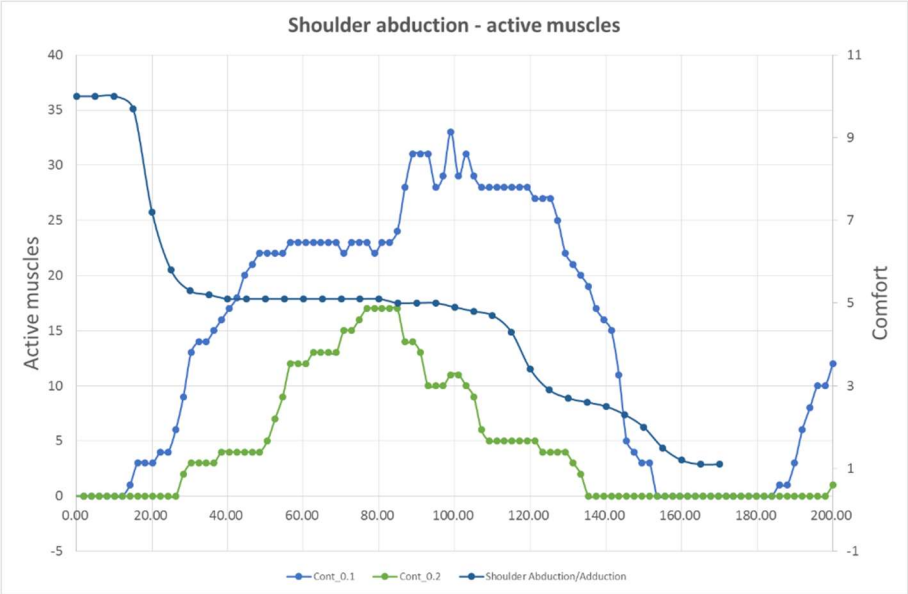


Fig. 9. Number of active muscles in shoulder abduction and threshold 0.01

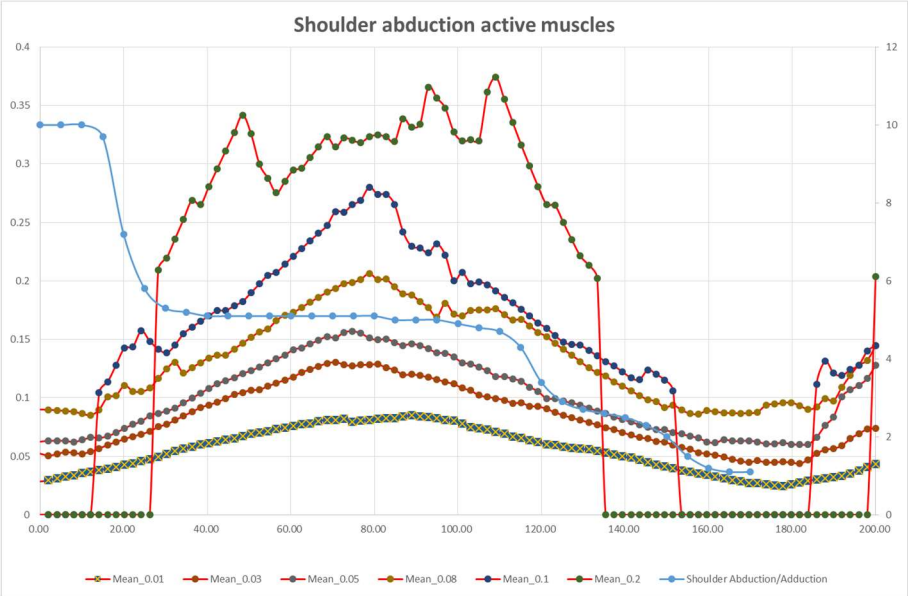
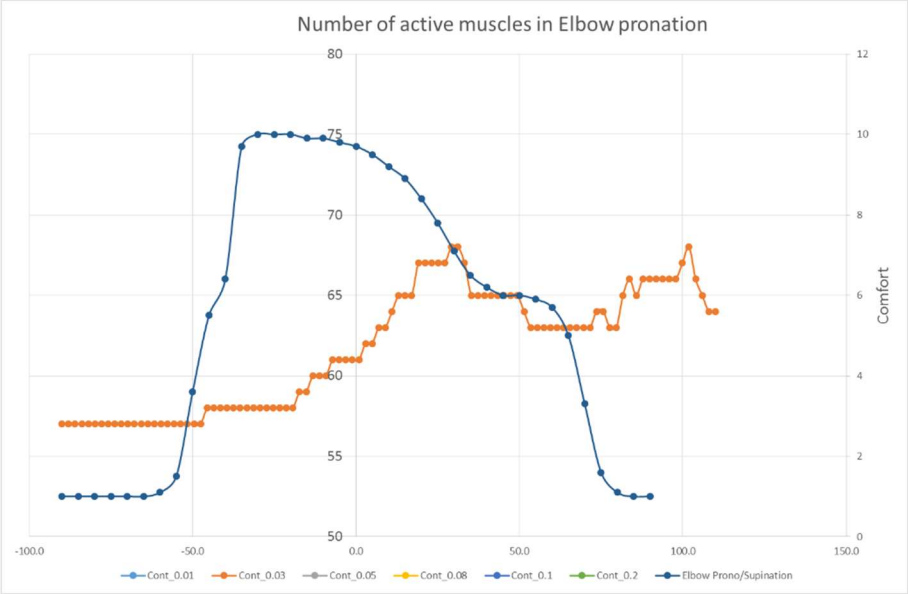


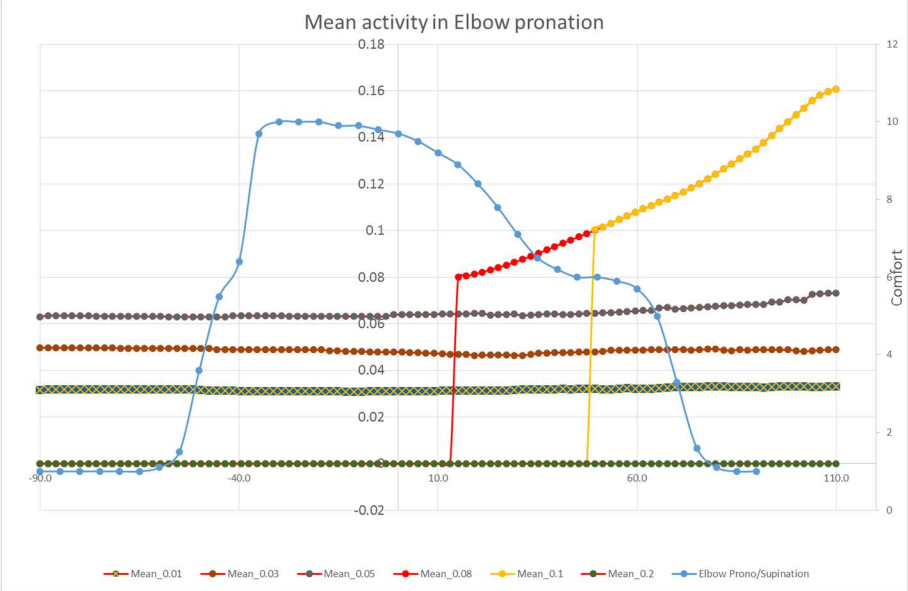
Fig. 10. Mean muscles activity in shoulder abduction movement.

From graphs we note that a to low loads level and a low number of involved muscles correspond an high comfort value, typically when the human body is in rest posture. When a movement starting from rest posture take place the number of active muscles increase and the activity of each muscle change but those aspects are not correlated.

As we can note observing in **Fig. 7** the Envelope, that is a most used Anybody's result, shows a maximum in the angles range where the Comfort is constant [30°, 110°]. When the shoulder reach the maximum abduction [110°, 170°] the Envelope decrease to the initial level but the Comfort drop down whereas, if we observe **Fig. 8** in the same range, the Counting of active muscles shows an increasing trend. This last parameter consider both the muscles naturally used to keep the global posture stable unchanging the CoG and the muscled used to perform the movements. Cutting the counting by a threshold the curves change in trend and in absolute values. A threshold between 0.1 and 0.2 (**Fig. 9**) seems to shows a change in correspondence of the Comfort curve change. Also in **Fig. 10** we note a change of mean activity from 0.08 threshold, where after the principal peak around 90°, a secondary peak appear at 100° where the Comfort start to decrease. Unexpectedly the Comfort level decrease even if both number of active muscles and muscle stress level decrease when the maximum extension is reached. In the particular case of shoulder abduction the maximum extension correspond to the arm in upper vertical position, when their weight load the articulation of the shoulder and not the muscles maintaining the position and the ligaments are at their maximum extension.

So we suppose that the Discomfort sensation at the extremities of movement's ranges is due to the high ligaments elongation and to local pressure on cartilage of articulations. Following figures show the same graphs for Elbow pronation, where the same considerations and value can be deduced. Also other articulation movements was analysed and results are coherent.





5. Conclusions

A study based on simulations of a Standing Human Body model by Anybody software was performed to analyse the relation between Postural Comfort and stresses on muscles. Some parameters significantly influencing Comfort was identified as *Mean Activity*, *Envelope* and *Number of Active Muscles*. Some other parameters needs attention because their influencing Comfort in the terminal part of the articular range such as ligament extension and joints loads.
However, some rules can be declared: when the body is in rest posture, the comfort is at top and active muscles and mean activity are at the lower level; when, because of movements or external loads, the Number of active muscle and also the

mean activity increase, the comfort decrease; when the ligaments extension or the articular loads increase, the comfort decrease; changes in mean activity and number of active muscle must be observed with a 0.1 threshold value.
Additional simulations are suggested in order to verify hypothesis on ligaments and articular joints. An experimental activity by comfort questionnaires and simulations comparison is suitable to check rules when several joints movements are combined in a single action.

References

[1] A. Naddeo, N. Cappetti, M. R. Vallone e R. Califano, «New trend line of research about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions,» in *Advances in Social and Organizational Factors*, Advances in Human Factors and Ergonomics" Conference, 2014.

[2] A. Naddeo, N. Cappetti e C. DÓria, «Proposal of a new quantitative method for postural comfort evaluation,» *International Journal of Industrial Ergonomics,* vol. 48, pp. 25-35, 2015.

[3] S. A. Southard e G. A. Mirka, «An evaluation of backpack harness systems in non-neutral torso postures,» *Applied Ergonomics,* vol. 38, pp. 541-547, 2007.

[4] Y.-K. Kong e B. D. Lowe, «Evaluation of handle diameters and orientations in a maximum torque task,» *International Journal of Industrial Ergonomics,* vol. 35, pp. 1073-1084, 2005.

[5] J. E. Fernandez, R. Agarwal, H. R. Landwehr, M. F. Poonawala e D. T. Garcia, «The effects of arm supports during light assembly and computer work tasks,» *International Journal of Industrial Ergonomics,* vol. 24, pp. 493-502, 1999.

[6] Z. Jianghong e T. Long, «An evaluation of comfort of a bus seat,» *Applied Ergonomics,* vol. 25, pp. 386-392, 1994.

[7] S. Hejazi, G. Rouhi e J. Rasmussen, «The effects of gastrocnemius–soleus muscle forces on ankle biomechanics during triple arthrodesis,» *Computer Methods in Biomechanics and Biomedical Engineering,* vol. 20, pp. 130-141, 2017.

[8] A. D. Wibawa, N. Verdonschot, J. P. K. Halbertsma, J. G. M. Burgerhof, R. L. Diercks e G. J. Verkerke, «A trap motion in validating muscle activity prediction from musculoskeletal model using EMG,» *International Journal of Bio-Science and Bio-Technology,* vol. 8, pp. 61-72, 2016.

[9] Z. Ji, H. Wang, G. Jiang e L. Li, «Analysis of muscle activity utilizing bench presses in the AnyBody simulation modelling system,» *Modelling and Simulation in Engineering,* vol. 2016, 2016.

[10] J. Z. Wu, K.-N. An, R. G. Cutlip, K. Krajnak, D. Welcome e R. G. Dong, «Analysis of musculoskeletal loading in an index finger during tapping,» *Journal of Biomechanics,* vol. 41, pp. 668-676, 2008.

[11] A. Apostolico, N. Cappetti, C. DÓria, A. Naddeo e M. Sestri, «Postural comfort evaluation: Experimental identification of Range of Rest Posture for human articular joints,» *International Journal on Interactive Design and Manufacturing,* vol. 8, pp. 109-120, 2014.

[12] Anybody Technology. [Online]. [Consultato il giorno 10 01 2017].

Designing movement into automotive seating - does it improve comfort?

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Abstract Comfort is important for a good driving experience and automotive seat technology is an important enabler of this. Movement through frequent changes in posture is beneficial for reducing fixed postures. This paper reports on a laboratory study to investigate a novel automotive seat movement concept aiming to delay the onset of driving-related musculoskeletal fatigue and improve feelings of comfort and wellbeing, making the driver feel refreshed and ultimately improving driver performance. The research involved comparison of three seat conditions while driving - no seat movement, fore-aft movement, cushion and backrest angle movement. The movement was designed to be at a fixed speed, slow, smooth and only slightly perceptible while driving. A sample of 10 participants was recruited to take part in a 60 minute drive for each condition - single blind, repeated measures, balanced order and sessions at a similar time of day. Discomfort and wellbeing questionnaires, driver Seat Fidgets and Movements (SFMs), posture capture and a de-brief were used as data collection methods. Results indicate that the two seat movement concepts were positively received. Statistically significant differences were found at minute 60 for buttock area discomfort, with less reported discomfort for the two movement conditions. As expected, overall discomfort ratings and SFMs frequency increased with time spent driving for all trials. Posture scores verified that driver posture was within comfortable ranges and as expected fairly static while driving.

Keywords: Driving; Musculoskeletal Fatigue; Automotive Seating; Car Seat Design

1 Introduction

Vehicle design can positively impact driver fatigue and lead to improved driver comfort, performance, wellbeing and safety. Driver fatigue is a result of the complex interaction of environmental, psychological, biological and vehicle factors exacerbated by conditions such as vibration, long duration sitting or high-workload driving [1].

Fixed postures from prolonged driving involve static muscle work and consequently blood vessel constriction, particularly in the spine, buttocks and thighs. As a result, local circulatory disruptions occur such that oxygen delivery, nutrient reserves and the removal of metabolic by-products are compromised, even for the low levels of sustained muscle contractions in driving. This process can cause local musculoskeletal fatigue, pain (e.g., low back pain (LBP), aches, cramps), discomfort, psychological fatigue and in the long-term

chronical musculoskeletal problems [2]. The health and comfort benefits of dynamic seating are well established in the design of office furniture [3] but there is a lack of evidence for this in the automotive field.

Considering that driving for extended periods of time inevitably leads to feelings of reduced comfort and that movement is beneficial for reducing local musculoskeletal fatigue, a novel automotive driver seat movement concept was explored. This paper reports on a laboratory study to investigate the concept of engineering movement into automotive driver seating aiming to delay the onset of musculoskeletal fatigue, increase feelings of comfort, wellbeing and refreshment, and ultimately improving the driving experience. Participants (n=10) performed one hour of simulated driving under three seat conditions - two seat movement conditions and a no seat movement condition (repeated measures).

2 Methodology

This section outlines the experimental methodology developed for the laboratory study.

2.1 Sampling

A sample of 10 healthy participants (5 males and 5 females) was recruited from the Midlands area to include a good anthropometric spread. There was no age restriction but participants needed to hold a full UK driving license, with at least one full year of driving experience and be regular drivers in the last 12 months. Permission to conduct the study was granted by Loughborough University Ethical Advisory Committee.

Participants were asked not to exercise one hour before the session and to wear comfortable, close fitting clothing (no heeled shoes). In the first session, on participants' arrival, the height and weight of participants were measured.

2.2 Laboratory development

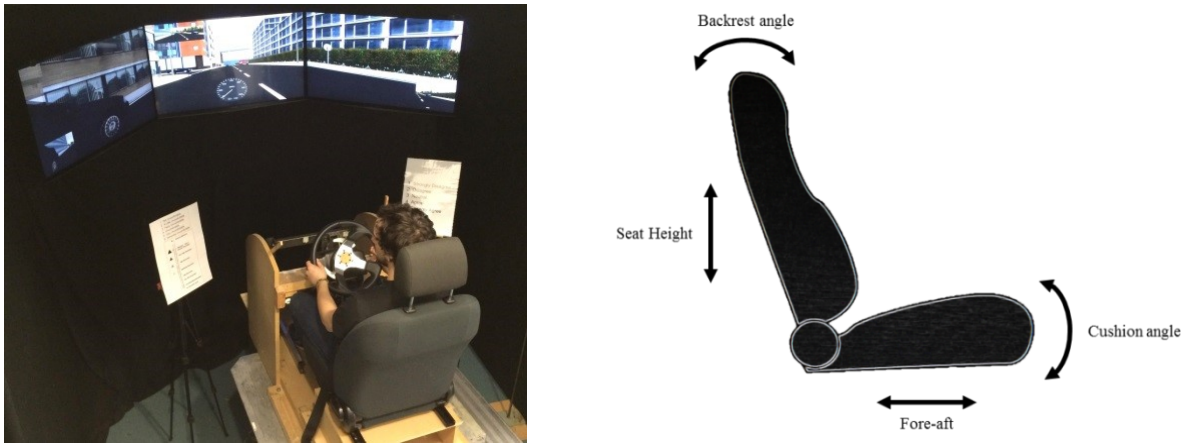
A realistic and repeatable simulation of the driving environment was used. A manufactured rig with the dimensions of a production car, automatic pedal transmission set-up and a non-adjustable steering wheel to control the driving simulator was mounted on to a platform, which was fixed to a 6 Degrees of Freedom (DoF) multi axis vibration simulator (MAViS) (Rexroth Hydraudyne B.V Micro Motion 600-6DoF-200-MK5 MAVIS) with closed loop control. A blackout driving environment was provided as feasibly possible. The driving simulation involved a 3-screen set-up, with four different 'follow driving' scenarios, including town and motorway routes, set up in a fixed sequence [4].

Before the first driving trial:

- A system characterisation was carried out with each participant using a Larson Davis Human Vibration Meter 100 (HVM100) to ensure they were exposed to the same target level of seat surface vibration, replicating a UK normal drive. The weighted acceleration equivalent value (aeq) was monitored. This was done while allowing participants to practice their simulation driving for a few minutes [5].
- A short fitting trial (standard iterative process) was conducted to set participants in their optimum driving position.

2.3 Seat movement development

A high quality seat (Figure 1(a)), four directions electronically-adjustable - fore-aft, vertical, cushion angle and backrest angle (Figure 1(b)) - with memory function was used. It was mounted on to the rig as close as possible to the dimensions of the manufacturer seat set-up of the production car. The full cab set up, e.g., steering wheel, pedals, control panel, was not replicated.



(a) (b)

Fig. 1. Simulated driving environment: (a) driving trial; (b) seat movement adjustable directions.

The seat movement aimed to change body contact points with the seat in order to affect driver position and refresh the driver and improve comfort. Iterative pilot studies were conducted in order to understand drivers' sensitivity/tolerance to the seat movement and to determine the seat movement ranges to be introduced in the seat.

A control system using Daisy Lab Software was developed for remote electronic operation of the seat by the researcher. The required seat movement was realised by input of the specific target position. Considering the capabilities of the seat movement (power and control), it was designed to:

- Not be annoying or disturbing to the driving task or cause any impediment to leg movement, steering and operating the pedals as well as dashboard full view.
- Be at a fixed speed, slow and smooth, within a small range and only slightly perceptible whilst driving.
- Have independent movement in each direction.

The final protocol was designed so that range of movement for each direction was interpolated for the 15 minute intervals (time between collection of discomfort ratings) and following a staircase protocol [6]. The research involved comparison of three seat conditions whilst driving:

- Condition 1 - No seat movement
- Condition 2 - Fore-aft seat movement
- Condition 3 – Cushion and backrest angle movement

Several malfunctions of the seat related to the seat lifter motor during pilot work lead to the decision not to risk using the seat height/vertical direction of movement in the study.

The three experimental conditions were evaluated on three separate days, at a similar time of day, single blind, repeated measures and in a balanced order. Each 90 minute session involved a 60 minute simulated driving task. The same protocol was used in accordance with the test condition - only the selected optimum driving position varied between participants.

2.4 Methods

A discomfort questionnaire was used in the study [6]. Part 1 collects body part discomfort and includes a body map [7] and a six point anchor from ISO 2631-1 [8]. Part 2 focuses on overall discomfort and comprises an adapted Borg CR-100 scale [9].

Discomfort scores were collected at each 15 minute time point (minute 0, 15, 30, 45, 60) for body parts - neck, shoulders, upper back, lower back, buttock area and ankles - and overall discomfort. An open question was also included asking if they had discomfort in any 'other' body area. The number of body regions was simplified to those mainly associated with driving and also considering the seat movement effects. The objec-

tive was to provide the least disruption to driving but at the same time ensure that the progression of discomfort over time was captured.

A wellbeing questionnaire was designed in order to evaluate the wellbeing of the driver. The descriptors were adapted from Ahmadpour et al. [10] and a five-point Likert scale (strongly disagree to strongly agree) was used to rate participants' responses. Time points sampled were minute 0 and 60.

Concerning subjective data collection, it should be noted that:

- Optimum visibility of the scales while driving was verified with the participant.
- Just before the driving trial (so that instructions were not forgotten), participants were trained on the use of the scales. On the second and third sessions, participants were reminded of the scales.
- Participants did not 'pull over' to provide ratings. This allowed continuous driving for the 60 minute trial.
- Ratings were collected at set time points but the driving workload was considered by the researcher (within 30 seconds). Failure to do this could affect the reliability of the data and compromise the driving.

An adapted version of Rapid Upper Limb Assessment (RULA) [11], a rank scoring/scale system focused on the upper body, was used to estimate posture. The score reflected the postural angles (upper arms, lower arms, wrist, neck, torso, legs) that the participant adopted at the sampled time. The protocol involved analysis of the video recordings of the driving posture adopted during the trial. The most typical/common posture within a 5 minute time frame was scored (at minute 15, 30, 45 and 60).

Driver Seat Fidget Movements (SFMs) is a measure of driver discomfort [5], also denominated in literature as Discomfort Avoidance Behaviours (DABs) or 'in chair movement'. It is a remote measurement technique whereby video data recorded of the driving session were reviewed and movements judged to be related to discomfort and not to the driving task were counted. The time and types of SFMs are described by Sammonds et al. [5].

At the end of the final session, participants were de-briefed on their perceptions of the seat movement.

3 Results and discussion

10 drivers (5 males and 5 females), aged 19-26, completed the seat movement study. The following comments should bear in mind that the ratings of body part and overall discomfort were generally low for the three conditions. This was to some extent expected, due to the use of a high-end production seat. Statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS) for the discomfort rating data and wellbeing scores.

A Friedman test showed that there were no statically significant differences between Condition 1, 2 and 3 at each time period (0, 15, 30, 45, 60 minutes) for body parts and overall discomfort as well as for the wellbeing ratings. An exception was buttock area discomfort at 60 minutes (Figure 2), where a statistically significant difference was found ($\chi 2 = 7.692$, $p = 0.021$), with less reported discomfort for the two movement conditions, and Condition 3 having the least discomfort. Concerning overall discomfort at 60 minutes (Figure 3), Condition 3 had a lower rating (non-statistical trend) than both Condition 1 (no movement) and Condition 2. Regarding the wellbeing ratings at 60 minutes (Figure 4), there was a trend for the two movement conditions (Condition 2 and 3) to have better ratings than Condition 1 (no movement) for the descriptors 'I feel relaxed', 'I do not feel physically fatigued', 'I do not have heavy legs'. Condition 3 has better ratings than Condition 1 (no movement) for all the descriptors.

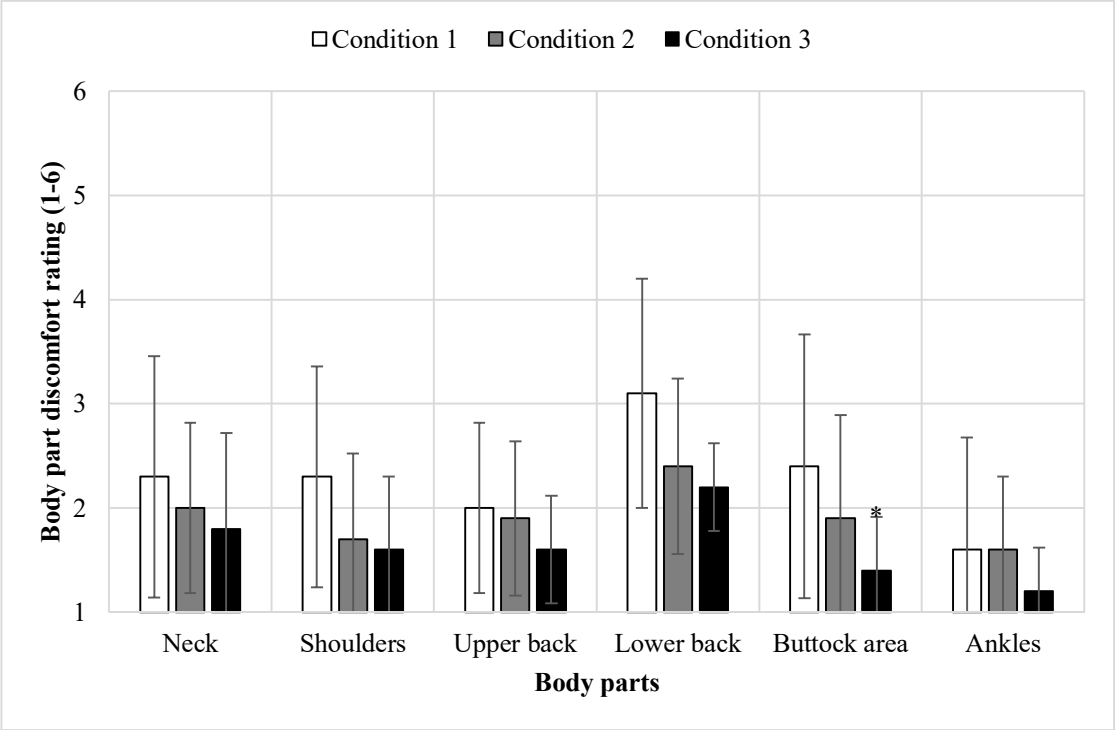


Fig. 2. Body part discomfort for Condition 1, 2 and 3 at 60 minutes of driving (*p<0.05).

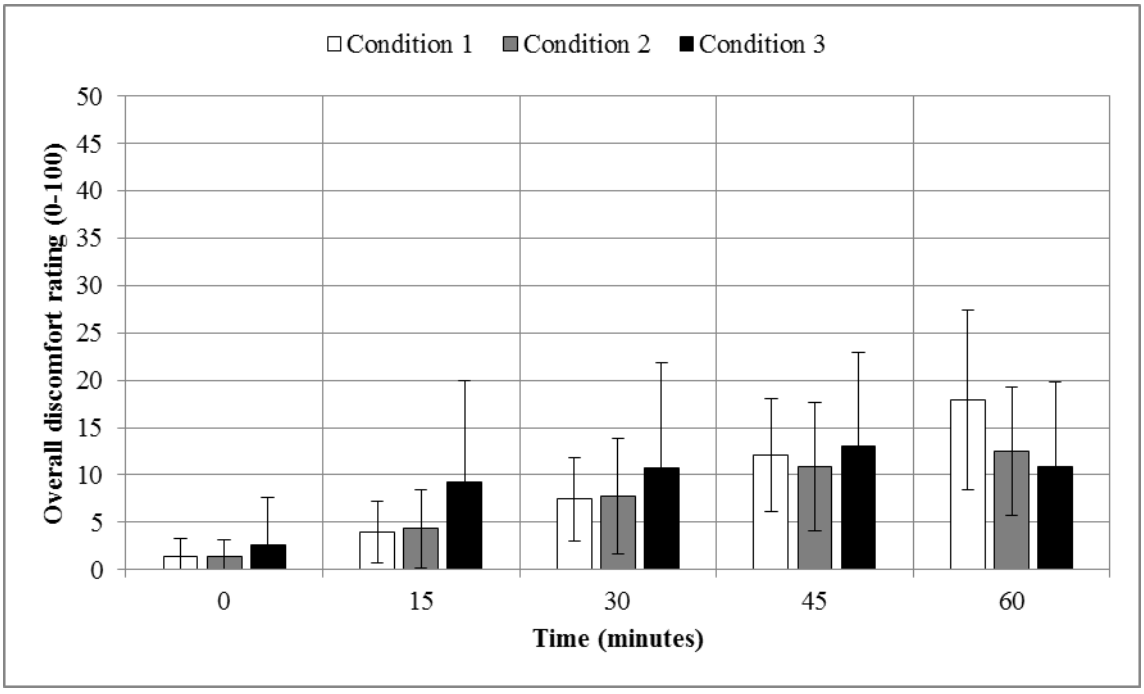


Fig. 3. Overall discomfort for Condition 1, 2 and 3 over the 60 minutes drive.

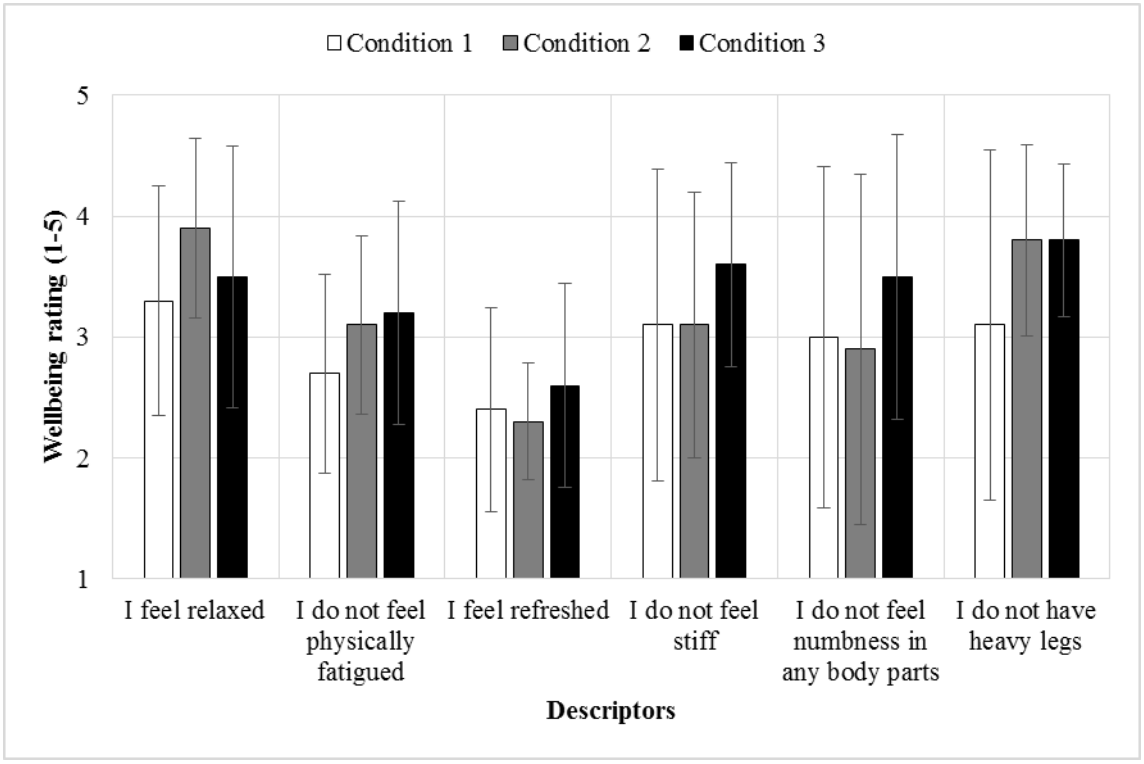


Fig. 4. Wellbeing ratings for Condition 1, 2 and 3 at 60 minutes of driving (*p<0.05).

Using mean rank (over the 60 minute drive), Conditions 2 and 3 had lower mean discomfort ratings than Condition 1 (no movement) for the neck, shoulders, lower back, buttock area and ankles. Condition 2 had lower mean discomfort ratings than Condition 3 for the neck, shoulders, upper back and lower back. Condition 3 had lower mean ratings than Condition 2 for the buttock area and ankles. As for mean overall discomfort, Condition 2 had the least discomfort.

As expected, the Friedman test indicates that for the three conditions there were a statistically significant differences in body part and overall discomfort over time (for the 60 minute drive) for:

- Neck - Condition 1 ($\chi2$= 17.984, p= 0.01); Condition 2 ($\chi2$= 13.159, p= 0.011); Condition 3 ($\chi2$= 14.055, p= 0.007)
- Shoulders - Condition 1- ($\chi2$= 20.567, p= 0); Condition 2 ($\chi2$= 12.046, p= 0.17)
- Upper back - Condition 1 ($\chi2$= 18.447 p= 0.001); Condition 2 ($\chi2$= 15.287, p= 0.004)
- Lower back - Condition 1 ($\chi2$= 26.101, p= 0); Condition 2 ($\chi2$= 19.016, p= 0.001); Condition 3 ($\chi2$= 19.167, p= 0.001)
- Buttock area - Condition 1 ($\chi2$= 19.129, p= 0.001); Condition 2 ($\chi2$= 15.695, p= 0.003)
- Ankles - Condition 2 ($\chi2$= 15.781, p= 0.003);
- Overall discomfort - Condition 1 ($\chi2$= 37.041, p= 0); Condition 2 ($\chi2$= 31.668, p = 0); Condition 3 ($\chi2$= 22.042, p= 0)

A Wilcoxon signed-rank Test showed also that there were statistically significant differences between the start (0 minutes) and end of the trial (60 minutes) for the three Conditions for body part and overall discomfort with better ratings at the end of the trial. Wellbeing ratings were also better at the end of the trial.

Posture scores verified that driver posture was fairly static during the 60 minute simulated drive. Posture scores were low and therefore postures were generally within comfortable ranges [11]. Preliminary findings from the SFMs analysis showed that, as expected, SFMs frequency increased with duration of driving for all trials [5].

Concerning the overall comments/participant verbatim from the de-brief conducted at the end of the final session, it can be inferred that the concept of seat movement was well received by participants. The majority of participants surmised that the discomfort levels they felt under the two 'seat movement' conditions were

lower than under the no movement condition. Moreover, the majority of participants was well aware of the seat movement and noticed specifically which movement was produced in each session. Feedback was given regarding positive effects of the resultant repositioning and small body movements, as well as feelings of awakening, alertness, and improved concentration. Additionally, seat movement was reported not to disturb the driving experience. These comments require further exploration in future studies.

4 Conclusions

Although not statistically significant, the results indicate that the two seat movement conditions showed a trend for lower ratings of body part and overall discomfort over time. Wellbeing ratings were also better for the seat movement conditions. Statistically significant differences were found at minute 60 for buttock area discomfort, with less reported discomfort for the two movement conditions. As expected, overall discomfort ratings and SFMs frequency increased with time spent driving for all trials. Posture scores verified that driver posture was within comfortable ranges and as expected fairly static while driving.

The concept of seat movement was well received by participants and did not disturb the driving experience. Positive effects were reported with regard to the resultant repositioning and small body movements, feelings of awakening, alertness, and improved concentration.

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References

1. Jagannath, M. and Balasubramanian, V., 2014. Assessment of early onset of driver fatigue using multimodal fatigue measures in a static simulator. Applied Ergonomics, 45 (4), pp.1140-7.
2. Gyi, D.E., 2013. Driving posture and healthy design. In: N. Gkikas, ed. Automotive ergonomics: driver-vehicle interaction. Boca Raton: CRC Press. pp.123-32.
3. Groenesteijn, L., Ellegast, R.P., Keller, K., Krause, F., Berger, H. and de Looze, M.P., 2012. Office task effects on comfort and body dynamics in five dynamic office chairs. Applied Ergonomics, 43(2), pp.320-8.
4. Smith, J., Mansfield, N. and Gyi, D., 2015. Long-term discomfort evaluation: comparison of reported discomfort between a concept elevated driving posture and a conventional driving posture. Procedia Manufacturing, 3, pp.2387-94.
5. Sammonds, G.M., Fray, M. and Mansfield, N.J., 2017. Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs). Applied Ergonomics, 58, pp.119-27.
6. Mansfield, N.J. and Griffin, M.J., 2000. Difference thresholds for automobile seat vibration. Applied Ergonomics, 31(3), p.255-61.
7. Porter, J.M. and Gyi, D.E., 1998. Exploring the optimum posture for driver comfort. International Journal of Vehicle Design, 19(3), pp.255-66.
8. International Organization for Standardization, 1997. ISO 2631-1: 1997. Mechanical vibration and shock - evaluation of human exposure to whole-body vibration. Part 1: General requirements. Geneva: International Organisation for Standardization.
9. Borg, E. and Borg, G., 2002. A comparison of AME and CR100 for scaling perceived exertion. Acta Psychologica, 109 (2), pp.157-75.
10. Ahmadpour, N., Robert, J.-M. and Lindgaard, G., 2015. Aircraft passenger comfort experience: underlying factors and differentiation from discomfort. Applied Ergonomics, 52, pp.301-8.
11. McAtamney, L. and Corlett, E.N., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Applied Ergonomics, 24(2), pp.91-9.

Quasi-vertical working position – innovation source for the personal urban car design of the future

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Abstract The paper presents an unconventional car driving position named by the author "quasi-vertical driving position." In principle it is considered to be also a position of travelling for passengers. For instance, quasi-vertical working position offers a significant advantage of reducing the loads in the buttock area, partially redistributing them to the knees and soles. Quasi-vertical position involves a new configuration of the cockpit including a new design for the seat of the car. Further on, the paper presents an experimental method for determining the distribution of the loads on the driver seat (adapted to the quasi-vertical driving posture) generated by the body weight; this depends on values of the geometrical parameters that define the quasi-vertical driving position. The method also aims at determining the recommended domain of comfort. This paper presents some widely accepted principles regarding the evolution of urban private car of the future. Finally, to illustrate how quasi-vertical driving position can influence the architecture and design of the urban personal car of the future, there are presented some original concept sketches of body design based on the quasi-vertical driving / travelling position.

Keywords: Quasi-vertical Driving Position, Experimental Ergonomic Evaluation, Urban Personal Car, Prospective Design.

1 Introduction

Among the inventions of the modern world a few have influenced our everyday life like the automobile. In its existence for about a century the automobile has offered freedom of movement in and out of cities at an affordable price. This mobility is necessary to take advantage of all the benefits of a modern city - from economic, social and cultural perspectives. Today there are many voices that call for an urgent need to reinvent the car as an important component for redesigning a transport system adapted to the anticipated needs for the future. The author proposes the concept of quasi-vertical driving / travelling position. Applied to urban passenger cars, the new concept will have strong consequences in terms of comfort, dimensions and appearance.

2 General premises and perspectives on the development of automobiles

The car become one of the most desirable objects in time, even associated with a dream or philosophy of life.

The evolution of the car can be tracked in parallel with the evolution of road infrastructure, but also with advances in the field of engineering. Also, over time, a number of changes have been made to legislation, transport and energy policies. Personal mobility is today recognized as a fundamental human need. There is a long history of how people and their goods were transported over the time. Nowadays, a number of major problems and vulnerabilities related to the transport system have been identified, such as the congestion of traffic at rush hours in crowded traffic areas and the lack of parking space in the city. These phenomena are particularly important so they have generated more and more discussions on the sustainability of the current car transport system. Reinventing or, in other words, the fundamental redesign of the car is seen as a necessity to provide solutions to the multitude of transport issues in the context of the complexity of urban life. This is a way to develop new types of automobiles but also other urban mobility systems that allow not only to maintain the current level of mobility, but, as the forecasts show, to be able to cope with an increase of this need. Strategically, new vehicles will have to reflect a new philosophy, essentially the major objective being to improve the quality of city life.

An important role in shaping the new identity of urban vehicles will be played by designers and stylists, who are also responsible for creating an attractive high-quality appearance. This will be a condition of success for the new revolutionary car concepts and their adoption in our everyday life and urban areas.

2.1 The development strategy of the automobility system

Recent interdisciplinary research has led to the formulation of a four-point development strategy for the transport system called "automobility system". It includes the following actions [1]:

1. Adoption of another car gene code that transforms the principles on which the automobile is now based on:

- electric engines - instead of those with combustion,
- electrical control system - instead of a mechanical one,
- intelligent and interlinked operations - instead of the independent ones.

2. The use of the Mobility Internet - which will allow vehicles to access in real time an enormous amount of traffic data so that journeys are more predictable and travel time will be shortened. Combining the new DNA code with the use of the Mobility Internet will allow the reinvention of personal urban mobility systems. It is anticipated that the new vehicles designed for the city will be much reduced in size, with much more reduced carbon footprint, cheaper to buy and with much reduced cost operation.

3. Combination of power-driven vehicles with energy-efficient buildings and intelligent utility networks to create distributed and flexible energy systems.

4. Development of an energy market that is controlled by electronic means under conditions of constantly changing rates - for electricity, road taxes, parking and vehicles. This electronically managed market will be able to optimize demand and supply.

2.2 General solutions for redesigning the new vehicle architecture

One of the important solutions for building the vehicle of the future to meet the above-mentioned efficiency requirements is to redesign the vehicle architecture.

A new conceptual solution is the transfer of some components necessary for the operation of the car from the actual car to the fixed road infrastructure as an alternative to the miniaturization solution and the weight reduction of the components[1].

The problems studied will be largely related to the electrification and connectivity of the components of the transport system.

Starting from these observations, we can see the trend for new cars to have an innovative exterior appearance characterized by new proportions and perhaps a significant reduction in body dimensions. This is likely to lead to weight reduction, a more compact architecture, and an improvement in aerodynamic characteristics. It is also predictable to use new, more efficient materials with new features.

An innovative vehicle architecture is a new challenge for designers and stylists, an extraordinary opportunity to create new functional and aesthetic prospects. To reinvent the car, designers are called to adopt bold technical solutions and extremely courageous forms.

3 "MANE" – a new CAD tool to assist the car architecture design

To reinvent the automobile architecture in a daring mood the designer needs to evaluate the tools of the proposed technical solutions. The experience has proved that a successful product can be made by combining the research methods that uses CAD and the testing of the theoretical solutions.

One important step in the carbody design process consists in choosing the style of the new car by presenting different new concept car designs to the marketing, styling and design responsive of the automotive company after analysing their impressions. The results are extremely useful if the new car concepts already presented have taken into account the technical and human constraints. That is why it is necessary to be able to perform a quick and simple ergonomic evaluation of the cockpit for each version of the carbody design proposed by the stylist. For this purpose the author conceived a new software (named "MANE") for the 2D research of the cockpit architecture which starts from the SAE Recommended Practices for vehicle design[2]. Using the CAD technology, the "MANE" software is a useful help for defining the cockpit geometry.

The program has a friendly graphical interface (Figure 2.) which allows the input of any anthropometric profile for the user (driver or passenger) as well as the definition of recommended comfort areas of values for the geometric parameters determining the position of the user's body (driver or passenger) (Figure 1.).

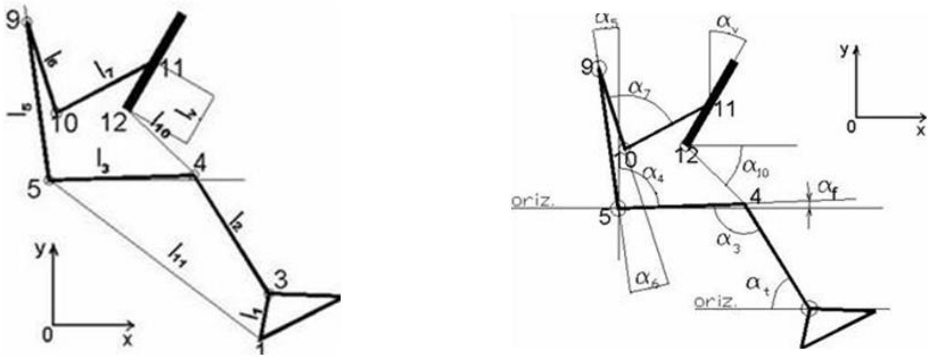


Fig.1 Angles and lengths whose values are recommended in order to ensure optimum comfort driving.

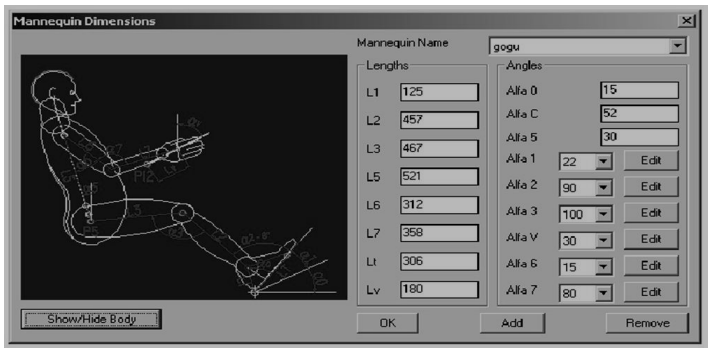


Fig.2 The main dialog box of the "MANE" program.

Based on an algorithm that substantially enhances the level of automation of the operations for this type of analysis, the program calculates and graphically displays the areas where the essential elements of the interior of the automobile (seat, steering wheel, windscreen) should be placed in order to satisfy the SAE general confort recommendations (Figure 3.)[2].

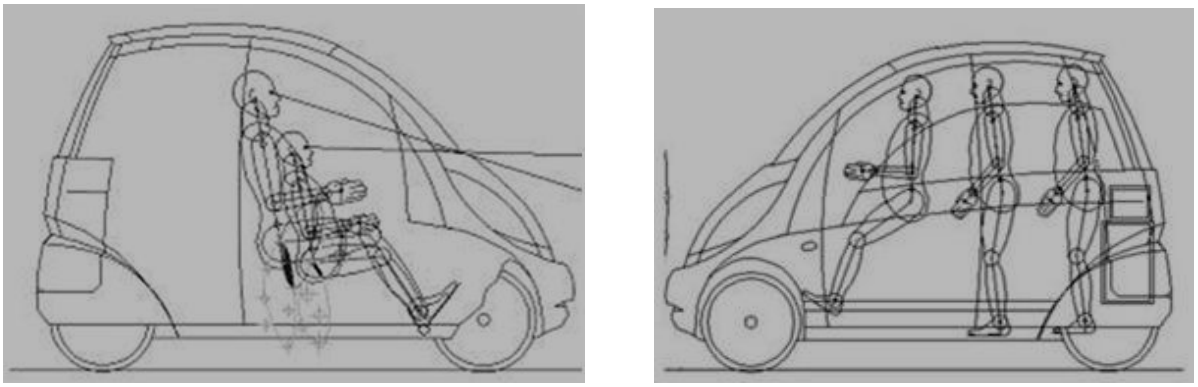


Fig.3 The representation of the mennequins inside cockpit by using the “MANE” program.

Experimental research can also be carried out in the case of driving positions not provided in the SAE *Recommended Practices for Vehicle Design*. One of the main purpose of these studies is to determine the recommended areas of values for the geometric parameters that characterize the comfortable driving / travelling position. Thanks to its flexibility, the "MANE" program allows the input of the new recommended values for the angles and lengths that resulted during the experimental research on the stand (Figure 3.). This makes possible the CAD design of unconventional and innovative automobile architectures that are associated with unusual driving / traveling postures[3].

As previously stated, making cars as compact as possible is a solution for the future vehicle architecture. In this context, there is a need to reduce the interior dimensions of the cockpit, and it is therefore necessary to study new possible driving / traveling positions. An important direction of research refers to the possibility of reducing the length of the vehicle and therefore of the cockpit. This leads to the design of a smaller working space in the longitudinal direction of the vehicle for the driver and passengers. Starting from this observation, it is obvious that a possible solution is the remodeling of the individual space necessary for each occupant of the car by its predominantly vertical redistribution.

4 Quasi-vertical driving position - an innovative solution for the urban automobile architecture

Intuiting an opportunity to reduce the size of the cockpit, the author proposes the original concept of “quasi-vertical driving position” for the driver but also applicable to the passenger. This position is defined by the almost vertical posture of the user's trunk with the back and buttocks supported by a special chair or support device and with the possibility for the soles of the feet to reach the floor. The knees area must be in contact with a special addapted support. In this way the body weight could be discharged in different proportions on each of these three contact surfaces (figure 4.). Based on the presented principles, a series of tests were conducted on a testing stand that basicaly simulates a seat adaptable to very different driving postures - including the quasi-vertical driving position described above.



Fig.4 The original concept of quasi-vertical driving position.

4.1 Testing the "quasi-vertical" driving position

For testing the new original driving position it was necessary to design and realize a new type of testing stand which allows quasi-vertical posture.

4.1.1 Equipment

The stand simulates a driving chair adapted to the quasi-vertical driving position (Figure 5). In the given situation the stand was provided with a special device that supports the tibias or knees. The feet should also rest on the soles.

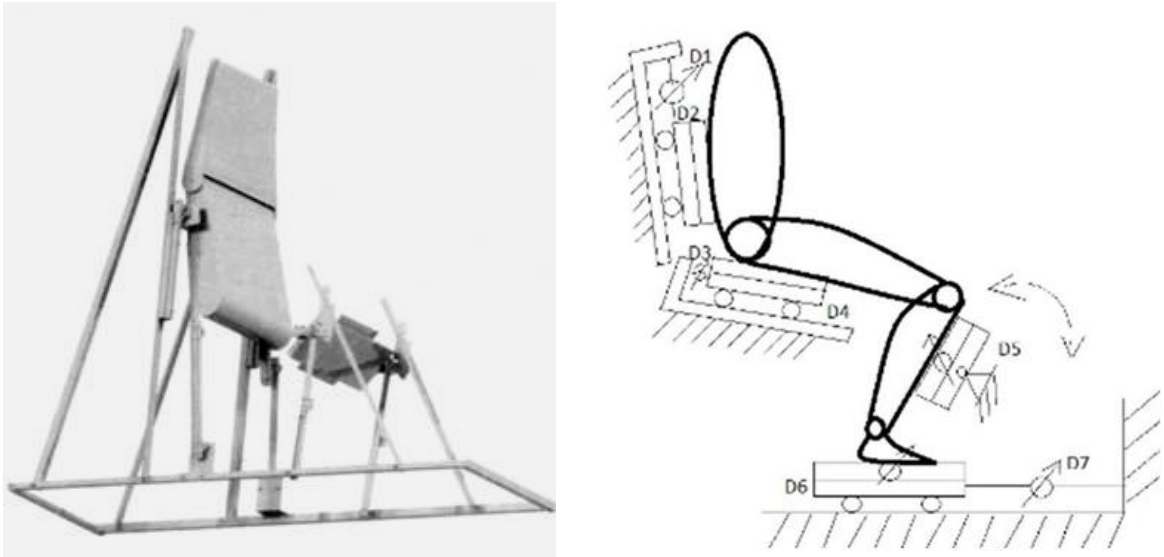


Fig.5 The basic structure of the testing stand for quasi-vertical driving position(on the left side) and the functional scheme of the forces measurement system (on the right side).

The new stand provides some important possibilities of adjustment of the seat position such as: seat cushion inclination and height, backrest inclination, the position of the knee support in relation to the seat cushion. The stand allows adjustments on a broad domain corresponding to test various hypotheses.

4.1.2 The measurement principles and the goals of the testing method

A first series of tests aimed at determining how the weight is distributed on the stand supporting elements (seat and floor). The test is carried out in static conditions for various configurations / driving positions, using different human subjects with different anthropometric dimensions. The seated cushion, the backrest, the tibia / knee support and the sole support are considered supporting elements. These elements and the dynamometer systems attached to each of them have been designed and adapted so that normal and tangential forces can be measured independently (Figure 5).

In Figure 5 there were made the following notations:

α_{SC}=seat cushion inclination

α_{bk}=backrest inclination; it was adopted: $\alpha_{bk}=100^0$,

D_1 = tangent force on the backrest,
D_2 = normal force on the backrest
D_3 = tangent force on the seat cushion
D_4 = normal force on the seat cushion
D_5 = normal force on the knee support
D_6 = normal force on the soles support
D_7 = tangent force on the soles support

The tests carried out have highlighted the significant influence that the seat geometry has on the way the weight of the human body is distributed over the chair support elements. In this stage of study, only the orientation of the chair elements (driving position) was considered. This is expected to be crucial in terms of comfort in the process of developing fatigue in the quasi-vertical working position.

In comparison with the usual driving position (currently used in automobiles) it was observed in the first analysis of the measurements made on the stand that the quasi-vertical driving position produces a substantially reduced seat cushion load (and accordingly a decreases of the body load in the seat area) compensated by the occurrence of significant but moderate loading of the knee and tibia support elements (corresponding to the increase of the body load in the respective areas). This load distribution in the quasi-vertical driving position offers the advantage of a much lower load in the pelvic area - so a much lower backbone load in the lumbar region (Table 1).

Table 1. The force measured on the supporting elements of the chair for $\alpha_{bk}=100^0$ as a function of α_{SC}.

	D_1	D_2	D_3	D_4	D_5	D_6	D_7
$\alpha_{SC}=-18^0$	2.0 [daN]	7.9 [daN]	4.0 [daN]	61.4 [daN]	23.3 [daN]	10.4 [daN]	2.5 [daN]
$\alpha_{SC}=-31^0$	2.0 [daN]	18.6 [daN]	11.9 [daN]	48.72 [daN]	30.22 [daN]	21.9 [daN]	3.1 [daN]

Therefore it is possible to anticipate a slower development of fatigue in this important area of the back that is largely responsible for the general feeling of fatigue. Instead of that, for the quasi-vertical driving position, it is possible to estimate the faster leg fatigue installation as a result of extra loads on the sole and tibia.

These preliminary data will be continued by experimental studies conducted in situations of great diversity taking into account factors such as the orientation of the seat elements, the mechanical characteristics of the materials used, the typology of the users, the nature and complexity of the tests (static or dynamic) and their duration. The results of these studies can be spectacularly reflected in the architecture of new compact passenger cars dedicated to the urban traffic of the future.

4.2 Proposals concerning the style of possible urban personal automobiles – which will use the "quasi-vertical driving/travelling position"

An advantage of using the quasi-vertical work position is to reduce the necessary accommodation for the driver and passengers. These dimensions directly influence the dimensions of the cockpit and therefore the exterior dimensions of the car. This makes possible a significant diminishing of the length of the vehicle in exchange of increasing its height.

It can be estimated that when using the new quasi-vertical working position the length of an urban vehicle for the transport of 4 -6 passengers could reach about 2.5 meters. In comparison, the Media Lab City experimental urban car has a length of 1.5 m in the folding position for parking and 2.5 m in a traffic configuration, while it can carry 2 passengers [1].

As a disadvantage of the architectural solution using the quasi-vertical working position, the center of gravity of the car is expected to be higher, which is an additional important issue for the dynamic behavior in traffic and especially at high speeds and curve travel. Therefore it is proposed to limit the top speed estimated to about 60-70 km / hour, which might prove enough for a travel in urban driving conditions often overcrowded. This is to be studied theoretically and experimentally.

It can be said that the new solution proposed for cockpit architecture, using the quasi-vertical driving position, has the potential to dramatically influence new cars both in terms of their external appearance and their operation in urban traffic.

It is obvious that the quasi-vertical position provided for occupants of the automobile will lead to a new aesthetics of urban transport vehicles, without any precedent for the moment, but with which the public may become familiar after a relatively short time. Figure 6 shows some stylistic variants of a car of this type - in the author's view.

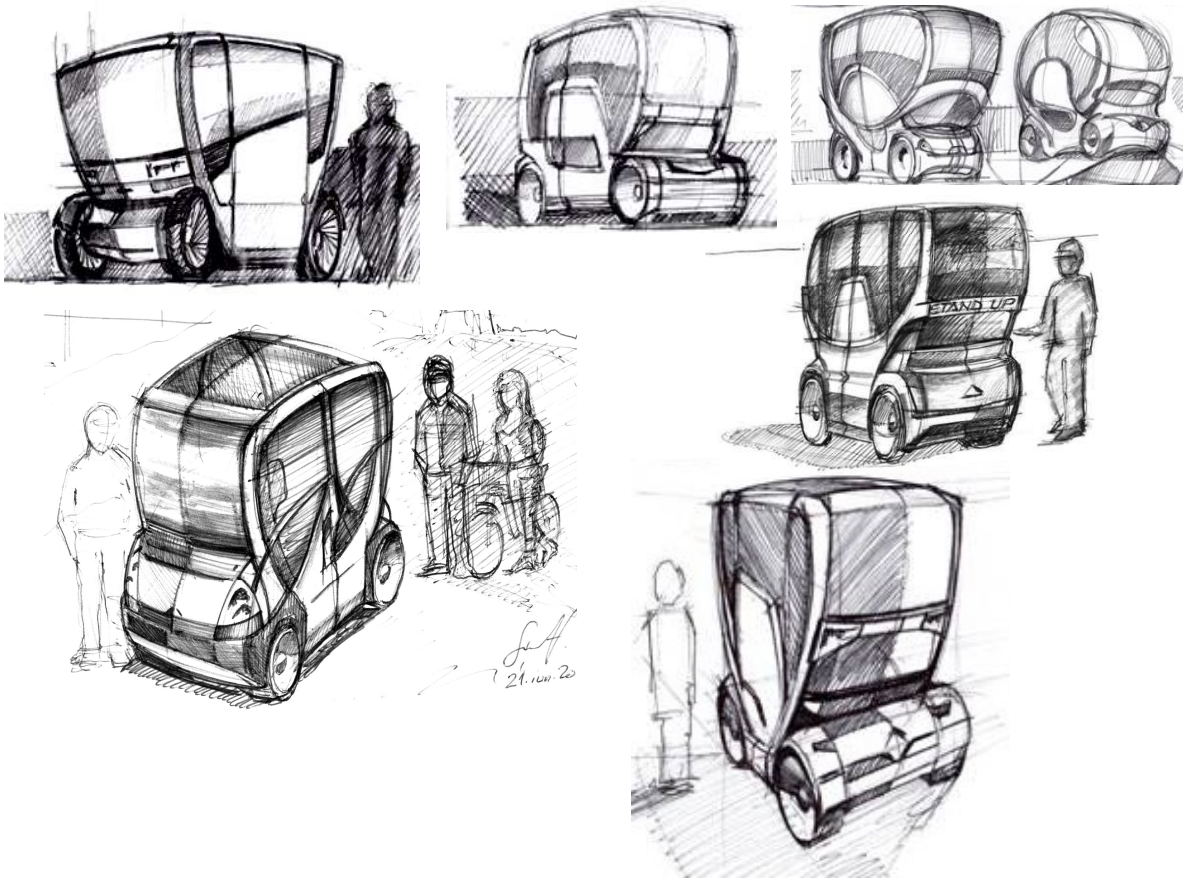


Fig.6 Stylistic variants for an urban passenger car provided with quasi-vertical working position (driving/travelling position).

5 Conclusion

The new theoretical concept of quasi-vertical work position - applied to both the driving position and the passenger position, offers new possibilities for reinventing the future urban automobile - both in terms of its operation and use as well as for the development of a new and original aesthetic of its interior and exterior appearance. The viability of the new ergonomic solution can be analyzed in the light of both the benefits it brings (including the significant reduction in body length) and the potential disadvantages associated with it (reduction of travel speed, and probably a faster occurrence of the users fatigue). The development perspectives of the car presented in the paper as well as the original proposals of the author will be the starting point for carrying out future studies.

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References

1. Mitchell, W.J., Christopher, Borroni-Bird C.E., Burns, L.D., (2010). *Reinventing the Automobile,* MIT Press, ISBN 978-0-262-01382-6, Cambridge Massachusetts.
2. Șișman, V., (2011). A*utomated styling assistant for new car design*, In: The Automobile and the Environment: International Congress of Automotive and Transport Engineering CONAT 2010, Edited by Anghel CHIRU, 2011, page 439-450, Cambridge Scholars Publishing, ISBN (13): 978-1-4438-2972-4, Newcastle upon Tyne,UK.
3. Șișman, V., (2015). *How to combine MANE (an original CAD assistant for car body design) with testing methods to reinvent the urban car*, în Papers of the International Conference on Engineering Graphics and Design, ICEGD 2015, Brasov, section 4, pag.57, Journal of Industrial Design and Engineering Graphics (JIDEG)
4. Stoica, R., Ciuntu, I., Ivan, S., Șișman V. (coordinating teacher). *Experimental study of the quasi-vertical position. (Studiu experimental asupra pozitiei de lucru quasi-verticale)*. License Thesis, Faculty of design, Transilvania University of Brașov, 2012-2016.

"Whee'll Fly" wheelchair: a new mobility device designed for air travelers with disabilities

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Abstract In the age where traveling has become less of a luxury and more of a necessity for a lot of people, most people see it as a routine activity usually without too many inconveniences. However, travelers with disabilities experience serious challenges in the airports, and inadequate seating on airplanes is often cited as the leading cause of discomfort. The rigidity of the standard seats will often aggravate the conditions of the passengers with disabilities and can make the flights unbearable. Most airline companies provide on their web-sites a list of reasonable accommodations they would be able to make for a disabled passenger. Some examples include assigning the passenger to an aisle seat with movable armrest to allow an easier transfer from the aisle chair to the seat, or provide a bulkhead seat to allow for extra legroom. Unfortunately, neither one of these solutions addresses the real issue of the pain and health concerns that come with sitting for hours at a time in a constrained position, on a rigid and inadequate seat. A few concepts are currently still in the design and feasi-bility-testing phase. Air Access is a concept that consists of a non-power wheelchair connected to a fixed-frame aisle seat thanks to a mechanism that would mate and lock the two elements, creating a regular airline seat. Unfortunately, it seems unrealistic that airlines would undergo the costly procedure to modify most of their aisle seats to accommodate for the removable wheelchair. Skycare Chair is a wheelchair equipped with a hand-operated lever system to move forward and backward. While this would provide additional independence to the user, it does not improve the comfort, but merely allows easier transitioning onto the standard seat. Finally, neither concept takes into account that people with severe physical disabilities may not have enough strength to hold their head autonomously without a headrest. The new concept of a wheelchair specifically designed for traveling called "Whee'll Fly" represents a step forward towards giving people with disabilities independence and a safe and comfortable flight, while providing the airlines a cost-effective solution. The research focuses on people affected by paralysis due to a spinal cord injury and other wheelchair users. The paper focuses spe-cifically on what characteristics the new design will have, to cater the need of physically impaired travelers, while complying with aircraft measurements and safety regulations. Additionally, the research explores the current technologies available on the market, both in terms of mechanisms and materials, essential to allowing an easy and sustainable transition for plane-manufacturing companies. Finally, using an evaluation tool devel-oped by the World Health Organization, the paper outlines critically how this new Assistive Technology device will improve the quality of life of the user, in terms of cost, physical safety and comfort. In conclusion, this project, by closely examining the needs of a specific user group, sheds new light on the neglected issue of traveling with a physical disability on today's increasingly standardized airplanes.

Keywords: Assistive Technology, air travel, disability, ergonomics, comfort

1 Introduction

With the introduction of the Air Carrier Access Act in 1986 stating that discrimination on the basis of disability in air travel is prohibited, as well as with the Americans with Disabilities Act (ADA) of 1990, airlines have had to comply in order to provide disabled people equal access to their aircraft. Nonetheless, the actions taken have merely been to accommodate for the minimum standard required by law and no airline or aircraft manufacturer has made a concrete effort into identifying reasonable and innovative ways to make travel accessible and safe for all. Aside from it being an ethical issue, it is also a missed revenue opportunity: between 2013 and 2015 alone, more than 26 million adults with disabilities travelled, by different means, for pleasure and/or business, generating an economic impact of nearly $17.3 billion, without even taking into account an accompanying adult. Among the ones who traveled by air 72% reported of major challenges directly with the airlines and 65% with airport facilities [1]. Passengers with disabilities are currently transported by using an aisle chair and then lifted into their seat. These basic wheelchairs are often very narrow in order to be wheeled along the aisle of the aircraft, with a straight back, minimal safety straps and rarely any head support. Interestingly, cabin crew members are forbidden from manually lifting passengers for health and safety reasons, but it appears as though the same concerns are overlooked when it comes to helpers. In addition, both flight attendants and helpers usually lack basic lifting skills making the process potentially dangerous for the passenger and the assistant alike. Additionally, the aircraft sometimes have fixed armrests, which would cause a less careful and safe transfer of the passenger. This research focuses on identifying the problem and the existing gap, investigating the current proposed solutions and then introducing and evaluating the new design concept named “Whee’ll Fly”, that aims at providing passengers with disability the independence, comfort and safety they deserve.

2. Assistive Technology devices on aircraft

The topic of Assistive Technology (AT) on aircraft is one that is not commonly researched, because of the resistance to change that comes from both the FAA, for safety reasons, and the airlines, because of financial concerns. The next four subsections will aim at giving an insight on what the current challenges are to traveling with a physical disability that requires the use of a wheelchair, as well as looking more in depth at what types of solutions designers are currently investigating and what their strength and weaknesses are. At the center of this section is a thorough description of Whee’ll Fly, the new concept developed by the author, including a look at some of the most relevant features of the design. Finally, an evaluation plan is laid out and explained in its parts.

2.1 The problem

Passengers using aisle chairs frequently report complaints in terms of comfort level, safety, independent mobility and personal dignity. Incidents of people sliding or dangerously falling off the aisle chairs once the straps are removed or during take-off, landing or turbulence can be seen in videos taken by the passengers themselves. Moreover, the narrow aisle width increases the risk of the passenger’s limbs getting stuck between the boarding chair and one of the aircraft seats while traveling down the aisle, especially if there are no mounted armrests.

Already in 1984 the Architectural and Transportation Barriers Compliance Board (ATBCB) sponsored an extensive research on the matter of aircraft aisle chairs, with the scope of providing non-binding guidelines to the industry on how to better design these products. Through surveys and the use of a human factors engineering consulting company, the ATBCB established that the boarding chair should provide appropriate body support and restraint, to allow for easy repositioning and independent mobility[2]. Additionally, aisle chairs should be designed for passengers with maximum disabilities, so conditions such as total loss of control in the limbs, weak head control and involuntary movements should be considered as basis for the design[2]. Once the passenger is positioned on the aircraft seat several other human factors and health issues arise. For example, the seat padding isn’t the prescription gel cushion that the passenger regularly uses on the customized wheelchair, which might lead to pain and pressures. While certain airlines will allow the passenger to use the cushion from their own wheelchair if specifically customized for their comfort, this will also reduce the space available to the passenger in the already narrow and rigid seat. Furthermore, the headrest is usually flat which doesn’t provide any lateral head support and since the seatbelt is merely for safety purposes, there are no physical restraints to provide thoracic support. The regular seat does not provide a footrest for people who may need to keep their

legs stretched out at all times. In addition to being exposed to these health hazards, the passenger is confined to the seat throughout the whole flight, without any kind of independence. In case the traveler needed to use the restroom, he/she would have to undergo once again the pain and humiliation of the initial transfer on board, this time in front of the entire cabin, only to reach an inaccessible lavatory.

2.2 Current solutions

Three solutions are currently being explored in the form of concepts by different design firms. The first one, Air Access, developed by the design firm Priestmangoode, is a concept that aims at facilitating air travel for passengers with reduced mobility by enabling an easier transition from gate to aircraft [3]. This design mainly consists of two components: a detachable wheelchair and a fixed-frame aisle seat on the aircraft. Once the passenger is safely positioned on the wheelchair, this could be rolled over to the fixed-frame aisle seat and a mechanism would mate and lock the two elements, creating a regular airline seat.
According to the designers the benefits of Air Access include the possibility to install it in every aisle seat of the aircraft since it wouldn't take extra room. This design though requires a large involvement on the airlines' part, since they would need to request these special seats from their manufacturers, increasing significantly the current cost of assembling the interiors of their fleet and forcing the redesign of all current aircraft.
A second concept currently being investigated is the Skycare Chair, designed by Brian Liang. This product would have wheels placed under the seat rather than at the sides and a hand-operated lever system to move forward or backward [4]. It offers independence to the person with disability when moving to and from the lavatory or from chair to gate. Nonetheless, the passenger would still have to sit in a standard airplane seat and would move to the Skycare Chair only for transportation, essentially making this a fancier aisle chair. Neither one of these concepts seems to take into account the need for a concave headrest pad.
Lastly, an organization called All Wheels Up is proposing a concept in which a regular power wheelchair would get on board the plane and specific restraints would ensure the safety and stability of it [5]. The idea is to recreate a similar system as the one currently on buses to accommodate wheelchairs and lock them in place. Nonetheless, the task undertaken by the organization appears extremely challenging given the narrow spaces available on regular, non-modified, passenger aircraft, and the current regulations that prohibit carrying any personal electric wheelchair on board of any commercial flight, due to specific types of batteries that are forbidden.
A combination of these concepts would provide the best results in terms of comfort, safety and independence. The main goals should be to design a product that is non intrusive for airlines, complying with FAA safety regulations and entirely focused on enhancing the flight experience for the user, by carefully including human factors principles in the design.

2.3 The new concept: Whee'll Fly

The proposed concept is for a new device called Whee'll Fly, to symbolize the mission of making flying accessible, safe and comfortable to passengers with the type of disabilities that would make them dependent on a wheelchair. This newly conceived electrical wheelchair will be specifically targeted and designed for travel. This concept differs from a traditional power wheelchair for two main reasons: it has to operate within the narrow spaces of the aircraft cabin and it has to comply with FAA safety regulations. The Whee'll Fly concept will be designed based on the measurements of the Economy class, since this is the narrowest cabin, hence the most challenging to adapt to. The newly designed wheelchair would be much more compact than a regular power wheelchair, with measurements similar to the ones of a standard aircraft seat. Researching on current aisle chairs' widths it was found that they tend to stay within the 17 inches range [6], in order to fit in most aisles. Since the main challenges of staying in a standard seat for a person with disabilities would be on a long duration flight, such as an international flight, this new design will be shaped to fit most larger planes. Among the most common types of aircraft used for international flights, the Boeing 767 has an aisle width of 19 inches [7]. In the Boeing 777-200 the aisle width is 18 inches. In similar Airbus planes such as the Airbus A330 and A350 the aisle widths are respectively 19 inches and 18.35 inches[8]. It is very hard to determine the exact size of the single seats for each aircraft because airlines tend to use different methods to measure, including measuring half of each armrest or only the seat itself.
Following this research, it was decided that the new power wheelchair design should have a width of maximum 17.5 inches to fit through the most common airplanes for long distance travels.
Because of the space constraints, for the user to stay on this wheelchair from origin to destination, the product

needs to have full range of motion, so in addition to moving forward and backward along the aisle, it will include side wheel movement. The length of the seat would not allow for it to rotate 90° into the assigned seat. To make up for this, the wheelchair is designed to have a mechanism to allow side movements, without rotating the upper half of the chair but only the bottom structure. The system would be based on a rotating disk attached to the bottom of the wheelchair, to which the wheels would be connected.

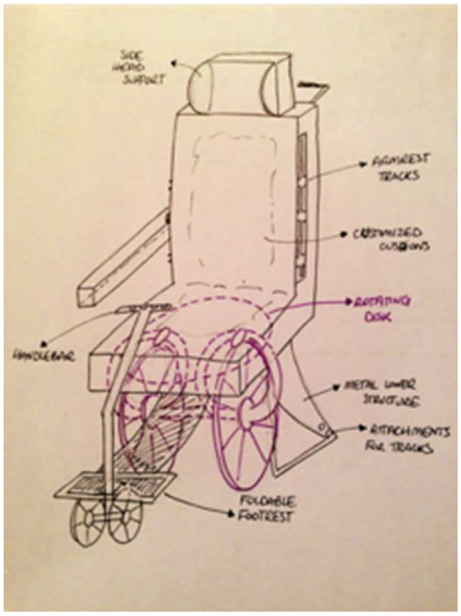


Figure 1. Sketch of the Whee'll Fly AT device

Other main characteristics, as shown in figure 1, would include customizable cushions, based on the different disability and the support each individual may need; side head support at all times, adjustable depending on how tight and rigid the neck area needs to be and on the ability of the individual with disability to hold his/her head up autonomously; safety straps and/or bars, soft and adjustable; movable arm rests, to allow for a more comfortable and correct posture. These will move on lateral tracks on the chair, and 3 different heights can be chosen. Additionally the design would include a battery operated handlebar to orient the wheelchair autonomously, a foldable footrest, allowing comfort and safety to the user, as well as an inclined back, to significantly reduce the risk of developing pressure sores while traveling, and a foldable option, to easily store the chair when not in use.

2.3.1 Seat track attachments

A revolutionary feature of this new design would be ability to fit into the same tracks as the regular aircraft seats. Since the wheels would be attached to a lower metal structure, this could be built to have the same connectors standard seats have, in order to lock the wheelchair to the seat tracks. Figure 2 shows an example of a regular seat track on an American Airlines regional aircraft. All seats in an aircraft can be removed and they can all be adjusted depending on the desired configuration. Companies such as Attax, promoting a new generation of automatic quick-release aircraft track fittings [9] as shown in figure 3, could facilitate the process of adapting multiple structures to the same track system in a more efficient way.



Figure 2. Standard seat track



Figure 3. Attax track fittings [8]

At the moment most of the major U.S. airlines require the passenger to give a 48 hour notice if an aisle chair has to be used[10] [11], or if special accommodations need to be setup, so the crew and maintenance department would have enough time to remove and store a seat if needed. It would be best to replace a bulkhead seat, to allow for a more flexible space for the wheelchair to move. It could then be re-attached once the plane arrives to destination.

2.3.2 Safety

The greater the ability of airplane seats to remain in place and absorb energy during an impact, the greater the likelihood of passenger survival[12]. Dynamic seat testing is conducted in line with Joint Aviation Authorities (JAA) Standards for Emergency Landing Conditions, known as Joint Aviation Requirements (JAR)[13]. As per JAR 25.562 there are two types of dynamic seat certification tests. Test I is a vertical test that consists in accelerating the seat to 14 g's and evaluating the lumbar load on the passenger. Test II is a horizontal test that puts the structure under 16 g pressures to evaluate its resistance. Before starting this test the seat structure is deformed, so to simulate floor warping, the worst of the possible flight conditions for the structure [14]. In addition, for the seat to be certified, the structure must be designed in such a way to give a reasonable chance to every occupant to avoid a serious injury when upward, forward, sideward, downward and rearward inertia forces are acting individually on it. The components of the seat, including the seat track attachments are designed to sustain elastic deformations, in order to absorb crash loads. In fact, total rigidity and stiffness of the seat would transmit the energy from the impact entirely to the passenger, who would likely not survive the crushing effect of a safety belt [15].
A typical passenger seat structure can be roughly divided into a lower (primary supporting) structure and an upper structure. If the Whee'll Fly design can prove to have as strong of a lower structure as the one of the standard seats, it could be considered compliant with FAA safety regulations. The power wheelchair would be created with a built-in brake system to fully block both the rotating disk and the wheels during flight.

2.3.3 Operation and Limitation

Once the passenger with disability is positioned on the wheelchair at the gate, he/she could operate the device all the way to the aircraft. On board of the aircraft the user should proceed backwards with the Whee'll Fly device, supervised by a flight attendant or travel companion, until the chair is parallel to the assigned seat. By using the handle bar as a steering wheel to rotate the front wheels, the rotating disk mechanism would start, allowing for a sideways shift into the correct spot. At this point, one of the flight attendants could secure the wheelchair onto the track fittings while making sure the chair brakes are tight to their maximum. If the passenger needs to access other areas of the aircraft during flight, with the help of a flight attendant, the wheelchair can be unlocked.
If the passenger didn't have enough upper body strength to operate the handlebar, the travel assistant or flight attendant could easily maneuver the chair on behalf of the passenger, without needing to engage in physically strenuous and risky activities, such as lifting or carrying weight. Further restrictions would be for people who would prefer a chair wider than 17.5 inches, because of the aircraft size limitations, and for people who need to maintain a very inclined position, because the comfort of the other passengers also needs to be preserved.

2.4 Evaluation plan

This final part of the research presents an evaluation plan for the proposed AT, to determine whether the consumer goals and desired outcomes would be met and to what extent. The World Health Organization (WHO) defines Quality of Life as "the individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns [16]". Experts have developed an instrument to measure the Quality of Life, the WHOQOL-100 [16], and table 1 shows the structure of it applied to Whee'll Fly. It shows six domains, each with multiple facets, representing the most relevant fields of Quality of Life for this research. Each of these has been rated on a five point scale (1-5) being 1 the poorest performance and 5 the optimal one, based on how well the AT device manages to prevent certain issues. Some of these areas will now be further investigated and elaborated on. It must be noted that any possible consumer dissatisfaction, equipment failure, and other poor outcomes are based on assumptions, since no testing has been done and no reference material is available for a similar product at the time of the research.

Table 1. WHOQOL-100 applied to Whee'll Fly design

Domain	Facets incorporated within domains	Points
Physical Health	Energy and fatigue	▲▲▲▲▲
	Pain and discomfort	▲▲▲
	Sleep and rest	▲▲▲▲
Psychological Health	Bodily image and appearance	▲▲▲▲
	Negative feelings	▲▲▲
	Positive feelings	▲▲▲▲
	Self-esteem	▲▲▲▲▲
	Thinking, learning, memory and concentration	▲▲▲
Level of Independence	Mobility	▲▲▲▲
	Activities of Daily Living (ADL)	▲▲▲▲▲
	Dependence on medical substances and medical aids	N/A
	Work Capacity	▲▲▲▲
Social Relationships	Personal relationships	▲▲▲▲▲
	Social support	▲▲▲▲▲
	Sexual activity	N/A
Environment	Financial resources	▲▲
	Freedom, physical safety and security	▲▲▲
	Health and social care: accessibility and quality	▲
	Home environment	N/A
	Opportunities for acquiring new information and skills	▲▲▲▲▲
	Participation in and opportunities for recreation/leisure	▲▲▲▲▲
	Physical environment (pollution/noise/traffic/climate)	N/A
	Transport	▲▲▲▲▲

2.4.1 Physical Health

In terms of energy and fatigue, Whee'll Fly performs exceptionally well (5 points) because of how easily it can be maneuvered with the use of the steering handlebar. In terms of pain and discomfort, while the chair is customizable, the dimensions still remain limited due to the plane configurations, which will inevitably limit comfort. One of the most critical issues would be pressure sores relief: the user could incline the seat backwards and a mechanism underneath the seat cushion could be integrated to slightly raise the right or left side of the chair without actually moving the whole structure. There are no optimal solutions to this problem at the moment though. Last, sleep and rest are assumed to be relatively good because of the adjustable armrests, head support and inclination.

2.4.2 Psychological Health

The design would be modern and simple, with the aim of integrating as much as possible the user in the airplane environment by avoiding bright colors and eccentric shapes. Nonetheless, in order to fit the wheels under the chair and make room for any kind of suspension system, the chair would probably have to be taller than a regular seat, which may create some discomfort for the user and/or the passengers around. In terms of self-esteem there is no doubt that being able to autonomously board the plane in a dignifying manner and to have more independence on board, guarantees an improvement for the user. Lastly, the learning process for this chair may require some practice and effort on the user's part, since it does require accuracy given the small spaces in which the wheelchair moves.

2.4.3 Level of Independence

The individual will be able to independently move along the aisle, reach their assigned seat and transfer to the bathroom area if needed. The improvement is drastic from being carried to their seat and not being able to move anymore throughout the whole flight. On the other hand, the fact that a crew member is still necessary to unlock the seat or to help the user navigate through the aisle is still a disadvantage to the design.

2.4.4 Social Relationships

Most of the complains that people with disabilities have about the solutions currently available relate to the amount of stress and pain that they cause, which impacts the quality of their entire traveling experience, on board and once arrived to destination. "Whee'll Fly" would increase the chances of the passenger to be well rested at landing and allow more social interactions.

2.4.5 Environment

The average cost of a standard power wheelchair is $7000 and it can fall anywhere from $3000 to $30,000 [17]. To absorb the large costs of a new wheelchair specific for travel, the product could be purchased by organizations dedicated to improve the quality of life for disabled individuals, and they could then rent out or make available the wheelchairs to whoever needs them. Examples of said organization would be All Wheels Up, the Travis Roy Foundation, Open Doors Organization and the Testaverde Fund for Spinal Cord Injury. Additionally, the airlines themselves could have the Whee'll Fly chairs available and, for a small surcharge, allow the passenger to "borrow" one for their roundtrip flight. From a safety standpoint, in case of unexpected turbulence while walking down the aisle, a non-disabled person could quickly hold on to part of the furniture and re-adjust his/her body balance, while the weight of a power wheelchair could create a hazard for the user and other passengers around.

3. Further research and conclusion

While Whee'll Fly is the proposed solution following this research, it is certainly not the only possible answer and there may be alternative ways to close the gap. Certain limitations were inevitably posed on the project, due to lack of resources and facilities, so further research and testing will be crucial to better identify a feasible design. For example, it has not yet been proven that the lower or primary supporting structure of the wheelchair could be similar enough to the one of the standard seats to pass the FAA safety tests and to be placed in the same track attachments. While the materials used could likely be the same, the entire distribution of loads might shift when the electrical mechanism underneath the wheelchair is installed. It should be investigated as well if, due to the weight of the chair and of the passenger, a suspension system were to be necessary while the

disk is rotating, in order to eliminate part of the friction with the floor when the chair moves sideways. Additionally, the FAA doesn't currently allow specific types of batteries on the aircraft, such as wet and spillable batteries or spare lithium batteries [18]. Further research should be done to identify a type of battery, able to power an electrical wheelchair for a much shorter amount of time than a regular power wheelchair. One option might also be to make this a rechargeable battery, to allow the passenger to power the wheelchair in between trips.

The Whee'll Fly device has been imaged as a travel specific wheelchair, adaptable for coach cabin on most aircraft, thanks to its reduced width of 17.5 inches. Additionally, it would include revolutionary features such as a side shifting function and a lower structure similar to the one of the standard seats, so to adapt to the regular seat tracks. This would allow for minimal financial impact on the airlines and aircraft manufacturer's part. Finally, the concept would be designed entirely keeping in mind the user perspective and basic human factors principles. The "Whee'll Fly" project aims at starting a deeper conversation on Assistive Technologies on aircraft and what designers, engineers and the aviation industry as a whole can do to close the gap between the radically different travel experiences of passengers with and without disabilities.

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References

1. Lipp, E. Disability Travel Generates $17.3 Billion In Annual Spending. PRNewswire, 2015. Retrieved from http://www.prnewswire.com/news-releases/disability-travel-generates-173-billion-in-annual-spending-300121930.html

2. American Institutes for Research. Guidelines for Aircraft Boarding Chairs. Bureau of Transportation Statistics, n.d. Retrieved from https://ntl.bts.gov/DOCS/T10.html

3. Etherington R. Air Access by Priestmangoode. Dezeen, 2012. Retrieved from https://www.dezeen.com/2012/08/23/air-access-by-priestmangoode/

4. Turner, T. Wheelchair for Air Travel. Yanko Design, 2012. Retrieved from http://www.yankodesign.com/2012/01/23/wheelchair-for-air-travel

5. All Wheels Up. Proposed Solution for Wheelchair Accessible Airplane Travel, 2016. Retrieved from https://www.allwheelsup.org/our-solution/

6. 1800 Wheelchair. Airplane Aisle Wheelchairs, n.d. Retrieved from www.1800wheelchair.com/category/wheelchairs-for-airplanes/

7. American Airlines. Planes, n.d. Retrieved from www.aa.com/i18n/aboutUs/ourPlanes/boeing767.jsp

8. Hamilton, S. Leeham News and Comment, 2013. Retrieved from www.leehamnews.com/2013/07/29/analyzing-the-airbus-plan-to-offer-a350-a330-regional-aircraft/

9. Attax Assembly Systems. Track Fittings Range, 2015, pp.13-18. Retrieved from http://www.attax.com/eng/wp-content/uploads/2015/06/ATTAX_Seat_Track_Fittings.pdf

10. Delta Air Lines. Travelers with Disabilities, n.d. Retrieved from http://www.delta.com/content/www/en_US/traveling-with-us/special-travel-needs/disabilities.html

11. United Airlines. Customers with Disabilities, n.d. Retrieved from https://www.united.com/web/en-US/content/travel/specialneeds/disabilities/default.aspx

12. Anderson, A.J. Aviation Safety: Evolution of Airplane Interiors. AERO, QTR_04(11), 5-11. Retrieved from http://www.boeing.com/commercial/aeromagazine/articles/2011_q4/pdfs/AERO_2011q4.pdf

13. HORIBA MIRA. Aircraft Seat Engineering & Certification, n.d. Retrieved from https://www.horiba-mira.com/our-services/aerospace-engineering/aircraft-seat-engineering---certification

14. Dhole N., Yadav V. and Olivares G. Certification by Analysis of a Typical Aircraft Seat. 12th International LS-DYNA Conference, 2012. Automotive (2), p.1.

15. National Research Council. Fire- and Smoke-Resistant Interior Materials for Commercial Transport Aircraft. Washington, DC: The National Academies Press, 1995. Retrieved from https://www.nap.edu/read/5073/chapter/4

16. Division of Mental Health and Prevention of Substance Abuse. WHOQOL Measuring Quality of Life, 1997. Retrieved from http://www.who.int/mental_health/media/en/68.pdf

17. Disabled World. Wheelchairs: Information & Reviews, 2016. Retrieved from www.disabled-world.com/assistivedevices/mobility/wheelchairs/

18. Burns, B and Lynn. Travel Tips Tuesday: Safely Packing Batteries for Your Trip. The TSA Blog, 2013, June 11. Retrieved from http://blog.tsa.gov/2013/06/travel-tips-tuesday-safely-packing.html

Neck posture and muscle activity with and without head support in a reclined sitting posture when watching IFE

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Abstract In designing a headrest it is important to define the ideal head position and neck angle. There is literature on the ideal head position, but not in the context of watching IFE in a business class aircraft seat. In this study (n=21) the neck muscle activity (EMG), expected long-term comfort and head/neck inclination were studied in a reclined position (as is possible in business class) when watching IFE in the condition of with and without head/neck support.
It appeared that there were no significant differences in EMG between both conditions. However, the posture was significantly different; without head support by a headrest the head was found to be more upright. Expected long-term comfort was rated highest in the condition with a headrest.
The fact that no difference was found in EMG indicates that humans tend to look for a head position that is neutral, in the sense of minimal (muscle) effort. Head support in a reclined position may have a positive psychological effect on the user.

Keywords: EMG, posture, neck angle, aircraft seat, neutral head position, headrest

1 Introduction

In designing a headrest it is important to define the ideal head position and neck angle. There is literature on the ideal head position with an upright or slightly reclined trunk, of which an overview can be found in and lower pressure on the intervertebral disks (Wilke, Neef, Caimi, Hoogland, & Claes, 1999).

Table 1. However, for a situation in which the trunk is reclined the literature is limited. For the position in the car e.g. Park, Kim, Kim, and Lee (2000) and Kilincsoy, Wagner, Bengler, Bubb, and Vink (2014) presented comfortable angles, van Veen, Hiemstra-van Mastrigt, Kamp, and Vink (2014) even in the context of tablet use, but for a more reclined position that can be found in a business class aircraft seat when watching in flight entertainment (IFE) the ideal neck position is not described.

As observed in studies by van Rosmalen, Groenesteijn, Boess, and Vink (2009), van Rosmalen, Groenesteijn, Boess, and Vink (2010), C. S. S. Tan, Van den Bergh, Schöning, and Luyten (2014), Meziat Filho, Coutinho, and e Silva (2015), Hiemstra-van Mastrigt (2015) and Smulders et al. (2016), most people prefer to sit in a reclined posture when watching Television (TV) at home and IFE during flight. Hiemstra-van Mastrigt (2015) found a preferred mean inclination for watching IFE in an economy class aircraft seat of 41˚, where Smulders et al. (2016) found 32˚ for watching IFE in a business class aircraft seat. van Rosmalen et al. (2009, 2010) propose a backrest angle of 40˚ for their prototype television seat for the home, based on an experiment with an office chair. A possible explanation for this preference may be the lower back muscle activity in such a slouched posture (Goossens, Snijders, Roelofs, & Buchem, 2003) and lower pressure on the intervertebral disks (Wilke, Neef, Caimi, Hoogland, & Claes, 1999).

Table 1. The comfortable (neutral) head position (as described in Vink (2016)). See Figure 1**Errore. L'origine riferimento non è stata trovata.** for a visual explanation of the given angle.

Reference	*n*	*Craniocervical angle (α)*
Raine and Twomey (1997)	160	41,1˚
Johnson (1998)	34	40,4˚
Ankrum and Nemeth (2000)	24	43,7˚
van Veen et al. (2014)	10	41,2˚

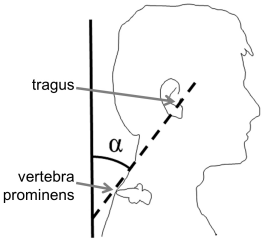


Figure 1. The craniocervical angle (α) between a line through the tragus and vertebra prominens (C7) and the vertical line (from Vink (2016))

1.1. Head flexion and the strain on the muscles

The head angle is – besides the orientation of the trunk – influenced by the viewing angle on the IFE screen. "The preferred line of sight becomes lower as the viewing distance decreases" (as cited in Ankrum and Nemeth (2000), and also been shown by Kroemer and Hill (1986)), indicating that in the economy class (where space is more scarce) an IFE screen should be below eye level and oriented perpendicular to the line of sight. Yoichi et al. (2012) states however, that a more horizontal line of sight is preferred for further distances of TV screens, and thus is more appropriate for business class with it's bigger screens, generous space (bigger eye-screen distance) and generous backrest recline.

When reclining (32-41˚) in a business class seat while watching IFE, the passenger may flex their head forward with respect to the trunk without head/neck support for a prolonged period of time (e.g. when watching one or multiple movies) to establish a good (horizontal) view on the IFE screen (see Figure 2), which was observed in the study by Smulders et al. (2016). However, prolonged (unsupported) neck flexion beyond 30˚ could lead to severe muscle fatigue and discomfort according to Chaffin (1973). This may result in pain and spasm in the neck muscles, which can lead to headache and pains of the head, face and behind the eyes (Dalassio, 1980; J. Travell, 1967; J. G. Travell & Simons, 1992).

In the studies of van Rosmalen et al. (2009) and Smulders et al. (2016) it was observed that participants lacked neck/head support when watching TV/IFE in the slouched posture. In the study by Hiemstra-van Mastrigt (2015) subjects stated discomfort in the neck when watching IFE. In a context mapping study by van

Rosmalen et al. (2010), participants requested a headrest for head support. The question is if head/neck support for watching IFE in a reclined posture will lower muscle activity and offer the passenger more comfort.



Figure 2. Subject watching IFE in slouched posture while flexing head forward with respect to the trunk (from Smulders et al. (2016))

1.2. Theoretical biomechanical analysis

Neck flexion theoretically stretches and contracts the neck muscles. In a simulation with the AnyBody™ model, it was found that the neck force increases in the musculus trapezius pars descendens (TRP-UP) and transverse (TRP-MID) due to stretching of the muscle, when the head keeps a horizontal view and the backrest reclines backwards.

To compensate for the force exerted by the trapezius muscle the sternocleidomastoideus (SCM) should theoretically be active if there is no headrest. The hypothesis is therefore that a headrest, which supports the head/neck while sitting in this slouched posture, will not change or lower neck muscle activity (e.g. SCM) and will benefit the comfort experience of the user.

2 Materials and methods

To study the effect of the headrest in a slouched position, EMG, posture and expected long-term comfort were recorded of 21 subjects sitting in a lounge seat with a backrest angle of 40 degrees. 12 subjects started with the condition with headrest and the other 9 without headrest. Surface RA-EMG was recorded of the TRP-UP and SCM for 5 minutes in each condition. Postures were recorded by camera in the different conditions. Expected long-term comfort was recorded by questionnaire.

2.1. Subjects

11 female and 10 male American, Chinese, Dutch and Iranian adults with no neck injuries and/or complaints in the past six months and who have flown in the past, participated in this study (Table 2). Subjects were asked to wear top clothing without a collar – preferably a T-shirt – for easy sensor placement.

Table 2. Anthropometrics of subjects

		Mean	*SD*

Male (n=10)	*Age [Years]*	31,9	6,4
	Stature [m]	1,81	0,04
	Weight [Kg]	87,2	21,6
Female (n=11)	*Age [Years]*	24,4	1,0
	Stature [m]	1,72	0,08
	Weight [Kg]	64,9	8,7

2.2. Experimental setup and stimuli

The study took place at two different locations with the same setup. Seven subjects were tested at the Human Factors and Ergonomics lab of Zodiac Seats US in the USA and fourteen at the ID-User Labs of the Delft University of Technology in the Netherlands.

Surface electromyography was used to measure muscle tension in the m. sternocleidomastoid (SCM) and m. trapezius upper fibers (TRP-UP) in three conditions: lying flat (condition A), sitting slouched watching with (condition B) and without (condition C) a headrest.

To stimulate full muscle relaxation in condition A (which functions as a benchmark of full relaxation), subjects lied down on a mattress with a pillow. To stimulate a TV/IFE watching posture, subjects sat slouched in an IKEA® POÄNG lounge seat with a 40˚ reclined backrest and leg support, facing a 15" LCD monitor (further named IFE screen) featuring a TED talk on the subjects' interests at 1,69m distance with its centre at each participant's eye height (as recommended by Yoichi et al. (2012)). In condition B the seat had a headrest, in condition C the headrest was removed (see Figure 3). It is important that subjects rest their arms on their lap in condition B and C, to limit influence of its 10% of the total body weight load (Roebuck, Kroemer, & Thomson, 1975; Snijders, Nordin, & Frankel, 1995) on muscle activity in the shoulder-neck region. The use of the fixed armrest would result in measuring different loads due to anthropometric differences among subjects.

After each condition subjects were asked to file a questionnaire on their expected long-term comfort in general (all-over experience), for the neck, head and eyes. For each body part a score needed to be given by drawing a vertical line on a horizontal score-line with 'not comfortable' and 'very comfortable' at its ends. For each given score, subjects were asked to substantiate in writing.



Figure 3. Left: condition B - subject sitting in the seat with headrest
Right: condition C - subject sitting in the seat without headrest

To put measured muscle tension into perspective, subjects conducted a maximal voluntary contraction (MVC) of the neck muscles by flexing the head against a load created by a TheraBand™ Red (medium strength) or Green (heavy strength; for some strong subjects), and extending the head against the headrest by the end of the study.

2.2.1. EMG sensor positions

The two electrodes were applied parallel to the muscle fiber direction on the dominant middle portion of the muscle belly (Delsys, 2012; Konrad, 2005). Muscle belly positions were palpated and the sensor for the TRP-UP was placed at C5/C6 level, ±2 cm lateral to midline (Sommerich, Joines, Hermans, & Moon, 2000) and the sensor for the SCM was placed on the lower 1/3rd between the sternal notch and mastoid process (Falla, Dall'Alba, Rainoldi, Merletti, & Jull, 2002). Since the head was kept parallel to the lateral plane, only muscle activity at one side was measured.

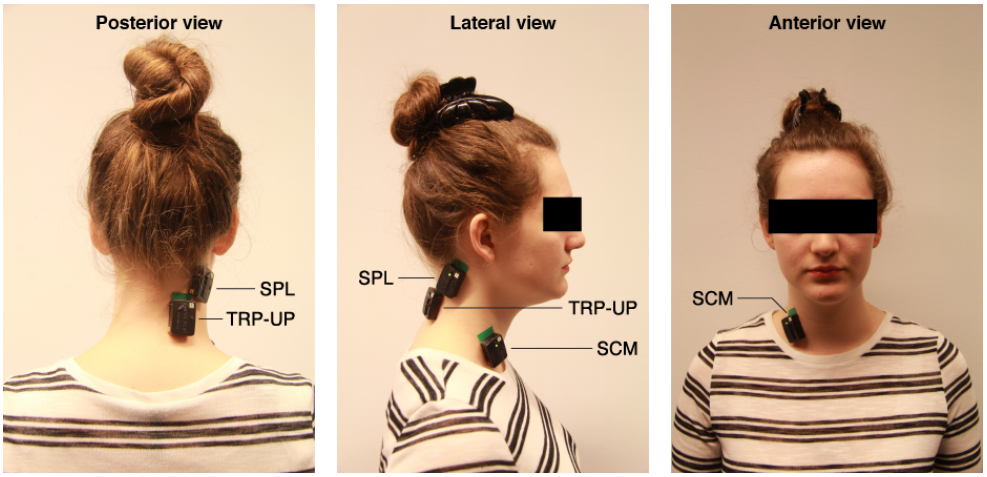


Figure 4. Posterior, lateral and anterior view of sensor placement on the splenius and semispinalis area (SPL), the upper trapezius fibers (TRP-UP) and the sternocleidomastoid (SCM)

2.3. Apparatus

In both the USA and The Netherlands locations the exact same Delsys® Trigno™ Wireless EMG System (2000 Hz sampling rate) and a laptop with Delsys® EMGworks™ were used to measure muscle activity of the neck muscles. A Mitutoyo® digital protractor angle gage and an iPhone 5 gyro were used to set the seat backrest to an angle of approximately 40˚. In the USA study an electric weight scale and a Seca® 700 analogue stadiometer were used to determine subjects weight and height. In The Netherlands an electric weight scale and a GPM antropometer were used. In the USA a Canon® 6D DSLR camera with a Canon® EF 24-105mm f/4.0L IS USM (set to 24mm) at a fixed position (1,38m lateral of the seat) was used to capture the posture at the sagittal plane. In The Netherlands, at the same distance and position a Canon® 60D DSLR camera with a Canon® EF-S 17-55mm f/2.8 IS USM (set to 17mm) was used.

2.4. Procedure

Subject briefing and preparation

Subjects were first briefed on the procedure of the study and were requested to sign a consent and NDA form, state their date of birth and nationality. Subjects were then requested to take off their shoes to measure their weight and length. Next, subjects were asked to take a seat in preparation of sensor placement.

Skin preparation and sensor placement

Areas for sensor placement on the subject's skin were cleaned by removing dead skin cells and other skin surface 'pollution' by sticking and pealing 3M Transpore™ surgical tape multiple times on the skin and then softly rubbing alcohol wipes on the skin (Delsys, 2012; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Konrad, 2005; Letizi, 2016). Sensors were placed on the subject's lateral right as described in §2.2.1.

Signal validity check

The validity of the EMG signal were checked by inspecting the baseline noise ratio, baseline offset and baseline shift (Konrad, 2005; Letizi, 2016). The raw EMG signal of the SCM was inspected by letting subjects flex their head forward to the opposite side (Soderberg, 1992). The same was done for the TRP-UP by having subjects raise their shoulders (Soderberg, 1992).

Condition A: lying on the ground

Subjects were asked to lie flat on a mattress with pillow and fully relax for 5 minutes first (see Figure 3). During this period the room was darkened to help subjects to fully relax. This measurement functions as the benchmark for full muscle relaxation. Thereafter the subjects were asked to stand up and to state their expected long-term comfort by questionnaire.

Preparing sitting position

Subjects were asked to sit in the lounge seat in a slouched posture (back against reclined backrest) while resting the head against the headrest, looking forward in a preferred head angle and rest the arms in their lap. For posture analysis, a lateral picture was taken of the subject's sagittal plane in the seat. The height of the IFE screen was adjusted to meet the subject's eye height with the IFE screen's centre (Yoichi et al., 2012). Thereafter the subjects were asked to stand up and select a TED talk movie on their interests.

Condition B and C

To prevent order effects, (approximately) half of the subjects started sitting in condition B and the other half of the subjects started in condition C.

Condition B: sitting slouched with headrest

Subject's were asked to sit in a slouched posture (back against reclined backrest) while resting the head against the headrest, rest the arms in their lap and looking at the IFE screen to watch a movie for 5 minutes (see Figure 3). During this activity, EMG signals were continuously recorded for 5 minutes. Thereafter a lateral picture of the posture was taken and the movie paused. The subject was asked to fill in the expected long-term comfort questionnaire. Thereafter the subjects were asked to stand up and take a break for 2 minutes, to minimize fatigue (C. F. Tan, Chen, & Rauterberg, 2010).

Condition C: sitting slouched without headrest

The headrest of the seat was removed. Subject's were asked to sit in a slouched posture (back against reclined backrest), rest the arms in their lap and looking at the IFE screen to watch a movie for 5 minutes, but without resting the head against the seat (see Figure 3). The same procedure as in *condition B* was followed.

Maximal Voluntarily Contraction

Lastly the subject was asked to conduct maximal voluntarily contraction (MVC) of the flexion and extension neck muscles. This was executed at the end of the study, since MVC has some discomfort effects due to extensive contractions of the muscles, which need some recovery afterwards.

Subjects were asked to push their head against the TheraBand™(flexion) – which was connected to the seat frame – as hard as they can for 3 seconds. They were verbal encourage when needed. Thereafter they had a recovery break of 30 seconds and repeated the exercise another two times. Delsys EMGworks® automatically determined the highest MVC of the three contractions. A similar procedure was followed to determine MVC for extension by placing the headrest back on the seat and ask subjects to push their head against the headrest (extension) as hard as they could for 3 seconds. This too was repeated another two times and the highest MVC was determined.

2.5. Measures

Muscle activity

Two subjects had to be excluded from the EMG study due to a software crash that resulted in lost data. Collected EMG data of the TRP-Up and SCM in conditions A, B and C and of the flexion and extension MVC's of each subject were processed with Delsys® EMGworks™. First the baseline offset was removed and the root-mean-square (RMS) was taken of the raw signal. Then the microvolt signal of the TRP-UP and SCM in conditions A, B and C were normalised by expressing them as a percentage of the corresponding maximum recorder MVC (%MVC); MVC extension for the TRP-UP and MVC flexion for the SCM. Expressing the signal in %MVC makes comparison between subjects possible, since EMG data is of a subject dependent nature. Of each data set an as large as possible sample without noise was taken to calculate a mean muscle activity of the TRP-UP and SCM in each condition, expressed in %MVC. In Microsoft Excel a paired t-test was taken to check for significant differences between the conditions ($p < 0.05$), as well for influence of testing order, gender and testing location.

Expected long-term comfort

One subject had to be excluded due to not filing one of the questionnaires. All rates were collected by measuring the given scores on the 10 cm long score-line with a ruler and all handwritten comments were typed down and were processed with Microsoft Excel. Since comfort values are not normally distributed, the Wilcoxon test was used in addition to a *t* test, to look for differences between conditions B and C. The significance between the scores for conditions B and C was calculated ($p < 0.05$) per rated area. In addition, influence of testing order, gender and testing location were tested on significance.

Head-neck posture

Two subjects had to be excluded from the study; one due to missing pictures of one condition, the other due to deformation of the seat by subject's weight, resulting in wrong backrest inclination. Lateral pictures taken from the fixed cameras were analysed using Adobe Illustrator. First reference points were placed on the hip, C7, tragus, canthus and visual target (the centre of the IFE screen), and then lines were drawn between those points (see Figure 5). Of each line the angle was recorded based on Psihogios, Sommerich, Mirka, and Moon (2001) and processed in Microsoft Excel. A paired t-test was taken of each angle to check for significant differences between the conditions ($p < 0.05$), as well for influence of testing order, gender and testing location.

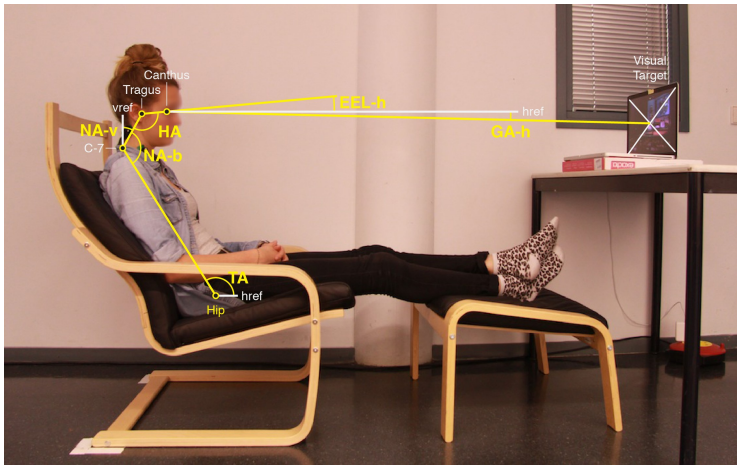


Figure 5. Lateral analysis of posture in Adobe Illustrator.
Angles describing the head-neck posture (based on Psihogios et al. (2001))

3 Results

The recorded mean muscle activity for conditions A, B and C, expressed as a percentage of the MVC, can be found in Figure 6. The EMG data shows no significant difference in both the TRP-UP as the SCM between condition B and C (see Table 3). However, the SCM significantly relaxed in condition B over A, however only with 0,5%MVC on average.

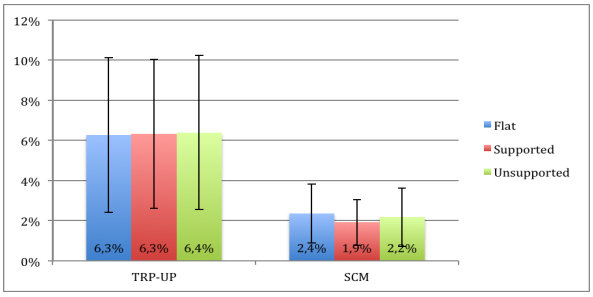


Figure 6. Mean muscle activity as a percentage of MVC (n=19)

Table 3. T-test of muscle activity as a percentage of MVC (n=19)

Condition	*SCM*	*TRP-UP*
AB	0,003 *	0,4
AC	0,2	0,2
BC	0,05	0,3

Expected long-term comfort scores for *general* (all-over) *comfort*, *neck comfort*, *head comfort* and *eye comfort* can be found in Figure 7. Subjects rated expected long-term comfort in *general*, in the *neck* and the *head* significantly higher in the condition with a headrest (condition B). There was no significant difference rated at the eyes. No significant influence of testing order on the comfort scores was found, except for *eye comfort* in condition B (p≈0,41).

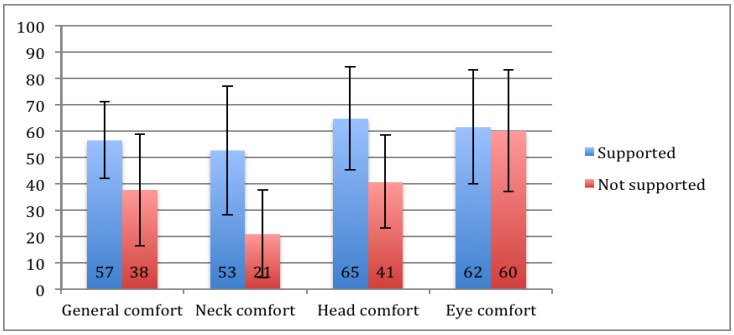


Figure 7. Mean comfort scores with SD (n=20)

The inclinations describing the head-neck posture in conditions B and C can be found in Table 4. The inclination data shows the posture was significantly different between condition B and C, except for HA (p≈0,13). Without head support (B) the head was found to be more upright in respect of without head support (C).

Table 4. Posture inclinations (for angle description, see **Figure 5**)

Angle	*TA*		*NA-b*		*NA-v*		*HA*		*EEL-h*		*GA-h*	
Condition	B	C	B	C	B	C	B	C	B	C	B	C
Mean	126,3˚	124,4˚	126,5˚	117,4˚	17,3˚	28,2˚	130,9˚	132,0˚	23,6˚	13,8˚	-2,6˚	-2,2˚
SD	2,1˚	2,6˚	4,7˚	5,1˚	5,0˚	4,6˚	6,0˚	6,4˚	5,6˚	5,3˚	1,0˚	1,2˚
Max	132,0˚	131,4˚	136,4˚	128,0˚	24,7˚	35,7˚	144,3˚	142,8˚	36,2˚	27,6˚	-0,9˚	0,6˚
Min	123,6˚	120,6˚	118,6˚	108,1˚	8,1˚	18,7˚	120,2˚	121,5˚	14,7˚	5,2˚	-5,5˚	-5,0˚
Difference (mean)	1,83˚		9,11˚		10,94˚		1,09˚		9,85˚		-0,41˚	
Wilcoxon	0,00026 *		0,00008 *		0,00008 *		0.12602		0,00012 *		0,00578 *	

4 Discussion

It appeared that there were no significant differences in EMG between both conditions B and C. Expected long-term comfort was rated highest in the condition with a headrest (B), indicating there may be a psychological effect by perceiving support and body contact, positively influencing perceived comfort. Franz, Durt, Zenk, and Desmet (2012) describe a similar effect on contact, were neck support benefitted the perceived comfort.

The expectation of having more comfort in the long term may actually positively influence the all over experienced comfort of a passenger during a flight, a phenomena described by Naddeo, Cappetti, Califano, and Vallone (2015) in the context of a bed. It is therefore recommended to further investigate the impact of head support on perceived comfort and discomfort. Additional simulations with AnyBody™ on e.g. the m. sternocleidomastoideus, m. splenius capitis and m. semispinalis would be preferable. Also the duration of EMG measurement in this study was limited. Since passengers may watch IFE for a prolonged period of time (e.g. watching multiple movies on a long-haul flight), it is recommended to study the long-term effects of this slouched posture, with and without head support, on muscle activity and fatigue and the passenger comfort and discomfort over time.

The posture between conditions B and C was significantly different. Without head support by a headrest the head was found to be more upright and placed above the rotation axes of the neck. The fact that no difference was found in EMG indicates that humans tend to look for a head position that is neutral. Neutral in the sense that the least energy is needed to keep the head upright. Regarding the seat experience, stability by head support is preferred. These data indicate that it is important for seats to facilitate a neutral position for the head and in a reclined seat head support may have a positive psychological effect on the user.

5 Conclusion

Head support for watching IFE in a slouched posture has no significant effect on muscle activity, since subjects will adapt their posture to have minimal muscle activity by placing the head above the rotation axes when support is lacking. However psychologically, head support will benefit the expected long-term comfort experience of the user.

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References

Ankrum, D. R., & Nemeth, K. J. (2000). *Head and Neck Posture at Computer Workstations-What's Neutral?* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Chaffin, D. B. (1973). Localized muscle fatigue-definition and measurement. *Journal of Occupational and Environmental Medicine, 15*(4), 346-354.

Dalassio, D. J. (1980). *Wolff's Headache and Other Head Pain*. Oxford: Oxford University Press.

Delsys. (2012). Trigno Wireless System User's Guide. Retrieved from delsys.com/Attachments_pdf/Trigno%20Wireless%20System%20Users%20Guide%20(MAN-012-2-3).pdf

Falla, D., Dall'Alba, P., Rainoldi, A., Merletti, R., & Jull, G. (2002). Location of innervation zones of sternocleidomastoid and scalene muscles–a basis for clinical and research electromyography applications. *Clinical Neurophysiology, 113*(1), 57-63.

Franz, M., Durt, A., Zenk, R., & Desmet, P. M. (2012). Comfort effects of a new car headrest with neck support. *Appl Ergon, 43*(2), 336-343. doi:10.1016/j.apergo.2011.06.009

Goossens, R. H. M., Snijders, C. J., Roelofs, G. Y., & Buchem, F. V. (2003). Free shoulder space requirements in the design of high backrests. *Ergonomics, 46*(5), 518-530.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of electromyography and Kinesiology, 10*(5), 361-374.

Hiemstra-van Mastrigt, S. (2015). *Comfortable passenger seats: Recommendations for design and research*. Delft: Delft University of Technology.

Johnson, G. M. (1998). The correlation between surface measurement of head and neck posture and the anatomic position of the upper cervical vertebrae. *Spine, 23*(8), 921-927.

Kilincsoy, Ü., Wagner, A., Bengler, C., Bubb, H., & Vink, P. (2014). *Comfortable rear seat postures preferred by car passengers.* Paper presented at the 5 th International Conference on Applied Human Factors and Ergonomics.

Konrad, P. (2005). The abc of emg. *A practical introduction to kinesiological electromyography, 1*, 30-35.

Kroemer, K. H. E., & Hill, S. G. (1986). Preferred line of sight angle. *Ergonomics, 29*(9), 1129-1134.

Letizi, J. (2016). [Personal communication, Delsys EMG training].

Meziat Filho, N., Coutinho, E. S., & e Silva, G. A. (2015). Association between home posture habits and low back pain in high school adolescents. *European Spine Journal, 24*(3), 425-433.

Naddeo, A., Cappetti, N., Califano, R., & Vallone, M. (2015). The role of expectation in comfort perception: the mattresses' evaluation experience. *Procedia Manufacturing, 3*, 4784-4791.

Park, S. J., Kim, C.-B., Kim, C. J., & Lee, J. W. (2000). Comfortable driving postures for Koreans. *International Journal of Industrial Ergonomics, 26*(4), 489-497.

Psihogios, J. P., Sommerich, C. M., Mirka, G. A., & Moon, S. D. (2001). A field evaluation of monitor placement effects in VDT users. *Applied ergonomics, 32*(4), 313-325.

Raine, S., & Twomey, L. T. (1997). Head and shoulder posture variations in 160 asymptomatic women and men. *Archives of physical medicine and rehabilitation, 78*(11), 1215-1223.

Roebuck, J. A., Kroemer, K. H. E., & Thomson, W. G. (1975). *Engineering anthropometry methods* (Vol. 3): Wiley-Interscience New York.

Smulders, M., Berghman, K., Koenraads, M., Kane, J. A., Krishna, K., Carter, T. K., . . . Schultheis, U. (2016). Comfort and pressure distribution in a human contour shaped aircraft seat (developed with 3d scans of the human body). *Work, 54*(4), 925-940.

Snijders, C. J., Nordin, M., & Frankel, V. H. (1995). *Biomechanica van het spier-skeletstelsel; grondslagen en toepassingen. Lemma, Utrecht*. Retrieved from

Soderberg, G. L. (1992). Recording techniques. *Selected topics in surface electromyography for use in the occupational setting: Expert perspectives*, 31-35.

Sommerich, C. M., Joines, S. M., Hermans, V., & Moon, S. D. (2000). Use of surface electromyography to estimate neck muscle activity. *Journal of electromyography and Kinesiology, 10*(6), 377-398.

Tan, C. F., Chen, W., & Rauterberg, M. (2010). *Experimental design for sternocleidomastoid muscle stress measurement.* Paper presented at the Proceedings of the 7th International Conference on Methods and Techniques in Behavioral Research.

Tan, C. S. S., Van den Bergh, J., Schöning, J., & Luyten, K. (2014). Towards Empathic TV Interaction using Body Postures.

Travell, J. (1967). Mechanical headache. *Headache: The Journal of Head and Face Pain, 7*(1), 23-29.

Travell, J. G., & Simons, D. G. (1992). *Myofascial pain and dysfunction: the trigger point manual* (Vol. 2): Lippincott Williams & Wilkins.

van Rosmalen, D. M. K., Groenesteijn, L., Boess, S. U., & Vink, P. (2009). Using both qualitative and quantitative types of research to design a comfortable television chair. *Journal of Design Research, 8*(1), 87-100.

van Rosmalen, D. M. K., Groenesteijn, L., Boess, S. U., & Vink, P. (2010). Eisen aan een loungestoel om naar een scherm te kijken. *Tijdschrift voor ergonomie, 2, 35, 4-10*.

van Veen, S. A., Hiemstra-van Mastrigt, S., Kamp, I., & Vink, P. (2014). Improving car passengers' comfort and experience by supporting the use of handheld devices. *Work, 49*(2), 215-223. doi:10.3233/WOR-131716

Vink, P. (2016). *Vehicle seat comfort and design*: TU Delft Library.

Wilke, H. J., Neef, P., Caimi, M., Hoogland, T., & Claes, L. E. (1999). New in vivo measurements of pressures in the intervertebral disc in daily life. *Spine, 24*(8), 755-762.

Yoichi, I., Kazuhiko, I., Naoaki, U., Kazuyuki, K., Hiroki, K., Satoru, K., . . . Ryoji, Y. (2012). *Ergonomic Design Guidelines for Flat Panel Display Televisions*. Retrieved from www.ergonomics.jp/official/page-docs/product/guideline/TV_guide_2012_Eng.pdf

Comparative Assessment of Aircraft Seat (Dis)Comfort via Planned Experiments

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Abstract. Over the years, air traffic has been constantly increasing: in 2013, over 3 billion passengers were carried by the world's airlines; according to a recent Airbus' global market forecast, air traffic will double in the next 15 years, showing 4.7% annual growth between 2013 and 2034 (Airbus, 2016). Despite the growing demand, airlines are still one of the lowest-scoring industries in the American Customer Satisfaction Index (ACSI) and seat comfort is the most unsatisfying aspect of flying (ACSI, 2016). As a matter of fact, improving seat comfort can provide an opportunity to gain competitive edge in aircraft industry. This paper focuses on the assessment of aircraft seating (dis)comfort via a statistical-experimental approach. Seating (dis)comfort data (both objective and subjective) were collected during an experiment involving 18 volunteers (9 males and 9 females) who tested two aircraft seats in upright and upright/reclined configuration, respectively. Data were collected under controlled experimental conditions. In order to minimize experimental uncertainty due to well-known noise factors (*i.e.* patterns of discomfort during the work week and during the workday, evaluation sequence, inter-individual variability), experimental trials were performed according to a crossover design. The whole experiment consisted of 54 experimental sessions; the duration of each session was approximately 40 minutes. In each test run, the participant performed a fixed task so as to minimize differences in postures and control the effect of body posture upon pressure distribution at seat-interface. Statistical data analysis aimed at: 1) investigating gender–based differences in seating (dis)comfort; 2) identifying critical discomfort body areas; 3) analyzing time-variation in seating (dis)comfort. The experimental results are in line with the acknowledged hypotheses that males and females are exposed to different loading patterns and experience different discomfort pathways, due to fundamental biomechanical differences in their sitting posture and anthropometric peculiarities. Moreover, results pinpoint that perceived discomfort increases significantly over time in several body areas.

Keywords: aircraft seat, seat-interface pressure, discomfort body area ratings, designed experiments.

1 Introduction

Seat comfort is one of the most important factors for passengers when choosing air carriers thus it can be used by airline companies to differentiate themselves from their market segment competitors [1].

Although the concepts of 'comfort' and 'discomfort' are commonly used in everyday language, unique acknowledged definitions for them do not still exist in the specialized literature on sitting (dis)comfort [2,3,4].

Some authors [5] consider comfort and discomfort as two opposites of a continuous, others propose comfort and discomfort as independent entities associated with different factors [6]. Comfort is associated with feelings of relaxation, well-being, satisfaction, aesthetics and luxury [7], while discomfort is more associated

with biomechanical factors that produce feelings of pain, numbness and stiffness. The absence of clear and acknowledged definition about (dis)comfort is associated to the lack of standard procedures for the assessment of seating (dis)comfort. From a technical point of view, seating (dis)comfort is commonly assessed by analyzing objective measurements (*e.g.* pressure data, posture and movement analysis) and/or subjective measurements (*e.g.* overall and local body (dis)comfort). Both types of measurements can be affected by uncertainties. Instrumental uncertainties are the easiest ones to estimate and they may be controlled by an accurate calibration of measuring equipment [8]; uncertainties in subjective measurements cannot be easily controlled [9], actually several different uncontrollable (noise) factors may systematically affect subjectively measured (dis)comfort.

On the other hand, because of subjective characteristics (*e.g.* demographics, anthropometric, physiological, psychological) people experience different levels of (dis)comfort in identical environments [10, 11, 12]. Several studies point out a correlation between anthropometry (weight, height, Body Mass Index - BMI) and main pressure variables [12, 13]. Between-subject variations in pressure measures can be very large and due to anatomical differences in the pelvic and femoral structure and size, especially between males and females [13]. Moreover, subjective characteristics influence also the perceived (dis)comfort: larger sized seats are rated more comfortable by taller users and shorter users rate smaller seats as more comfortable [11, 14]. Furthermore, there is evidence that males and females are exposed to different loading patterns and experience different discomfort pathways, due to fundamental biomechanical differences in their sitting posture [15, 16].

In (dis)comfort assessment not only subjective characteristics should be considered, but also the effect of time in terms of sitting duration (*i.e.* travel time) as well as patterns of discomfort during the work week and during the workday. Smulders et al. [17], showed that the discomfort in an airline business class seat increases over time. In fact, also the most comfortable seat could become uncomfortable during prolonged periods of time; for long haul air, it is revealed that blood flow to tissues of the buttock region may be restricted and this compression exceeds hydrostatic capillary pressure creating pain and (dis)comfort sense [18]. Besides, Bazley et al. [19], demonstrated patterns of discomfort during the day and during week: discomfort is higher in the middle of the week than at the beginning or at the end of the week; discomfort level rises during the day.

This paper focuses on a statistical-experimental approach for the comparative assessment of aircraft seats (dis)comfort. Subjective (dis)comfort ratings provided by potential passengers as well as pressure distribution at the user-seat interface were analyzed in order to investigate the following questions:

1. Does (dis)comfort perception significantly differ across gender?
2. How do (dis)comfort perception change over time?
3. Which body parts are more sensitive to discomfort?

In order to minimize measurement uncertainties due to above mentioned noise factors (*e.g.* patterns of discomfort during the work week and workday, inter-individual variability) and guarantee repeatable test conditions, experimental trials were performed according to a crossover design and adopting an *ad hoc* experimental protocol.

The paper is organized as follows: in the second section a description of materials and methods is provided depicting an overview of experiment, the experimental plan and protocol; statistical analysis of objective and subjective data is presented in the third section; the results of seating (dis)comfort comparative assessment are summarized in the fourth section; finally, conclusions are drawn in the fifth section.

2 Materials and Methods

2.1 Overview of experiment

The whole experiment consisted of 54 test sessions involving 18 volunteer participants (9 males) who evaluated two aircraft seats in upright and upright/reclined configuration (*i.e.* 3 experimental seat conditions). All participants were required to be free from severe musculoskeletal disorders (MSDs) in the last year and to have taken a flight in the last two years. In order to ascertain the above requirements, volunteers were asked to

fill an informative questionnaire and a MSDs checklist so as to provide information on location, intensity and duration of any musculoskeletal injury experienced in the last year. The data from MSDs checklist were used only for participant selection purpose but they were not included in any data analysis. The range, mean and standard deviation (SD) of the participant main anthropometric characteristics (*viz.* age, height, weight, and Body Mass Index-BMI) are reported in Table 1.

Table 1. Range, Mean and Standard Deviation (SD) of age, weight, height and BMI of the participants grouped by gender.

	Num.	*Age [year] [min-max]*	*Weight [kg] [min-max]*	*Height [m] [min-max]*	*BMI [kg/m^2] [min-max]*
Males	9	[27.0-41.0]	[73.1-101.8]	[1.60-1.90]	[22.8-34.7]
Mean		34.6	88	1.77	28.03
(SD)		(4.25)	(8.53)	(0.08)	(3.46)
Females	9	[26-44]	[55.5-75]	[1.55-1.73]	[21.15-27.55]
Mean		33.9	66	1.66	24.1
(SD)		(5.9)	(5.41)	(0.05)	(2.08)

2.1.1 Seats

Participants assessed the comfort of two economy class seats (hereafter identified as seat A and seat B) for regional aircraft market. The seats under study differed mainly in reclining, in backrest and armrest dimensions (*i.e*. only seat B was reclining with high backrest and long armrest). Seat A, being not reclining, was tested only in upright position (AU) while seat B was tested both in upright (BU) and reclined position (BR).

2.1.2 Objective and Subjective Measurements

Objective measures consisted of overall and local user-seat interface pressures. Pressure data were collected continuously during each test session, using two Tekscan (South Boston, MA, USA) pressure mats (5330 CONFORMat™), one for cushion and the other for backrest. Each pressure mat comprises 1024 (32 x 32) thin (1.78 mm) resistive sensors that could easily conform to the contour of the seat and measure up to 250 mmHg (5 PSI). Each mat has an active area of 471.4 mm x 471.4 mm and sensor pitch is 14.73 mm (0.5 sensor/cm^2). Pressures were recorded at 50 Hz. Pressure data from the two mats were divided into eight groups: left/right upper back, left/right lower back, left/right buttock, left/right thigh.

Subjective evaluations were collected using two different forms for seating comfort and discomfort. The seating comfort form (SCF) comprises 13 statements, one for the overall seat comfort and the others for the comfort of specific seat-pan and backrest attributes (*e.g.* seat pan and backrest profile, interface pressure, back support, stability and cushioning) carefully chosen so as to differentiate between seats and to point out the critical features for passenger comfort improvement. The SCF does not cover aesthetic considerations. The SCF includes two rating scales: a 11-point numerical rating scale (NRS) ranging between 0 and 10, with the minimum defined as no comfort score and the maximum as extreme comfort score; a 4-point Likert scale scored as 1= strongly disagree, 2= disagree, 3= agree, 4= strongly agree [20].

The seating discomfort form (SDF) is based on a body map and a 10-point category ratio scale (CR-10) [20, 21]. Specifically, the body map divides the body into 35 parts (6 front and 29 back) as reported in Fig. 1.

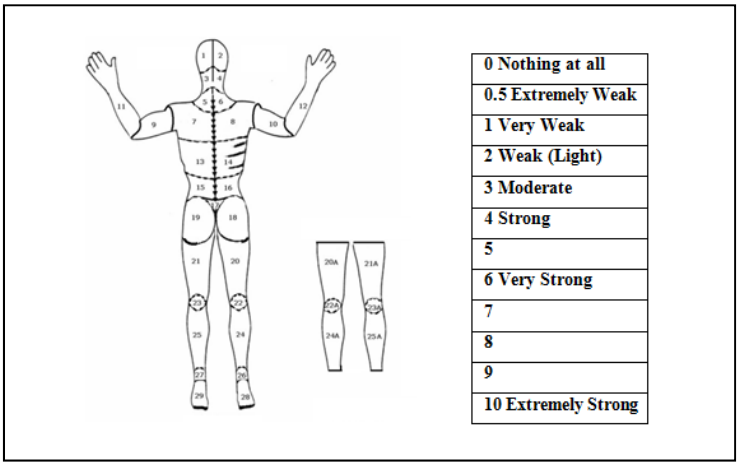


Fig. 1. Seating discomfort form (SDF)

2.2 Experimental Plan

The three experimental seat conditions (*i.e.* AU, BU, BR) were compared using a cross-over trial design with each participant assessing all seat conditions. Since three main noise factors (*i.e.* weekly range, daily range and inter-individual variability) could interfere with the main investigated (dis)comfort responses, the 18 seat conditions sequences were defined using 3x3 Greek Latin squares with 4 replications. The adopted experimental design allowed to randomize the order in which the participant evaluated each seat condition so as to avoid the systematic influence of the identified main noise factors on the (dis)comfort response. In order to avoid carry-over effects, a lower bound of 72 hours for wash-out period was fixed between consecutive test sessions involving the same participant.

2.3 Experimental Protocol

In the laboratory environment, seats were placed in two rows of two types per seat. Participants sat in the second row. Since the range for seat pitch in economy class is from 28 to 33 inches, a pitch of 32 inches was fixed in order to realistically replicate legroom. Each participant was involved in three test sessions scheduled according to the experimental plan described in the previous section. Each test session lasted about 40 minutes. Participants were asked to wear comfortable clothes, free of heavy seams and buttons, wallets and belts. Before the beginning of each test session, the participant was instructed how sit carefully to minimize wrinkles on the pressure mats. During the test, the participant sat comfortably in an upright/reclined posture with:

- feet flat on the floor so as to form a thigh-leg angle equal to 90°;
- back resting against the backrest;
- forearms not resting on the armrests;

The imposed posture aimed at controlling the effect of body posture upon peak and mean pressure over the seat pan and the backrest. In each test run, subjective (dis)comfort rating and pressure distributions were collected. Comfort evaluations (*i.e.* comfort scores and agreement degree with feature-specific comfort statement) were collected using SCF at the beginning (T0) and at the end (T2) of each test session; whereas discomfort evaluations (*i.e.* local discomfort scores) were collected using SDF in the middle (T1) and at the end (T2) of each test session.

3 Statistical Data Analysis

Statistical data analysis aimed at analyzing overall and local user-seat interface pressure distributions and testing significance in:

- differences in comfort ratings among the three seat conditions under study;
- gender-based differences in perceived discomfort on different body parts;
- effects of sitting duration on perceived discomfort on different body parts.

In order to analyze local occupant-seat interface pressure, each map was divided in 8 different areas, 4 for backrest, and 4 for seat pan, as in Fig. 2. Pressure data collected by resistive mats were analyzed by building synthetic indicators for overall and local user-seat interface pressure (*i.e.* min, max, peak, average, relative standard deviation) and by evaluating the comfort loss due to differences between the real load distribution and the ideal load distribution. Specifically, assuming that the posture in aircraft seat is similar to the posture in car seat, the ideal load distribution is the one derived in [11, 22] from the pressure distribution providing a low level of discomfort when driving a premium car.

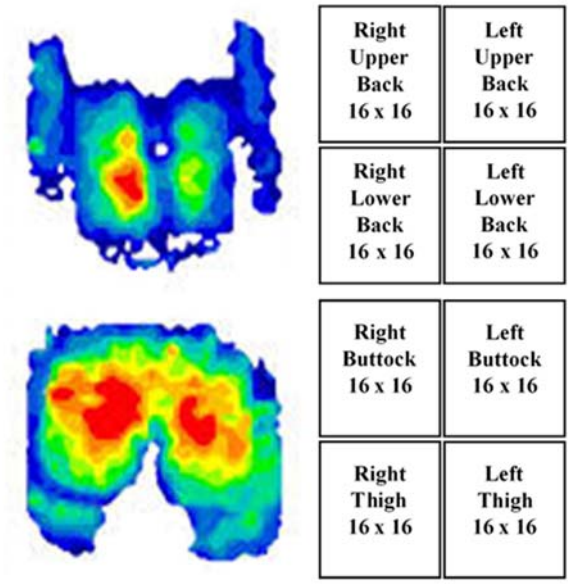


Fig. 2. Body Pressure map areas.

In order to verify the significance of differences in comfort scores among the three seat conditions, a non-parametric Kruskall-Wallis Test was implemented, and significant differences (if any) were investigated via Wilcoxon Matched-Pairs Signed Ranks Test for post hoc pairwise comparisons with p values adjusted (padj.) using Bonferroni's correction. A non-parametric Mann Whitney Test was implemented to investigate gender–based differences on local discomfort scores collected at T2. Finally, effects of sitting duration on perceived discomfort were analyzed by performing Wilcoxon Signed Ranks Test on local discomfort scores collected at T0, T1, T2. All statistical tests were considered "significant" or "marginal" when p (or padj.) ≤ 0.05 and $0.05 < p$ (or padj.) ≤ 0.1, respectively.

4 Results

No significant differences in comfort scores among the three seat conditions were found by Kruskal Wallis Test, except for the "slip feeling" ($p = 0.0004$). The post hoc analysis via Wilcoxon Matched-Pairs Signed Ranks Test pointed out that BR had the worst comfort rate for "slip feeling" (BR vs AU, $p = 0.003$; BR vs BU, $p = 0.0009$).

On the other hand, also the seat interface pressure analysis did not highlight relevant differences among the different seat conditions. Descriptive statistics (*i.e.* average, relative standard deviation, min and max) for seat interface pressure measures (*i.e.* peak pressure, mean pressure, total pressure, active area, total force and discomfort index - DI) are reported in Table 2. The DI was calculated as the mean squared distance between exercised load and ideal load [11, 22] for backrest and seat pan separately.

The results of Mann Whitney Test for the analysis of gender–based differences on local discomfort scores revealed that at T2 the males perceived significantly higher discomfort over back head and neck (for all seat conditions) and over thighs and legs (only for BR and BU).

The results of Wilcoxon Signed Ranks Test for the analysis of the effect of sitting duration (T2 vs T0) on local discomfort scores, highlighted that seat conditions BU and BR performed over time worse than AU. Specifically, the results showed a significant increase of discomfort over time for the following body parts: middle and lower back, buttocks and thighs (for all seats conditions); back head and neck (for BU and BR); shoulders and arms (for BR and marginally for AU); knees (for AU and BR).

Table 2. Descriptive statistics for seat interface pressure measures.

Seat		*Peak Pressure* (N/cm^2)	*Mean Pressure* (N/cm^2)	*Total Pressure* (N/cm^2)	*Active Area* (cm^2)	*Total Force* (N)	*DI*
BACKREST							
AU	*Mean*	1.03	0.14	45.55	743.14	98.87	0.880
	RSTD	0.48	0.17	0.26	0.24	0.26	
	Min	0.26	0.09	20.04	249.58	43.49	
	Max	2.17	0.18	66.87	962.74	145.12	
BU	*Mean*	1.16	0.14	38.42	625.50	83.38	0.934
	RSTD	0.75	0.22	0.29	0.25	0.29	
	Min	0.31	0.08	13.91	188.81	30.19	
	Max	3.03	0.19	55.67	872.45	120.81	
BR	*Mean*	1.05	0.14	45.08	695.82	97.83	0.921
	RSTD	0.46	0.19	0.24	0.19	0.24	
	Min	0.34	0.10	10.85	197.50	23.55	
	Max	1.98	0.19	64.69	920.20	140.39	
SEAT PAN							
AU	*Mean*	2.65	0.51	333.30	1480.89	723.36	0.990
	RSTD	0.19	0.17	0.21	0.12	0.21	
	Min	1.39	0.36	224.50	1017.86	487.23	
	Max	3.03	1.29	451.04	1605.03	978.89	
BU	*Mean*	2.55	0.49	334.22	1487.71	725.35	0.980
	RSTD	0.16	0.16	0.19	0.09	0.19	
	Min	1.51	0.29	214.93	1130.72	466.46	
	Max	3.03	0.62	441.30	1638.56	957.75	
BR	*Mean*	2.45	0.45	311.32	1493.71	675.66	0.945
	RSTD	0.22	0.17	0.18	0.08	0.18	
	Min	1.26	0.31	214.30	1158.93	465.09	
	Max	3.03	0.60	419.49	1662.43	910.41	

5 Conclusions

The comparative assessment of aircraft seating (dis)comfort highlighted no relevant differences between the two seats under studies in terms of pressure distribution at seat interface as well as comfort assessment.

Vice-versa the local discomfort ratings provided for seat B were generally higher and worse over time than for seat A, reaching at 30 minutes, in correspondence of sacrum, a median discomfort value corresponding to "strong discomfort" for females and "moderate discomfort" for males. Experimental results are in line with main literature findings on sitting (dis)comfort and recent field study [16, 23] examining differences in pressure sensitivity for areas of the human body in contact with the seat pan and backrest of a vehicle seat:

- males and females experience different discomfort pathways, due to fundamental biomechanical differences in their sitting posture and anthropometric peculiarities: in our study, though sacrum is the most critical area across both genders, males experience a moderate perceived discomfort for more body areas than females;

- perceived discomfort increases over time but some body areas can be assumed more pressure sensitive than others since they show significant increase in perceived discomfort already after 15 minutes.

References

1. Da Silva Menegon L., Vincenzi S. L., De Andrade D. F., Barbetta P. A., Merino E. A. D., Vink P., Design and validation of an aircraft seat comfort scale using item response theory, 2017, Applied Ergonomics, 62, 216-226.
2. Corlett E. N., Bishop R. P., A technique for assessing postural discomfort, 1976, Ergonomics, 19(2), 175-182.
3. Zhang L., Helander M. G., Drury C. G., Identifying factors of comfort and discomfort in sitting, 1996, Human factors, 38(3), 377-389.
4. De Looze M.lP., Lottie FM K.E., Van Dieen J. A. A. P., Sitting comfort and discomfort and the relationships with objective measures, 2003, Ergonomics, 46(10), 985-997.
5. Kolcaba KY, Kolcaba RJ., An analysis of the concept of comfort, 1991, Journal of Advanced Nursing, 16(11), 1301-10.
6. Helander MG., Zhang L., Field studies of comfort and discomfort in sitting, 1997, Ergonomics, 40(9), 895-915.
7. Bubb H., Spanner-Ulmer B., Ergonomics and Design, 2009, In Industrial Engineering and Ergonomics, Springer Berlin Heidelberg, pp. 481-497.
8. Li W., Yu S., Yang H., Pei H., Zhao C., Effects of long-duration sitting with limited space on discomfort, body flexibility, and surface pressure, 2017, International Journal of Industrial Ergonomics, 58, 12-24.
9. Yang Z., Sun S., Chen G., Evaluating sitting comfort with questionnaire and body pressure distribution: Overview and design, 2009, In Computer-Aided Industrial Design & Conceptual Design, CAID & CD 2009.
10. Lewis L., Patel H., Cobb S., D'Cruz M., Bues M., Stefani O., Grobler T., Distracting people from sources of discomfort in a simulated aircraft environment, 2016, Work, 54(4), 963-979.
11. Vink P., and Brauer K., Aircraft interior comfort and design (ergonomics design management: theory and applications), 2011.
12. Hiemstra-Van Mastrigt S., Comfortable passenger seats. Recommendations for design and research, 2015.
13. Paul G., Daniell N., Fraysse F., Patterns of correlation between vehicle occupant seat pressure and anthropometry, 2012, Work 41, 2226–2231.
14. Groenesteijn L., Vink P., De Looze M., Krause F., Effects of differences in office chair controls, seat and backrest angle design in relation to tasks, 2009, Applied ergonomics, 40(3), 362-370.
15. Vos G. A., Congleton J. J., Moore J. S., Amendola A. A., Ringer L., Postural versus chair design impacts upon interface pressure, 2006, Applied ergonomics, 37(5), 619-628.
16. Vink P., Bazley C., Jacobs K., Modeling the relationship between the environment and human experiences, 2016, Work, 54(4), 765-771.
17. Smulders M., Berghman K., Koenraads M., Kane J. A., Krishna K., Carter T. K., Schultheis U., Comfort and pressure distribution in a human contour shaped aircraft seat (developed with 3d scans of the human body), 2016, Work 54(4), 925-940.
18. Tan C.F., Chen W., Rauterberg G.W.M., Said M.R., The self-reported seat discomfort survey on economy class aircraft passenger in the Netherlands, 2013, Australian Journal of Basic and Applied Sciences, 7(6), 563-570.
19. Bazley C., Nugent R., and Vink P., Patterns of discomfort, 2015, Journal of Ergonomics, 5(1), 1-7.
20. Shen W., Parsons K. C., Validity and reliability of rating scales for seated pressure discomfort, 1997, International Journal of Industrial Ergonomics, 20(6), 441-461.
21. Borg, Gunnar A., Psychophysical bases of perceived exertion, 1982, Med sci sports exerc. 14(5), 377-381.
22. Mergl C., Entwicklung eines verfahrens zur optimierung des sitzkomforts auf Automobilsitzen, 2006, Doctoral dissertation, Universität München.

23. Vink P., Lips D., Sensitivity of the human back and buttocks: The missing link in comfort seat design, 2017, Applied Ergonomics, 58, 287-292.

The rationale behind wide-body trains with two plus three seating in Sweden

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Abstract At KTH, the Royal Institute of Technology in Stockholm, several studies have been made on train passengers' valuations and train interiors. The background was the experience that passengers want both high-level journey experience and low ticket prices. The question is whether these contradictory requests are possible to combine? This paper reveals some of the studies and results obtained at KTH during a 15-year period starting in the 1990´s.

The studies: 1) Engineering studies showing interesting cost efficiency if shorter trains could be used while having the same capacity and high comfort experience as in ordinary passenger trains. KTH economic analysis showed that train riding could be made up to 10 per cent more cost-effective in a wide-body train with 20-25 per cent higher capacity. This is positive, but do passengers accept to travel in a 2+3 seat arrangement?

2) Monetary passenger valuations of comfort and space were collected by stated preference interviews with passengers in regular trains. 3) Cost-benefit calculations showed that passengers would accept two-plus-three (2+3) seating. 4) A study was made on how people choose seats in regional trains with 2+2 and 2+3 seating. A model was used to calculate passengers' valuation of each seat position. These results confirmed that 2+3 seating is no big issue even taking into consideration that the middle seat is less valued, at least if there are unknown co-passengers in the other seats. 5) Trains with 2+3 seating and 3,45 m external carbody width were designed and introduced as "Regina" in Swedish regional and middle-distance services during the end of 1990's. 6) Passengers experience of travelling in Regina was investigated by passenger interviews. Passengers appreciated the roominess of the wide Regina trains and few valued the furnishing with 2+3 seating negatively.

Finally, as part of the Swedish "Green Train" project a train interior mock up with 2+3 seating was built and research experiment with test subjects conducted. The researchers varied seven design attributes – in particular regarding seats – due to a statistical design. Results show that both comfort and roominess experience can be quite good even in the middle seat among three seats if the legroom and the width are at least as large as in normal Swedish Intercity trains. However, having five narrow seats in a train without wide body is not an appreciated solution.

This paper aims at summarising all these studies for a wider audience, while most of the work is only presented in Swedish language working reports. This also includes short descriptions about the various scientific methods used.

Keywords: Train riding, comfort, Passenger experience, wide train, seating design

1. Introduction – Effectiveness and attractiveness

Many people judge train travel being too expensive and in a few cases not attractive enough. The ordinary ticket-prices for second-class train travelling in Sweden is often fore expensive thatn going by bus or two persons in a car. Flying is often more expensive but going by bus or car on longer distances is about half the cost. With this in mind the Railway Group at KTH in Stockholm has studied ways to reduce cost for train services.

Many modern long distance train services, especially new high-speed trains, have attracted many new travellers. Train is even threatened by low price airlines. At medium and regional distances trains have sometimes harder to compete with buses and cars. In addition to high ticket prices these trains are not attractive enough. Our studies show for example that regional commuters have high demands on comfort, often as high demands as the business travellers [12].

We believe it is necessary to approach the cost level of bus services and car driving to reach a good market share in the future. At the same time it is very important to design train services with high attractiveness. The conclusion is that the cost level can be significantly reduced, if trains can be reduced in size, while retaining the same number of seats. Figure 1 illustrates the idea or concept of space utilisation, which is to make shorter trains for a given number of passengers. In this example space utilisation is raised by three means:

1. The second train, the EMU, has traction equipment and passenger seats in the same vehicle, i.e. the separate power vehicle (locomotive) is omitted.
2. The EMU does not have a separate café, but ambulant catering at the seats.
3. The EMU is wider, permitting 2 + 3 seating.

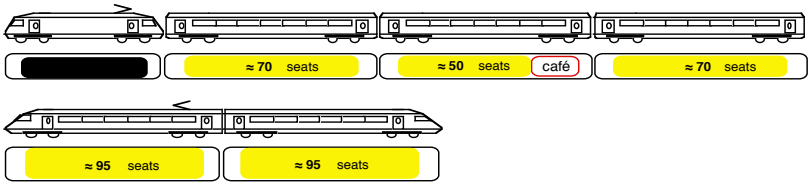


Figure 1. Increasing space utilisation – using smaller trains (EMUs, Electric Muktiple Units) for the same seating space. Although being an extreme case the picture compares the principal difference between a short loco hauled train and a wide multiple unit train with the same number of seats.

Two interesting options for increased space utilisation are double-deckers and wider car bodies. Both have a potential to reduce the train operator's cost for passenger services.

In many countries the main motivation for double-deckers and wide trains are limited infrastructure capacity, as in Switzerland and England [14, 15]. European single-level high-speed Inter-City trains have typically 2 – 2.4 seats per metre of train. The French TGV-Douplex is a double-decker with about 2.8 seats per train metre. However, the Japanese wide-body Shinkansen trains provide approximately 3.3 seats per train metre [1].

Potentially a double decker can have up to 50 % more seats than a single decker and a wide train with 2 + 3 seating can have up to 25 % more seats than a train with 2 + 2 seating. It is however judged by KTH that double-deckers and wide-body trains have in reality about the same numbers of seats per train metre. With these presumptions both concepts have a potential to reduce the train operator's cost by 5-10 % [12].

Our estimation at KTH indicates that wide-bodied multiple units are somewhat more expensive to purchase and to maintain. The result is about 10% reduction in traffic costs.

2. Perception and valuation of comfort in trains

KTH studies with passengers have been made with many dimensions such as perceptions, attitudes, valuations, willingness-to-pay and passenger satisfaction. When it comes to space it is for example relevant to ask

about how much space passengers perceive and how they perceive the design. But it is also very useful to investigate the value of space and good design.

2.1 Determining passengers' perceptions

For various reasons, we might sometimes want to find out how passengers perceive different factors or characteristics. A company that produces vehicles and traffic services might want to know whether the passenger/customer sees the product in the same way as the producer. A study conducted by KTH showed that passengers were not at all aware of certain possibilities that are available on the Regina train. Only half, for example, know that seats could be adjusted despite this being a very commonly expressed wish.

2.2 Methods to investigate the value of space, design and specific attributes

In these methods, the traffic system and its benefit to travellers are the focus of interest. Travellers choose a transport mode, e.g. car, bus, plane or train, depending on how great they perceive the (generalised) cost to be, how they value the travel modes and the journey offered by each.

Economic theory states that "utility", or in terms of money "willingness to pay", is the sum of money that makes half a group of people choose a particular measure if that was the cost they had to pay. The other half would value the measure lower and would thus not be prepared to pay so much. An example:
The Department of Traffic Planning conducted its first Stated Preference interviews in trains in the late 1980s. [4, 5, 6, 7, 8, 9, 10, 11]. Kottenhoff's summarise a number of these studies in his thesis [9] and in a conference paper[11]. At that time also Wadman and Wardman [12, 13] made or summarized many studies of attractivness and design factors in trains. Keddie, assisted by Wardman, much later studied similar aspects in a study 2013 [14] named "Demand Impacts of Seating Layouts for Rollong Stock on Commuter Routes". This study and the ones here reported have to great extent used similar methods.

The following example gives a popular explanation to the concept of "value", which is close to the economic term "utility": Two trains are standing at the same platform. They have the same departure and arrival times but one of them has a much higher level of comfort due to its interior design. On the other hand, it costs 5 € more to travel on this train. If 50% of the passengers then choose the simpler, cheaper train and the other half the more comfortable, more expensive train, we define that the passengers value the difference to the same value as the difference in price; 5 € per journey.

2.3 Passengers' acceptance of sitting 3+2

Among railway professionals it has been discussed and sometimes questioned whether wide-body trains are attractive to passengers, if used as to accommodate more seats. In particular, the issue of the "middle seat" when sitting 2 + 3 has been discussed.

As an improvement in the utilisation of space can be suspected to have a negative effect on comfort, this issue has been studied in detail. Passengers' behaviour and valuations have been investigated in a number of studies using stated preference interview technique [3, 4], at KTH and ITS, Leeds during the 1990´s. Preferences are presented as willingness-to-pay for various kinds of measures [9, 13].

Our first studies (presented in [9]) focused primarily on space-related comfort attributes such as legroom, reclining backrests and the number of seats side by side (across the width of the car). The value of complete interior design concepts has been studied in new and refurbished trains, such as Swiss and German double deck trains as well as German and Swedish InterRegio cars [8, 10].

2.4 The 2 + 3 study

A six-month study in 1996/97 [2] investigated passengers' seating preferences with four methods. The data was collected on regional trains having an outside width of about 3.1m. It is then possible to use a 3 + 2 seating arrangement using bus seats (≈48 cm) but not using the standard train seat width (≈53 cm).

The data collection started by observing in what way people choose seats from main stations where the train was empty, or almost empty. This produced RP (Revealed Preference) data. Passengers on the same trains were then interviewed using three Stated-Preference (SP) methods.

A computer interview contained a standard pair-wise choice experiment (SP) and a best/ worst SP experiment about similar attributes. Finally, a third SP experiment was conducted in which people had to choose

seats on drawings with seat arrangements, where only two seats were still free. Figure 3 shows an example of the seats that were taken during one observation. This revealed passenger preferences.

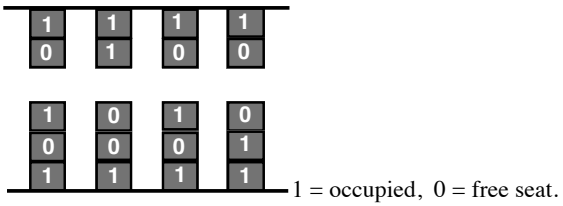


Figure 2. An example of an observation in an X14 car. Grey represent seats,

Results show that sitting by the window and having the adjacent seat free are the requests with the highest values on a utility scale. Although face-to-face or face-to-back had an average value close to zero, it ranked fairly high in terms of importance. Clearly passengers have strong views about the way they sit in this context.

Table 2 shows how much people seemed to value the attributes of the seats. To sit by the window is positive, trading off for a 8% change in ticket price. Sitting in the middle seat is negative, even if there are no people around, but not so negative as it is with other passengers beside. In case the train has to be equipped with more narrow seats (about 5cm narrower) this is negative according to the referred study. It is also quite negative not to have an armrest, bur this is not considered in the model below.

Table 1. Values of attributes used for the evaluation of 2 + 3 seating [5].

Attribute	Value (%) of fare
Sitting by the window	+7.5
Sitting at the side where there are three seats aside	-2,0
Sitting in the centre seat of three seats	-4.7
Sitting in a narrow seat	-2.4
Having your own armrest	+5.6
The seat beside you is free	+11.6

For each seat in the train the relevant attribute values can be summarised. (The attribute of having one's own armrest has not been used in the calculations for the diagram below.)

2.5 Valuation model for comparison of 2+3 with 2+2 seating

A model was designed with the data from the 2+3 seating study [2]. In this valuation model is anticipated that the values of the seating attributes can be added for each seat. The large variation in seat value depends on and decrease with the load factor. The value of getting a seat decreases by 15 - 20 % from a situation in which there are few passengers on board and everybody has a window seat with no passenger next to them to the situation in which almost all the seats are occupied. The difference between 2 + 2 and 2 + 3 seating is much smaller, 0 –2 %. At most load levels the "middle seat" is not occupied, which contribute to the small difference in value between 2+2 and 2+3 seating. Figure 4 shows how the value of riding a train decreases with the load. We define the relative value of riding to be 0 % when you are almost alone. The figure shows how the value decreases in relation to this.

In a 2+2 train the passengers choose window seats up to half load and the value stays at 0 %. Then the value decreases because other passengers take the free seats by the aisle. At full load the value of the train journey is in average 15 % lower than in the empty train.

In a 2+3 train the value of riding also decreases but in a slightly different way. The value stays at 0 % up to 1/5 load. The next peoples seat themselves by the window at the 3-side. Next the seat by the aisle at the 2-side will be taken and finally the middle seat at the 3-side.

At full load the value is about 2-3 % lower than in a 2+2 train but in a big range there is no difference. 3+2 seating can by average load hold out more privacy seats. Summing up passengers' valuations, 2+3 seating is slightly negative, but less than two per cent of the fare.

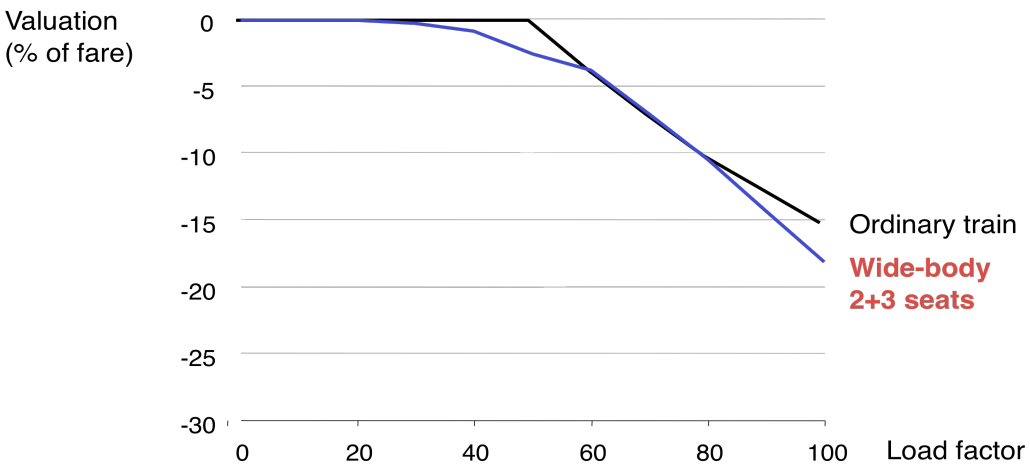


Figure 3 Average passenger valuations of seating in relation to the load factor (beläggning).

3. Wide-body Regina and passenger assessments of space and comfort

It is concluded that wide-body trains with corresponding ticket price reduction would be one of the means of improving the competitiveness of rail services. Wide-bodies is an alternative to the higher double-deckers.

The Swedish EMU wide trains are called Crusaris Regina. Bombardier Transportation had up till June 2001 orders on 108 cars, to be delivered in 2- and 3-car consists.

In the first year (2001) a survey was made by one of the regional transit companies (X-Trafik), with Regina, with travel time up to 2 hours. In total, 375 ordinary more or less experienced regional passengers responded to the survey, thereby expressing their overall graded valuation on the new trains as well as making their own spontaneous comments. A total of 312 comments (positive or negative) were made on comfort, train interiors and facilities, covering most aspects from chairs, ride quality and noise, air conditioning, space, general appearance, boarding and debarking convenience, etc. It is interesting to note, that just one (1) negative comment was made on the 3-seating arrangement and another three slightly negative comments on the width of the chairs (which can be related to carbody width). On the contrary, there were six positive comments on "spacious appearance", which may be interpreted as a positive feeling partly due to the wider interior space.



Figure 4 The interior of a wide body Regina in Bergslagen version, Sweden. The inner width is 319 cm.

These first indications showed what would be similar results in a KTH assessment of Regina services in Bergslagen region [15]. Among the results in this "validation study" we find that 18 out of 156 free text comments mentioned a spacious impression of the Regina interior, but 8 passengers where not pleased with their impression. Regarding seating 22 had positive comments, but 29 had negative comments, most of them about the simple/missing tables or hard seats. No one mentioned 2+3 seating as such.

A passengers' grading of comfort and space experience showed good higher average scores for the Regina interior compared to "ordinary Intercity coach" (with 2+2 seting, reclineble seats, reading lamps etc.)

Table 2 Passengers average scores of comfort and space in Regina and ordinary Swedish Intercity coach

	Comfort average grade	Space average grade
Ordinary Intercity coach	5,4	5,4
Wide Regina with with 2+3 seating	7,3	6,9

A simple willingness-to-pay question revealed that 2+ % lower fare is more important than not having the wide bodied Regina 2+3 seating arrangement, for more than 50% of the passengers. From this interview and previous KTH studies it is concluded that wider carbodies with 2 + 3 seating is of almost no significant concern to most train passengers . In fact, there are very few passenger reactions to it.

4. Mock-up study with test subjects

A test mock-up was built 2008 at Konstfack (The University College of Arts, Crafts and Design in Stockholm). It was used by KTH researchers to test various seat designs and seating measures. A total of 80 test subjects took part in tests to evaluate the feeling of comfort, perception of space and feeling of privacy in various seating alternatives.



Figure 5 The test subjects were asked to try out the different seating arrangements and state their perception of comfort, room, and personal space for each.

The mock-up contained a number of seating arrangements of different sizes and design. The designs were varied after statistical rules (experimental design). The test subjects were asked to give their perceptions, and more specifically their "feeling" of comfort, room and personal space. All test subjects had to test and grade eight seat profiles; different combinations of seven seating attributes. Their grading of the three dimensions; comfort, space and privacy were as dependent variables in linear regression modelling.

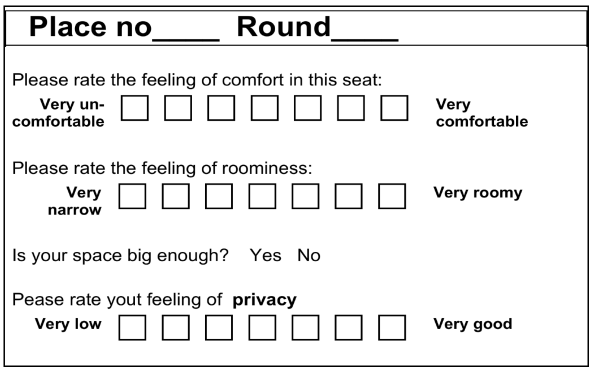


Figure 6 By evaluating the different scores for comfort, room, and personal space we were able to determine for example how much each cm of legroom, under seat height, seat width and back inclination means.

The independent variables were: 1) leg-room/cc, 2) rounded seatback, 3) your setback is reclined, 4) seatback in front of you is reclined, 5) own armrest/ seat width, 6) sitting by window and 7) sitting in middle seat.

The respondents "travelled" a few minutes in each seat profile accompanied by recorded real train interior sound. After each short "journey" they were asked to make the grading. Their grading were used as dependent variables and the attribute levels in the profiles were used as the independent variables. Results are summarised graphically in figure 7.

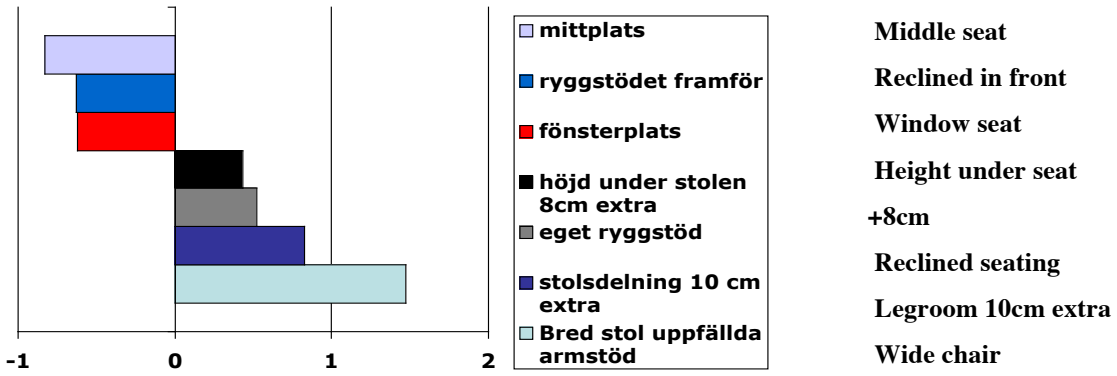


Figure 7 Average points showing how perception of space is affected by different attributes. It can be seen that sitting in the middle decreases the space perception the most, but that for example an (extra) wide chair should be able to compensate for that negative perception.

One result is that the perception of space and feeling of comfort can be kept at a high level even with increased space efficiency by 2+3 seating. But this requires careful design measures. Things to do can be seen in figure 7 for example a wider chair in the middle, 10 cm extra legroom and more height (8cm) under the seat in front. All this will affect a feeling of more space.

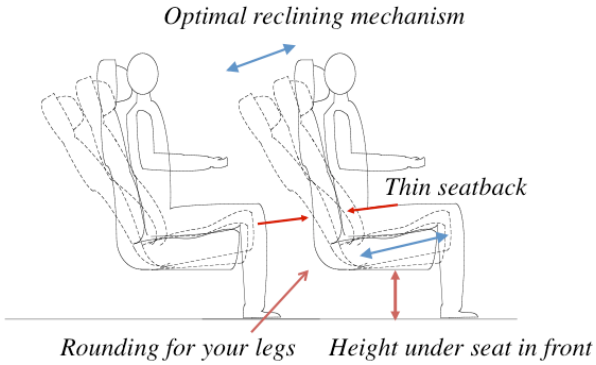


Figure 8 Passengers get a higher feeling of space if the legroom is enough and this feeling can be supported by more height under the seat in front and an intelligent recliner mechanism and thin seatbacks.

5. Discussion and conclusions

A fundamental technical and economic analysis on efficient and attractive passenger train operations has been conducted in a university-based research environment (Railway Group of KTH), in co-operation with Swedish industry, rail administrations and rail operators [1]. Recommendations are partly under implementation. Among others, a first version of wide-bodied trains were developed and introduced on Swedish regional lines. The wide-body train is an alternative even to double-decker trains in Sweden.

The general advantages of space-efficient trains are higher capacity, lower energy consumption and - most important to us - lower cost per passenger kilometre. In some other countries, for example Japan, Switzerland and France space-efficient trains have been introduced mainly for capacity reasons.

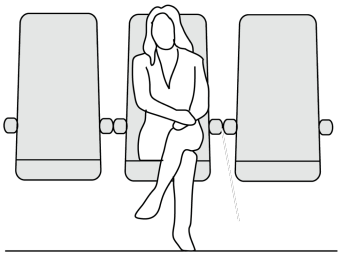


Figure 9 For passengers to accept the middle seat, the seat should be wide enough (say 45 cm) with enough leg-room (at least 10+ cm margin in front of your knees). Individual armrests also increase passengers' perception af space.

A wide-body train with 20 - 25% more seats will be about 5-10 % cheaper per passenger-km for the (Swedish) operator. The reason is that shorter trains have lower investment, maintenance and energy costs. This will - in principle - make it possible to reduce the ticket costs. If ticket costs are reduced by more than 2 % most passengers will prefer the wide 2 + 3 trains before ordinary 2 + 2 trains with more expensive tickets.

Passengers don't like narrow seats, so an important thing with 2+3 seating is that seats should not be narrow. This is a more important factor than the number of seats abreast. The passengers in the 3-seat side can be quite well compensated for their space experience by making 10 cm extra legroom than at the 2+2 seats. An own armrest is also appreciated.

2+3 seating in trains with British or standard European car body profile width is not supported by our findings. It would though fit in load profiles in Scandinavian and some other countries. In the case of Regina the inner width is 3.19 meter. For enabling full-width Swedish train seats another 5-10 cm would be desirable. It should be able to achieve with thinner car body walls.

The possible use of wide trains is further discussed by KTH researchers Nelldal [16], Andersson et.al. [1, 17]. A more popular version about "Attractive and Efficient Trains Interiors" is made within the Swedish Green Train project in 2009 [17, 18, 19]. These reports also shows many other design aspects for future trains.

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References

All reports in Swedish have summaries in English.

[1] Andersson, E., Kottenhoff, K., Östlund, S.: Efficient Passenger Trains for the future. Presented at WCRR´99, Tokyo, 1999.
[2] Båge, P.: Är breda tåg lönsamma? (Are wide trains profitable?), KTH Traffic Planning, TRITA-IP 97-53 (1996/97)
[3] Hensher, D.: Stated preference analysis of travel choices: the state of practice, Transportation vol 21, No2 May 1994, pp 107-134
[4] Hensher, D., Louviere, J., Swait, J.: Stated Choice Methods – Analysis and Application, Cambridge University Press, 2000
[5] Kottenhoff, K., Evaluation of passenger car interiors – German InterRegio-cars, Norwegian InterCityEkspress and Regional X10-trains, (1993) KTH Traffic Planning, meddelande 86, TRITA-TPL-93-11-96
[6] Kottenhoff, K.:Train Interiors and the Value of Space, KTH Traffic Planning, TRITA-IP AR 94-14 (1994), Presented on poster at WCRR´94 in Paris.
[7] Kottenhoff, K., Nelldal, B-L., Troche, G.: Effiziente Zugkonzepte für den InterRegioVerkehr, ETR (Eisenbahntechnische Rundshau) 1-2 1999
[8] Kottenhoff, K.: Utvärdering av SJ experimentvagn B20 – resenärers kvalitativa och kvantitativa preferenser av högkapacitetsvagn "IRmax" på olika linjer (Evaluation of SJ Experimental Passenger Coach B20), KTH TRITA IP-AR 98-68 (1998)
[9] Kottenhoff, K., Evaluation of Passenger Train Concepts – Methods and Results of Measuring Travellers' Preferences in Relation to Costs, KTH Traffic & Transport Planning, TRITA-IP FR-99-48 (1999)
[10] Kottenhoff, K.,: Evaluation of Bombardier double-deck train ”Competence” – Passengers’ valuation of the train and its’ interior on different lines. 1999. (in Swedish), KTH Traffic & Transport Planning, TRITA-IP AR 99-72
[11] Kottenhoff, K: – Evaluation of Passenger Train Concepts – Practical Methods for Measuring Travellers’ Preferences in Relation to Costs, 3rd KFB Research Conference in Stockholm, June 2000
[12] Wadman, P., Wermelin-Börjesson, A.: Wide-bodied EMUs offer extra capacity at low cost. Railway Gazette International, August 1999.
[13] Wardman, M., Whelan, G., Rolling stock quality improvements and user willingness to pay, ITS working paper 523, University of Leeds, March 1998
[14] Meddie, K., Demand Impacts of Seating Layouts for Rolling Stock on Commuter Routes, ATOC, In Association with University of Leeds
[15] Kottenhoff K., Utvärdering av ny bred motorvagn – att sitta fem i bredd i Regina (Assesment of a new wide EMU – to sit five abreast in Regina), KTH Traffic Planning TRITA-INFRA 02-014 (2001)
[16] Nelldal, B-L: Wide-body trains, vehicle concepts for different markets – a study of design, capacity and economy. (English version 1999), KTH Traffic & Transport Planning, TRITA-IP AR 98-69
[17] Andersson, E., Kottenhoff, K., Nelldal B.,: Extra wide-body passenger trains in Sweden. Presented at WCRR´2001, Köln, Paper 99, 2001
[18] Andersson, E., Kottenhoff K., Attractive and Efficient Train Interiors, Gröna Tåget project, KTH Railway Group, No. 0903, 2009
[19] Fröidh O., Kottenhoff K., Andersson, E., Green Train concept and interior design, KTH Railway Group,
(Division of Traffic and Logistics, Division of Rail Vehicles, Royal Institute of Technology (KTH), IJRT 18, accepted Dec.2013, Published 2014

Dimensional Factors Including a Seat Spaciousness Feeling, Saito A. et.al., Ergonomics Human Science Division, QR of RTRI, Vol. 43, No. 2, Jul. 2002

Seat Assessment – A Discussion of Comfort and Discomfort Models and Evaluation Methods

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Abstract Regarding the great amount of time people are spending sitting in various ways during the day, it is not surprising that remarkable effort is spent to make sitting as harmless and comfortable as possible. Seating comfort is therefore a reoccurring topic in the scientific community of human factors and ergonomics. In the literature, the concept of comfort and discomfort is used to describe the subjective perception as well as objective measurements. Looking closer into the published methodology and research findings, there is no common course of action. After describing the state of the art of different comfort and discomfort models, current subjective measurement methods and experimental designs, a discussion follows that shows the need of implementing further experimental standards and suggests reinvestigating the underlying constructs for subjective assessments. The aim of the article is to give stimuli for the future of sitting assessment and to revitalize the discussion.

Keywords: Sitting, comfort, discomfort, model, evaluation

1 Introduction

'Take a seat' – as an outspoken invitation or only in our heads, it does not matter: We gladly follow and are sitting almost all of our waking hours. During meals, on the way to work, in the office or during the spare time, part of the human population developed a sedentary lifestyle [1]. A study in Germany showed that people who are mainly working in an office are sitting up to 9.6 hours per day [2]. Besides the common knowledge of the negative physical effects of sitting, people still like to sit and want to do so comfortably. Additionally, due to the shift to highly automated or even autonomous driving and more informational jobs, the importance of interior comfort will increase. Since drivers will no longer be mainly occupied by the driving task, they can focus more on comfort aspects. In addition, with higher automation levels the variance and occurrence of secondary tasks conducted by the driver are expected to rise [3]. This will lead to more complexity of vehicle comfort compared to the current, relatively strict seating position. Furthermore, a vast number of seating products is delivered globally and is evaluated by users from different language regions.
This leads to the issue of how comfortable seating is truly defined. For a long time, the scientific community of human factors and ergonomics addressed topics related to the evaluation and optimization of sitting. The research objectives are to determine positive and negative sensations associated with sitting, and to correlate those with objective measurements or physical effects on the human body. Therefore, the terms and definitions of comfort and discomfort are usually used. Until today, there is ongoing interest in the research of sitting comfort and discomfort. Scopus finds 412 documents for 'comfort AND sitting' and 362 document for 'discomfort AND

sitting' since the year 2007 (as of April 5, 2017). However, what exactly and how do the authors measure or assess this concept? Since there is an understanding within the scientific community that discomfort can be measured more objectively than comfort [4–6], many discomfort studies are to be found.
Most of comfort/discomfort publications are in English and presume that the concept of discomfort is self-evident. This is understandable since the term of 'discomfort' is a common English word [7]. But there is, for example, no equivalent to be found in the German language. So if a study was conducted in Germany but published in English, the instruction for discomfort measurement is usually documented for instance as "the participants were asked to rate perceived discomfort in the body regions […]" [8, p. 213]. In another example, a publication based on research from a university in Italy describes the subjective measurement method for example with the sentence "experimental tests provided subjects with the possibility of expressing a comfort rating […] with the evaluation scale ranging from 1 (minimum score) to 10 (maximum score)." [9, p. 28]. Besides the fact that one of the publications use 'discomfort' and one 'comfort', such short descriptions suggest that the participants know what to evaluate when they are asked for their comfort or discomfort feeling. The publications usually do not give information about the language the reported study was conducted in or if explanations were given to the test persons about discomfort.
Assuming either that the used language in the study was actually English or that it was the local language but no explanation for discomfort given, both are subject to criticism. Participant studies with questionnaires assessing personal sensations need to be conducted in the mother tongue of the participants to ensure the conformity of understanding between the experimenter and the test subjects. Since there is at least no exact German translation for discomfort, if the participants do not receive an explanation of the used comfort/discomfort concept, the experimenter cannot be sure that the measurement is valid and that all participants are rating the same perception. As a result, the following questions arise: Do test persons in different nations understand the same concept in their assessment/rating? Are test results from different languages comparable? Even if the understanding of terms and definitions were equal for all studies, the test methods are not. There are many different scales and experiment designs used in comfort and discomfort studies.
The aim of the current article is to open up a discussion on comfort/discomfort models, measurement tools and experimental designs based on the current state of the art. Additionally, the authors will present statements for the future research on comfort/discomfort.

2 State of the Art

The following section presents the status of knowledge regarding comfort/discomfort models, comfort and discomfort measurement tools, and experimental design for seat evaluations based on a literature review.

2.1 Comfort and Discomfort Models

In 1958, Hertzberg published the first comfort model, defining comfort as the absence of discomfort [10]. Shortly after this, Wachsler and Learner published one of the first studies defining parameters of seating comfort [11]. According to them "the major difficulty of measurement and evaluation is the lack of an accurate definition of 'comfort'" [11, p. 315]. Their definition of the concept of comfort and discomfort is in line with the assumption of Hertzberg. They defined discomfort as an indirect measure for comfort [11]. Another approach during that time was to define comfort and discomfort as opposite endings of a continuous one-dimensional scale [12]. Even more comfort/discomfort models followed. Zhang, Helander and Drury stated a different approach by defining comfort and discomfort as independent dimensions [4]. Based on a cluster analysis, independent subjective sensations while sitting on an office chair were separated into two groups. The term 'discomfort' is assigned to the group consisting of sensations affiliated with poor biomechanics and fatigue whereby 'comfort' describes the group of feelings with aspects of well-being [4]. The developed model based thereon, shown in Figure 1, indicates that comfort and discomfort should be seen as independent assessments which can co-occur. One year later Helander and Zhang [13] confirmed the model. Additionally, they emphasized that comfort and discomfort can be evaluated in parallel, and that only comfort is influenced by design and aesthetics [13].

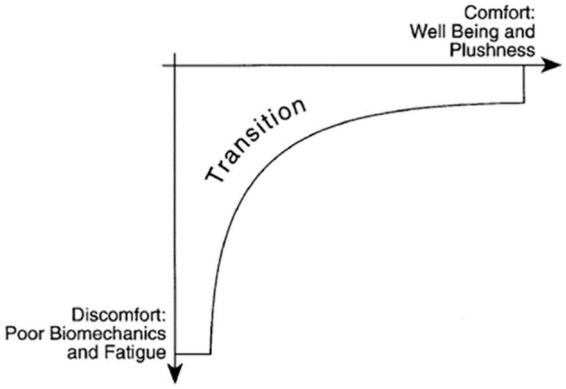


Fig. 1. Comfort and discomfort model by Zhang et al. [4].

The following theoretical discomfort model enhanced the findings of Zhang et al. and supported the statement that comfort and discomfort are independent of each other [5]. This discomfort model emphasizes the assumption of a stronger correlation between discomfort and objective measures compared to comfort based on the fact that the influences on discomfort are more direct [5], shown in Figure 2.

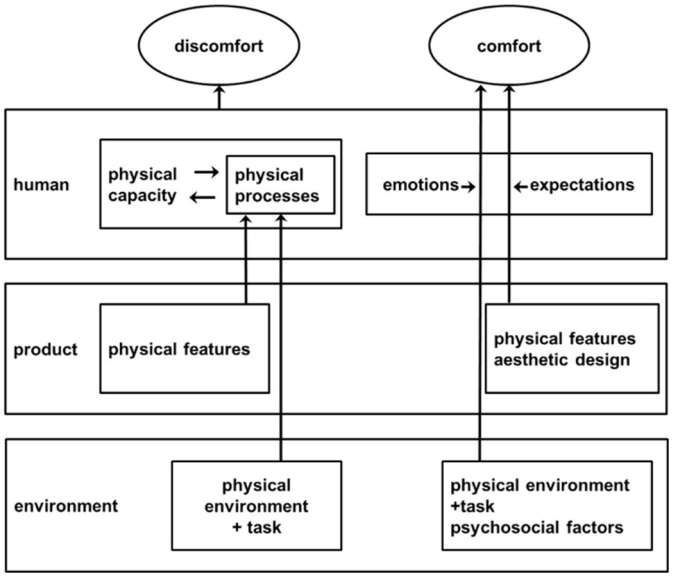


Fig. 2. Theoretical discomfort model by Looze et al. [5].

Moes criticized that the model of Looze et al. does not cover quantitative discomfort evaluations, e.g. correlations between discomfort and seat pressure distribution, and therefore developed a different discomfort model based on scientific findings from literature [6]. The model corresponds to a linear process in which the interaction between a human and a seat leads to physical effect within the human body, which, if perceived, the person explicitly interprets as discomfort or even pain [6].
Vink and Hallbeck published a further comfort/discomfort model, shown in Figure 3, based on the previous mentioned models [14].

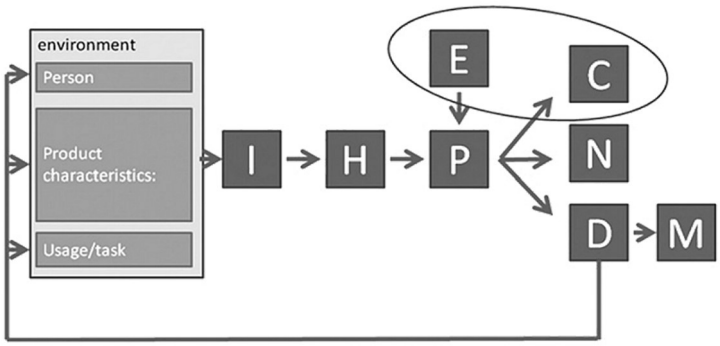


Fig. 3. Theoretical comfort and discomfort model by Vink and Hallbeck [14]

Their model describes, similar to Moes' model, that the interaction with the environment (I) leads to physical effects (H), which in combination with subjective expectations (E) influence the subjective perception (P). A person then interprets this perception as discomfort (D), 'nothing' (N), or depending on the personal expectations as comfort (C). An intense discomfort feeling usually leads to the urge to change the environment in order to achieve an improvement. In extreme cases, discomfort can lead to musculoskeletal disorders (M) [14].
The latest published comfort perception model by Naddeo et al. again references the model by Vink and Hallbeck [15]. The model proposes four main aspects strongly affecting the subjective comfort: biomechanics, physiological factors, environmental contribution, and cognitive factors. Each aspect is again divided into sub-aspects [15].

2.2. Comfort and Discomfort Assessment

There are basically two groups of methods for comfort and discomfort assessments: subjective assessment methods and objective assessment methods. The subjective methods include questionnaires, scales and interviews. Objective assessment methods determine comfort or discomfort by physical measurements. The subjective methods are also used to develop the objective assessment methods. Therefore, subjective comfort or discomfort ratings are correlated with physical (objective) measures, e.g. seat pressure parameters [16].
Numerous subjective assessment methods for sitting comfort or discomfort are published in the literature. Shen and Parson compared six different discomfort scales regarding reliability and validity [17]. The sitting subjects rated different pressure stimuli applied on their thigh within two separate sessions using each of the six different scales, and they evaluated the six scales afterwards. The CP-50 scale scored best in all three points (reliability, validity and subject ratings). Therefore, several studies conducted at the Chair of Ergonomics of the Technical University of Munich used the CP-50 scale [16, 18–20] in combination with a body map based on the findings of Corlett and Bishop [21].
Other scales are also used to rate the subjective comfort or discomfort, among others, semantic differential scales (SD-scales) with 5-points each [22], a 6-point scale [23], a 7-point scale [24], a 9-point scale [25], a visual analog scale (VAS) [26] also in combination with a modified CR-10 scale [27], or a local perceived discomfort scale (LPD) in combination with a 10-point scale [8].
Most of the previously mentioned publications aimed to develop objective comfort or discomfort assessment methods by researching correlations between physical measures and subjective comfort/discomfort ratings. Selected results from the studies are parameters of the seat pressure distribution correlate with the discomfort rating [16, 18], the sitting duration has an effect on the discomfort [8, 24], and the discomfort depends on the sitting posture [20].

2.3. Experimental Design of Seat Assessment Studies

In addition to different subjective measurement tools used in the published experiments, the test designs also differ. The sitting duration before the subjective ratings of the participants range between 10 seconds [28] and two hours [18], and also repeated measurement designs are used [8, 26]. In the different experiments, the subjects either had to evaluate the global (dis)comfort [28], or had to rate the specific comfort or discomfort for defined parts on a body map. The number of defined body parts varies between six [24] and 30 [19]. While sitting, the subjects of some of the experiments had to conduct secondary tasks like playing a computer/video driving game [19, 29], reading a book [8], or even driving a real car [30]. However, apparently the secondary task has no significant effect on the discomfort rating [8, 31].

3 Discussion

The high number of publications within the last years addressing the topic of sitting comfort and/or discomfort, show the still present interest and the remaining scientific research need in this field. The individual publications offer models and valid scientific methods to be used. Nevertheless, the previous sections, presenting only an excerpt of the published scientific literature, already show that there is no common ground within the community. Not even about which term is to be used ‘comfort’ or ‘discomfort’ in an international relation, and whether they are opposites or independent entities. Moreover, do ‘comfort’ and ‘discomfort’ even mean the same to the different experimenters and subjects? The published subject studies are conducted in different countries with different languages, and all use the same term even though there is no equivalent translation for it in the subjects’ and authors’ native language. So how do the experimenters assure that subjects understand the semantics of what they are supposed to evaluate? This premise and problematic issue is currently not adequately addressed in the literature. And without the certainty that subjects of one experiment and those in different countries understand ‘comfort’ and ‘discomfort’ in the same way, the results of both studies are only limitedly comparable.

Most of the comfort and discomfort models are theoretical and based on literature reviews [5, 6, 14, 15]. However, is it reasonable to use results from literature, which use different comfort or discomfort models and divers assessment methods, to compare them and to develop a new model based on this?

Even if all experimenters and subjects agreed on the same understanding of comfort and discomfort, the large number of used subjective rating scales can still be discussed. Comparing results of different studies, which claim to measure the same but with very different measurement tools, seems not efficient. This common practice becomes even more questionable given the different standards of experimental designs for comparable research questions.

4 Conclusion

The aim of this article was to show the need to discuss the current state of the art of sitting (dis)comfort. The authors consider the present inconsistencies regarding terms, models, measurement tools and the differently designed experiments as critical. The published findings are highly individual to a certain extent, and therefore complicated to compare and interpret.

In the short term, an agreement on standards regarding the used term, assessment tools and experimental designs, would increase the quality and enable a better comparability of sitting (dis)comfort studies.

In the medium to long term, a debate on principles might be appropriate. The entire human seat interaction should be reinvestigated methodically from scratch to research a possible generally valid model. Such a new scientific approach has to be carried out internationally to assure that the differences of language and culture are taken into account.

Even so, very interesting findings have already been published, this necessary discussion within the scientific community could enhance the knowledge of everyone involved, increase the level of scientific quality, and open up future opportunities for this important research field.

References

1. Owen, N., Healy, G. N., Matthews, C. E., Dunstan, D. W., 2010. Too much sitting: the population health science of sedentary behavior. Exercise and sport sciences reviews, 38(3), 105–113. doi:10.1097/JES.0b013e3181e373a2.
2. Techniker Krankenkasse, 2013. Beweg Dich, Deutschland!: TK-Studie zum Bewegungsverhalten der Menschen in Deutschland . Hamburg: Techniker Krankenkasse Pressestelle.
3. Kyriakidis, M., Happee, R., Winter, J. de, 2015. Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. Transportation Research Part F: Traffic Psychology and Behaviour, 32, 127–140. doi:10.1016/j.trf.2015.04.014.
4. Moes, N. C., 2005. Analysis of sitting discomfort, a review. In P. D. Bust & P. T. McCabe (Eds.) (pp. 200–204). London: Taylor & Francis.
5. Looze, M. P. de, Kuijt-Evers, L. F. M., Dieën, J. van, 2003. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics, 46(10), 985–997. doi:10.1080/0014013031000121977.
6. Zhang, L., Helander, M. G., Drury, C. G., 1996. Identifying Factors of Comfort and Discomfort in Sitting. Human Factors: The Journal of the Human Factors and Ergonomics Society, 38(3), 377–389. doi:10.1518/001872096778701962.
7. Oxford Dictionaries (2017). discomfort.
8. Hiemstra-van Mastrigt, S., Kamp, I., Veen, S. van, Vink, P., Bosch, T., 2015. The influence of active seating on car passengers' perceived comfort and activity levels. Applied Ergonomics, 47, 211–219. doi:10.1016/j.apergo.2014.10.004.
9. Naddeo, A., Cappetti, N., D'Oria, C., 2015. Proposal of a new quantitative method for postural comfort evaluation. International Journal of Industrial Ergonomics, 48, 25–35. doi:10.1016/j.ergon.2015.03.008.
10. Hertzberg, H. T. E., 1958. Seat comfort. "Annotated bibliography of applied physical anthropology in human engineering," WADC Technical Report, 30–56.
11. Wachsler, R. A., Learner, D. B., 1960. An Analysis of Some Factors Influencing Seat Comfort. Ergonomics, 3(4), 315–320. doi:10.1080/00140136008930493.
12. Shackel, B., Chidsey, K. D., Shipley, P. A., 1969. The Assessment of Chair Com-fort. Ergonomics, 12(2), 269–306. doi:10.1080/00140136908931053.
13. Helander, M. G., Zhang, L., 1997. Field studies of comfort and discomfort in sit-ting. Ergonomics, 40(9), 895–915. doi:10.1080/001401397187739.
14. Vink, P., Hallbeck, S., 2012. Editorial: Comfort and discomfort studies demonstrate the need for a new model. Applied Ergonomics, 43(2), 271–276. doi:10.1016/j.apergo.2011.06.001.
15. Naddeo, A., Cappetti, N., Vallone, M., Califano, R., 2014. New trend line of research about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions. In T. Ahram, W. Karwowski, & T. Marek (Eds.), AHFE 2014, Krakow, Poland, 19-23 July 2014 .
16. Zenk, R., Mergl, C., Hartung, J., Sabbah, O., Bubb, H., 2006. Objectifying the Comfort of Car Seats. In APR. 03, 2006 (SAE Technical Paper Series). Warrendale, PA, United States: SAE International. doi:10.4271/2006-01-1299.
17. Shen, W., Parsons, K. C., 1997. Validity and reliability of rating scales for seated pressure discomfort. International Journal of Industrial Ergonomics, 20(6), 441–461. doi:10.1016/S0169-8141(96)00068-6.
18. Mergl, C., Klendauer, M., Mangen, C., Bubb, H., 2005. Predicting Long Term Riding Comfort in Cars by Contact Forces Between Human and Seat. In JUN. 14, 2005 (SAE Technical Paper Series). Warrendale, PA, United States: SAE International. doi:10.4271/2005-01-2690.
19. Ulherr, A., Zeller, F., Bengler, K., 2017. Simulating Seat Discomfort: An Experimental Design for Using Digital Human Models. In AHFE 2017, Los Angeles, USA.
20. Zacher, I., Bubb, H., 2004. Strength Based Discomfort Model of Posture and Movement. In JUN. 15, 2004 (SAE Technical Paper Series): SAE International400 Commonwealth Drive, Warrendale, PA, United States. doi:10.4271/2004-01-2139.
21. Corlett, E. N., Bishop, R. P., 1976. A Technique for Assessing Postural Discomfort. Ergonomics, 19(2), 175–182. doi:10.1080/00140137608931530.
22. Naddeo, A., Cappetti, N., Califano, R., Vallone, M., 2015. The effect of external and environmental factors on perceived comfort: the car-seat experience. In Human Factors and Ergonomics Society Europe Chapter 2015 Annual Conference, Groningen, Netherlands.
23. Smith, J., Mansfield, N., Gyi, D., Pagett, M., Bateman, B., 2015. Driving performance and driver discomfort in an elevated and standard driving position during a driving simulation. Applied Ergonomics, 49, 25–33. doi:10.1016/j.apergo.2015.01.003.
24. Na, S., Lim, S., Choi, H.-S., Chung, M. K., 2005. Evaluation of driver's discomfort and postural change using dynamic body pressure distribution. International Journal of Industrial Ergonomics, 35(12), 1085–1096. doi:10.1016/j.ergon.2005.03.004.
25. Shen, W., Galer, I. A. R., 1993. Development of a pressure related assessment model of seating discomfort. In Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting (Vol. 10).
26. Grondin, D. E., Triano, J. J., Tran, S., Soave, D., 2013. The effect of a lumbar support pillow on lumbar posture and comfort during a prolonged seated task. Chiropractic & manual therapies, 21(1), 21.
27. Kyung, G., Nussbaum, M. A., Babski-Reeves, K., 2008. Driver sitting comfort and discomfort (part I): Use of subjective ratings in discriminating car seats and correspondence among ratings. International Journal of Industrial Ergonomics, 38(5-6), 516–525. doi:10.1016/j.ergon.2007.08.010.
28. Ebe, K., Griffin, M. J., 2001. Factors affecting static seat cushion comfort. Ergonomics, 44(10), 901–921.
29. Burke, L. I., Storer, R. H., Lansing, L. L., Flanders, S. W., 1996. A neural-network approach to prediction of vehicle driving comfort. IIE Transactions (Institute of Indus-trial Engineers), 28(6), 439–452.
30. Fischer-Von Rönn, N., Meywerk, M., 2014. Predicting the ride comfort of passenger cars for single-obstacle crossings through an innovative feature extraction method consisting of non-linear geometric approximations of wavelet-transformed acceleration

data and airborne sound. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 228(4), 357–369. doi:10.1177/0954407013508277.
31. Ulherr, A., Hasselmann, K., Kuhn, K., Bengler, K., 2015. The Effect of Secondary Tasks on the perceived Seating Discomfort. In 19th Triennial Congress of the International Ergonomics Association, Melbourne, Australia, 9-14 August, 2015.

How Driving Style affects Public Transport Passengers' Experienced Comfort

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Abstract Ride quality is part of the total comfort experience for any passenger. It can be seen as the result of the infrastructure, vehicle characteristics as well as how the driver handles the vehicle, i.e. the driving style. Literature show that interest has been focused on vehicle dynamics: vibration, noise, temperature and the traveller's posture. However, little research has been focusing on how driving style; the driver's input or control of the vehicle affects the passengers' experience of the ride.

An array of complementary methods has been applied, beginning with traffic authority's statistics of comfort complaints, via on board interviews and field measurements with accelerometers in regular bus and metro services, ending with an experimental design exposing test subjects to field like situations. The experiment with test subjects investigates the role of various driver behaviours and the magnitude of discomfort. The experiment with test subjects was made 2009 and follow up tests with ordinary passengers in regular buses were made 2016 in order to validate the previously developed model.

The following conclusions have been drawn from the methods used:

- The driving style does affect the perceived comfort level in several ways, for example comfort feeling, possibility to read or work, keeping balance and fall accidents as well as travel sickness.
- The problems of poor ride quality are "medium size" in most cases.
- Passengers are affected by jerks, strong braking, uneven speed (so-called "pumping") and hard cornering. Jerks are most often mentioned spontaneously.
- The four indicators developed help quantifying the impact on experienced comfort. They should be of use to design driver assistance tools. No one would deliberately drive badly if they know that they were doing it, and therefore: better informed drivers will lead to a better ride experience.

Finally we summarize four observations about the driving style and comfort levels in Stockholm. First, the acceleration measurements and interviews with ordinary passengers show that ride comfort generally is somewhat higher in the Stockholm metro than in the buses. The problems experienced in the metro most often relate to uneven driving, also called jerky driving by passengers. Secondly, it appears there are differences between drivers. However, most of them are intermediate regarding comfort levels. Most of the measured ride comfort levels for a number of runs in ordinary bus services actually lay on the boundary of unapproved comfort, according to the scale developed by this project. Thirdly, it appears that about one tenth of the drivers differ with considerable uncomfortable driving. Fourth, there are some drivers who drive a lot better than average drivers. Actually, their favourable driving style indicates a potential for increased ride comfort among all drivers.

Keywords: Public transport, Driving style, Ride comfort, Passenger experience

1 Introduction

This introduction defines general comfort in public transport, ride comfort and driving style.

1.1 General comfort in public transport

Comfort is a construct that can be divided into many attributes related to visual, audible, sensory and psychological dimensions [1 ,2, 3]. There are a lot of factors that affect people to use public transport and their satisfaction with their choices. Is the experienced comfort level an important part of passengers' perception and valuation of a journey? Studies show that "hard" factors like travel time, departure frequency and travel cost are more important for mode choice [4, 5]. People chose journeys with high comfort, for example regional commuter trains when the comfort is high [4, 6, 7]. Kottenhoff [1] shows that a number of comfort attributes in trains may be traded off against 5-10% higher ticket price. This value can also be expressed as time saving.

1.2 The significance of ride comfort

Ride comfort is a construct that often has been defined in relation to the vibrations in a vehicle during ride. It is that part of the comfort construct that can be related to technically measurable or experienced vehicle movements and sometimes also sound. Most effort has been but into the dynamic response of buses to road irregularities, [e.g. 10], and ditto for the rail mode. In this respect ride comfort "is associated to mechanical vibrations characterized by frequencies included in an interval from 0.5 to 80 Hz". It is affected by the dynamic interactions between the vehicle and the uneven road pavement [8, 9]. Some studies have even concentrated on how the driver himself is affected by the road-friendliness. Less research effort has been made to study how the drivers affect the passengers – the relationship between drivers' driving style and passengers' experience of comfort. This is most often not primarily related to the road quality, but there are exemptions, for example in developing countries [10, 11]. Castellanos [12] developed a hardware and software to evaluate passenger comfort in public transportation, still with some focus on vibrations.

In Stockholm-buses, about every third public transport passenger is not fully pleased with the drivers' driving style [13]. The satisfaction level was higher in rail modes (metro 74%, commuter train 85%) than in local and regional buses (69%). Even complaint statistics gives a hint that people care about ride comfort in local public transport.

Also lower frequency movements that may cause motion sickness, belongs to ride comfort problems. This is so in both rail and buses, however, consisting more of female and children [14, 15]. It is the longer journeys by public bus that provides the greatest problems [15]. It turns out that when the journey is done with varying speed, "pumping", but also on curvy roads, the incidence of motion sickness is triggered. Frequencies around 0.2 Hz, ie. acceleration and braking about every five seconds gives especially large problems for people sensitive to motion sickness [14, 15, 16]. Motion was not studied per see in this project because of the short journeys in the experiment made.

The effects of bad driving style can lead to more effects than just reduced comfort experience. The travel time is more difficult to be used for reading and work [17]. At higher deceleration, curve acceleration and jerk levels passengers may fall [18,19]. The dominating sources were driver handling with sudden breakings followed by accelerations.

There is some relationship between "eco- driving" and better ride comfort [20]. A study of the effect of eco-driving on bus passengers' comfort ratings showed that there where some good ride comfort short-term effects [21], but that study did not try to penetrate the different reasons for bad comfort experience.

1.3 The significance of driving style

Driving style deals with the drivers' handling of controls in relation to the traffic situation. One can say that a driving style is built up of a number of driving behaviours. But a more narrow proposal says that "driver's style is based on the measure of how fast a driver is accelerating and decelerating" [22]. In public transport it is not self evident that very slow driving is the best driving because all buses and trains are part of a system built on timetables and coordination between lines. The driver applies and trades off various driving behaviours to

form an appropriate driving style in each case. There are for example different ways to slow down, stop and take a curve and to maintain velocity.

1.4 Project goal

The goal of this project is to understand the passengers discomfort in relation to various bad driving style/behaviours and quantify the relationship. This should be a basis for development of driver assistance tools. A working report was published as a KTH report in Swedish 2011. [23]

2 Setting up an experiment with test riders

The authors are interested in how comfortable and accepted different driving styles are in real bus services. In an exploratory first phase, acceleration data was collected in bus, tram, metro and train services. This sample was later evaluated by the project's new model. The following assumptions/hypotheses have been developed on the basis of the deficiencies we saw in an exploratory stage: 1) Vertical accelerations and vibrations from the road or rail do not primarily depend on driving style. 2) Uneven driving, sometimes called "pumping" decrease comfort experienced (and can give some people motion sickness). 3) Heavy breaking and accelerations, i.e. high quasi-static acceleration levels, reduces comfort. 4) Recurring sharp cornering with high quasi-static lateral accelerations reduces comfort experience and 5) Jerks are perceived as uncomfortable. Hypotheses 2-5 have been tested in this work.

Different driving behaviors should be described and quantified in the experimet. The passengers' experience should also be quantified. In this case the experienced dimensions can be levels of "driver skill" and "comfort".

There are good reasons to make a statistical experiment. One is the efficiency of this method – we could investigate several attributes in every step of the experiment. Another benefit is that the test subjects have some difficulty to uncover what is happening. We anticipated this would lead them to use their feelings about the ride comfort instead of their intellectual perception.

Running a test vehicle with test persons similar to real bus operation was performed. They should express their feelings of comfort or tolerance of discomfort. With this in mind a field test was designed and set up. A problem when using test subjects for the judgment of tolerated comfort level, is that they might misunderstand their role. There is a risk that they will just perceive the level of jerks or shaking and grade these, as if they were replacing accelerometers (Alm, I. 1989), instead of their personal feeling about the perception.

Table 1. Statistical design for the experiment. Each of the 8 lines describes one driving style profile on the loop.

Driving style profile	*1. Acc/retard*	*2 Jerks*	*3. Curving*	*4. Speed regulation Pumping*	*Acceptance share*
1.	Soft	Soft	Hard	Uneven	14%
2.	Hard	Hard	Soft	Even	0%
3.	Hard	Hard	Hard	Uneven	4%
4.	Soft	Hard	Hard	Even	3%
5.	Hard	Soft	Hard	Even	57%
6.	Hard	Soft	Soft	Uneven	48%
7.	Soft	Soft	Soft	Even	98%
8.	Soft	Hard	Soft	Uneven	27%

Three response scales for the test subjects' judgments were used: The driver's skill, speed and comfort rating. The subjects rated their experience of these three measurements for each run on the sample loop.

These four driving behaviors were found to be important and should be included:

• Quasi-static acceleration levels at start and brake.
• Quasi-static acceleration levels / lateral accelerations during cornering.
• Jerks, especially at stopping (intersections and stops).
• Uneven speed profile; "pump driving, sewing machine driving".

A typical Stockholm city bus, a 12 m Scania bus with rear engine, was used for the test runs. BusLink in Stockholm was kind to provide the bus and a test driver. The test was made in a Stockholm suburb (Bredäng). The road loop was 3.4 km long with 8 bus stops. One run of the loop took 7-8 minutes.



Fig. 1. The 3.4 km test loop with 8 stops in Bredäng, Stockholm. Each of the 8 turns represented a profile in the statistical experiment and took 7-8 minutes to run.

There were 51 test passengers in total. One single driver represented eight different drivers with eight different driving styles. See table 1. Three types of data were collected at the eight runs on the loop:

- Ratings of driving skill, perceived speed and ride comfort from the 51 subjects. The ratings should be marked on a scale, 100 mm long – from extremely bad to extremely good without intermediate marks.
- Subjects also had to answer if the skill and comfort level for each run was god enough.
- The measured accelerations in three directions from the runs (sampling with 40Hz).

2.2 Test subject ratings and acceptance of profiles

The rating scales used for respondents' ratings were done as a 100 mm long line, where each mm represents 1 point. The respondents were asked to put a cross at each of the three lines; for driver's skill, speed and comfort. To be able to include a logit analysis in the experiment, subjects were also asked to answer if a certain run, or driving profile, was good enough or at least acceptable. These binary answers were very useful.

A first analysis shows that all four driving attributes are significant and thereby mean something to passengers' acceptance. For example, in average 39% accept the driving profiles with low longitudinal quasi-static accelerations while just 26% in average accept the profiles with hard braking.

Data analysis included two main steps: 1) Production of preliminary indicators in Matlab from the acceleration data and 2) testing of these preliminary indicators in SPSS towards passenger comfort ratings (from earlier measures) to find the best fit. With this two-step method, optimal indicator decryptions were approximated. Simple binary correlation, but also linear regression models and logistic regression models have been used to analyze the various data dependencies. Many ideas were tested for diving high correlations.

All bad driving behaviors were highly correlated with test persons' judgments. For example hard braking causes a highly significant negative response from the test subjects. Furthermore, the highest correlation level was for jerks, but it is doubtful to show this, because it may be misinterpreted. In fact the test driver made so hard jerks in the test runs that they merely exist in regular public transport services. The conclusion is that the data measured by accelerometers must be used to describe driving behaviors. To design useful indicators is a challenge.

2.3 Building indicators for uncomfortable driving style

An easy way to visualise ride comfort is by putting a glass of water on the vehicle floor. Today various representations of accelerometer data can be shown by smart phone apps, but the algorithms are not explicit. So, what about the indicators used for eco driving indication? They should have some correlation with ride comfort but their algorithms are not primarily for comfort. They are not even described in a standardized way [22]. Logically sharp cornering, jerks and travel sickness measures must not be included in these. The good thing is that some of the equipment used for eco driving assistance, should be able to complement with passenger experience algorithms.

Wåhlberg [23] proposed an integration of acceleration levels over time. He used what he calls "Celeration" which is the integrated sum over time of all absolute values of accelerations. After some reasoning we decided that the use of RMS values is a better measure. The higher levels of "celeration" are then emphasized to reflect how accelerations likely affect passengers on board.

2.4 Vibrations Indicators

ISO2631 standard is based on measuring accelerations amplitudes at different frequencies. It is not made to explain bad driving behavior, rather vibrations caused by bad road quality and vehicle suspension.

The purpose of the field trials was to develop indicators and measures for poor ride quality. Indicators should reflect such driving style that travellers do not like. The latter may take the form of the perceived level of comfort, even if one could imagine other reasons why you do not like driving style.

One would imagine that having a single aggregate indicator for the (bad) service and related driving style. A more disaggregated way to measure and create measurement is to divide the different driving styles and related comfort effects. Below are some principles for such measures:

- The indicator will show how the driver is driving badly. This means that it should be clear whether the driver braked too hard, accomplished jerk, driving too fast in curves or cards with uneven pace.
- Indicators should go to merge. The weighted signals can be summed.
- The indicators should ideally be independent of each other. Unfortunately, it is quite difficult to find measurement signals from which one can find independent indicators.
- Road geometry, roughness and condition should not mean too much.
- The indicators and measures should be able to control driver aids and educational tools.

A large number of indicators have been designed, in Matlab, and tested in SPSS. The tests have been made by searching for good fit between the passengers' judgments (points) and indicator output from that specific driver style. Both linear regression and logic models have been used.

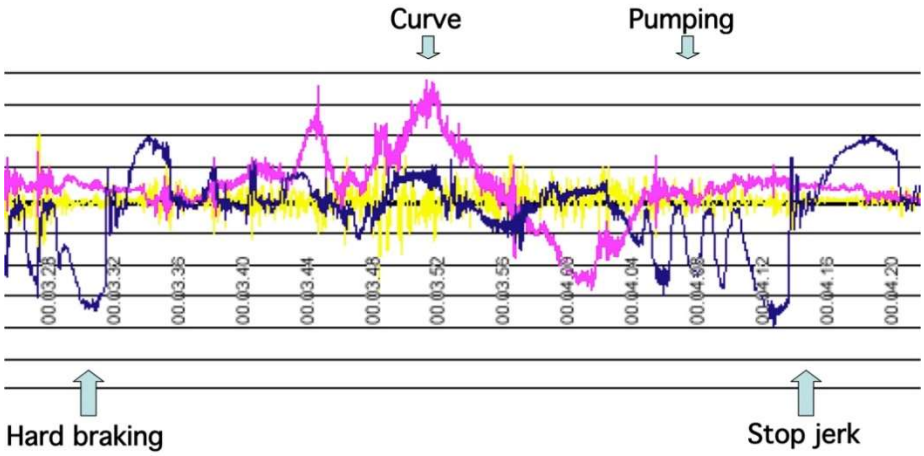


Fig.2. Printed driving profile data (No3). The four types of assumed comfort disturbances, high quasi-static retardation (blue line), high lateral acceleration curve (red line), uneven 'pump' driving (blue) and jerks (blue) are checked. The yellow line shows vertical accelerations, which were not dealt with in this project.

The indicators should reflect bad driving style, but indicate the specific driving behaviours, for example hard braking or uneven speed. In this paper driving style is the general term while driving behaviour stands for the specific (bad) behaviour.

From the experiment, three types of data sets exist; 1) the statistical design, 2) sampled acceleration data for X, Y, Z directions and 3) test-passengers experience; assessment-data. Passengers' grading correlate highly with the experiment design, especially with the driving behaviour; jerk. Does this mean that jerks always imply worse experienced comfort than other bad driving behaviours? No, it depends on the actual level of the driving behaviours – how hard they are.

Each indicator should also show in what ways the driver is driving poorly. This means that it should be clear whether the driver brake too hard or drive too jerky, drive too fast cornering or drive on an uneven pace.

The four indicators have been developed to suit the experiment where a test track of 3 km length and 7-8 min run time was used.

Two indicators are tricky. They need more insight and complicated estimation procedures. The third indicator shall show the sensitivities for jerks, especially at traffic and bus stops. The fourth indicator shall show passengers sensitivity to uneven driving.

The jerk indicator, stop-jerk (Ij); builds on the assumption that test subjects did not integrate all jerks, but was mainly influenced by the (8) worst jerks when assessing their ride comfort. The design and calculating steps for the jerk indicator has been:

1. The accelerometer data is filtered with a low pass filter with cut-off frequency 8 Hz (Butterworth type).
2. Jerks are derived out from the low pass filtered accelerometer data. Acceleration change / time and magnitude of the acceleration shift.
3. The eight largest jerk peaks are identified.
4. Finally, the 95th percentiles of the eight peak values are calculated.

Uneven speed or Pumping is described by an indicator that calculates how many "clear enough pumping" that occurs by a certain time. The indicator Pump_3_2 (Ip32) has been designed and calculated as follows. The figure 3 means 3 sec period time and 2 indicates minimum variation of acceleration level (Δax). The number of points where the value of ax was different from zero counts.

2.5 Model for the relation between discomfort and the 4 driving behaviors

A linear model [1] shows the relation between ride comfort and acceleration data:

$$Dc = p_{ad} \times I_{ad} + p_c \times I_{lat} + p_j \times I_j + p_p \times I_{p32} \quad (1)$$

where

Dc = drive dis-comfort measure. Scale is about 0-100+ Higher level is worse.

p_{ad} = parameter showing the sensitivity for accelerations and decelerations.

p_c = parameter showing the sensitivity for curving; lateral accelerations.

p_j = parameter showing the sensitivity for jerks.

p_p = parameter showing the sensitivity for "pumping"; uneven accelerations.

I_{ad} = indicator for acceleration and deceleration levels.

I_{lat} = indicator for curving; lateral levels.

I_j = indicator for jerks.

I_{p32} = indicator for "pumping"; uneven accelerations with certain levels, 3s period time and 2m/s2 variation of acceleration level (Δax).

All indicators have been calibrated for best explanatory power for the measured accelerations and the test passengers' ratings, when used together (formula 1). By an iterative process the specifications that gave the highest match between the certain bad driving behaviours and the test subjects grading were selected. The estimated comfort indicators represent disaggregated comfort levels for a 5-10 min run.

3. Application of the model on data from real services

In the next phase, acceleration data was systematically collected in a number of selected bus lines and metro. It became obvious that drivers had different behaviors and driving styles. About one tenth of the drivers produced divergent "comfort" levels, like statistical outliers. These "real" data sets were used to analyze ordinary services.

The point of our statistical experiment and the estimated parameters is that we can disaggregate the vehicle movements and analyze the different components' contribution to the ride comfort experience. That is the four selected driver behaviors in our model. The results from such a use of the parametric model is shown by figure 7, where 14 different runs on the same route are shown; a stretch on city trunk-bus line 4 in Stockholm.

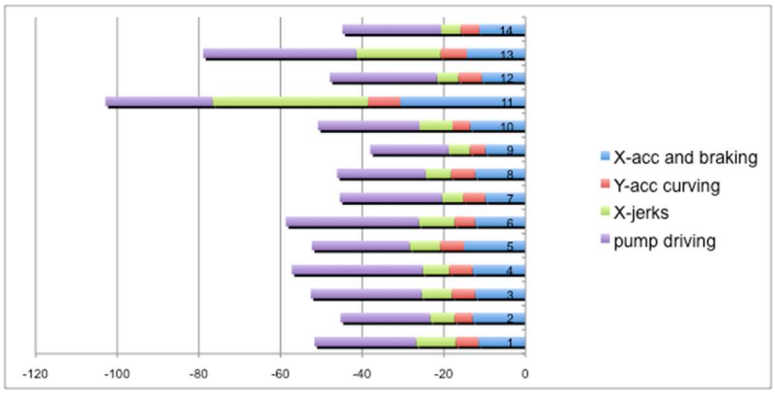


Figure 3 The diagram shows discomfort levels and the contribution from various types of bad driving behavior for 14 trips on part of line 4 Odenplan – Stockholm East Station.

The worst driver style, in trip no.11 (fig. 3), exposes passengers to an unacceptable discomfort (just over 110). Even the second worst driver, in trip no.13, runs significantly worse than average drivers who have discomfort scores around 50. A discomfort score of 100 comes from the level at 100 mm – fully unacceptable – in the questionnaire for runs with test passengers.

The answers from the binary interview question; if test passengers accept a certain test loop, reveal that the acceptance limit is located around 50 (mm). This means that, for the sample from route 4 two runs show entirely unacceptable comfort levels. For run 13, quasi-static braking levels is the most significant reason, while for run 11 hard jerks make the biggest contribution to discomfort.

It should be said that even though the field experiment was made in a bus, the estimated discomfort model have been applied on acceleration data from both regular bus and metro services.

4. Validation experiment in 2016

With the purpose of validating the model from 2009 the following experiment was designed and preformed in winter 2016. In order to validate the model it was decided to repeat the same kind if test as in 2009 but this time with real passengers and real bus lines. After the test the results obtained were compared with the results (the linear regression analysis) from 2009.

The test consisted in two main tasks at the field: recording acceleration data in real bus lines at the same time that the passengers were ask to evaluate the comfort. The acceleration data was again collected in the format of 40 samples each second. The further work was to match these two types of data and look for the relationship as described before. The matching of the data was done using SPSS.

Some modifications of the method were made in order to fulfill requirements that the experiment in regular services required. As the surveys were given to regular passengers, in a real scenario, there is a need of getting a high number of answers because different passengers may be receiving different stimulus inputs; it is necessary to sample far higher numbers of passengers than would be the case in the laboratory. Each passenger who is to be tested has paid for his seat and, in general, does not wish to be interrupted to any great extent. Most are

willing to perform some small task after polite requests, but interference to any large extent is intolerable both to the passenger and to the transport operators.

The field test lasted in 5 following working days. Different types of roads were tested, depending on the assigned bus line. 10 different bus drivers were submitted to the test. These drivers run a total of 29 different rounds and a total number of 398 forms were collected.

In the previous test (2009), the passengers were asked to evaluate each (7 min) run of the bus after it was completed, so they had experienced the entire journey in the bus. However, in the current test, the passengers were boarding and leaving the bus randomly along the bus line. Therefore some assumptions needed to be taken.

Because of the poor reliability of this first assumption, the driver is not driving equally during the entire run. Therefore a new method was developed: The runs of the bus were divided into 10 minutes long fractions. That is to say, every 10 minutes the 4 indicators were obtained. Therefore the passengers had to be clustered into 10 minutes fractions also. The division of the passengers was not exact, because the flow of passengers was continuous. Finally the passengers were sorted to the fraction when they had spent the longest time.

Both acceleration data collection and passenger surveys were successful, the expected results regarding the number of surveys was achieved on time and high percentage of passengers accepted to fill in the survey.

Concerning the reliability of the answers of the passengers the results were not the expected ones. Many passengers did not really understand the aim of the survey and instead of judgment of the journey they were experimenting they graded the comfort, skills and velocity according to their general experience in buses. This was noticed since some of the passengers filled in the whole form in less than 30 second of journey. All of the surveys were taken as relevant even knowing it was not like this.

Regarding the drivers, no "bad drivers" were found. This means that no extreme behaviours could be recorded. That becomes a difficulty concerning the data matching. The linear regression may need a much higher number of samples to be representative if all the values are clustered in a mean range. Despite this, new indicator parameters were estimated and the statistical analysis was performed.

With the goal of validating the model from 2009, the idea was to perform the following analysis:

- Use the linear regression model from the 2009 test to calculate the expected comfort experience with the accelerations recorded and compare the results with the passenger's own grading.

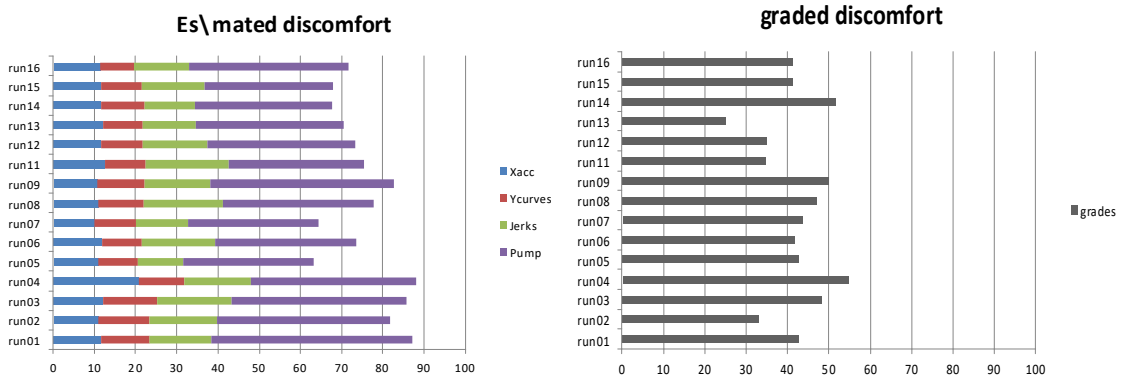


Fig. 4 & 5. Model predicted discomfort levels for 16 runs & How Driving style affects passengers' experienced comfort

Looking at the two graphs obtained, it could be seen that discomfort predicted was higher than the passenger's grades. Comparing the graphs with the results from 2009 the main problem is the pumping indicator.

However these results were not bad at all, it proved what was expected regarding the driving behaviours from the drivers during the test. As there were no extreme "bad drivers" all the results were clustered in a short range. This showed that the model worked in somehow but the coefficients needed to be recalibrated if the accelerometer from the bus would be the detector to be used.

5. Summary and discussion

The following claims and conclusions have been nade:

- The driving style does affect the perceived comfort level in several ways, for example comfort feeling, possibility to read or work, keeping balance and fall accidents as well as travel sickness.
- The problems of poor ride quality are "medium size" in most cases.
- Passengers are affected by jerks, strong braking, uneven speed (so-called "pumping") and hard cornering. Jerks are most often mentioned spontaneously.
- The four indicators developed help quantifying the impact on experienced comfort. They should be of use to design driver assistance tools. No-one would deliberately drive badly if they know that they were doing it, and therefore: better informed drivers will lead to a better ride experience.

Our work shows that driver behaviours matter to passengers. We have used two ways of investigating this; explicit and implicit methods. Explicit means bad driver behaviour that the riders are aware of. This has been seen by complaints, customer satisfaction statistics and in our comfort questionnaire. (These explicit results are not fully reported in this paper.) The statistical experiment can be said to be implicit. We tried to design driving styles so complex that the test riders should not be fully aware of the underlying instructions (about bad driving behaviours) to the test driver.

Passenger satisfaction data, questionnaires about comfort and the experiment with test passengers all support the assumption that ride comfort matters. It also gives a hint of the type of problems that passengers' experience. But it does not tell if the ride comfort level is good enough in regular service. The project assumptions and hypothesis (in brackets) can then be further commented:

1. Heavy accelerations, i.e. high quasi-static levels, reduces comfort. This applies both to start accelerations and braking, but it was found that the highest levels most often occur at braking. Our field experiment shows that people significantly do not accept or dislike high levels.
2. "Jerks are perceived as very uncomfortable. They also affect the ability to maintain balance." Our field experiment showed the highest negative reaction was for jerks, at least of the high magnitude that was used in the experiment.
3. "Recurring sharp cornering with high lateral accelerations to both sides reduces comfort experience and can make some people motion sick." Hard cornering reduced the comfort grading negatively. Regarding travel sickness, a few passengers reported they felt it to some degree after the eight loops in the experiment, but we cannot make conclusions about the distinct reasons.
4. "Uneven driving, sometimes called pumping, decrease comfort experience and can make some people motion sick." Both interviews and the field experiment showed that people don't like uneven driving. It affected the comfort and driver skill ratings negatively. Our estimations show that 3 s period time (1/3 Hz) is worst for discomfort.
5. "Vertical accelerations and vibrations do not reflect the type of ride quality that mainly depends on driving style." This is partly true, but we experienced that motion in different directions correlate. High longitudinal and lateral motions also lead to some vertical motions, which we detected.

An open question is how discomfort real time information can be used. It does not have to be presented to the driver, at least not all the time. Indicators used for driver education may be integrated values for a longer time period. It is also a benefit if indicators are possible to merge with each other. Than summary ride-comfort scores can be presented to the driver or the driving instructor. It can also be recorded and used by the public transport company management. These considerations must be made. It also has to do with the driver's role. Is he mainly a vehicle operator – a bus or metro vehicle driver – or is he a front person in a company selling services? Our ideas and results should be especially helpful in the latter case. By that, drivers are given clear knowledge and public transportation can seriously attract even travellers with high demands while creating professional pride.

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References

[1] Kottenhoff, K., Evaluation of Passenger Train Concepts – Methods and Results of Measuring Travellers' Preferences in Relation to Costs, KTH Traffic & Transport Planning, TRITA-IP FR-99-48 (1999)

[2] Oborne, D., 1978. The ergonomics of passenger comfort, Swansea: Applied Ergonomics.

[3] Oborne, D. & Clarke, M., 1975. Questionnaire surveys of passenger comfort, Swansea: Applied Ergonomics

[4] Wardman, M., Whelan, G., Rolling stock quality improvements and user willingness to pay, ITS working paper 523, University of Leeds, March 1998

[5] Karlsson, J. & Larsson, E., 2010. Passengers' Valuation of Quality in Public Transport with Focus on Comfort, Göteborg: Chalmers University of Technology.

[6] Kottenhoff K. & Lindh C., The value and effects of introducing high standard train and bus concepts in Blekinge, Sweden, Transport Policy, 1995 - Elsevier

[7] Fröidh O., Market effects of regional high-speed trains on the Svealand line, Journal of transport geography, 2005 - Elsevier

[8] Eriksson B., Friberg O., Ride comfort optimization of a city bus, Structural and multidisciplinary optimization, 2000 - Springer

[9] Bonin G., G Cantisani, G Loprencipe, M Sbrolli, Ride quality evaluation: 8 dof vehicle model calibration, 4th International SIIV, 2007 - siiv.net

[10] Xinping, Y., Chaozhong, W., Duafeng, C., and Liqun, P., 2013. Effects of driver's unsafe acceleration behaviors on passengers' comfort for coach buses. ASCE

[11] Sarang, P. S., Sunill B. S., Virandra V. S., Analysis of Driver's Skills from Passenger's Comfort, E&TC, MITCOE, Pune, Maharashtra, India, International Journal of Advanced Research in Computer and Communication Engineering, Vol. 4, Issue 6, June 2015

[12] Castellanos, J. C. & Fruett, F., 2013. Embedded system to evaluate the passenger comfort in public transportation based on dynamical vehicle behavior with user's feedback, Campinas, SP, Brazil: Elsevier, Measurement 47 (2014) 442–451.

[13] Sockhol Transport, SL, 2009

[14] Golding J. F., Motion sickness susceptibility, Department of Psychology, University of Westminster, U.K. Autonomic Neuroscience: Basic and Clinical 129 (2006) 67–76

[15] Turner M. & Griffin M.J., 1999. Motion sickness in public road transport: the effect of driver, route and vehicle, s.l.: ERGONOMICS

[16] ISO2631

[17 Sundström, J., Difficulties to read and write under lateral vibration exposure: contextual studies of train passengers ride comfort, KTH Diva-Portal.org 2006

[18] Albertsson, P. Falkmer T, Is there a pattern in European bus and coach incidents? A literature analysis with special focus on injury causation and injury mechanisms, Accident Analysis & Prevention, 2005 - Elsevier

[19] Berntman M, Holmberg B, Wretstrand A, Bus travel safety-A travel chain perspective, - Paper delivered at the Institute of Transport Studies, Monash University Social Research in Transpor, 2010 - researchgate.net

[20] Strömberg, H.K., Karlsson MA., Comparative effects of eco-driving initiatives aimed at urban bus drivers – Results from a field trial, Transportation Research Part D: Transport and Environment, Volume 22, July 2013, Pages 28–33

[21] Wåhlberg, A, 2005. Short-term effects of training in economical driving: Passenger comfort and driver acceleration behavior, Uppsala: International Journal of Industrial Ergonomics .

[22] Murphey, Milton & Kiliaris, Driver's style classification using jerk analysis, Department of Electrical and Computer Engineering at the University of Michigan-Dearborn, Dearborn, 48128, USA, Computational Intelligence in Vehicles and Vehicular Systems, 2009. CIVVS '09. IEEE Workshop

[23] Kottenhoff, K. & Sundström, J., 2011. Samband mellan körstil och åkkomfort, Stockholm: KTH 2011

[24] Förstberg, J., Ride comfort and motion sickness in tilting trains, TRITA-FKT Report, 2000

A Seated Human Model for Predicting the Coupled Human-Seat Transmissibility Exposed to Fore-Aft Whole-Body Vibration

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Abstract Occupant discomfort, induced by vibration transmitted through a vehicle seat, can be evaluated by measuring vibration on the contact interface of the occupant and seat. In the previous study [14], measuring five contact points of the back-backrest, including center point (ISO 2631-1), was considered as an important factor for assessing occupant comfort in frequencies where seat structure resonances occur. To enhance occupant vibration comfort in the early seat design stage, predicting the dynamic response of the coupled human-seat system on various contact locations is necessary. In this study, a low order seated human body Finite Element (FE) model was developed for predicting vibration transmissibility of the human-seat system in frequencies up to 30 Hz. Thus, the structural resonances of the vehicle seat frame such as fore-aft mode, which lies between 10 to 30 Hz, ware also considered. The human body model was divided into six body segments such as head, upper torso, mid torso, lower torso, thighs, and shanks. These segments were represented with one-dimensional rigid elements, connecting with five individual joints. The human contacts between the human body and seat surfaces, including backrest (six contact points), seat-pan cushion, and feet, were represented with three-translational stiffness and damping elements. Mass of other parts of the human body such as arms, hands, and feet were also included in the model, considering the proportion of mass distribution of the sitting posture. Throughout the optimization process, the parameters of the model were obtained to predict the transmissibilities between the seat base and various locations of the contact surface of the human and seat backrest. To correlate and validate the developed coupled human-seat system model, experiments were conducted to measure the occupied vehicle seat transmissibilities between the vibration platform and contact surfaces of the human and seat. Additionally, the seat structure and human body segments were measured to obtain vibration mode shapes of the human-seat system. The input of the table was generated using statistically uncorrelated independent waveform of tri-axial input vibrations to obtain fore-aft transmissibility. The human-seat system vibration modes were also compared and verified with experiment by calculating MAC (Modal Assurance Criterion) between the human-seat model and the corresponding experiment data. The results showed that two human body vibration modes coupled with foam were observed below 10 Hz, such as fore-aft and vertical movements of the human body. In addition, the coupled human and seat structure fore-aft modes were observed at around 19.9 Hz and 20.5 Hz. Fore-aft transmissibility of the model at various locations of contact provided reasonable correlation with the measured data.

Keywords: Human-seat system, Finite Element Modelling, Transmissibility, Resonance frequency, Mode shape.

1 Introduction

Practical applications to help assessing occupant discomfort, induced by vibration, have been widely studied. Especially, many biodynamic models have been developed to predict the vibration transmitted through vehicle seat for the seat occupant comfort analysis [1-7]. For automotive application, assessing occupant comfort can be better studied when both the human body and the seat structural dynamics are considered. Several studies showed that seat structure has major vibration resonances at frequencies of 10 to 60 Hz [8, 9]. This frequency range is in the region where the seated human body is also highly susceptible to vibration [10-13]. One of quantitative approaches to evaluate comfort of the human-seat system is to measure vibration transmitted to contact surface of the occupant and seat [12]. They suggested five measurement points on backrest, including the center point suggested by ISO 2631-1 [14], should be considered to capture the interaction of the occupant and seat structural dynamics.

Biodynamic models, as one of major tools to predict transmission of vibration through a seat, should be able to reflect the seat structural dynamics at various contact surface points [15]. The model, which can capture the seat structural dynamics, can be applied to assess the occupant comfort by implementing the quantitative evaluation method, particularly developed by [12]. Many researchers developed various types of biodynamic models: lumped-parameter models, multi-body dynamics models, and finite-element models [1-4, 6, 7]. However, most of physical models used to predict vibration comfort were applicable only in frequencies below 10 Hz. The seat structures considered in these models were mostly simplified by assuming the seat to be rigid in $f < 10$ Hz. In addition, some of biodynamic models were represented with a simple rigid mass.

In this study, a low order FE (Finite Element) human-seat model was developed to evaluate the occupant ride comfort by predicting the transmission of vibration of the human-seat system at frequencies up to 30 Hz. This model represented the backrest-back contact with six different locations. In addition, the developed human-seat model also considered the seat structural dynamics and its interaction with the human body model. This model was validated with the measured data through FRF (frequency response function) analysis and by comparing vibration mode shapes using MAC (Modal assurance criterion).

2 Method

To achieve both efficiency and accuracy of predicting vibration transmissibility, a low order FE (Finite Element) model has been developed and described in this section. The model was developed using linear dynamic frequency domain analysis method to predict the transmission of the vibration to the occupant body. The human model was developed using the Altair® HyperMesh® software [16]. The developed model was solved using frequency response analysis available in MSC Nastran [17] to obtain modal modes and transmissibility.

2.1 Model geometry and parameters description

As shown in Fig. 1, the developed human body model represented the 50th percentile male with weight and height of 73kg and 1.73m, respectively. The human body had a sitting posture, leaning on inclined backrest seat

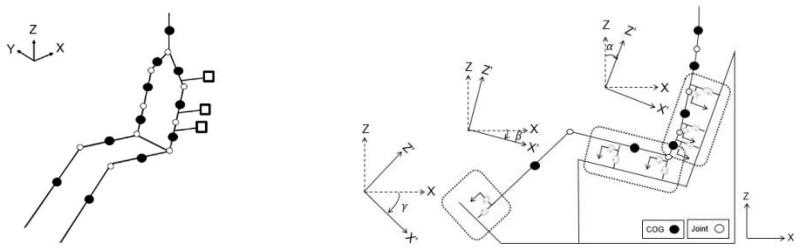


Fig. 1. Geometry of the low order FE seated human body model: (Left) Isometric view, (Right) Side view (Black dot: Location of center of gravity of mass; White dot: Location of joints, Square box: Location of backrest contact outputs)

Table 1. Description of body mass, location of mass, and mass moment of inertia properties

Body Segments	Longitudinal length (mm)	Mass (kg)	Longitudinal CM position (mm)	MOI (x-axis) Sagittal	MOI (y-axis) Transvers	MOI (z-axis) Longitudinal
Head	210.0	5.1	125.0	0.027	0.020	0.030
UPT	171.0	15.6	60.9	0.233	0.198	0.094
MPT	216.0	11.92	97.2	0.129	0.121	0.081
LPT	146.0	8.15	88.4	0.065	0.060	0.053
Thigh	427.0	23.93	177.0	0.462	0.095	0.462
Shank	514.3	8.32	225.4	0.102	0.017	0.097

Table 2. Extraction of human joint parameters

Joint	Stiffness [Nm/rad]	Damping [N ms/rad]
Neck	348.9	6.8
Thoracic	2420	540
Lumbar	2080	540
Pelvis	5730.6	76
Knee	250	104

Table 3. Extraction of human-seat contact parameters

Contact	Stiffness TX [N/m]	Stiffness TZ [N/m]	Damping TX [Ns/m]	Damping TZ [Ns/m]
SBUPR	9943.2	1589.2	112.5	9.3
SBMDL	10666.5	1689.2	112.5	9.3
SBLWR	8653.7	1303.8	550	45
SPRR	6649.2	61632.0	16.7	110.5
SPFRT	663.6	5767.0	16.7	110.5
Feet	2.06e12	5500	100	350

with fixed angle of 20°(α) backward with respect to vertical axis. In addition, the angle between the lower body of the human model and seat-pan also had a fixed inclination angle of 15°(β) with respect to horizontal (fore-aft) axis. The feet were supported by 45°(γ) inclined footrest from the vertical axis. The human body model consisted of six body segments such as head, upper torso, mid torso, lower torso, thighs, and shanks. These segments were represented with one-dimensional rigid elements, connecting with five individual joints. Mass of other parts of the human body such as arms, hands, and feet were also included in the model, considering the proportion of mass distribution of the sitting posture. In addition, inertia properties of the individual segments were estimated based on literatures [18]. They assumed the body segments radii of gyration are proportional to the individual segment lengths. Based on the assumption, the moment of inertia of each model mass was calculated with respect to sagittal, longitudinal. and transvers planes of the body (Table 1). Note that the developed human model was symmetric to the mid-sagittal plane, thus only half of the model (left hand side) parameters were described.

The human joints were represented with single-rotational (around y-axis) stiffness and damping element (revolute joint) (Table 2). Initial assumption of using revolute joints were based on literatures in which the principal resonances occurring during vertical and fore-aft excitation were contributed by the rotational movements of the body in the sagittal plane [6, 19]. In addition, the lateral movement of the body caused by the joint properties were assumed to be negligible. Initial joint parameters were determined based on the model presented in [6].

Contacts between the human body and seat surfaces, which include backrest, seat-pan cushion, and feet, were represented with X and Z translational stiffness and damping elements for each contact (Table 3). Especially, backrest and seat-pan cushion contact interfaces contained number of contact locations: six backrest contacts (two upper (SBUPR), two middle (SBMDL), two lower (SBLWR) torso areas), four seat-pan cushion contacts (two buttocks (SPRR) and two thigh (SPFRT) areas).

Throughout the initial process of the model validation, the joint and contact parameters were adjusted by implementing an optimization tool in MSC.Nastran. This has a capability to optimize parameters of structure, which the optimization algorithms were based on gradient-based optimization method. Objective function was to minimize the difference between the predicted and measured transmissibilities at individual contact locations for narrow frequency band with interval of 1.5 Hz. However, using an optimization tool had a limitation on the quality of accuracy due to the large number of model parameters. Therefore, further optimization was performed by studying the effect of varying individual baseline values by multiplying with various coefficients (e.g. 0.1, 0.5, 1.0, 2.0, and 4.0). Based on the results obtained from parameter variation study, the optimized transmissibilities at individual locations of the model were achieved.

The automotive foam was modelled with three-dimensional (3D) element using isotropic elastic linear material. The geometry of the foam was modelled with a rectangular shape, assuming the effect of the slight differences of the foam thickness due to the foam contour at different contact points were negligible. The density of the material was set to be almost zero, instead, the concentrated mass of one-dimensional (1D) element was

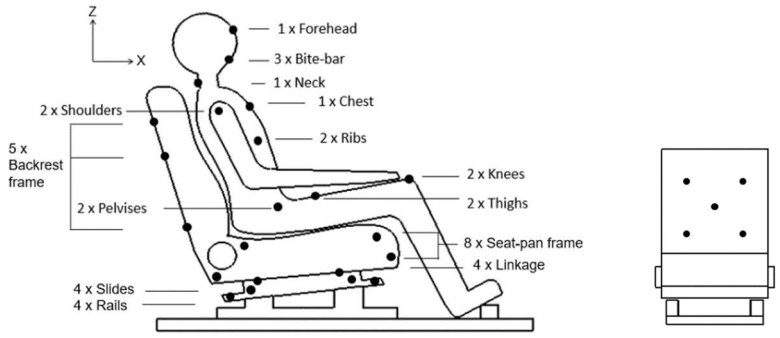


Fig. 2. Measurement locations on the occupant body (sixteen locations), vehicle seat structure (twenty-five locations) and backrest contact interface (five locations) of the human and seat. (Black dots: Locations of accelerometers)

utilized and connected to seat structure independently. The concentrated mass represented the actual foam mass, whereas 3D foam presented other properties such as Young's modulus (0.7MPa for backrest foam and 1.3MPa for seat-pan foam), Poisson's ratio (0.45), and structural damping (0.12) properties of the foam. The reason for modelling 3D foam with very low density was to avoid unwanted local modes created by foam 3D elements in frequencies up to 30 Hz. Young's modulus and Poisson's ratio of the linear elastic material foam was estimated based on the uniaxial compression and shear test data presented in [20]. Note that the vehicle seat structure FE model was provided from a seat company, which the vibration responses of the unoccupied seat structure was optimized and validated with the measured data at frequencies up to 30 Hz.

2.2 Measurement for validation

To estimate the stiffness and damping parameters of the human model (e.g. joints and contacts), transmissibilities were measured at various locations of contact interface (backrest) between subjects and a vehicle seat. In addition, vibration modes of the human-seat system were identified in frequencies up to 30 Hz by measuring additional locations on both human body segments and the occupied seat structure (Fig. 2). The vehicle seat used in the measurement was same as the one implemented in developing the human body model. The human-seat system was supported on a rigid vibration table, which generates vibration in three-translational independent directions. The human-seat system was exposed to the uncorrelated Gaussian random vibration in fore-aft, lateral, and vertical directions. The nominally flat constant-broadband acceleration spectra of $1 m/s^2$ r.m.s in frequency range of 0.5-100 Hz were used for the duration of 60 seconds in each individual axis. Output and input accelerations in x, y and z directions were obtained using PCB 356A03/019 triaxial accelerometers with a mass of 1 gram. The data were obtained using LMS Test.Lab v14 software package and LMS SCADAS Mobile front-end software for all conditions [21].

Three male subjects with the body size of approximately 50th percentile were participated in the measurement (Table 4). The subjects were informed of the purpose, method, procedure, and risks of the experiment and gave their consent prior to the experiment. All subjects were instructed to sit on a vehicle seat, which the posture of the occupant and the seat inclinations were positioned same as described in the model (Fig. 1). Subjects were asked to stare at a point marked on a wall located in straight ahead. Accelerations were recorded in time-domain and frequency response function was calculated between the input and output signals, which had a sample frequency of 256 Hz and frequency resolution of 0.5 Hz with data averaged for 60 times with 50 % overlap.

Table 4. Three subject characteristics in terms of height and weight

	Height (m)	Weight (kg)
Subject 1	172	80
Subject 2	171	78
Subject 3	173	73

Frequency response function (FRF) between the vibration table and contact interface were calculated using cross-spectral density function method. FRF is derived from the complex ratio of cross-spectral density of input and output acceleration to the power spectral density of input acceleration as shown in Equation (1).

$$H_{kl}(f) = \frac{G_{i_k o_l}(f)}{G_{i_k i_l}(f)}; \quad k = x, y, z \text{ and } l = x, y, z \tag{1}$$

Where $G_{i_k o_k}(f)$ is the cross-spectral density of the input and output, and $G_{i_k i_k}(f)$ is the power spectral density of the input.

The fore-aft vibration mode shape of the occupied seat structure was also extracted from the measured data using LMS Test.Lab software [21]. The extracted fore-aft vibration mode was further analyzed using MAC (Modal Assurance Criterion) value, defined by Equation (2), to compare the similarities of the arbitrary complex vector $\emptyset_1$ and $\emptyset_2$ from two set of mode shapes. The MAC take a value between 0 and 1. When two vibration mode shapes are closely correlated, it becomes close to the value of 1.

$$MAC_{(1,2)} = \frac{(\{\emptyset_1\}^T\{\emptyset_2\})^2}{(\{\emptyset_1\}^T\{\emptyset_1\})(\{\emptyset_2\}^T\{\emptyset_2\})} \tag{2}$$

The MAC values were calculated between the predicted mode shapes and the measured mode shapes in this study to check the correlation.

3 Results

Contact transmissibilities (magnitudes and phases) obtained from both the human-seat model and the measurement were compared in f < 30 Hz. The obtained vibration mode shapes were also compared using MAC.

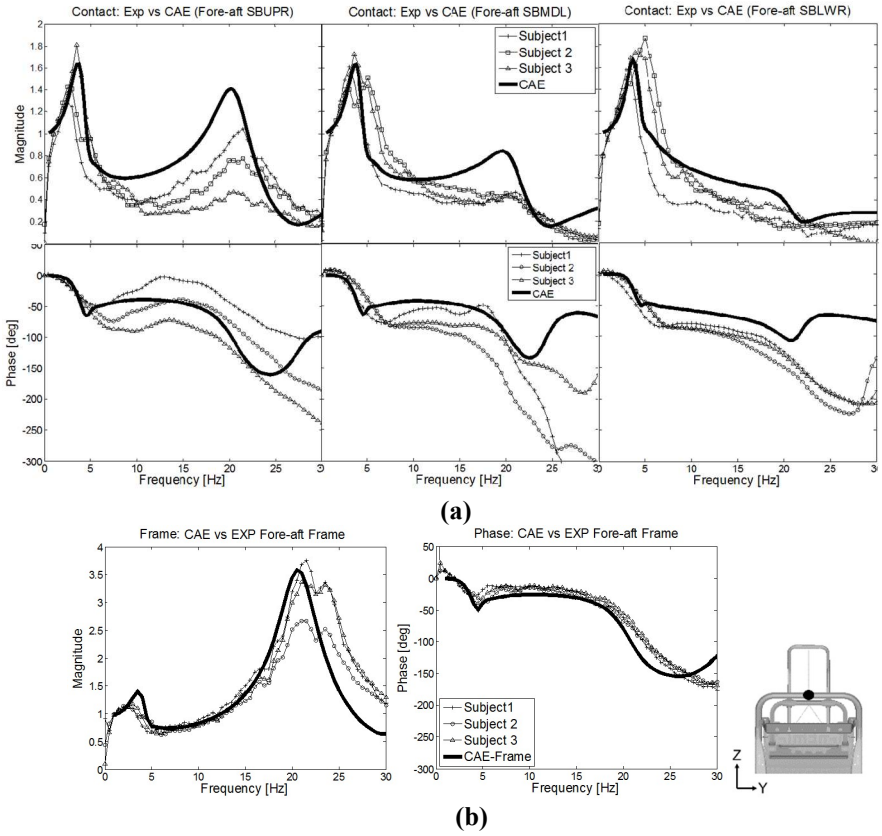


Fig. 3. FRF (Transmissibility magnitude and phase) comparisons of the model and measured data obtained from (a) the contact interface between the occupant back and backrest at three different locations (SBUPR: Backrest upper-left; SBMDL: Backrest middle (measured center); SBLWR: Backrest lower-left); (b) FRFs of seat frame obtained at the upper center frame (Black dot)

3.1 Validation of the model transmissibility with measured data

The magnitudes and phases of the simulated fore-aft transmissibility of the developed model were compared to the corresponding measured values at frequencies up to 30 Hz (Fig. 3(a)). The transmissibilities obtained at three different locations of a backrest-back contact were shown in the order of upper (SBUPR), middle (SBMDL), and lower (SBLWR) locations. In addition, the seat frame response was also compared at the centre location of the backrest frame (Fig. 3(b)). The prediction of transmissibilities were in good agreement with the measured data. For all three contact responses, the phases showed some discrepancies at frequencies greater than 20 Hz.

3.2 Modal mode shape

Two major human body vibration modes (coupled with foam) were obtained in the human-seat model at frequencies below 10 Hz (Fig. 4). The first vibration mode showed the fore-aft motion of the human body. This fore-aft body mode deformed the backrest foam in axial direction and the seat-pan foam in shear direction (Figure 4 (a)). The second vibration mode represented the vertical motion of the entire body moving up and down. This body vibration mode caused backrest foam to be deformed in shear direction, whereas seat-pan foam was deformed in axial direction (Figure 4 (b)). Additionally, two fore-aft vibration modes of the seat structure were observed at 19.9 Hz and 20.5 Hz. These fore-aft motions of the seat structure caused the upper part of the human body moving out of phase with each other (Figure 4 (c) and (d)). MAC values of the human body mode shapes were calculated with the subject 1 measured data. In addition, MAC values were calculated among measured subjects to check the accuracy of the obtained vibration modes (Table 5).

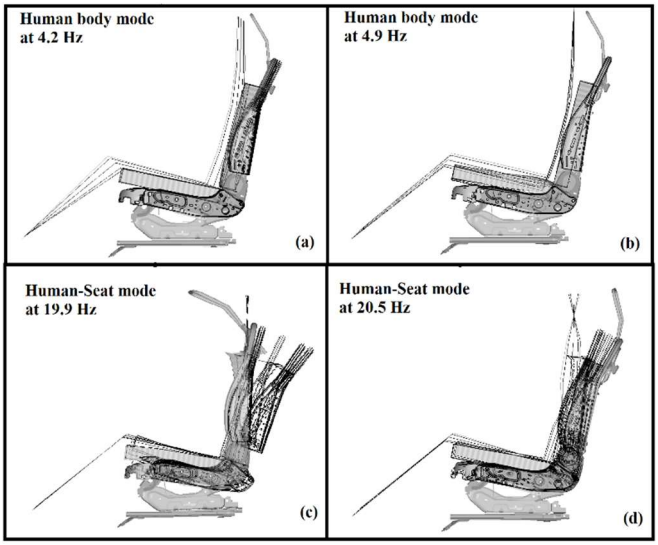


Fig. 4. Three vibration mode shapes of the human-seat model: (a) and (b) indicate human body modes of fore-aft and vertical mode shapes found at f < 10 Hz. (c) and (d) indicates the coupled human-seat mode found at f > 10 Hz.

Table 5. MAC values comparing the similarities of individual vibration mode shapes between the model and the measurement (subject 1) – First row; and MAC values calculated and averaged by comparing the individual subjects – Second row.

MAC	Mode 1 (4.2 Hz) (human body fore-aft)	Mode 2 (4.9 Hz) (human body vertical)	Mode 3 (19.9 Hz) (1st human-seat backrest frame fore-aft)	Mode 4 (20.5 Hz) (2nd human-seat backrest frame fore-aft)
Subject 1	0.72	0.74	0.98	0.84
Calculated among measured subjects	0.63	0.81	0.99	0.78

4 Discussion

The compared transmissibilities and vibration modes showed good level of correlation between the model and measured transmissibilities. Although transmissibilities obtained from the model showed some discrepancies, the overall trends were shown to be similar to those of the measured data. In the measured data, at around 20 Hz where the fore-aft seat structural resonance occurred, the transmissibility of the backrest varied with the vertical locations on the backrest. The measured results showed the clear changes in transmissibilities such that as the location changed from the upper to the lower area, the magnitudes were reduced at f > 10 Hz. Likewise, the similar behavior was observed in the human-seat model. At around 20 Hz, the human-seat system was largely dependent on the backrest dynamic performance. However, the human body dynamics also had a considerably large influence on transmissibility, evidenced by the subject 3. The change in transmissibility with respect to vertical locations for subject 3 was shown to be insignificant, compared to other two subjects. Thus, some discrepancies shown in magnitude may be addressed with the following reason. The number of subjects (three subjects) participated in the measurement was relatively small. The inter-subject variability of the measurement, particularly at the upper location, was shown to be large at high frequencies (f > 15 Hz). This was closely relevant to the subject sitting (leaning) posture. It was observed that subject 3 was sitting with some force against the upper torso by straightening arms when the hands were positioned on the lap. This showed that the occupant ride comfort evaluated by physical measurement could lead to some errors, which may underestimate the actual vibration transmission. Discrepancies shown in phase at above 20 Hz were due to the 2nd fore-aft human-seat frame mode obtained at 20.5 Hz in the human-seat model (Fig. 4 (d)). In the measurement, the 2nd fore-aft human-seat peak was also found at around 22 Hz (Fig. 3. (b)). However, the mode obtained in the model showed more distinctive human body motion moving out of phase with the seat structure. This human body mode attributed to the phase change at around 20 Hz. In addition, as the two fore-aft modes were very closely located (19.9 Hz and 20.5 Hz), two clear peaks were unable to be captured in the model contact transmissibility (Fig. 3 (b)). The discrepancies of the phase might be further improved by comparing the model with measured data obtained by attaching the accelerometer on the human body side, not on the seat surface. For the middle contact point, although the location of the measurement was different from that of the model, the transmissibilities measured on the upper-left and upper-right, and on the lower-left and lower-right sides were very similar to each other. Thus, the mid location was compared by assuming the transmissibility measured at mid location was the average of the left and right side of the mid contact points.

Contact parameters, which represented the human soft tissue, had a large influence on the magnitude at fore-aft resonance frequency of 19.9 Hz. As can be seen in Table 3, the stiffness obtained in the mid contact location was higher than other two locations. This result was reasonable as the occupant was shown to have relatively large contact force around the mid torso area [22]. The magnitudes at the resonance of 4 Hz were relatively less influenced by the backrest contact damping parameters. Further improvement at both magnitude and phase could be achieved by adjusting damping parameters at backrest contacts. Due to the complexity of the human body, several assumptions were made to model the parameters more effectively. For joints, any directions other than y-axis revolute joint were assumed to have negligible influence on the fore-aft whole-body vibration (WBV). In addition, for contact parameters, the deformation occurred in shear directions (e.g. vertical and lateral directions for backrest contact) were assumed to be similar to each other at each individual contact location.

The human vibration modes found in this study were consistent with the modes found in literatures. The fore-aft and vertical body modes found at 4.2Hz and 4.9 Hz were corresponding to [8, 23, 24], which the peaks under fore-aft WBV were found in the range of 4-5 Hz, 2.7-5.4 Hz and 4-5 Hz. The individual vibration mode shapes obtained from the human model seem to be reasonable, evidenced by MAC values presented in Table 5. As compared to MAC values calculated among measured three subjects (e.g. range between 0.7 and 0.8), the MAC values calculated between the model and measured subject 1 were shown to have a reasonable correlation. Considering the different individual body characteristics (although chosen to be 50th percentile) such as mass, and soft tissue distribution over body, MAC value of 0.7-0.8 among measured subjects were to be a relatively good achievement. The model developed in this study considered a particular type of vehicle seat with different foam properties and different inclination angles as opposed to studies presented in many literatures. Therefore, to further validate the current human model, additional study on vibration response of the current human model under rigid seat condition would be recommended. In addition, the current model may require further validation with a different vehicle FE seat model, which has a different foam characteristics and structural dynamics. Further improvement of the model may be achieved through the suggested validation process.

5 Conclusion

This paper presented a newly developed low order FE human model combined with a FE vehicle seat model. The human-seat model was developed to evaluate the occupant ride comfort by predicting vibration transmission of the occupant-seat system under fore-aft whole-body vibration at various contact. The model showed a capability of reflecting the effects of the seat structural dynamics, which can be used as a tool to assess the discomfort induced by vibration in frequencies up to 30 Hz.

References

1. Kim, S.K., White, S. W., Bajaj, A. K., Davies, P., 2003. Simplified models of the vibration of mannequins in car seats. Journal of Sound and Vibration, 264(1), 49-90.
2. Kato, K., Kitazaki, S., Tobata, H., 2004. Prediction of Seat Vibration with a Seated Human Subject Using a Substructure Synthesis Method. SAE International, 2004-01-0371.
3. Stein, G.J., Mucka, P., Chmurny, P., 2007. Measurement and modelling of x-direction apparent mass of the seated human body-cushioned seat system. J Biomech, 40(7), 1493-503.
4. Liang, C.C., Chiang, C.F., 2008. Modeling of a Seated Human Body Exposed to Vertical Vibrations in Various Automotive Postures. Industrial Health, 46(2), 125-137.
5. Qiu, Y., Griffin, M.J., 2011. Modelling the fore-and-aft apparent mass of the human body and the transmissibility of seat backrests. Vehicle System Dynamics, 49(5), 703-722.
6. Liu, C., Qiu, Y., Griffin, M.J., 2015. Finite element modelling of human-seat interactions: vertical in-line and fore-and-aft cross-axis apparent mass when sitting on a rigid seat without backrest and exposed to vertical vibration. Ergonomics, 1-13.
7. Zhang, X., Qiu, Y., Griffin, M.J., 2015. Developing a simplified finite element model of a car seat with occupant for predicting vibration transmissibility in the vertical direction. Ergonomics, 1-12.
8. Qiu, Y., Griffin, M.J., 2003. Transmission of fore–aft vibration to a car seat using field tests and laboratory simulation. Journal of Sound and Vibration, 264(1), 135-155.
9. Lo, L., Fard, M., Subic, A., Reza, J., 2013. Structural dynamic characterization of a vehicle seat coupled with human occupant. Journal of Sound and Vibration, 332(4), 1141-1152.
10. Griffin, M.J., 1990. Handbook of human vibration. Academic press, (London: Academic Press Limited).
11. Fard, M., Lo, L., Subic, A., Jazar, R., 2014. Effects of seat structural dynamics on current ride comfort criteria. Ergonomics, 57(10), 1549-1561.
12. Ittianuwat, R., Fard, M., Kato, K., 2016. Evaluation of Seatback Vibration Based on ISO 2631-1 (1997) Standard Method: The Influence of Vehicle Seat Structural Resonance. Ergonomics, 1-15.
13. Kim, E., Fard, M, Kato, K., 2016. Characterisation of the human-seat coupling in response to vibration. Ergonomics, 1-16.
14. Interantional Organisation for Standardisation, 1997. Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements. ISO 2631-1.
15. Siefert, A., 2016. Occupant Vibrations - A Challenge for Seat Development. SAE Technical Papers, 2016-April(April).
16. Alrair Computing, 1997. HyperMesh Reference Manual -: Version 2.1. Altair Computing, Incorporated.
17. MacNeal-Schwendler Corporation, 1985. MSC/NASTRAN Handbook for Linear Analysis., Los Angeles, California: MacNeal-Schwendler Corporation.
18. De Leva, P., 1996. Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. Journal of Biomechanics, 29(9), 1223-1230.
19. Matsumoto, Y., Griffin, M.J., 2001. Modelling the dynamic mechanisms associated with the principal resonance of the seated human body. Clinical Biomechanics, 16, Supplement 1(0), S31-S44.
20. Grujicic, M., Pandurangan, B., Arakere, G., Bell, W. C., He, T., Xie, X., 2009. Seat-cushion and soft-tissue material modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants. Materials & Design, 30(10), 4273-4285.
21. Van der Auweraer, H., 2001. Structural dynamics modelling using modal analysis: applications, trends and challenges. in Proceedings of the 2001 IEEE Instrumentation and Measurement Technology Conference. Budapest, Hungary.
22. Makhsous, M., Hendrix, R., Crowther, Z., Nam, E., Lin, F., 2005. Reducing whole-body vibration and musculoskeletal injury with a new car seat design. Ergonomics, 48(9), 1183-1199.
23. Mandapuram, S.C., Rakheja, S., Ma, S., Demont, R.G., Boileau, P.E., 2005. Influence of Back Support Conditions on the Apparent Mass of Seated Occupants under Horizontal Vibration. Industrial Health, 43(3), 421-435.
24. Abdul Jalil, N.A., Griffin, M.J., 2007. Fore-and-aft transmissibility of backrests: Variation with height above the seat surface and non-linearity. Journal of Sound and Vibration, 299(1-2), 109-122.

An effective Multibody and Genetic Algorithm approach to active tyre-suspension-seat system design

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Abstract The factors contributing to the arousal of the feeling of comfort perceived by passengers travelling on a vehicle are multiple and subjectively variable. In a strictly vibrational field, however, this feeling can be rigorously made dependent on the tyre-suspension-seat dynamic system, driveline and engine vibrations. Over the years, many different criteria and models have been developed to enable the optimal estimation of the design parameters for these systems. It is widely accepted that acceleration and its variation are the most detrimental parameters that impact the physical comfort of passengers. In conventional *passive suspension* systems, the spring-damper characteristics may be adjusted to emphasise only one of several conflicting objectives, such as passenger comfort, road holding, and suspension deflection. In *active suspension* systems, on the other hand, the feedback-controller actuator assembly allows the designer to balance these objectives in a more efficient manner. Some limitations of this approach are related to the extremely wide spectrum of magnitude and frequency of external forces that the tyre-suspension-seat system must be able to control and mitigate. The numerous models and systems of optimisation that have been developed do not generally consider time exposure limits established by unification agencies and road authorities. This paper presents an active tyre-suspension-seat system control for passenger cars, utilising both a non-linear multibody model and Genetic Algorithm (GA) controls. The developed active tyre-suspension-seat system control also allows various time exposure limits and an active damping element to be considered. The minimisation of seat acceleration in the entire frequency spectrum has been obtained by considering an active control and passive mechanical parameters concurrently as design variables, using 3 degrees-of-freedom (DoF) multibody model of a quarter car body and wheel assembly. Road Roughness is used to determine vertical component acceleration, treated as the input variable in the GA control. The results of simulations and experimental data drawn from a case study verified that the proposed active system is very effective at isolating passengers from vibration.

Keywords: Optimal acceleration; Seat stiffness; Genetic algorithm; Vehicle; Vibrations.

1 Introduction

Ride comfort strongly depends on the level of in-vehicle vibration experienced, induced principally by road roughness. The International Roughness Index (IRI) is the most commonly employed measure for describing road roughness, while the ISO 2631-1 standard defines how to quantify human whole-body vibration (WBV) experienced by the driver and passengers during the ride, in relation to health and comfort. The IRI is defined by means of a quarter car model. The quarter car model was introduced by Karamihas and Sayers in 1996 [1], and has become the most widely used numerical model adopted by researchers and regulatory bodies ever since [2-4].

The vibration due to road roughness that is transmitted to passengers can be evaluated principally by measuring acceleration on the seat at different frequencies, whereas acceleration intensity can only be assessed and

optimised, but can never be completely eliminated in the entire frequency range.
Optimal control theory has predominantly been applied in the past to determine feedback gains for active suspension systems [5, 7], but also for many other systems [8-10]. Numerical optimisation methods have also been applied to passive suspension design, where the mechanical parameters (spring and damping values) are the design variables [11].
In the literature, however, there is no shared method which considers the time exposure limits established by unification agencies in the optimisation process. Thus, the maximum acceleration intensity values in the existing active suspension systems are usually minimised irrespective of the vibration duration. Higher acceleration intensity values are only accepted in order to optimise road holding and/or suspension deflection. However, an accurate adjustment of the active suspension system cannot disregard the estimate of the vibration duration perceived by the human body.
In this paper, an active tyre-suspension-seat system control for passenger cars that uses both active Genetic Algorithm (GA) control and a non-linear multibody model is introduced. A 3 degrees-of-freedom (DoF) multi-body model of a quarter car body and wheel assembly is used in an active control and passive mechanical parameters concurrently as design variables, to optimise seat acceleration in the entire frequency spectrum, as recently suggested by Bestle [12] and Schiehlen [13]. Seat vertical acceleration is used as a parameter in order to evaluate WBV and, thus, also passenger comfort. Among the control system also considers time exposure limits established by unification agencies and road authorities.
A multibody model places road roughness, vehicle speeds, suspension values of elasticity, damping, and inertial and seat vertical displacement and acceleration in relation. The use of parametric suspension 3D models allows the exact determination of variability in inertia and structural values, creating an interactive model that is applicable to a wide range of vehicles.
The paper is divided into three main sections. Section 1 defines the tyre-suspension-seat dynamic model and the GA control system, and describes their validation using experimental measures. Section 2 deals with the optimisation problem and genetic algorithm procedure, and discusses issues regarding the analysis, design results and their possible interpretations. Final considerations and conclusions are drawn in Section 3.

2 Active tyre-suspension-seat model

By viewing road roughness as an acceleration input the effect of travel speed on seat displacement and acceleration can be studied and optimized with a GA control of an equivalent non linear multibody model. The schematic representation of the quarter car multibody model with the 3 DoF multibody model adopted in this study can be seen in Fig. 1a.

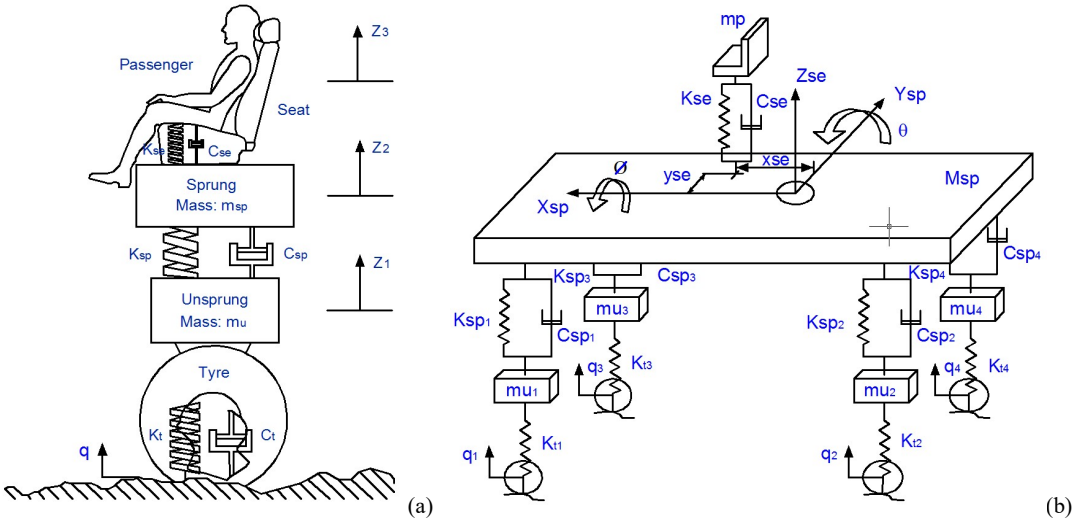


Fig.1. (a) 3 DoF multibody model of a quarter car body; (b) 8 DoF multibody model of entire car.

A 3 DoF multibody model was selected for the analysis of a quarter car body vehicle dynamics, instead of a more detailed 8 DoF model (Fig. 1b) which would also allow longitudinal and transversal load displacement to be considered. The complex calculation appears to be unnecessary for the most frequent applications, since the 8 DoF model provides substantially different values from the 3 DoF model only in cases of considerable longitudinal and transversal load displacement [14].
Table 1 outlines the design variables considered for the model, their initial values, and the range of variation. The initial values correspond to those of a medium-sized sedan for which the experimental tests are available to validate the model. The variability was set in such a way that most of the medium-sized vehicles currently on the market were included in the study.
The developed 3 DoF multibody model can be applied to optimise all vehicles designated for the transport of people, the only exception being modern heavy vehicles, since these may exhibit features such as additional suspension between the chassis and the cab.

Table 1. Design variable: initial values and variation range.

	m_u [kg]	m_{sp} [kg]	m_p [kg]	k_t [kN/m]	c_t [Ns/m]	k_{sp} [kN/m]	c_{sp} [Ns/m]	k_{se} [kN/m]	c_{se} [Ns/m]
Initial value	25	250	80	100	800	25	2150	4	1500
Upper bound	25	300	80	100	800	40	2500	6.5	3000
Lower bound	25	230	80	100	800	10	1800	3	1000

The equations of motion of the multibody model place road roughness, vehicle speeds, suspension values of elasticity, damping, and inertial and seat vertical displacement and acceleration in relation. The equations of motion (in matrix form) of the model are expressed by:

$$[\mathbf{M}]\{\ddot{\boldsymbol{z}}\} + [\mathbf{C}]\{\dot{\boldsymbol{z}}\} + [\mathbf{K}]\{\boldsymbol{z}\} = \{f(t)\} \tag{1}$$

where $[\mathbf{M}]$, $[\mathbf{C}]$ and $[\mathbf{K}]$ are the mass, damping and stiffness matrices, respectively.
The initial mass properties of the system used to validate the model are defined by: the seat-person mass m_p= 80 kg, the car-body sprung mass m_{sp}= 250 kg, and the unsprung mass m_u= 25 kg. An active element foresees a force proportional to the absolute vertical velocity between sprung mass and unsprung mass. This device, characterised by proportionality constants C_{sp}, is known as skyhook dampers, and is more effective in reducing car body motions than passive dampers [13]. The forcing function $\{f(t)\}$ depends on the spring-damper model of the tyre, with k_t= 100,000 N/m and c_t = 800 N·s/m, and the road disturbance ($q(t)$). Fig. 2 shows the sinusoidal shape of the road profile characterised by height h = 0.05 m and length l.

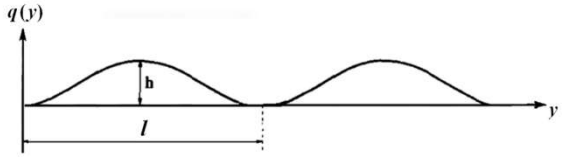


Fig.2. Road surface profile.

In dynamic equations road disturbance is given by:

$$q(t) = \frac{h}{2}(1 - \cos(\omega t)) \tag{2}$$

where the forcing frequency is given by:

$$\omega = \frac{2\pi \mathrm{V}}{l} \tag{3}$$

and where V is the vehicle velocity. The remaining six unknown parameters comprise the set of design variables:

$$\{x\} = \{k_t, C_t, k_{sp}, C_{sp}, k_{se}, C_{se}\}^T \tag{4}$$

As previously stated, seat acceleration is considered to be the most detrimental parameter that impacts the physical comfort of passengers. This is expressed in an objective function as:

$$\min \int_0^T \frac{|\ddot{z}_3(t)|}{|\ddot{q}(t)|} dt \tag{5}$$

where T is the time interval analysed.
Specifically, we are interested in finding the values of the design variables that minimise the ratio of seat acceleration to the input acceleration in the time interval T, throughout the forcing frequency range ($0 \div \omega_{max}$). The spectrum of the forcing frequency can be considered dimensionless as a function of the first frequency of the system itself:

$$\lambda = \frac{\omega}{\omega_{first}} \tag{6}$$

and can be linked to the speed of the vehicle and to the irregularities of the road surface. In particular, the values of $q(t)$ are easily linked to the power spectrum IRI of the shape represented in Fig. 3 [15-16].

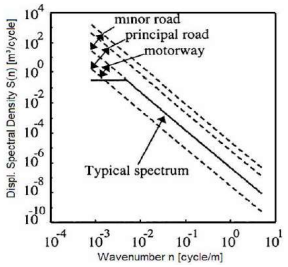


Fig.3. Power spectrum for different road surface.

The constraints during optimisation represent the required road-holding ability and suspension working space. For the case studied, these constraints can be expressed as:

$$|q(t) - z_1(t)| - 0.051\ m \leq 0 \tag{7}$$

$$|z_2(t) - z_1(t)| - 0.125\ m \leq 0 \tag{8}$$

In particular, the equation (7) allows the road-holding ability or safety to be checked constraining tyre compression, while the equation (8) allows the suspension working space to be checked constraining the excursion of suspension (Fig. 4).

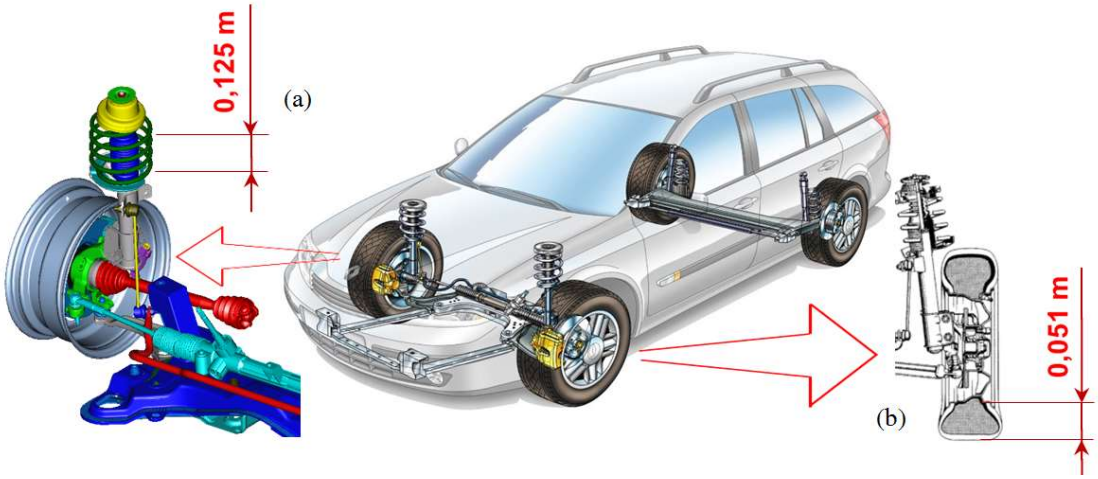


Fig.4. Constraints: (a) suspension working space; (b) road-holding ability or safety.

2.1 Experimental validation

The precision of the 3 DoF multibody model was evaluated by comparison with the experimental data. In particular the seat vertical acceleration was measured by passing over a crossbar with a height h= 0.05 m and length l=0.05m (Fig. 5) at velocity V_1= = 27 km/h ± 1 km/h e V_2= 40 km/h ± 2 km/h in a vehicle for which the values of the sprung and unstrung mass and of the design variables are reported in the first row of Tab. 1.



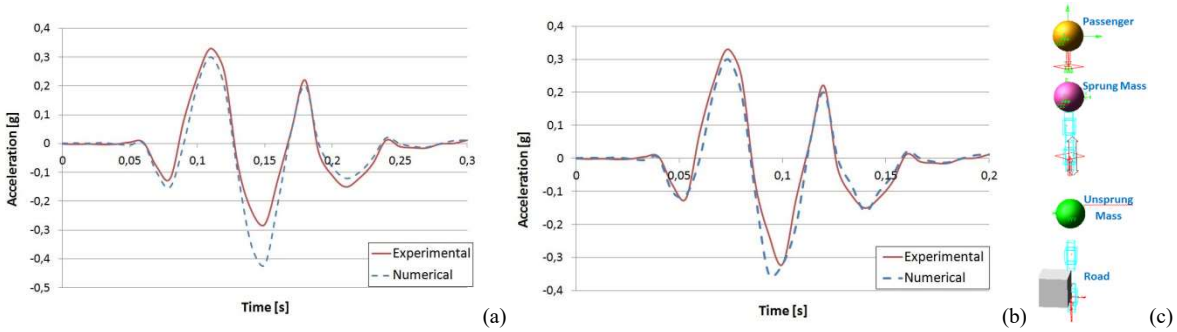
(a) (b)

Fig. 5. (a) Crossing the crossbar; (b) accelerometers on the seat.

The values of height h= 0.05 m and length l=0.05 m correspond, in the numerical multibody model, to the following forcing function:

$$q_{1,2}(t) = \frac{0.05}{2}\left(1 - \cos\left(\frac{2\,\pi\,V_{1,2}}{2.5*0.05}\,t\right)\right) \tag{9}$$

where 2.5 is the factor of correction for transforming the rectangular input into a sinusoidal shape; V_1= 27 km/h ± 1 km/h e V_2= 40 km/h ± 2 km/h. In Fig. 6 the experimental and numerical seat vertical acceleration are compared. The results confirm the appropriateness of the numerical model.



(a) (b) (c)

Fig. 6. (a) Numerical and experimental seat acceleration measures in cross-beam at V_1=27 km/h e (b) V_2= 40 km/h; (c) multibody model with commercial code MSC ADAMS.

2.2 Genetic algorithm optimization procedure

The Goldberg [17] and Haftka and Gurdal [18] genetic algorithm optimization procedure has been implemented to optimize seat vertical acceleration. The GA for optimization starts from an initial set, or first generation, of randomly chosen designs with uniform probability distribution. The population of each generation will have feasible design variables in terms of their allowable ranges. Each design is represented by a finite-length binary string that consists of smaller strings that decode to a value for each design variable. The six design variables strings are taken to have 6 binary sites so that there are $2^6 = 64$ possibilities for each variable and $(2^6)^6 = 6.9 \times 10^{10}$ possible designs. That is, the design variables only take on values from a discrete set.

An initial population of solutions is created by using random samples. The population is then coded into chromosomes, a binary representation of a solution (consisting of the components of the decision variables known as genes in the genetic algorithm).

The whole population of chromosomes represents a generation. An evaluation function rates solutions in terms

of their fitness. Here, fitness is a numerical value describing the probability for a solution (genome) to survive and reproduce. Only a portion of the population (survivors or solutions with higher fitness values) is selected for creating a new population. This new population is created by using a crossover operator. Crossover is a procedure for exchanging pieces of choromosome data with one another. Crossover allows genes that generate good fitness to be preserved and enlarged in a new generation of the population. Mutation is a genetic operator and it randomly flips the bits of an offspring's genotype. This is equivalent to perturbing the mated population stochastically. Mutation prevents the population from homogenizing in a particular set of genes such that any gene in a generation has a certain probability of being mutated in future generations. The crossover rate and mutation rate are the proportion of the chromosomes involved in crossover or mutation with respect to the whole population. The new population is being mixed up to bring some new information into this set of genes, and this needs to happen in a well-balanced way. Once the new generation is created, the aforementioned steps are repeated until some convergence criteria are satisfied, such as running time or fitness.

To implement the genetic algorithm for the optimum suspension design problem, we set the required precision to be zeroth decimal place for each design variable. The domain of variable k_{sp}, has length 30000. The precision requirement implies that the range [10000; 30000] needs to be divided into at least 30000 equal size ranges. This means that 15 bits are required for the first part of the gene: $2^{14}=16384 < 30000 < 2^{15}=32768$. The domain of variable c_{sp} has length 7000. The precision requirement implies that the range [1800; 2500] should be divided into at least 7000 equal size ranges. Hence 13 bits are required as the second part of the gene. Similarly, 12 bits should be assigned to k_{se} and 11 bits should be assigned to c_{se}.

According to Table 1 minimizing the objective function using only four design variables (k_{sp}, c_{sp}, k_{se} and c_{se}), 51 bits in all chromosomes are initialized randomly. During the evaluation phase each chromosome is decoded and the parameter value calculated for the objective function. Some chromosomes are better in terms of reducing the value of objective function than others, and these are then given more opportunities (large weights) to be involved in producing the next generation. The individual solution in the new generation is either the same as some solution in present generation or produced by crossover or mutation. Crossover is done by exchanging the same segment of two chromosomes, say, the last 10 bits, while mutation is done by changing a bit in a chromosome from 0 to 1 or from 1 to 0. After the new generation is obtained, the previous steps are repeated until convergence criterion is met. In general, lower values of the objective function will be achieved through iteration of generations. The best chromosome corresponds to the minimum objective function.

The minimum objective function was weighted according to the values of table 2 (World Health Organization) to take into account the time exposure limits. In this way the time interval analysed (T) becomes a new design variable in GA optimization procedure.

Table 2. Vibration exposure table.

Vibration magnitude m/s²	15m	30m	1h	2h	3h	4h	5h	6h	8h
30	450	900							
25	315	625	1250						
20	200	400	800						
19	180	360	720	1450					
18	160	325	650	1300					
17	145	290	580	1150					
16	130	255	510	1000					
15	115	225	450	900	1350				
14	98	195	390	785	1200				
13	85	170	340	675	1000	1350			
12	72	145	290	575	865	1150	1450		
11	61	120	240	485	725	970	1200	1450	
10	50	100	200	400	600	800	1000	1200	
9	41	81	160	325	485	650	810	970	1300
8	32	64	130	255	385	510	640	770	1000
7	25	49	98	195	295	390	490	590	785
6	18	36	72	145	215	290	360	430	575
5.5	15	30	61	120	180	240	305	365	485
5	13	25	50	100	150	200	250	300	400
4.5	10	20	41	81	120	160	205	245	325
4	8	16	32	64	98	130	160	190	255
3.5	6	12	25	49	74	98	125	145	195
3	5	9	18	36	54	72	90	110	145
2.5	3	6	13	25	38	50	63	75	100
2	2	4	8	16	24	32	40	48	64
1.5	1	2	5	9	14	18	23	27	36
1	1	1	2	4	6	8	10	12	16

Vibration Exposure Table

Daily exposure time

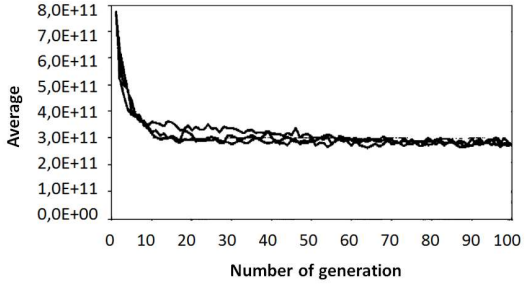


Fig. 7. Average values of 100 populations at each generation.

For a preliminary study, the number of generation and the population size are fixed and only the mutation rate and crossover rate are allowed to change. The average value of the last generation oscillates as the mutation rate changes, which is less informative than the minimum value. From these two figures it can be seen that 1% may be a reasonable choice for the mutation rate since there is good convergence to the minimum value of the objective function for a variety of crossover rate. Also, a population size of 100 and a 25% crossover rate seem to yield robust performance in terms of minimizing the objective function.

As a result of the preliminary analysis, 1%, 25% and 100% are chosen as the appropriate mutation rate, cross-over rate and population size, respectively, and the only changeable quantity for this problem is the number of

generations, which will be determined by using the convergence criterion during the iteration. In Fig. 7 is shown the average value of the objective function at each generation. The results of four simulation runs are plotted. The convergence is evaluated using the average value of the population. The design variables corresponding to the optimum value of the objective function are: k_{sp} = 34 kN/m, c_{sp} = 2010 Ns/m, k_{se} = 3 kN/m and c_{se} = 1000 Ns/m respectively.

3 Results and discussion

Table 3 shows values of the design variables for four independent runs of the GA. It also shows the peak absolute acceleration value of the seat for the vehicle, subjected to road profile.
The seat suspension values, k_{se} and c_{se}, are consistently at or near their lower bounds, providing a 'soft suspension', possibly keeping the forces applied to the seat, and hence its acceleration, low. The best design, as measured by the lowest objective function value, was obtained from run 2.

Table 3. GA result for active suspension design.

Design variable	*Run 1*	*Run 2*	*Run 3*	*Run 4*
msp [kg]	250	250	250	250
kt [kN/m]	100	100	100	100
ct [Ns/m]	800	800	800	800
ksp [kN/m]	32	34	35	30
csp [Ns/m]	2150	2100	2200	2300
kse [kN/m]	4	3	3,5	4,5
cse [Ns/m]	1000	1000	1100	1200
$max\|\ddot{q}(t)\|$ [m/s^2]	4.5	3.8	4.2	4.4

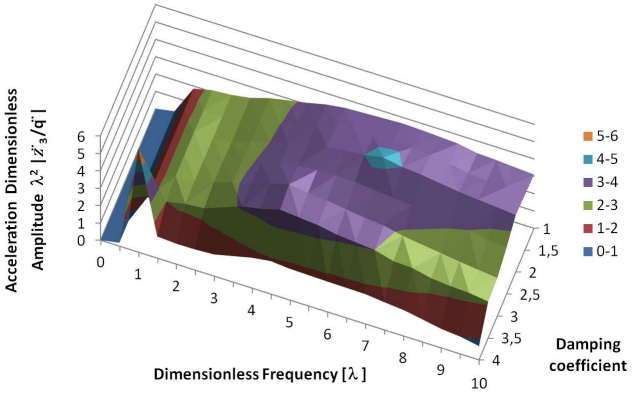


Fig. 8. Acceleration amplitude Vs frequency and damping coefficient.

Fig. 8 indicates the optimized vertical acceleration value (response gain) on the seat subjected to variable frequency and suspension damping coefficient. Fig. 9 outlines optimum damping values for shock absorber retrieved from the optimization process.
It is easy to determine that the obtained values, evaluated in terms of RMS, apply to the second zone of the diagram "*confort reaction to vibration*" established by ISO 2631- (1997) (Fig. 10).

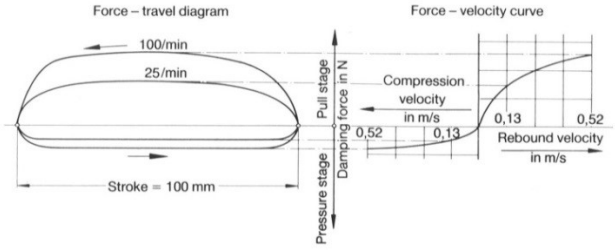


Fig. 9. Optimum damping values for shock absorber.

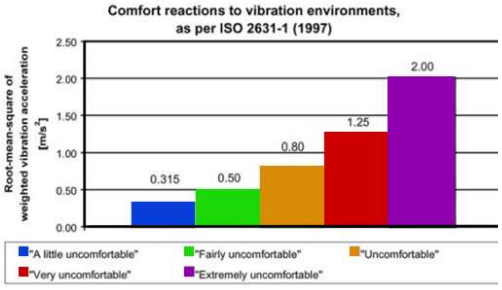


Fig. 10. Comfort reaction to vibration.

4 Conclusions

This paper proposes an active suspension system for passenger cars, applying genetic algorithm control to a 3 DoF multibody model. The goal was achieved by optimizing the best vertical acceleration on the seat for different road profiles in the entire possible frequency range considering also time exposure limits established

by unification agencies and road authorities. Road irregularities have been determined by means of the International Roughness Index (IRI), whereas the acceleration values obtained were compared to the "comfort reaction to vibration" values established by ISO 2631 (1997). The simulation results proved that the proposed active suspension system leads to a measurable improvement in the vehicle passenger comfort conditions. Moreover, it has been observed that the methods applied lead to stable and efficient optimization procedures which make them suitable to be used as design tools during the development of new vehicle concepts.

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References

1. Sayers, M., & Karamihas, S. 1996. Estimation of rideability by analyzing longitudinal road profile. Transportation Research Record: Journal of the Transportation Research Board, 1536, pp.110-116.
2. Tusset, A. M., Rafikov, M., & Balthazar, J. M. 2009. An intelligent controller design for magnetorheological damper based on a quarter-car model. Journal of Vibration and Control, vol. 15(12), pp.1907-1920.
3. Gündoğdu, Ö. 2007. Optimal seat and suspension design for a quarter car with driver model using genetic algorithms. International Journal of Industrial Ergonomics,vol. 37(4), pp.327-332.
4. Litak, G., Borowiec, M., Friswell, M. I., Szabelski, K. 2008. Chaotic vibration of a quarter-car model excited by the road surface profile. Nonlinear Science and Numerical Simulation, vol 13(7), pp. 1373-1383.
5. Berkovitz, L. D. 2013. Optimal control theory Vol. 12. Springer Science & Business Media.
6. Ambu, R., Bertetto, A. M., & Falchi, C. 2014. Design of a prototype system operant in lunar environment. Strojniški vestnik-Journal of Mechanical Engineering, Vol.60, N°10, pp.629-637
7. Gao, H., Sun, W., & Shi, P. 2010. Robust Sampled-Data $ H_ {\ infty} $ Control for Vehicle Active Suspension Systems. IEEE Transactions on Control Systems Technology, vol.18(1), pp.238-245.
8. Calì, M., Speranza, D., and Martorelli, M., 2017. Dynamic spinnaker performance through digital photogrammetry, numerical analysis and experimental tests. In Advances on Mechanics, Design Engineering and Manufacturing. Springer International Publishing, pp. 585–595.
9. Calì, M., Oliveri S.M., Gloria A., Martorelli, M., Speranza, D., 2017. Comparison of commonly used sail cloths through photogrammetric acquisitions, experimental tests and numerical aerodynamic simulations. 27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017.
10. Calì, M., & Savio, F. L., 2017. Accurate 3d reconstruction of a rubber membrane inflated during a bulge test to evaluate anisotropy. In Advances on Mechanics, Design Engineering and Manufacturing. Springer International Publishing. pp. 1221-1231.
11. Haug, E.J., Mani N.K. and Krishnaswami, P. Design sensitivity analysis and optimization of dynamically driven systems, in: E.J. Haug, ed., Computer Aided Analysis and Optimization of Mechanical System Dynamics (Springer-Verlag, Berlin, 1984) pp.555-632.
12. Bestle, D. Optimization of automotive systems, in: E.J. Haug, ed., Concurrent Engineering: Tools and Technologies for Mechanical System Design (Springer-Verlag. Berlin, 1993) pp.671-683.
13. Schiehlen, W. Symbolic computations in multibody systems, in: M. Pereira and J. Ambrosio, Computer-Aided Analysis of Rigid and Flexible Mechanical Systems (Kluwer Academic Publishers, Dordrecht, 1994) p.101-136
14. Grott, M. (2010). Design of Suspension Systems and Control Algorithms for Heavy Duty Vehicles (Doctoral dissertation, University of Trento).
15. Cebon D., 2000, Handbook of Vehicle-Road Interaction, Swets & Zeitlinger, Exton, Pa, (USA).
16. Sun, L., Cai, X., & Yang, J. 2007. Genetic algorithm-based optimum vehicle suspension design using minimum dynamic pavement load as a design criterion. Journal of Sound and Vibration, 301(1), pp.18-27.
17. Goldberg, D.E. 1989. Genetic Algorithms in Search, Optimization, and Machine Learning (Addison-Wesley, Reading, Massachusetts.
18. Haftka R.T. and Gurdal, Z., 1993. Elements of Structural Optimization, 3rd rev. and expanded ed. (Kluwer Academic Publishers, Dordrecht.
19. Baronio, G., Motyl, B., & Paderno, D. 2016. Technical Drawing Learning Tool Level 2: An interactive self learning tool for teaching manufacturing dimensioning. Computer Applications in Engineering Education, 24(4), pp.519-528
20. Gianini, C., 2006. Tecniche avanzate di progettazione strutturale. ATHENA audiovisuals.

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Using Biomechanical models in Motion Comfort of Automated Driving

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ABSTRACT

In automated vehicles we may use the travel time for work or leisure activities, but this requires high comfort levels preventing self-driving car sickness. Comfort of automated driving is a complex field calling for new vehicle interior concepts, driving interfaces and vehicle motion control strategies.

Motion sickness and (dis)comfort relate to mechanical and visual motion cues and their disparity. Sickness relates most to frequencies from 0.1-0.5 Hz, and comfort relates most to frequencies above 0.5 Hz (ISO 2631, 1997). Users of automation will engage in other tasks for instance operating personal devices which will affect the requirements on comfort in particular for manual operation while being subjected to vibration. The act of driving makes drivers virtually insensitive to motion sickness, while passive passengers typically suffer most, especially when deprived from visual information about self-motion obtained from out the window views. An aggressive driving style adopted by the automation will result in excessive body motion, leading to discomfort and hampered performance in the operation of personal devices.

Current standards assess the overall vibration discomfort of seated people by summation of frequency weighted accelerations at the seat, the back, and the feet (BS6841, 1987; ISO2631-1, 1997). While accelerations at seat, back and feet have been shown to relate to comfort, it is widely accepted that head motion as perceived by the vestibular organ and vision is a key determinant of (dis)comfort and motion sickness. Thus we need to take into account the "seat-to-head transmissibility (STHT)" to assess vestibular and visual contributions to motion perception and comfort.

This contribution will present experimental and modelling efforts to investigate and predict STHT. A model of lumbar stabilization will be presented separating reflexive and co-contraction contributions, and a detailed neck model will be presented including vestibular feedback loops. Results include analysis of the contribution of feedback and co-contraction in spinal stabilization, in relation to seating condition, instruction and presence of vision. Finally an outlook will be given on using biomechanical modelling to investigate and enhance motion comfort of automated driving.

KEYWORDS: Comfort, posture, vibration, driving, spine

1. Forbes PA, Dakin CJ, Vardy A, Happee R, Siegmund GP, Schouten AC, Blouin JS. (2013). Frequency response of vestibular reflexes in neck, back and lower limb muscles, Journal of Neurophysiology, 110(8): 1869-1881.
2. Forbes PA, de Bruijn E, Schouten AC, van der Helm FCT, Happee R. (2013). Dependency of human neck reflex responses on the bandwidth of pseudorandom anterior-posterior torso perturbations. Experimental Brain Research 226(1): 1-14.
3. Happee R, de Bruijn E, Forbes PA, van der Helm FCT. (2017). Dynamic head-neck stabilization and modulation with perturbation bandwidth investigated using a multisegment neuromuscular model. On line, J. Biomechanics.
4. Östh J, Eliasson E, Happee R, Brolin K. (2014). A Method to Model Anticipatory Postural Control in Driver Braking Events. Gait & Posture 40 (2014) 664-669.
5. van Drunen P, Koumans Y, van der Helm FCT, van Dieën JH, Happee R. (2015). Modulation of intrinsic and reflexive contributions to low-back stabilization due to vision, task instruction and perturbation bandwidth. Experimental Brain Research 233(3): 735-749.
6. van Drunen P, Maaswinkel E, van der Helm FCT, van Dieën JH, Happee R. (2013). Identifying intrinsic and reflexive contributions to low-back stabilization. J Biomechanics 46 (8) 1440-1446.

Multi-target driven design of a smart aircraft accessibility system for people with reduced mobility: the BEAIR®[1] project

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Abstract The number of persons with disabilities represents a significant part of world's population. There are more than 1 billion people with disability that is about 15% of the world's population or one in seven people. In Europe, there are around 80 million persons with disabilities (physical disabilities 72.5%). On the other hand, population aging in Europe, along with the high correlation between age and disability, implies that the share of the disables among the European citizens is bound to increase significantly. With regard to transport, the lack of accessibility contributes to the disadvantages experienced by people with disability. The paper shows a multi-target driven design of a smart aircraft accessibility system for people with reduced mobility (the BEAIR®) in which the comfort assessment has been made through the explicit FEM simulation approach. Obtained results have been compared with values coming from literature. The development of the BEAIR® concept has been initiated by making use of the Quality Function Deployment (QFD) approach, which has led to the identification of the key equipment characteristics, in fulfillment to the applicable regulations and laws, as well as to the stakeholders needs (the PRM, Passenger with reduced mobility). Among the needs, one of the most relevant is the mitigation of the bedsores problem, which occurs mainly when the PRM is subjected to long haul flight. To mitigate the said issue, and properly address the design of cushion, a simulated ergonomic analysis has been performed as described in the present paper, prior qualification and ergonomic tests. The simulation has been iterated so to achieve an optimal design in shape, material and stiffness of the cushion.

Keywords: Multi target driven design, optimization, comfort assessment, FEM explicit codes, reduced mobility people.

1 Introduction

People with disability face widespread barriers in accessing services (health care, education, employment, transport etc.). With regard to transport, the lack of accessibility contribute to the disadvantages experienced by people with disability. The need of accessibility in the air transportation has been widely discussed and specific laws, directives and recommendations have been issued to cope with this important topic.

[1] BEAIR is a patented and registered trademark owned by Paolo Berro

1. EU legislation on air passenger rights (Regulation EC 1107/2006) and Code 14 CFR Part 382 “Non-discrimination on the Basis of Disability in Air Travel” issued by US Department of Transportation.
2. The European Civil Aviation Conference (ECAC) Doc No. 30, Section 5 includes specific recommendations in relation to the design of aircraft to make them more accessible to disabled people
3. Code 14 CFR Part 382 “Nondiscrimination on the Basis of Disability in Air Travel” issued by US Department of Transportation
4. Canada Aircraft Accessibility for Persons with Disabilities: Code of Practice for Fixed-Wing Aircraft with 30 or More Passenger Seats

The intent of developing suitable equipment is to provide an effective solution to allow disabled passenger transportation with the least effort, in terms of cabin crew and assistant needed to assist the enplaning phases, with the best comfort for the disabled passenger and with the lowest operating costs for the airline. In fulfilling the said intent a key design element is the cushion, which plays a key role in providing the desiderated comfort characteristics of this class of equipment.
An accurate design of the said key element is needed to mitigate, if not even eliminate, one of the most painful outcomes of the travel experience of disabled persons, the bedsores.
Once the problem of bedsores has been faced, the comfort-related issues have to be understood. The (dis)comfort problem can be addressed in the framework proposed in Vink and Hallbeck (2012) and in Naddeo et al. (2014) that further extended Vink and Hallbeck’s model to incorporate instruments relating to the working environment and evaluation. The center of the problem is in the cushion of the seat and in the way to assess its (dis)comfort through the use of parameters like the Contact area and the pressure at interface between buttocks and seat. In this topic, as described by Vink (2005), the interactions between seats and humans can be recorded by many sensors. There is local input in the form of visuals, smell and sound; and whole-body input in the form of temperature, propriocepsis, pressure and touch. All of these have an influence on perceived comfort and discomfort. Most studies investigate the effect of pressure variables, such as mean and peak pressure (Hostens et al. 2001, Moes 2007), contact area (Paul et al. 2012; Kyung and Nussbaum 2008; Vos et al. 2006) and pressure distribution (Mergl 2006; Zenk 2008). Mergl (2006) and Zenk (2008-1; 2012), for example, defined the ideal pressure distribution for a car driver. Even though pressure distribution seems to be the best objective measure for discomfort (De Looze et al. 2003), it is influenced by other variables, such as posture (Tessendorf et al., 2009; Oyama et al. 2003; Zhiping and Jian, 2011; Naddeo et al., 2015-2), movement (Wang et al, 2011; Ciaccia and Sznelwar, 2012), expectations (Naddeo et al., 2015-1) and first sight (Vink, 2014) – none of which are taken into account in the majority of studies. Helander and Zhang (1997) and de Looze et al. (2003) state that discomfort is more related to physical factors, while comfort is more related to luxury and feelings of refreshment. The first aspect, related to discomfort, can be evaluated by defining a simulation framework in which the factors that probably influence the discomfort perception can be numerically evaluated.
This paper presents a methodology of comfort evaluation based on simulations; these simulations were used to validate and identify a preliminary shape of the cushion assay, playing this latter an important role in fulfilling the end user comfort requirements, particularly for what concerns the bedsores generation problem, being this latter one of the key requirements expressed by the end user. A preliminary cushion shape and material has been therefore identified, by mean of the ergonomic simulation tool, as it is possible to see in the captures aside and below. The results have provided an initial evaluation of the passenger comfort, which will be further investigated during the technical feasibility study. The parameters observed demonstrate also that the results achieved through the above-mentioned tools are very close to those attainable through lab test.



Fig. 1. Handling a disabled woman.

2 Methods

In the paper [22], a Quality Function Deployment Analysis has been performed, to the development of power assistive wheelchair. The results have showed that, among the most relevant needs expressed by the end user there are the following, expressed in natural language "To have a comfortable seat"; "To have a comfortable backrest". An important issue, strictly related to the characteristic of the said items, and therefore to the comfort of disabled passengers (passenger restricted to wheelchair, defined as PRM by IATA), is the arising of pressure sores on long flight. Pressure sores (also known bedsores) occurs after few hours of exposing weight bearing zones of the body, such as tailbone, to constant of slightly variable positive pressure loads, such as those typical of the flight envelope which a passenger restricted to wheelchair use, experiences. Pressure sores indeed are caused by a not suitable treatment and assistance during the flight (the passenger restricted to wheelchair shall be periodically moved and shifted to avoid pressure being localized always in the same position). Being demonstrated the relation between the pressure sores and seat cushion [23] a tailored design of the seat cushion has been identified as a key mitigation action in preventing the said problem. A key role, from a technical perspective, in fulfilling the said needs, is played by the material and by the shape of the cushion, in the lower part, where the tailbone is contact to, and in the backrest.
The QFD study mentioned above, in the paper "Application of Quality Function Deployment in Design of Mobile Assistive Devices", has also allowed to identify other pivotal and key items in the design of the BEAIR® concept, not described in the present paper, which is restricted to the study of the cushioning.

3 Cushioning study

In order to perform a good simulation, several steps were followed:
All materials were physically tested by compression test following the ASTM standards and materials' models were be set in order to reach a numerical/experimental correlation of mechanical behavior with an error always less than 5%, in terms of true-stress-true-strain curve and hysteresis/mechanical parameters.
The Cad model of the new mattress was created in CATIA® Environment by Dassault Systemes® using a hybrid modeling approach (CGS – Constructive Solid Geometry and Surface Modelling). In order to create the model of the human, we used a still developed MBS model in SolidWorkd that is fully parametrized in terms of anthropometric measures and human segments dimensions (length, volume, external surface shape). Both the models of mattress and human body were imported in the Hypermesh© environment in order to create meshes for FEM analysis. The meshed models were imported in VPS© (Virtual Performance Solutions) by ESI® (A dynamic explicit finite element solver) environment for prepare the model to run.
Several hypotheses were made in order to simplify the calculations:

1. The tests were made in seated position in order to perform a simple/symmetric analysis;
2. The manikin was positioned in a typical human-joints-layout and the joints were blocked in that position.
3. All the manikin segments were treated as rigid body connected each other, in order to avoid to calculate flesh deformation during the interaction. This Hypothesis did not affect the calculation and the results because the seat was tested in static conditions.
4. In order to simulate the body sinking in the cushion, a vertical velocity, from up to down, was imposed to the manikin. The mass distribution was set using the real human mass distribution into segments while the gravity force was neglected due to the use of a constant velocity.
5. The equivalent mass of the manikin was calculated by integrating the calculated pressure at interface on the contact surface.
6. The lower layer off the cushion was blocked on the seat's structure by a 3DOF clamps (Z direction and rotations off plane)

Materials have been modeled by a nonlinear/viscous material very well useful for simulating the mechanical behavior of foams. The calculations have been performed in order to have the following outputs:

1. Map of pressures at interface between human body and cushion
2. Map of pressure at interface between the layers, in order to understand how much each layer of cushion works in terms of energy adsorbsion and loads distribution
3. Z displacements of each node in contact with human body
4. Peak of pressures

The comfort assessment was made through a formula (that is under NDA because of the ongoing publication of an International Patent), that takes into account the following 5 parameters based on scientific literature (papers [24-30]:

1. The average pressure at interface
2. The Variance of the pressure on the surface of the cushion
3. The specific pressure distribution on buttocks, upper thigh and lower thigh
4. The maximum pressure
5. The sinking into the cushion

4 Design Case

BEAIR® concept is an aeronautical vehicle systems, passenger aircraft seat structures, aircraft seating configurations, passenger in flight safety, passenger aircraft seat fastening systems and aircraft boarding and deplaning methods. It is an improved systems, with devices and provisions, for protecting, saving and transporting PRM into, out of, and within aircraft interiors. The design case to which the methodology described hereby has been applied, is the development of the BEAIR® seat cushion.
The idea is to develop a methodology that allow to perform a DOE on different combinations of foams to be used in cushion filling having, like target, the optimization of the comfort performances. In this way, the innovation introduced by the proposed seat can fulfill not only the legislative and safety requirements, but also the comfort requirements.
The methodology consists of the following steps:

1. Design of a two layered cushion;
2. Choice of different foams that can be used in cushion filling;
3. Choice of three different foam-thicknesses in the available height;
4. Definition of a Full DOE about possible combinations;
5. Simulation running;
6. Results' analysis in terms of mechanical behavior and in terms of predicted perceived comfort.

A pilot study was performed in that way and results are shown in the following figures:

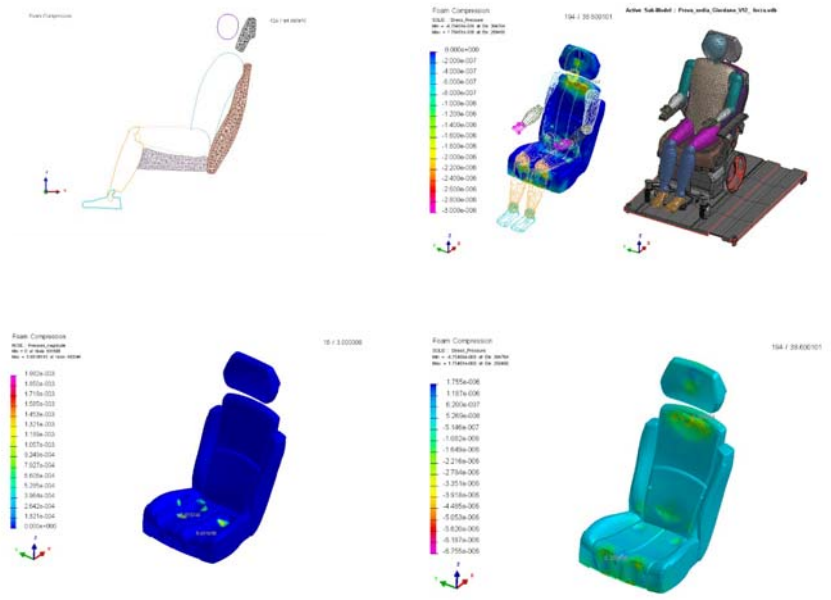


Fig. 2. FEM Simulations' results

5 Results

The use of QFD and the tools described in the present paper, enable the application of the paradigm of collaborative engineering in the design of disabled person aids, more specifically to those as the BEAIR® equipment, which is a concept of aeronautical seat designed specifically with the intent of improving the end user comfort during the flight phase. The BEAIR® concept incorporates many of the engineering characteristics (design items) identified in the paper "Application of Quality Function Deployment in Design of Mobile Assistive Devices", with a tailored and specific cushion shape, designed on the basis of the flight loads.



Fig. 3. BEAIR® Virtual Protoype

6 Discussion

Further improvements and outcome from the present study will be the implementation of the results of the study in an effective solution / equipment for disabled person transportation such as the BEAIR® concept. Possible improvements are foreseen by adopting a controlled stiffness cushion, on the basis of biometric data of the PRM. The data and the approach provided by the methodology discussed can be used as part of the

control system of an enhanced seat cushion, sensorized and programmable as described in the paper "Seat cushion design for elderly wheelchair users based on minimization of soft tissue deformation using stiffness and pressure measurements". The control system, having the capability of recalculating the best set of stiffness values, in real time, will be able to adapt the seat stiffness characteristic along the flight phase, thus to increasing the comfort not only of passengers restricted to wheelchair, but also to other class of persons, such as normal passenger or even crewmember of military aircraft planes (see Air force publication "The Effects of Ejection Seat Cushion Design on Physical Fatigue and Cognitive Performance").

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References

1. Vink P. and Hallbeck S., “Editorial: Comfort and discomfort studies demonstrate the need for a new model”, Applied Ergonomics. 43, 271-276, doi:10.1016/j.apergo.2011.06.001, 2012.
2. Naddeo, A., Cappetti, N., Vallone, M., Califano, R., 2014. New trend line of research about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions. In Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE, edited by T. Ahram, W. Karwowski and T. Marek.
3. Vink, P., 2005. Comfort and design: principles and good practice. Boca Raton: CRC Press 2005, ISBN 0-8493-2830-6.
4. Hostens, I., Papaioannou, G., Spaepen, A., Ramon, H., 2001. Buttock and back pressure distribution tests on seats of mobile agricultural machinery. Applied Ergonomics 32(4): 347–356.
5. Moes, N.C.C.M., 2007. Variation in Sitting Pressure Distribution and Location of the Points of Maximum Pressure with Rotation of the Pelvis, Gender and Body Characteristics. Ergonomics 50(4): 536–561.
6. Paul, G., Daniell, N., Fraysse, F., 2012. Patterns of correlation between vehicle occupant seat pressure and anthropometry. Work 41: 2226–2231.
7. Kyung, G., Nussbaum, M.A., 2008. Driver sitting comfort and discomfort (part II): Relationships with and prediction from interface pressure. International Journal of Industrial Ergonomics 38 (5–6): 526–538.
8. Vos, G.A., Congleton, J.J., Moore, J.S., Amendola, A.A., Ringer, L., 2006. Postural versus chair design impacts upon interface pressure. Applied Ergonomics 37(5): 619–628.
9. Mergl, C., 2006. Entwicklung eines Verfahrens zur Objektivierung des Sitzkomforts auf Automobilsitzen. PhD thesis, Lehrstuhl für Ergonomie, Technische Universität München.
10. Zenk, R., Franz, M., Bubb, H., Vink, P., 2012. Spine loading in automotive seating. Applied Ergonomics, 43, 290-295, doi:10.1016/j.apergo.2011.06.004.
11. Zenk, R., 2008. Objektivierung des Sitzkomforts und seine automatische Anpassung, PhD thesis, Technische Universität München.
12. De Looze M.P., Kuijt-Evers L.F.M., Van Dien J.H., 2003. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics, 46, 985-997, doi:10.1080/0014013031000121977.
13. Tessendorf, B., Arnrich, B., Schumm, J., Setz, C., Tröster, G., 2009. Unsupervised monitoring of sitting behavior. Proceedings of the 31st Annual International Conference of the IEEE EMBS. Minneapolis, Minnesota, USA. 2–6 September.
14. Oyama, H., Noro, K., Mitsuya, R., Takao, H., 2003. Development of a new working posture for VDT. Conference proceedings of HUMACS conference 2003, Tokyo, Japan: Waseda University, 12–15.
15. Zhiping, L., Jian, W., 2011. Influences of Sitting Posture and Interface Activity on Human Physical and Psychological Reaction. Proceedings of the 5th International Conference on Bioinformatics and Biomedical Engineering (ICBBE). 10–12 May 2011, Wuhan, China.
16. Naddeo, A., Cappetti, N., Califano, R., Vallone, M., 2015-1. The Role of Expectation in Comfort Perception: The Mattresses’ Evaluation Experience. Procedia Manufacturing. 3, 4784-4791
17. Naddeo A., Cappetti N. and D'Oria C., 2015-2. Proposal of a New Quantitative Method for Postural Comfort Evaluation, 2015, International Journal of Industrial Ergonomics 48: 25-35

18. Wang, B., Jin, X., Chen, B., Tao, X., 2011. Assessment of driver movements during prolonged driving using seat pressure measurements. Proceedings of the Human Factors and Ergonomics Society 55th annual meeting. 1568–1572.
19. Ciaccia, F., Sznelwar, L., 2012. An approach to aircraft seat comfort using interface pressure mapping. Work 41 (1): 240–245.
20. Vink, P., 2014. The sweetness of discomfort: Designing the journey. Inaugural Lecture, Delft University of Technology, June 4, 2014.
21. Helander M.G., Zhang L., 1997. Field studies of comfort and discomfort in sitting. Ergonomics, 40, 895-915, doi:10.1080/001401397187739.
22. Kuen-Horng Tsai,* Chun-Yu Yeh, Hsin-Chang Lo, Chun-Ting Li, Chan-Peng Cheng, Guan-Liang Chang. Application of Quality Function Deployment in Design of Mobile Assistive Devices. 2008. Journal of Medical and Biological Engineering, 28(2): 87-93
23. Brienza DM,,Karg PE, Geyer MJ, Kelsey S, Trefler E, 2001, The relationship between pressure ulcer incidence and buttock-seat cushion interface pressure in at-risk elderly wheelchair users. Arch Phys Med Rehabil. 2001 Apr; 82(4): 529-33.
24. Technical report AFRL-HE-WP-TR-2006-0163 "The Effects of Ejection Seat Cushion Design on Physical Fatigue and Cognitive Performance". 2006. Air Force Research Laboratory Human Effectiveness Directorate Biosciences and Protection Division
25. Biomechanics Branch ASHRAE. Thermal environmental conditions for human occupancy. BSR/ASHRAE Standard 55P. Fourth Public Review. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 2003.
26. Bartels, V.T., 2003. Thermal comfort of airplane seats: influence of different seat materials and the use of laboratory test methods. Appl. Ergon. 34, 393-399.
27. Chen, Z., Li, Y., Liu, R., Gao, D., Chen, Q., Hu, Z., Guo, J., 2014. Effects of Interface Pressure Distribution on Human Sleep Quality. DOI: 10.1371/journal.pone.0099969.
28. Chen, Y., Guo, Y., Shem, L., Lium, S., 2013. The quantitative effects of mattress and sleep postures on sleep quality. International Asia Conference on Industrial Engineering and Management Innovation (IEMI2012) Proceedings, 107-115.
29. DeVocht, J. W., Wilder, D. G., Bandstra, E. R., Spratt, K. F., 2006. Biomechanical Evaluation of Four Different Mattresses. Applied Ergonomics 37 (3): 297-304. doi:10.1016/j.apergo.2005.07.002.
30. Hamberg-van Reenen, H.H., van der Beek, A.J., Blatter, B.M., van der Grinten, M.P.,Mechelen, W., Bongers, P.M., 2008. Does musculoskeletal discomfort at work predict future musculoskeletal pain?. Ergonomics 51(5), 637-648.

Buying a mattress – A question of comfort or valid technical measurements

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Abstract In a study absolved in 2017, the Research group of physiological anthropology at the University of Kiel asked 31 mid-aged people to rate twelve different criteria that could be important when buying a mattress. In addition to these given criteria the subjects could add factors that are missing. In a second part of the study the subjects reclined two times on three different mattresses at different daytimes, assessed comfort, firmness, Post-pulse oscillation.
In addition to this questionnaire, the mattresses were tested technically according to EN 1957:2012 and DIN Spec. 68200:2016-05 in order to gain objective, measured data. The main objective of this study was to find out which criteria are relevant for the user and whether perceptible comfort criteria are universally valid and intrapersonal constant.

Keywords: Mattress, comfort, multiple questioning, resilience, firmness

1 Introduction

The research group of physiological anthropology of the University of Kiel has its focus on the interface between human and technical environment. We are trying to discover product deficiencies and develop solutions in order that the product can be used by humans for a long period of time without harm. There is no other product which is so popular, used for so many hours every day and in such a close contact to the human body like mattresses. Manufacturers as well as testing institutions are using standardized test methods as given in the EN 1957:2012 (durability). Are these standardized test methods meet the criteria in which the consumer is interested? Is the weighting of published results in magazines of comparative testing companies reflecting the consumer interests?

In order to review our key activities in a first step the research group of physiological anthropology wanted to know from the consumer point of view, what are the criteria that are the basis for the decision when buying a mattress? Are these criteria measurable in a natural scientific way or are there important aspects, which are related to personal preferences?

Looking at advertisements of mattress manufacturers it is evident that nearly every brand is using slogans like “very comfortable” or “special comfort”. In a time where an increasing number of products (which includes mattresses) are bought via internet it is getting more and more important that claims of manufacturers are checked.

2. Realization of the study

2.1 Part 1

In spring 2017, a study was conducted in which men and women were asked about aspects that are important to them when buying a mattress. They were asked to evaluate twelve given aspects regarding their importance on a scale from 1 = unimportant to 10 = very important. In addition to these aspects, the subjects were able to specify or add criteria in an open response format (questionnaire Q1). After filling out this questionnaire, the subject's anthropometrical data was collected.

2.2 Part 2

The second part of the study is split into two sections (2A and 2B). The subjects evaluated three anonymously presented mattresses. Identical surveys were conducted at different time of day on the same test samples under identical ambient conditions. The subjects have not been informed about the purpose of the second section or if any modifications have been made.

In sections 2A and 2B the following modifications have been done. After section 2A the positon (1, 2, 3) of every mattress was changed. In section 2B the subjects had to start with a different mattress at a different position (1, 2, 3).

After lying on them for a short time, they were asked to estimate / rate the comfort, the post-pulse oscillation, and their interest in buying the mattresses. In addition, the subjects were asked to assess the firmness of the mattresses. These questions were recorded on a scale from 1 to 10 via questionnaire Q2A and Q2B.

Ahead of part 2 all mattresses were measured in their technical characteristics according to DIN EN 1957:2012. Important parameters are listed under 2.4.

2.3 General Setting

The following picture gives an overview of the test setting in the second part of the study 2A and 2B. Three different mattresses in the dimensions 90cm x 200cm have been evaluated by 31 subjects. The mattresses have been presented on three identical simple beds. In order to minimize the influence of the bed base rigid slatted frames were used.



Fig. 1. General setting in the second part

2.4 Test objects / Mattresses

The following Table 1 describes the three different mattresses technically.

Table 1. Test objects (technical description)

Technical measurement	Mattress A	Mattress B	Mattress C
Firmness acc. to EN 1957	4,9	8,0	4,4
Technical hardness acc. to EN 1957 [N/mm]	7,3	5,3	8,3
Hysteresis acc. to EN 1957 [%]	30,5	24,0	18,4
Point elasticity acc. to DIN 68200 [mm]	66	67	39
Post-pulse oscillation acc. to DIN 68200 [number of bounces]	4	5	12
Remaining height acc. to EN 1957 [%]	54,3	36,5	35,4
Length x Width x Height [cm]	201,0 x 91,5 x 24,5	200,0 x 91,5 x 22,5	200,0 x 90,0 x 18,5
Type of mattress core	PU-foam	Latex-foam	Bonell-spring

In addition to the values in Table 1 the following Force deflexion graphs give detailed information about the cushioning / spring characteristics.

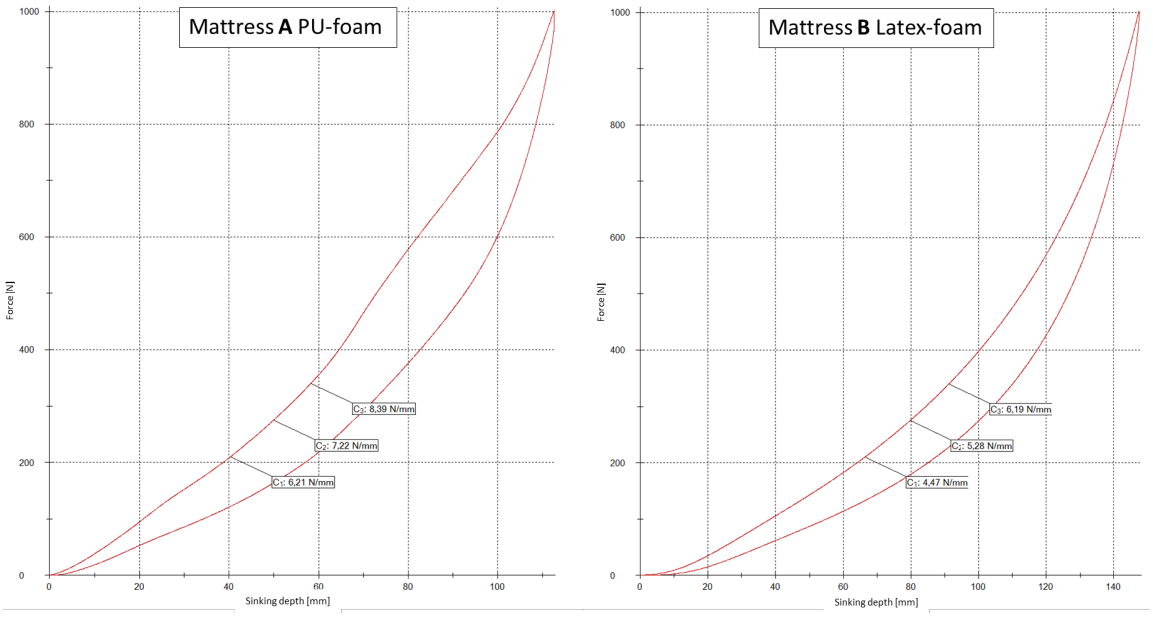


Fig. 2. Force deflexion graph mattress A, B (technical description)

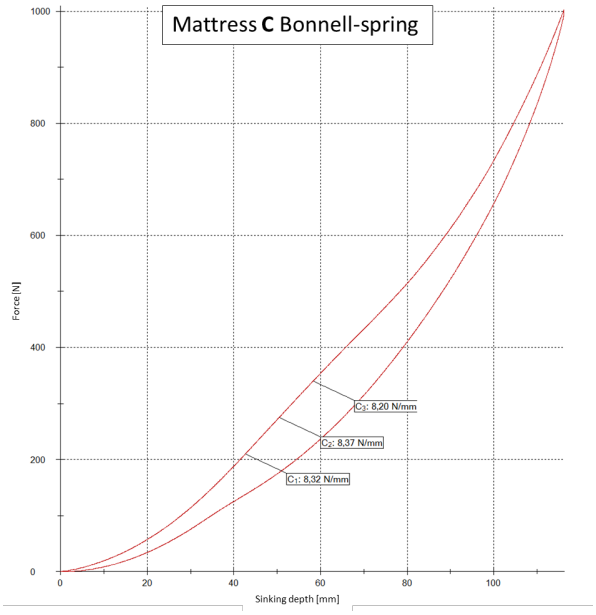


Fig. 3. Force deflexion graph mattress C (technical description)

2.5 Subjects

Via paper-bulletin at the University of Kiel as well as an popular internet-platform people were asked to join a study regarding mattresses. 33 subjects took part in the study. The evaluations of 15 men and 16 women have been considered.

Table 2. Subjects

	Height	Shoulder width (bideltoid)	Waist circumfence	Hip circumfence	Weight	Age
Min.	153,5	34,5	65	84	52	20
Max.	193	50,5	120	134	119	55
Arithmetic average	174	40	84	101	73	31
Standard deviation	9,5	4,1	13,8	11,9	18,7	9,5

3 Results

The following graph (Fig. 4) gives an overview of the results regarding the questionnaire Q1. The subjects were asked to rate twelve different criteria in a scale from 1 (unimportant) to 10 (very important). Although the subjects did not know about the aim of the study, comfort is the most important criteria for the user when purchasing a mattress. In contrast to design or manufacturing company/brand, comfort is scored very high (9.7).

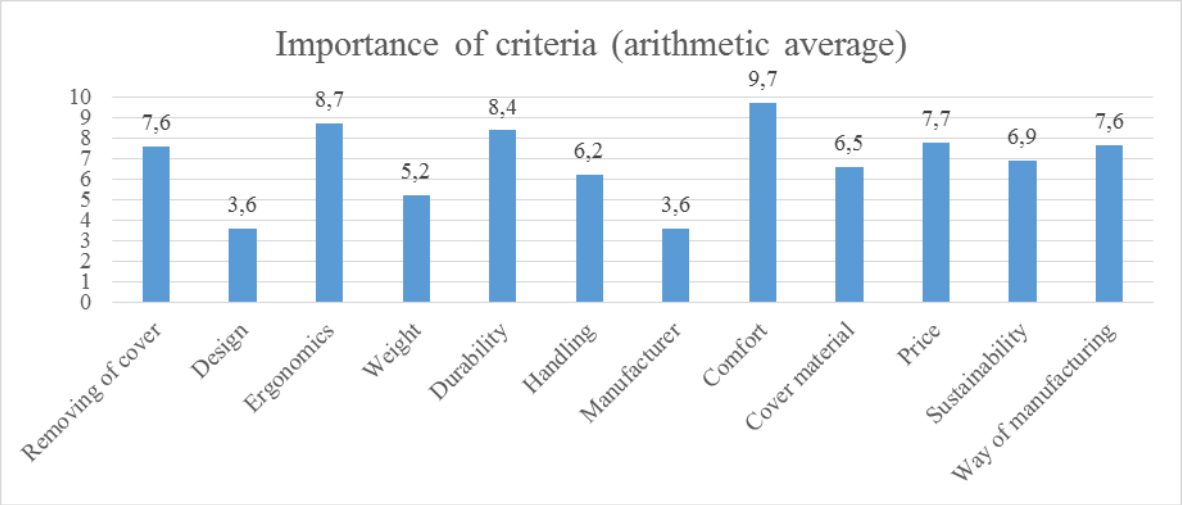


Fig. 3. Results Part 1

Comparing the two sections 2A and 2B it seems as if the subjects are able to give constant rating of the firmness. Regarding comfort rating the spread between section 2A and 2B is higher.

4 Conclusions

The difference/spread between the two evaluations (section 2A and 2B) of the mattresses (before noon after noon) is not the same regarding the different aspects that have been rated. Therefore, the evaluation of the comfort of a mattress could be influenced by the time of day. The subjects are quite refreshed after a good night sleep and more or less exhausted after a hard day at work.

The bigger spread in the rating of comfort of each mattress might also be due to a different intrapersonal definition of comfort.

References

1. DIN EN 1957:2013-01 Furniture - Beds and mattresses - Test methods for the determination of functional characteristics and assessment criteria
2. DIN Spec 68200:2016-05 Möbel - Betten und Matratzen - Prüfverfahren zur Bestimmung funktioneller mechanischer Eigenschaften von Zonenmatratzen und zonierten Liegesystemen

Height adjustments on backpack-carrying systems and muscle activity

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Abstract Systems for adjusting the height of shoulder belt attachment are part of the carriage systems and therefore a component of the interface between human and machine. The aim of this study was to investigate the neuromuscular response to a mechanical height adjustment of a carrying system when moving the arms. We hypothesized (1) that different height adjustments lead to changes in the muscle activity and (2) that the shoulder horizontal provides a benchmark for the optimal attachment height of the shoulder belts. 23 male participants worn a carriage system that allowed 3 different heights of shoulder belt attachment. Muscle activity of the m. trapezius and m. deltoideuas was quantified, while the participants conducted standardized arm movements. For subjects with an initial attachment height of 2cm below the shoulder horizontal, the m. deltoideus was significantly reliefed after the elevation of the shoulder belt. The significant relief of the m. trapezius began at a elevation over the shoulder hoizontal. Above an attachment height of more than 2cm above the shoulder horizontal, no further muscle unloading was achieved. Apart from these significant influences, a height adjustment can provide a systematic unloading or deloading of the shoulder musculature. Even, the magnitude and direction of changes in muscle activity led to rather individual responses, the intra-invidual responses are consistent. Therefore, support systems should provide the range of an individual setting.

Keywords: Electromyography, height adjustment, carriage system

1 Introduction

Insufficient wearing comfort during prolonged carriage can lead to the development of muscle injuries (including supportive tissue), such as shoulder traction injury and rheumatic diseases [1–4]. Thus, efforts needs to be undertaken, to provide the optimal fit of the device to the task and the specific requirements for anthropometry [5]. These requirements include, the distribution of the load on the appropriate muscles and, at the same time, ensuring the control of the operator. Support systems must connect a rigid framework to the flexible human body. Some criteria for designing this interface have been evaluated in numerous studies. It is confirmed that the use of a hip belt distributes a part of the load from the shoulders to the pelvis [6]. Although there are no uniform recommendations for the optimal position of the load along the longitudinal axis of the body, it appears that the height depends on the intended use [7–10]. Furthermore, the maximal load is dependent on the target group [11–13]. The development of height adjustments is also a part of the solution. However, there is currently no research on the effectiveness of existing systems.

Using a hip belt, height adjustments should relief the shoulder muscles. While in most technical developments, the hip belt remains stationary on the pelvis, a loading or unloading of the shoulders can be achieved by a stepwise adjustment of the attachment height of the shoulder belt. Here, the shoulder belt can be attached below, above or at the same level as the shoulder horziontal. An examination of the optimal connection height with respect to the flexibility of the shoulders and arms segments is missing so far. For this study we assumed that an attachment below the shoulder horizontal leads to an increased freedom of arm movements. The required flexibility can be taken from the material of the shoulder strap.

This gain in freedom of movement, however, goes hand in hand with a higher vertical load on the shoulders. A connection above the shoulder horizontal is assumed to lead to the opposite. While the shoulder is partially full relieved, the rotation about the body longitudinal axis is clearly restricted. Whether the connection directly on the shoulder horizontal offers the optimal compromise of freedom of movement and shoulder load is also unclear.
The analysis of myo-electrical signals has been proven to be a powerful method to analyze the neuromuscular response to changes of design features, such as weight, belt strength or the centre of gravity [14,15]. Neuromuscular fatigue when carrying different weights has been analyzed by e.g. Piscione and Gamet [16] and Southard and Mirka [17]. Only Varghese et al. [18] investigated the freedom of arm movements assessed by the neuromuscular signals. Since, this study foccussed on the reliability of the set-up, there was no gain in knowledge about the influence of sizing the device. However, intra-classcorrelation coefficients of >0.81 (standard error of measurement <4%) were found to be good for flexion and extension exercises of the m. deltoideus (middle) and the m. trapezius (descendence).
The aim of this study was to investigate the neuromuscular response to a mechanical height adjustment of a carrying system when moving the arms. We hypothesized (1) that different height adjustments lead to changes in the muscle activity and (2) that the shoulder horizontal provides a benchmark for the optimal attachment height of the shoulder belts.

2 Methods

2.1 Participants

23 male subjects (age 25,6 ± 5,1 years; weight 79,4 ± 11,0 kg; height 181,4 ± 9,1 cm; torso length 49,6 ± 5,9 cm) participated in this study. The inclusion criteria comprises healthy, male subjects aged 18-45 years. Exclusion criteria included subjects with professional experience in the postural, extensive wearing of heavy equipment and subjects with musculo-skeletal injuries or complaints in the back, neck and arm area. Prior the study, all subjects were informed about the risk of the study and gave their written consents to participate in this study.

2.2 Study Protocol

Subjects were positioned upright standing in front of a target construction. The targets for arm reaching tasks were adjusted to each subject's anthropometrics. The basic position was defined as just standing with hanging arms (0°). Target (1) was reached by the fingertips when the subject's arm was stretched 90° posterior, with the elbow slightly flexed and straight fingers. Target (2) was reached when the arm was lifted 135 ° with elbow slightly bent and straight fingers. In order to reach goal (3), the test person had to reach across the body. The hip and the upper body were not allowed to rotate. The height of the target was defined as the difference between the shoulder height and the upper arm length. All movements were conducted with the right arm. The set of exercises included 10 repetitions of reaching each target starting from the basic position. Movement velocity was defined at 46 movements per minute and controlled by a metronome. Sets were repeated for each of three devices' adjustment heights. The hip belt was kept closed and was maintained at the same position during the change of shoulder belt height. Only the shoulder belts were released and then tied back to the individual level comfort.
The carriage system (Dräger, PSS 7000) was equipped with a customized dummy of a breathing gas bottle (weight 11,5kg). The system allowed 3 height adjustment (S, M and L) with steps of 5cm in between the steps. The distance between the middle of the hip belt and the attachment height of the shoulder belt at the backplate for Size S was 40 cm. The distance between the attachment points of the two shoulder belts at the backplate was 15 cm. The width of the shoulder belt padding was 8 cm. All subjects wore a t-shirt underneath the device.
In order to enable further investigations of the role of the shoulder horizontal, participants were devided in to three sub-cohorts. The criterion was the relative height of the shoulder belt to the shoulder horizontal at the device setting M. The following criteria were established: initial height of should belt attachement (1) is more than >2cm *below* the shoulder horizontal (n = 12), (2) corresponds to ± 2cm of the horizontal (n = 7) and (3) is >2cm above the horizontal (n = 4).

2.3 Electromyography

Muscle activity was measured from the *m. deltoideus anterior* (DEA) and the *m. trapezius descendence* (TRD). The myo-electrical signal was derived bi-polar. Skin preparation involved sanding the dry skin and cleaning with alcohol. Electrodes (Ag/AgCl, Ambu, blue sensor N, inter-electrode distance 20mm) were placed according to the recommendations of the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENMIAM) projects [19]. The electrodes position at the DEA was defined at finger width distal and anterior to the acromion. The orientation was the line between the acromion and the thumb. Electrodes at the TRD were placed at 50% on the line from the acromion to the spine on vertebra C7. The orientation corresponded to the line between the acromion and the spine on vertebra C7.

Isolated arm movements were undertaken to identify mal-signals due to crosstalk. The myo-electrical signal was detected, amplified (myon 320) and post processed. Post processing included 2nd order butterwother filtering (10-500Hz), rectification and moving average smoothed (20ms). Root mean square (RMS) was calculated for each of 10 cycles of arm movement from basic to target position and back to basic position. Cycles were identified, using an accelerometer. Then, 10 RMS were averaged. Here, recent studies of cyclic movement [20] recommended at least seven repetition to increase the signal-to-noise ratio.

2.4 Statistical analysis

Within the entire cohort, 11 subjects were selected randomly to study the test-re-test reliability. These subjects repeated the measurements three times with five minutes rest in between the sets. Intra-class correlation (ICC) coefficient and standard error of measurement (SEM) were calculated to evaluate the set-up reliability. ICC 3.1 [21] (two-way mixed; single measure; absolute agreement) was applied. According to Sleivert and Wenger [22] ranges of reliability were set at: 1-0.8 as "good", 0.79-0.6 as "fair" and less than 0.6 as "poor" reproducibility. Standard error of measurement was additionally applied to obtain confidence intervals ($p<0.05$) [23]. SEM was calculated as relative to the mean difference between the items.
A paired Student t-test ($p<0.05$) was utilized to proof differences in muscle activity (RMS) after changing the adjustment height. The meaning of the differences was determined by Cohen's d [24]. Pearson correlation was calculated to analyze the (1) relationship between the relative height and the muscle activity (RMS) and (2) the interaction between DEA and TRD activity. Additional analysis included the correlation between the RMS and relative intra-individual change of RMS and the subject's metrics.

3 Results

3.1 Reliability

The reliability of the test set-up was analyzed in a test-retest design. The items were analyzed differentiated according to the muscles, movement and height setting of the device (Table 1). Apart from the reproducibility of the muscle signal of the DEA with straight arm movement (ICC = 0.470, 95% CI 0.077-0.870), all signals could be reproduced well (ICC≥0.8). The SEM confirms this with values of constant ≤3%, with the exception of the activity of the DEA with a straight arm movement (SEM = 9%).

Table 1. Intraclasscorrelation coefficients (ICC) and Standard error of measurement (SEM) for intra-session test retest reliability (n=11). Differentiation of the muscle signals considered arm movements (straight, up and down) and height adjustment of the device (S, M and L). SEM is calculated as relative to the mean difference between the items.

			m. trapezius desc.			m. deltoideus		
Motion	**Size**	**Items**	**ICC**	**95% CI**	**SEM**	**ICC**	**95% CI**	**SEM**
straight	S	3	0.929	0.810-0.980	3%	0.835	0.601-0.952	9%
up	S	3	0.910	0.762-0.974	1%	0.913	0.771-0.976	1%
cross	S	3	0.962	0.892-0.989	1%	0.968	0.909-0.991	1%
straight	M	3	0.789	0.514-0.937	1%	0.470	0.077-0.807	0%
up	M	3	0.850	0.631-0.956	2%	0.855	0.641-0.958	1%
cross	M	3	0.924	0.797-0.979	2%	0.821	0.590-0.943	1%
straight	L	3	0.851	0.648-0.953	1%	0.857	0.661-0.955	2%
up	L	3	0.834	0.615-0.947	1%	0.970	0.919-0.991	2%
cross	L	3	0.912	0.779-0.973	1%	0.947	0.861-0.984	2%

3.2 Effect of height adjustment on muscle activity

In the analysis of the neuromuscular response to the height adjustment, the authors dispense with a subdivision of the signals according to the movements, in order to obtain an overall picture. The comparisons were always conducted from the higher towards the lower setting (L>M, L>S and M>S). The results show a significant ($p <0.05$) response on the height adjustment (Table 2) for the TRD, in particular, to the height adjustments of L to M ($p = 0.03$, $d = 0.27$) and L to

S (p = 0.02, d = 0.28). The Cohen's d indicates a mean effect size. In addition, it can be seen that, only for these two activities, the upper and lower differences refer to a clear direction of change (decrease).

Table 2 Average differences of muscle activity due to height adjustments for 23 participants. Significance level was set at p=0.05. Cohen's d describes effect size with weak (d<0.2), average (d<0.3) and strong (d≥0.3) effects.

Muscles	Pairs	Mean difference [V]	lowest difference [V]	uppest difference [V]	p	Cohen's d
m. deltoideus	Size L-M	-0,003	0,031	-0,038	0,84	0,02
	Size L-S	0,023	0,055	-0,010	0,17	0,17
	Size M-S	0,026	0,067	-0,014	0,20	0,16
m. trapezius	Size L-M	0,009	0,017	0,001	*0,03**	0,27
	Size L-S	0,014	0,025	0,002	*0,02**	0,28
	Size M-S	0,004	0,014	-0,005	0,38	0,11

No significant change was found in the response of the DEA. The change from the highest setting (L) to the lowest setting (S) indicates an increase in activity. However, this difference is not significant.

3.3 Muscle activity in relation to the shoulder horizontal

In order to examine the significance of the shoulder horizontal as a reference height, the subjects were divided into subgroups. Group (1) mainly included persons with a long torso. The initial attachment height M was at least 2 cm below the shoulder height. In this group (n = 12) the increase in the attachment height towards the shoulder horizontal tends to lead to a deloading of the musculature. The reduction in the DEA activity of -3% is significant (p <0.05). A further deepening of the binding (M> S) leads to an increase in the activity of the DEA (+3%). However, this difference is not significant. The activity of the TRD also showed no significant changes. The median values changed by -1% (M>S) and -5% (M>L).

In group (2) with an initial attachment height that corresponds ±2cm to the shoulder horizontal, the DEA responds similar to group (1). The height adjustment from M to S results in a non-significant increase (+4%) of activity, whereas the increase of height results in a non-significant relief (-7%) of the DEA. On the other hand, the TRD showed a significant lower activity after the increase of the attachment height (-8%) and a non-significant loading (+2%) with a reduction in the height.

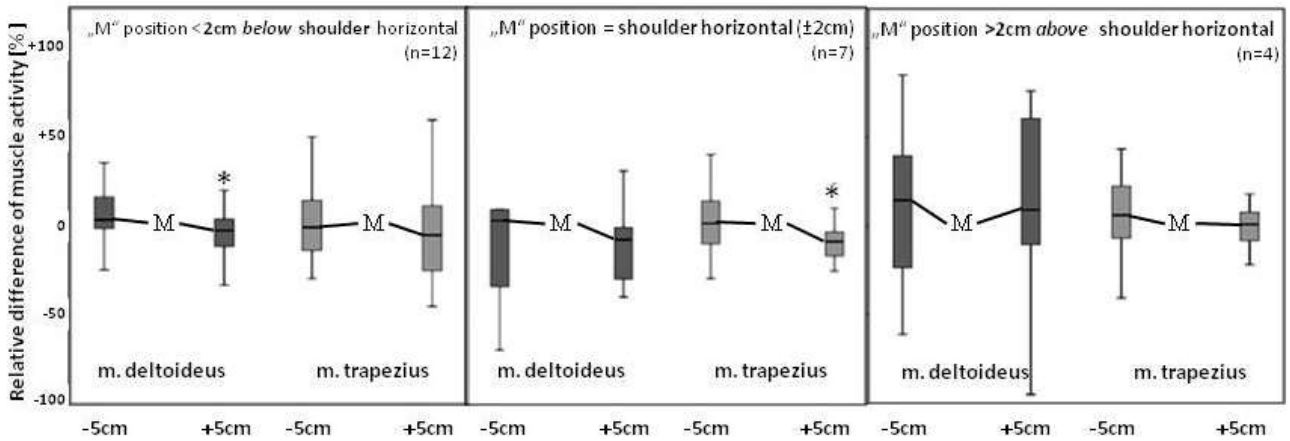


Fig. 1. Relative changes of the muscular activity after height adjustment, initially changing from size M. Subjects were grouped according to their initial attachment height relative to the shoulder horizontal. From left graphs to right: (1) Initial height at least 2cm below, (2) ± 2cm overlap and (3) at least 2cm above shoulder horizontal.

For group (3) no inferential statistics were possible due to the low sample size (n = 4). The DEA responded to changes from height M in both directions with +15% (M>S) and +9% (M>L). The changes in the TRD median were +6% (M>S) and +1% (M>L).

4 Discussion

This study examined the muscular response to the change in the attachment height of the shoulder belts to a carriage system. The focus was on questions as to whether the adjustment generally leads to changes and whether the shoulder horizontal is suitable as a reference for an optimal attachment height.
The examination design was found to be reliable. Only the straight arm movement with height M led to a "poor" ICC coefficient (DEA). An explanation of this exception could not be found in this study. Since the activity when carrying the size M has been used as a reference for changes in the height setting, this limitation must be considered in the further discussion of the results.

4.1 The effect of height adjustment on muscle activity

The adjustment of the attachment height leads in single cases to significant changes in the muscle activity. The shoulder muscles and thus the m. trapezius is considered to be the main operator when carrying loads [25,15]. Under severe mechanical stress, rapid fatigue must be expected [17]. The results of this study show that a reduction of the attachment height leads to an increased activity of the TRD. Thus, a height adjustment is generally suitable for influencing the shoulder load and therefore the fatigue development. The activity of the DEA does not change systematically, considering the totality of all directions of movement. Here a positive correlation between the attachment height and the muscular activity was assumed, since during low attachments, the flexibility of the belt material can provide a higher range of movement of the shoulder. This assumption could not be confirmed. Indeed, the avoidance of compensatory movements of the hip and the spine around the longitudinal axis were part of the instructions. However, it could not be controlled. For this, the set-up needs to be complemented with motion analysis technique.
Given the assumption that a compromise between the shoulder load and the freedom of movement at different attachment heights can be depicted in the activities of the TRD and DEA, this study presents rather a different picture. Here, Table 2 shows that the interval between the largest and smallest changes in muscle activity does not show a clear direction of change. Here, individual patterns of motion and motor control seem to be important.

4.2 The shoulder horizontal as reference height

In this study we also investigated the role of the shoulder horizontal as a reference for the optimal attachment height. The elevation of the belt attachment from an initial height of 2cm below the shoulder horizontal, resulted in a relief of the DEA. This relief does not appear to continue significantly with the further increase above the shoulder horizontal and appears to turn into an additional load, even if this realization is not significant. The TRD relief, on the other hand, begins from the horizontal when the belt loses contact with the shoulder surface. This unloaded state continues with even higher connections. In this cohort reliefs of maximal 7% were possible. The results indicate that from a height of more than +2cm above the shoulder horizontal, no further relief of the TRD can be achieved. Starting from this initial height, the DEA's activity increases while lowering and increasing the height. However, this may have different causes. Increased carrying capacity and restriction of freedom of movement can also lead to an increase in activity. With n = 4, this result is not significant. If this result could be confirmed with a larger number of participants, this would be an indication that an optimal connection height for the DEA lies in this area.
In prolonged application the user can distribute the load to appropriate muscle groups and control this distribution in the sense of loading and unloading. However, further system developments need to ensure that this range is provided from all initial height levels.

4.3 Limitations of the study

The authors are aware of some limitations of the study. The single application of electromyography provides only a partly insight into the interaction of body and device. While the value of additional motion analysis has already been discussed, a pressure analysis along the contact surface between the belt and the body [6] may also provide further useful information. Here, the proof of reproducibility of individual shoulder belt stretching is one important aspect thats needs to be taken into account.
There was no empirical basis for classifying the sub-cohorts according to the initial height of attachment. The solution found here nevertheless reflects the best compromise between the positions on the shoulder horizontal, the adjustment height per stage (5 cm) and the cohort size.

4.4 Conclusion

The systematic change of the attachment height of the shoulder straps partly leads to predictable, muscular reactions. An increase in the attachment height tends to relief the muscles. However, there is no general correlation between the level of attachment and the muscle activity. Here, individual reaction might be prevalent. For this purpose, the adjustment systems should provide the possibility to adjust according to individual preferences. Whether the shoulder horizontal provides a reference for the optimal connection height, could not be clarified. There are indications that attachments 2cm above the shoulder horizontal do not lead to any further relief of the muscles. This result, however, needs to be approved and then, could provide an upper limit for shoulder belt attachment.

5 References

1. Anderson JA (1984) Shoulder pain and tension neck and their relation to work. Scandinavian journal of work, environment & health 10: 435–442. http://www.ncbi.nlm.nih.gov/pubmed/6535246
2. Knapik J, Harman E, Reynolds K (1996) Load carriage using packs: A review of physiological, biomechanical and medical aspects. Applied Ergonomics 27: 207–216.
3. Kuorinka I, Koskinen P (1979) Occupational rheumatic diseases and upper limb strain in manual jobs in a light mechanical industry. Scandinavian journal of work, environment & health 5: 39–47. http://www.ncbi.nlm.nih.gov/pubmed/317539
4. Westgaard RH (1988) Measurement and evaluation of postural load in occupational work situations. European Journal of Applied Physiology and Occupational Physiology 57: 291–304.
5. Gemperle F, Kasabach C, Stivoric J, Bauer M, Martin R (1998) Design for Wearability. In: IEEE Computer Society (ed). IEEE International Symposium on Wearable Computers (ISWC): October 19 - 20, 1998,. IEEE Computer Society, Los Alamitos, Calif.
6. Golriz S, Walker B (2012) Backpacks. Several factors likely to influence design and usage: A systematic literature review. Work 42: 519–531. http://www.ncbi.nlm.nih.gov/pubmed/22523041
7. Bobet J, Norman RW (1984) Effects of load placement on back muscle activity in load carriage. European Journal of Applied Physiology and Occupational Physiology 53: 71–75.
8. Brackley HM, Stevenson JM, Selinger JC (2009) Effect of backpack load placement on posture and spinal curvature in prepubescent children. Work 32: 351–360. http://www.ncbi.nlm.nih.gov/pubmed/19369727
9. Macias BR, Murthy G, Chambers H, Hargens AR (2008) Asymmetric Loads and Pain Associated With Backpack Carrying by Children. Journal of Pediatric Orthopaedics 28: 512–517.
10. Stuempfle KJ, Drury DG, Wilson AL (2004) Effect of load position on physiological and perceptual responses during load carriage with an internal frame backpack. Ergonomics 47: 784–789.
11. Al-Khabbaz YS, Shimada T, Hasegawa M (2008) The effect of backpack heaviness on trunk-lower extremity muscle activities and trunk posture. Gait & Posture 28: 297–302.
12. Goh J-H, Thambyah A, Bose K (1998) Effects of varying backpack loads on peak forces in the lumbosacral spine during walking. Clinical Biomechanics 13: S26-S31.
13. Hadid A, Epstein Y, Shabshin N, Gefen A (2012) Modeling mechanical strains and stresses in soft tissues of the shoulder during load carriage based on load-bearing open MRI. Journal of Applied Physiology 112: 597–606.
14. Holewijn M (1990) Physiological strain due to load carrying. European Journal of Applied Physiology and Occupational Physiology 61: 237–245.
15. Simpson KM, Munro BJ, Steele JR (2011) Effect of load mass on posture, heart rate and subjective responses of recreational female hikers to prolonged load carriage. Applied Ergonomics 42: 403–410.
16. Piscione J, Gamet D (2006) Effect of mechanical compression due to load carrying on shoulder muscle fatigue during sustained isometric arm abduction: An electromyographic study. European Journal of Applied Physiology and Occupational Physiology 97: 573–581.
17. Southard SA, Mirka GA (2007) An evaluation of backpack harness systems in non-neutral torso postures. Applied Ergonomics 38: 541–547. http://www.ncbi.nlm.nih.gov/pubmed/17112458
18. Varghese R, Hui-Chan CWY, Wang E, Bhatt T (2014) Internal consistency and test-retest reliability of an instrumented functional reaching task using wireless electromyographic sensors. Journal of Electromyography and Kinesiology 24: 593–600. http://www.ncbi.nlm.nih.gov/pubmed/25026882
19. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G (2000) Development of recommendations for SEMG sensors and sensor placement procedures. Journal of Electromyography and Kinesiology 10: 361–374.
20. Hug F, Dorel S (2009) Electromyographic analysis of pedaling: a review. Journal of Electromyography and Kinesiology 19: 182–198.

21. Shrout PE, Fleiss JL (1979) Intraclass correlations: Uses in assessing rater reliability. Psychological Bulletin 86: 420–428.
22. Sleivert GG, Wenger HA (1994) Reliability of measuring isometric and isokinetic peak torque, rate of torque development, integrated electromyography, and tibial nerve conduction velocity. Archives of Physical Medicine and Rehabilitation 75: 1315–1321.
23. Weir JP (2005) Quantifying Test-Retest Reliability Using the Intraclass Correlation Coefficient and the SEM. The Journal of Strength and Conditioning Research 19: 231.
24. Cohen J (1988) Statistical power analysis for the behavioral sciences. (2nd ed.), Lawrence Erlbaum Associates, Hove, London.
25. La Fiandra Michael, Harman E (2004) The Distribution of Forces between the Upper and Lower Back during Load Carriage. Medicine & Science in Sports & Exercise 36: 460–467.

Air quality aboard high speed trains

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Abstract This paper presents an experimental investigation of the IAQ aboard several italian high-speed trains on different railway lines. High-speed train coaches are peculiar environments characterized by the presence of several discomfort factors associated to the thermal, acoustic and luminous conditions, as well as to the air quality (hereafter IAQ). Among these coexisting discomfort factors, IAQ is possibly the most difficult to keep under control, because of the heavy crowding in the coaches. In this study IAQ has been quantified using the concentration of CO_2, whose time evolution has been recorded for the full duration of each trip. Results show very large concentrations with peak values up to 2500 – 2800 ppm that determine large fractions of dissatisfied and significantly impair the subjects' ability to carry out mentally demanding tasks. This is unfortunate since many people try to make profitable use of their travel time to study or work. The typical time evolution of CO_2 shows large fluctuations which are inconsistent with constant ventilation, and imply the existence of variable inflows during the trip. Some indications on the size and timing of such variations are presented. There is currently no threshold value for the CO_2 concentration aboard public transportation vehicles in Italy. It is however unreasonable that any limit of acceptability can be larger than the value of 1750 ppm that can be inferred from the recent European standard EN 16798-1 for indoor environments with "low expectations". Our results indicate that the limit value of 1750 ppm is often exceeded and occasionally largely exceeded. Possible solutions based on CO_2 monitoring are proposed, which are aimed at lowering the concentration peaks and eliminating or at least attenuating existing fluctuations.

Keywords: IAQ, CO_2, Acceptability, High-speed trains

1 Introduction

Due a favorable combination of cost, convenience and reliability, high speed trains have become extremely popular in Italy in the last fifteen-twenty years. From the viewpoint of passenger comfort, high speed trains are challenging environments because of at least three elements: 1) they represent prototypical environments characterized by multifactorial discomfort due to the thermal, acoustic, luminous conditions as well as to the air quality (hereafter IAQ); many different factors must accordingly be taken into account simultaneously. 2) there is a large density of subjects, especially in the early morning and late afternoon, that further complicates matters. 3) from a very basic cost-to-benefit perspective, it is obvious that the demand from passengers of least moderate comfort conditions is fully justified. On the positive side, this is a very static environment where the density of subjects, along with their locations, postures and activities can be taken as constants during the trip, which simplifies comfort planning, and assessment. High speed trains have sealed windows, so

that they must rely on well-designed and well-operated ventilation systems in order to provide acceptable IAQ to passengers. Contaminants aboard trains are both of anthropogenic (CO_2 exhaled by passengers) as well as non-anthropogenic nature (substances released by the plastic materials and detergents). Because the density of passengers is often quite large, and the majority of trains is relatively new (2 to 10 years old), it is expected that the most serious pollution has anthropogenic nature.

While CO_2 has been proven not to be a problem in itself [1], even at fairly large concentrations (up to 3000 ppm), it is nevertheless a very useful quantity as a tracer of the other substances released by the human body, which are largely responsible for the poor IAQ perceived by the occupants of crowded indoor environments. Poor IAQ is not only unpleasant, but it is also known to be detrimental to the performance of even simple tasks [2, 3, 4]. Numerous studies have been performed of the concentration of CO_2 aboard high speed trains [5, 6, 7, 8]. However they do not focus on the detailed time evolution of CO_2, which prevents any investigation of the way the ventilation system is actually operated.

This study consists of two parts: in the first part, measurements of the time evolution of CO_2 aboard high speed trains are presented. In the second part, model predictions of the CO_2 concentration are calculated, and by matching predictions to measurements, air inflow rates are estimated. Finally, the appropriateness of such rates is discussed in the light of existing technical standards.

2 Methods

Measurements have been carried out at different times from June 2014 to February 2016, on different trains, operated by both Italian high speed railway companies. Standard coaches have between 70 and 80 seats. Air conditioning is centrally operated. Air immission takes place along the sides of the coach, just below the windows, while extraction occurs near the floor level.

The surveyed high-speed lines include a) Bologna – Florence, b) Florence – Rome, c) Rome – Naples. These lines imply travel times between 35 and 95 minutes. Lines b) and c) include a large number of short (< 1 km) or intermediate length (1 to 5 km) tunnels. Line a) is characterized by two very long tunnels which make up for about 90% of the entire line. Table 1 provides a synthesis of measurements, including date, line, duration, number of passengers and largest measured CO_2 concentration.

Table 1. Summary of measurements.

Measurement number	*Date*	*Line*	*Duration (minutes)*	*Number of passengers*	*Largest CO_2 concentration (ppm)*
1	June 4, 2014	c)	80	57	2900
2	June 4, 2014	c)	75	55	2800
3	June 4, 2014	c)	80	37	1600
4	June 4, 2014	c)	85	28	1700
5	November 17, 2015	c)	85	46	1700
6	November 17, 2015	c)	70	60	1700
7	February 2, 2016	c)	75	20	900
8	February 2, 2016	b)	95	45	1200
9	February 2, 2016	a)	40	50	2100
10	February 11, 2016	a)	35	50	2140

Measurements 1 to 9 have been performed using a ToxiRae PGM-1850 CO_2 meter with a resolution of 100 ppm. Measurement 10 has been performed using a P-P CO2000 CO_2 meter, with a higher resolution of 10 ppm. The acquisition rate has been set at 1 every 5 minutes for the former, 1 every 2 minutes for the latter. Nominal accuracy is ± 50 ppm for both meters. Accuracy has been checked by repeatedly carrying out measurements in rural areas where pollution is minimal and the expected CO_2 concentration is around 400 ppm. Sensor readouts have been accordingly corrected based on these calibration results.

3 Results

Figure 1 shows four prototypical time evolutions of the concentration of CO_2.

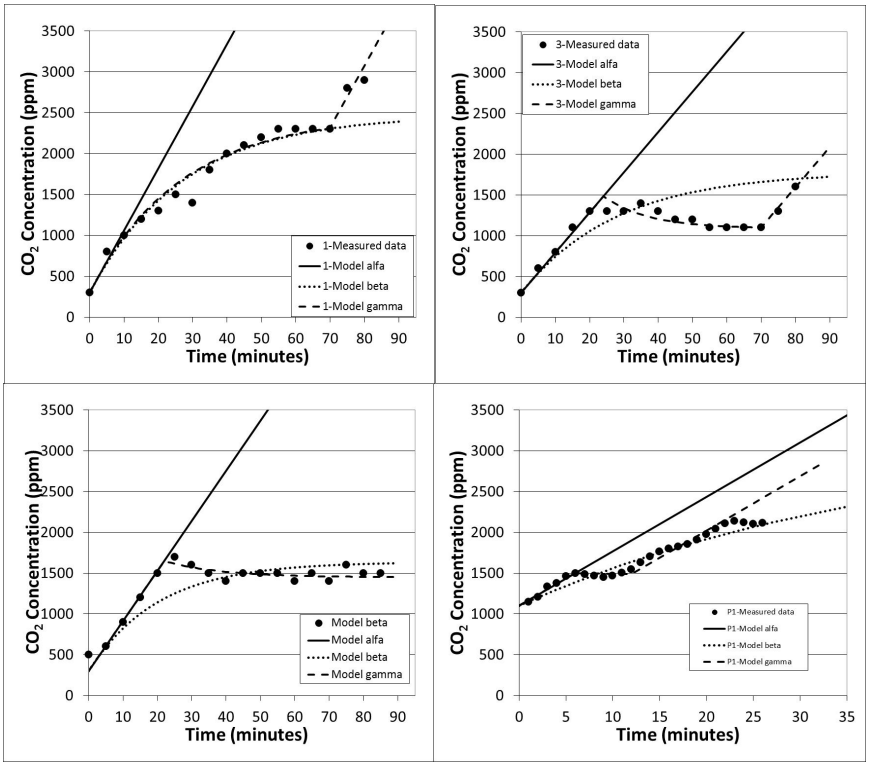


Fig. 1. Time evolution of CO_2 concentration. a) measurement # 1, b) measurement #3, c) measurement # 5, d) measurement #10

Figure 1a shows a steady growth of the concentration with an asymptotic trend that extends throughout most of the trip, followed by a sudden jump in the last ten minutes of the trip. Figure 1b shows a linear growth during the initial part of the trip (around 20 minutes). This is followed by a stage where CO_2 concentration stabilizes first, and then slowly declines. Here again a sudden jump appears in the last ten minutes of the trip. Figure 1c is similar to Figure 1b, but there is no indication of CO_2 declining at any stage and no discontinuity in the last minutes of the trip. Figure 1d shows a steady growth of the CO_2 concentration that continues for the entire trip duration. This latter measurement has been performed on line a) where two very long tunnels account for about 90% of the trip length. Figure 1d shows that very limited ventilation is provided when the train is in the tunnel, which leads to a significant CO_2 buildup. The same behavior is observed in measurement # 9 also carried out on the same line. This might be due to technical difficulties in supplying large quantities of fresh air while the train is inside long tunnels.

4 Discussion

4.1 Predictive models

Measurements have been carried out on non-stop trains, which keeps the number of passengers in a car roughly constant. Also constant has been assumed to be the metabolic activity of passengers, set equal to 0.95 met, which is the value given in Table B.3 of ISO 8996 [10] for seated subjects. With this metabolic activity, the rate of immission of CO_2 in the environment is $R(CO_2) = 14.7$ l/h per person [11].

Three simple predictive models have been tested in order to gain insight into the actual operating scheme and effectiveness of the ventilation system.

Model α assumes zero air inflow (Q = 0). Model α has no free parameters and exhibits a linear growth of the CO_2 concentration in time

$$CO_2 = (CO_2)_{start} + \left[\frac{N_S R(CO_2)}{V}\right] \times t \tag{1}$$

where N_S is the number of subjects in the coach, V is the effective coach volume, $R(CO_2)$ is the emission of CO_2 by each subject, which in its turn is linearly proportional to his/her metabolic activity.

Table 2. Summary of best-fitting model parameters.

Measurement number	*Model α*	*Model β*	*Model γ*	
	Q *(m^3/h)*	*Q* *(m^3/h)*	*Q/t1/t2* *(m^3/h)/min/min*	*χ2*
1	0	370	373/3/69	1.81
2	0	225	318/31/70	1.81
3	0	530	687/23/70	0.38
4	0	490	656/30/70	1.04
5	0	425	584/22/85	0.66
6	0	660	785/13/70	3.03
7	0	775	820/5/65	1.33
8	0	850	847/1/95	0.72
9	0	95	95/1/40	0.83
10	0	250	722/6/11	1.54

Model β assumes a single, constant air inflow rate (Q = constant) for the entire duration of the trip. The air inflow rate is the only free parameter of the model. The time evolution of CO_2 according to model β is

$$CO_2 = \frac{A}{B} - \left(\frac{A}{B} - (CO_2)_{start}\right) \times e^{-\frac{B}{t}} \tag{2}$$

where

$$A = \frac{N_S R(CO_2)}{V} + \frac{(CO_2)_{ext} Q}{V}, \qquad B = \frac{Q}{V} \tag{3}$$

Model γ assumes that the air inflow rate is either zero or a constant value. This model has three free parameters: the non-zero air inflow rate Q and the two times, t_1 when the airflow rate becomes non zero and t_2 when the airflow gets back to zero. The time evolution of CO_2 has been calculated using a combination of equation (1) in the absence of air immission and equations (2) and (3) with non-zero air immission.

Each of these models has been fitted to the CO_2 concentration data collected during each measurement. Table 2 summarizes the model parameters Q (m^3/h), t_1 and t_2 (minutes) which give the best fit to data. Model α and model β usually provide very poor overall fits to experimental data, although they can be adequate for limited fractions of the trip duration. Model β also provides a good overall fit to measurements 7, 8 and 9.

Model γ performs appreciably better and is often quite accurate. The quality of the fits to the experimental data using model γ has been objectively assessed using the $\chi 2$ statistics, also included in Table 2.

Best fitting models (α, β and γ) are also graphically shown in Figure 1 using lines of different styles superposed on experimental data (filled dots). The visual comparison between measured values on one side and model predictions on the other clarifies that models α and β are just too simplistic to provide an acceptable description on the time evolution of the CO_2 concentration. The fact that model γ can actually reproduce at least the general trend of measurements implies that the ventilation system is actually operated based on some sort of either manual or automatic active feedback mechanism. A more extensive experimental campaign is in progress in order to gain a deeper insight into this issue.

4.2 Acceptability of CO_2 levels

Table 2 shows that the largest CO_2 concentrations reached during the trips range from 1000 ppm up to almost 3000 ppm. In four trips the maximum level has exceeded 2000 ppm and in two of such cases the level has been above 2200 ppm for an extended period of time. In order to gauge the acceptability of such levels, it is fundamental to select the appropriate limit value. Unfortunately, there is currently no threshold value for CO_2 concentration specific for trains, in italian or international standards. The recent European standard EN 16798-1 includes in its Table I.4 four values of CO_2 concentration for four different categories, hare replicated in Table 3. The standard is conceived so that it can be used both for design and for assessment, so despite the fact that the values are officially quoted as "default design CO_2 concentrations", they can be applied to assessment as well. Also EN 16798-1 nominally deals only with buildings. However, from the point of view of IAQ perception it is hard to see any difference between a building an a train coach: both should be designed and operated so that people can live and/or work therein for extended periods of time, with near optimal performance and acceptable global comfort conditions.

Table 3. Limit values of CO_2 concentration in environments with different quality requirements (from EN 16798-1).

Category	Corresponding CO_2 concentration above outdoors in PPM for non-adapted persons
I	550 (10)
II	800 (7)
III	1 350 (4)
IV	1 350 (4)

Based on these considerations it appears not only reasonable but also legitimate to apply the values of Table 3 inside the high speed train coaches that form the target of this investigation. Because category III is identified by EN 16798-1 as the appropriate category for environments where occupants have "low expectations", the associated differential (indoor-outdoor) concentration of 1350 ppm has been selected as the relevant limit value for the standard class high-speed train coaches investigated in this study. This is indeed a fairly relaxed limit, and future reconsideration of train coach comfort might well opt for the more stringent category II limit. Because the typical outdoor CO_2 concentration in rural areas is about 400 ppm, this corresponds to an effective indoor CO_2 limit concentration of 1750 ppm. Table 2 shows that even this "generous" limit value has been exceeded in four out of the ten cases reported in this study, which implies that poor IAQ is by no means an exception aboard high-speed trains. This is unfortunate since many people use the train journey to study/work, and the quality of their learning performance is likely to be negatively impacted [2 – 4]. Qualitatively, it also possible that this might contribute to a less than ideal performance during the day.

The results of this study are in line with the results of a similar work carried out on long-distance buses [12] where even larger concentrations were found. Although high-speed trains and long-distance buses have widely different characteristics in terms of technology, design and operating costs and ultimately expected level of comfort, both often fail to provide an even acceptable comfort to passengers in terms of IAQ.

5 Recommended action and conclusions

As discussed in a previous section, high-speed trains are challenging environments for creating and maintaining comfort conditions, due to the large density of subjects. However, because of two favorable characteristics, the constant density of subjects in a coach and the constant metabolic activity of subjects, they are amenable to relatively simple ventilation strategies. The most simple-minded approach would be to keep the air immission rate set at a constant level for the entire trip duration. Because this level should be a function of the number of passengers, and the latter is not known a priori, this might be a somewhat impractical solution. An alternative and more viable option is a CO_2-based ventilation strategy. The system would then operate like a traditional heating system on the combination of a lower and a higher set point. The air immission rate would increase when CO_2 sensors indicate level near the threshold of acceptability (the high set point, 1750 ppm), and would decrease when the environmental CO_2 concentration drops below the low set point (indicative value around 1200 – 1400 ppm). As a final remark, it is recommended that the ventilation system is not switched-off during stops, which appears to occur now. Relying on the natural ventilation induced by door opening and by the inflow/outflow of passengers from the coaches leads to wildly fluctuating and unpredictable ventilation rates.

References

1. Zhang X., Wargocki P., Lian Z., 2015. Physiological responses to carbon dioxide and human bio-effluents. Proceedings of the 11th International Conference on Industrial Ventilation, Shanghai, China, October 26-28, 2015, pp. 70-78.
2. Wyon D.P., Wargocki P. Effects of indoor environment on performance, 2013. ASHRAE Journal March 2013, 46-50.
3. Allen J.G., Mac Naughton P., Satish U., Santanam S., Vallarino J., Spengler J.D., 2015. Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers: A Controlled Exposure Study of Green and Conventional Office Environments. Environmental Health Perspectives, 124(6), 805-812.
4. Satish U., Mendell M.J., Shekhar K., Hotchi T., Sullivan D. Streufert S., Fisk W.J., 2012. Is CO_2 an indoor pollutant? direct effects of low-to-moderate CO_2 concentrations on human decision-making performance. Environmental Health Perspectives, 120(12), 1671-1677.
5. Cho Y., Kwon S.-B., Park D.-S. Analysis of indoor air quality in high speed train passenger cabin in Korea, 2007. Proceedings of Conference IAQVEC 2007, Sendai, Japan, October 28-31, 2007.
6. Kwon S.-B., Cho Y., Park D.-S. Relationship between carbon dioxide concentration and presence of tunnel section of the high speed train passenger cabin in Korea, 2007.Proceedings of Conference IAQVEC 2007, Sendai, Japan, October 28-31, 2007.
7. Xu B., Cui P., Xu H., Chen H., Lin Y., 2013. Commuter exposure to particle matter and carbon dioxide inside high-speed rail carriages. Transportation Research Part D, 20, 1-6.
8. Lee Y.-I., Park D., Hwang D.-Y., Jeong W.-S., Barabad M. L., 2015. Prediction of CO_2 concentration in Korea train express (KTX) cabins. International Journal of Environmental Monitoring and Analysis, 3(1), 17-21.
9. CEN Ergonomics of the thermal environment – Indoor environmental input parameters for the design and assessment of energy performance of buildings. EN Standard 16798-1. Brussels: European Committee for Standardization, 2017.
10. ISO Ergonomics of the thermal environment – Determination of the metabolic rate. ISO Standard 8996. Geneve: International Standardization Organization, 2004.
11. ASHRAE Ventilation for acceptable indoor air. ASHRAE Standard 62-1. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2016.
12. del Gaudio M., Lenzuni P., Qualità dell'aria nei mezzi di trasporto pubblici su gomma, 2016. Rivista Italiana di Ergonomia, Special Issue 1/2016 – Proceedings of the 11th Congress of the Italian Ergonomics Society, Naples 2016, pp. 59-64 (in italian).

Solutions for improving aircraft passengers' experience during boarding and disembarking

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Abstract: Efficient boarding of aircrafts is critical to ensure planes make as many fly hours per day as possible, but fast boarding also keeps passenger satisfaction at a high level. Interferences during the boarding procedure are one of the main reasons of delay and increase of turnaround time, becoming a relevant problem for airline companies. Observations of the boarding process, at the gate as well as inside the aircraft, revealed the main bottle necks in the boarding process: (1) Hand luggage: Storage space is not sufficient and/or not used efficiently; (2) Preparation: Passengers are not well prepared for the boarding process; (3) Communication: Audio announcements are unclear and unfocused; (4) Navigation/Way finding is complex. Translating these bottle necks as possibilities for improvement, a group of 15 students have been asked to design solutions for the airport and aircraft interior that reduce boarding and disembarking time and improve the passenger boarding experience. Concepts ranged from an app to scan your hand luggage at home and make a reservation for overhead bin space; to a redesigned waiting area to help passengers prepare for boarding; to new boarding methods and redesigned aircraft seats. In this paper, several design concepts are presented in more detail.

Keywords: passenger experience, hand luggage, boarding, aircraft interior

1 Introduction

Efficient boarding of aircrafts is critical to ensure short turn-around times, thereby also increasing the efficiency of flight schedules, since airplanes are able to make more flying hours per day [1]. Interferences during the boarding procedure are one of the main reasons of departure delays, thereby increasing the turn-around time, and leading to higher costs. Hence, passenger boarding is becoming a relevant problem for airline companies. Reduced boarding times might also affect passenger satisfaction; if waiting time and stress at the airport can be reduced, passenger experience can be improved.

Although a lot of research has been performed on the effectiveness of different boarding methods [2], the focus of these studies is to optimize the time of getting passengers into an airplane, as a process flow. However, not all effective boarding strategies are passenger-friendly, since most boarding methods separate passengers that are travelling together [3], while about 50% of all aircraft passengers travel in groups (two or more persons) [4]. Next to that, boarding methods are often simulated in an ideal situation, e.g. 100% conformity, but do not take into account actual passenger behaviour [5], or their comfort experience.

Therefore, the goal of this study is to, first, observe actual passenger behaviour during boarding process of an aircraft (at the gate as well as inside the aircraft) and measure the effect on comfort experience; and sec-

ond, to design solutions for the airport and aircraft interiors that reduce boarding and disembarking time while at the same time improving the passenger boarding experience.

2 Method

Three groups of five Industrial Design Engineering master students from Delft University of Technology were asked to study the main bottlenecks in current boarding behaviour of aircraft passengers. In the second phase, the fifteen students individually designed concepts in order to reduce boarding and disembarking time while at the same time improving the passenger boarding experience.

2.1 Passenger behaviour at the gate

One of the student groups observed two boarding procedures performed by KLM Cityhopper (KLC) at Amsterdam Schiphol Airport (AMS), the Netherlands, at gate B16 specifically. This is a self-boarding gate, meaning that passengers scan their own boarding pass, after which the gate opens to pass through in order to get to the airplane. The flights were within Europe, short to medium distance, performed by single aisle layout aircrafts such as the Airbus A320. The number of participants observed was roughly 70 passengers for each flight, thus 140 in total.

Audio recordings together with observations were used to analyse passenger behaviour, concerning adequacy and clearness of guidance provided by the airline to the passengers waiting to board through the gate. Audio announcements were recorded with a sound recorder (model Roland R-09). The background noise at the gate was also measured with the sound recorder. The recordings were divided by audibility and relevance of the information concerning passengers boarding through the specific gate B16. Visual communication of information (e.g., digital information screens above the gate) was photographed and described.

2.2 Passenger behaviour inside the aircraft

The other two student groups observed passenger boarding behaviour inside the aircraft. One of the student groups observed the boarding process of two KLM Royal Dutch Airlines flights; the other group observed passenger behaviour as well as conducted a questionnaire aboard a Boeing 737-800 (single aisle aircraft) on three different flights operated by Transavia.

2.2.1 KLM flights

Since filming was not allowed due to privacy restrictions, during the boarding procedure two observers were assigned to a location inside the aircraft by the purser (one at the front and one in the middle of the aircraft). From their fixed location, one of the observers took notes while the other observer completed a predefined template regarding causes of interference. Two different types of aircrafts were observed: one single-aisle Boeing 737 (AMS-SVO, 163 passengers) and one dual-aisle Boeing 777-300 (AMS-SAO, 387 passengers). The flight to Moscow (AMS-SVO) had been selected since this is often a hand luggage critical flight, whereas for the flight to Sao Paulo (AMS-SAO), passengers tend to take oversized luggage and extra bags with them on this flight which often leads to a chaotic boarding process.

The predefined template consisted of possible causes of delay with regards to hand luggage and time spent on it: weight of hand luggage, height of the overhead compartments, unprepared passengers, jackets (undressing), no available space, and relocating luggage.

2.2.2 Transavia flights

Passenger behaviour was observed aboard a Boeing 737-800 (single-aisle aircraft) on three different flights operated by Transavia (AMS-PSA, AMS-BCN, BCN-AMS). Additionally, questionnaires were distributed among the passengers.

Observations

On each flight, there were two observers who boarded before the passengers started boarding. Per flight, the actions during boarding of all passengers and crew members interacting with or passing six rows of seats were observed. The observations started when the first passengers started to board the aircraft and continued until pushback (airport procedure during which the aircraft is pushed back from the gate). The observations were focused on the interactions the passengers had with others and the items they carried, before being fully seated. In addition, announcements and unexpected events were noted. When interactions or events caused a queue in the aisle, this was also noted. Pen, paper, and a list of abbreviations for predefined interactions were used to write down the observations. Google Spreadsheets was used to process the data.

Questionnaires

During the three different flights, in total 261 passengers (43% male, 56.2% female) aged 12 years and older (M=41.8 years, SD=18.1) completed the questionnaire. On each flight there were four crew members and a maximum of 189 passengers on board. Questionnaires were distributed inside the airplane cabin, after take-off. The questionnaire asked passengers about their nationality, gender, and age; purpose of their flight; rating their feeling and experience before and during the boarding process; the complexities they experienced while boarding; and their expectations regarding the boarding process. Stress before boarding, Stress during boarding, Difficulty level, Expectations and Experience were measured using a 5-point Likert scale. Data was processed using SPSS and Google Spreadsheets. The interferences (i.e., factors that make the boarding process complex) were measured using open questions.

2.3 Design opportunities

The same group of 15 students have been asked to translate the bottle necks from the observations and questionnaire results into possibilities for improvement, and to design solutions for the airport and aircraft interior that reduce boarding and disembarking time and improve the passenger boarding experience.

3 Results

3.1 Passenger behaviour at the gate

Current auditory and visual communication methods have low focus, low relevance and are not up to date. Only 27% of the announcements that could be heard at the gate were relevant to the passengers boarding via that gate. In the gate area, audio announcements are currently the main means of communication between airline and passengers; however, information is easily lost because of the loud background noise, and passengers that do not pay attention to the announcements.

From interviews with gate agents at the gate area at Amsterdam Schiphol Airport, it became clear that face-to-face communication is preferable when giving personalized and relevant information to individual passengers.

3.2 Passenger behaviour inside the aircraft

3.2.1 KLM flights

For the hand luggage critical flight (AMS-SVO), crew had already labelled the luggage that possibly would not fit in the overhead compartments in advance at the gate, to prepare for possible relocation to the hold. Typical for the AMS-SAO flight was the large number of shopping bags from the airport which needed to be stored in the overhead bins. Shopping bags (tax-free items) are causing problems since these do not have to fit the hand luggage size and weight requirements. Specifically for the double-aisle aircraft (AMS-SAO flight), it was observed that passengers travelling together and are seated in the middle row enter this row from the same aisle, and also stow their luggage on this side only, resulting in one side being overloaded while the opposite one is almost empty. Because of this, passengers might need to relocate their belongings to the other aisle. If passengers would be aware of this situation, this can be avoided.

From the observations it became clear that the most time consuming problems are: relocating seat or luggage, taking off jackets/clothes, and rearranging personal items in the luggage. This last one is also occurring the most often. A lot of passengers enter the plane unprepared and seem to decide what they want to have with them in the seat in the aisle. Although passengers are meant to put loose belongings, like a jacket, underneath their seat, passengers prefer to store these in the overhead bins. Passengers are taking off their coat/jacket in the aisle, and multiple passengers were reorganizing the contents of their bags and deciding what they needed at their seat, while blocking the aisle for other passengers. In business class, much less aisle interference occurred, as people have more space to pass each other and overall have more freedom of movement. Also, experience might play a role since frequent flyers are more efficient in boarding.

Another conclusion is that the first boarding passengers caused immediate queuing. The first people to board seemed to take more time during boarding, possibly due to unawareness since the queue is forming behind them (out of sight).

3.2.2 Transavia flights

Observations

The disruption of flow is mainly caused by luggage and fellow passengers. Most people that put their luggage inside the overhead bins, experienced problem putting their luggage in the bins and took a moment in the aisle to sort personal items out of their luggage. Secondly, communication between passengers is observed frequently. Passengers have discussions inside the aircraft while boarding, for example with fellow passengers on personal belongings (when relocating luggage). Third, it was observed that passengers had trouble putting their luggage into the overhead luggage bins due to other luggage earlier placed. It can be concluded that the overhead bins are too small for the luggage taken on board by the passengers. Another important observation was that announcements about the luggage were not spread optimal over the boarding time. Passengers did not hear the announcement, because they were either still in the jet way or already seated.

Questionnaire

Luggage, fellow passengers, stress, expectations, and experience are factors of perceived complexity. Most comments were made about luggage (11.1%), fellow passengers (9.6%) and queue formation (6.9%). Lack of communication between fellow passengers and between passengers and crew, about the placement and sorting of the luggage. These factors lead to a disruption of the flow of passengers.

3.2.3 Main bottlenecks

From the observations at the gate and observations and questionnaires inside the aircraft, four main bottlenecks have been defined to be used as a starting point for design solutions:

(1) Hand luggage: Storage space is not sufficient and/or not used efficiently;
(2) Preparation: Passengers are not well prepared for the boarding process;
(3) Communication: Audio announcements are unclear and unfocused;
(4) Navigation/way finding is complex.

4 Design solutions

The four main bottlenecks have been translated to design opportunities as a starting point for the ideation: Make better use of available space for hand luggage; Help passengers prepare for the boarding process; Use more focused and clear communication; and Give passengers more guidance and reassurance. Below, several ideas and design concepts are presented in more detail.

4.1 Make better use of available space for hand luggage

The main cause of interference and delay regarding the process of storing hand luggage during boarding seems to be that passengers are not prepared and are taking off jackets and rearranging personal items from their bags in the aisle. Passengers lack awareness that they might be delaying the flight and might even cause greater delays if the aircraft misses the appointed time slot. One of the solutions is to make hand luggage storage more accessible during the boarding procedure for all passengers, for example by providing a close and clean storage to put personal belongings inside or near the seat, leaving more space in the overhead bins. The luggage can be distributed more efficiently by creating a feedback system for passengers and their luggage, e.g. by indicating free available space. Making it possible to reserve bin space might also prevent discussions with crew or other passengers about personal belongings. Furthermore, to help passengers sort out their luggage (items they need during the flight), a travel organizer was designed to put all personal items into one bag/compartment that can easily be taken out to prevent people blocking the aisle.

Another solution is to create an app for passengers to measure their hand luggage at home by taking a picture (Fig. 1). The passenger can receive feedback whether their luggage is allowed on board, and whether it fits. For the airline, the additional advantage is a possible forecast of hand luggage that passengers will carry.

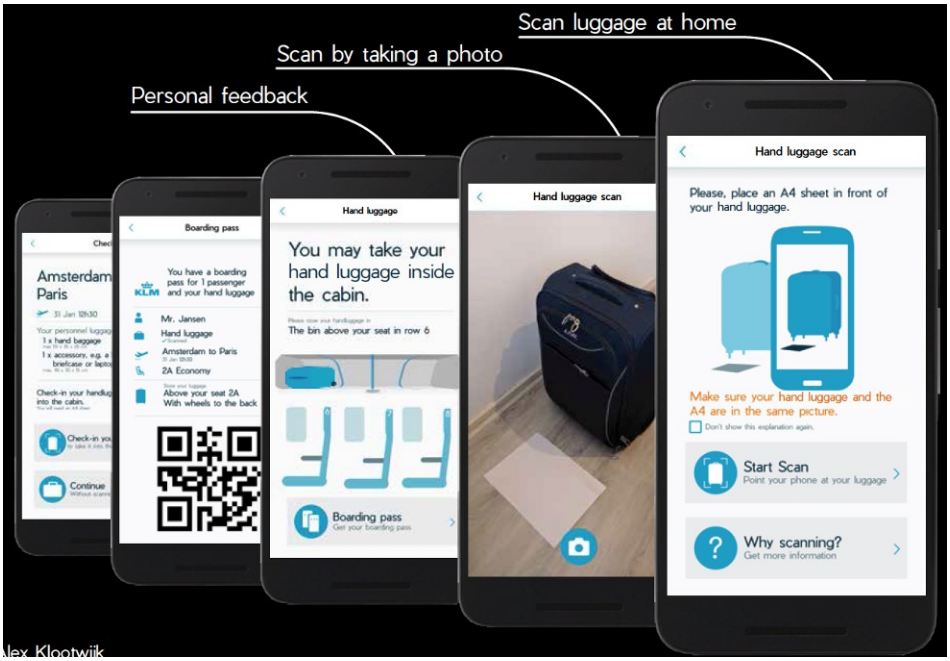


Fig. 1. Scan hand luggage at home with an app to get direct feedback whether or not luggage will fit *(by: Alex Klootwijk)*

4.2 Help passengers to prepare for the boarding process

Creating more awareness on the influence passengers have on a smooth boarding process and on-time departure and thereby changing their behaviour is one of the solutions. One of the options to help passengers prepare is by making better use of visual communication means (e.g. LCD screens at the gate). But, awareness and preparation is not only relevant at the gate, also at home, while packing the luggage, or even while booking tickets. A journey guidance app could give personalized information, e.g. by providing packing tips, and showing the boarding process with possible disturbances.

At the gate, passengers usually are in a waiting and relaxing mood. More towards the plane, their attitude is changing from relaxed to hurried, and personal space is compressed. Inside the plane, the personal space is even more compressed. Therefore, the ideal moment for passengers to be open to suggestions and communication is at the gate. The waiting time can be used as preparation time, and by projecting informative visualisations onto the floor at the gate area, passengers are encouraged to, for example, in advance take off their jackets, or take out the items they need during the flight (Fig. 2).

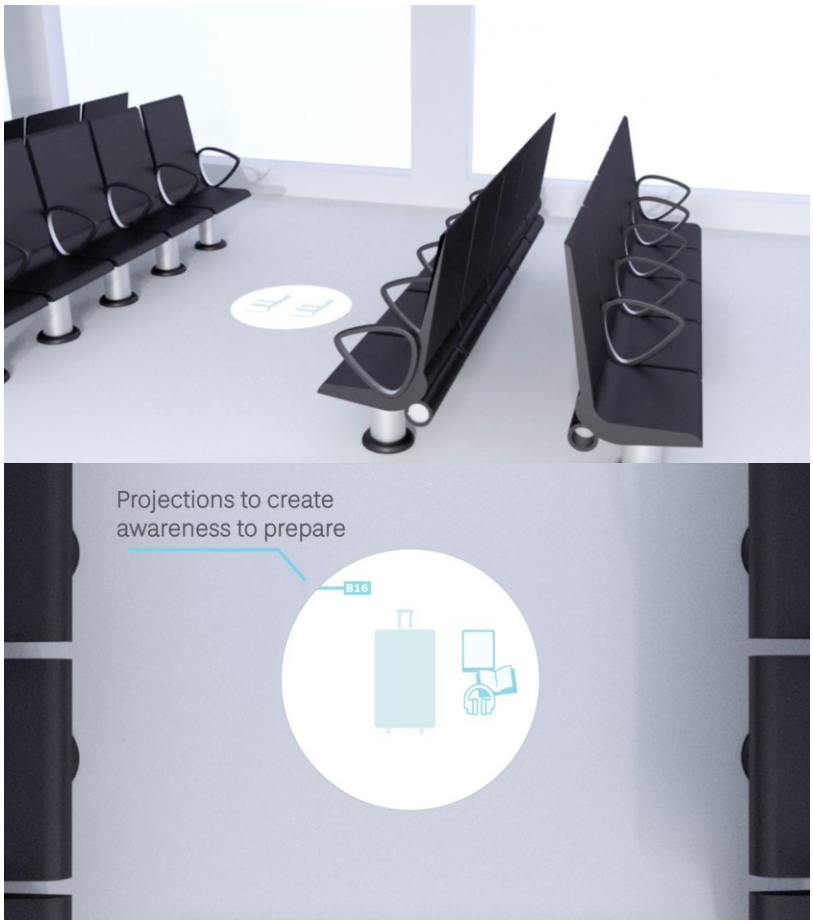


Fig. 2. Information projection at the gate area to make passengers aware how to prepare for boarding *(by: Petek Tezcan)*

4.3 Use more focused and clear communication

Opportunities for a more focused and clear communication with airline passengers are for example a personalised information feed, or showing an instruction video at the gate area on how to prepare/how to board. Reducing audio announcements to create a "silent airport" terminal can lead to a more pleasant waiting time. In order to achieve this, other communication media should be used, such as video's, or more innovative: lighting. Using lighting as a means of communication is effortless for passengers. Lighting can be projected onto the floor so it catches attention when people are looking down onto their smartphones, and change when boarding gets closer. Lights have a certain flow and direction, different for the different phases until boarding starts, to make passengers feel that they need to move and take action. Due to the surprising effect, it offers passengers a new experience and might provide a better mood (Fig. 3).

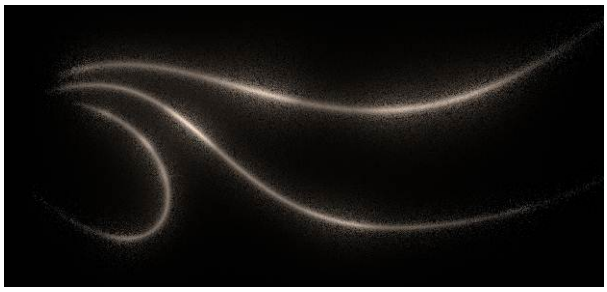


Fig. 3. Lighting as a means of communicating urgency (time) and direction (flow) by pulsating movements *(by: Magnus Pettersson)*

4.4 Give passengers more guidance and reassurance

Passengers are less stressed when they know what to expect, meaning an app could guide them through the entire journey. It could also guide each passenger when to board by allocating timeslots, and motivate passengers to board on time by using incentives (e.g., discount on in-flight purchases). Another design opportunity is the way finding, specifically the in-plane signage, for example by making the seat numbers visible on the seats, e.g. with LED lighting or printed on antimacassars. Furthermore, the point of view when selecting a seat on the aircraft does not represent the actual 3D environment. Providing a 2.5D/3D seat map or an indoor navigation app using augmented reality (AR) or even a personalised notification light [6] could help passengers to find their seat more easily.

5 Discussion

The design concept solutions presented here are to be used as inspiration and although they seem promising, further study is needed to investigate the feasibility of the concepts. Research is needed on how it is functioning in an actual operating environment (e.g. during flight/boarding process) and whether it indeed affects passenger experience in a positive way.

Due to privacy concerns, observations at the gate and inside an aircraft were performed using pen and paper instead of video observations. Most observations were done in the back end of the aircraft, while most flow disruptions occurred in the front of the plane, which was not clearly visible to the researchers.

It also became clear from the research that every flight has its own specifics. The jacket interference (thick winter coats) and tax free shopping items, for example, are issues related to season and destination, whereas there were also hand luggage problems observed specifically for double-aisle aircrafts.

The study by De Lille et al. [7] also shows that there is a need to improve passenger comfort during luggage stowage when boarding. A possible reason for this could be the uncertainty regarding room for the hand

luggage. One of their concepts was a multi-functional tray table, which has storage possibilities but could be used as a normal table when the top level is closed. The tablet, a phone, music player or magazines could be inside the tray table, fixed with elastic strips.

6 Conclusion

Observational research on actual passenger behaviour during aircraft boarding has revealed that main bottle necks are hand luggage, lack of preparation, communication and navigation/way finding. In this paper, several design concepts have been presented in more detail, including an app to scan hand luggage at home, information projection at the gate area to make passengers aware on how to prepare for boarding, and using light instead of audio as a means of communication.

This paper has shown that there are other design opportunities, beside boarding strategies, for airport and aircraft interiors to reduce boarding time. Unlike most boarding methods, this will be able to improve passenger experience and does not require additional actions or touch-points.

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Glossary: The abbreviations used in this study to indicate flights are 3-letter IATA codes of the following airports: Amsterdam Airport Schiphol (AMS), Barcelona Airport (BCN), Pisa (PSA), Sao Paulo (SAO), Moscow Sheremetyevo (SVO).

References

1. Steffen, J. H., 2008. Optimal boarding method for airline passengers. *Journal of Air Transport Management*, 14(2008): 146–150.
2. Jaehn, F., Neumann, S., 2015. Airplane boarding. *European Journal of Operational Research*, 244(2): 339–359.
3. Ferrari, P., Nagel, K., 2005. Robustness of efficient passenger boarding stragies for airplanes. *Transportation Research Record*, 1915(1): 44–54.
4. Bazargan, M., 2011. A linear programming approach for wide-body two-aisle aircraft boarding strategy. *International Journal of Operations and Quantitative Management*, 17(3): 193–210.
5. Schultz, M., Kunze, T., & Fricke, H., 2013. Boarding on the critical path of the turnaround. In: *Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM'13)*, June 10–13, 2013, Chicago.
6. Akkerman, S., 2016. Improving Boarding Efficiency and Experience. MSc Thesis, Delft University of Technology.
7. De Lille, C., Santema, S., Bouwens, J., Schultheis, U., Vink, P., 2016. Designing the cabin interior knowing high and low peaks in a passenger flight. *AEGATS 2016 conference*, April 12-14, 2016, Paris, France.

Effect of specific characteristics on overall impression of business footwear

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Abstract

Comfort perception is important in footwear development, as it may impact customer purchasing decisions and satisfaction with the shoe. However, little is known about which features of a shoe actually generate comfort. While athletic and casual footwear have been subject to comfort perception studies, other types of shoes (e. g. business footwear) have been widely disregarded. Therefore, this study aims to investigate the importance and interdependence of comfort-related and biomechanical characteristics of business shoes. 187 male subjects (age: 39.1 ± 13.7 years) gave subjective ratings on specific characteristics of business shoes using an electronic questionnaire. Subjects were asked to rate overall impression (OI), overall fit (FIT), pressure marks (PM), cushioning (Cush), upper flexibility (UpFlex), and sole flexibility (SoleFlex). Cush, UpFlex, and SoleFlex were rated regarding perceived importance, magnitude, and liking. All ratings were given on visual analogue scales except for PM. Instead, a graphic representation of a foot was used to locate PM, and total number of PM was extracted as the target variable. Spearmans Rho (r_s) was calculated to investigate the relationship between magnitude and liking of Cush, UpFlex, and SoleFlex. Predictability of OI was tested using linear regression with FIT, PM, and likings of Cush, UpFlex, and SoleFlex as predictor variables. SoleFlex, UpFlex, and Cush were rated similarly in importance (median: 79 to 81, IQR: 20 to 24). Magnitude and liking were in stronger relation for SoleFlex (rs = 0.69) and UpFlex (rs = 0.77) than for Cush (rs = -0.53). FIT had the highest influence on the predictability of OI (R^2 = 0.48) in univariate analyses. A multivariate regression including all variables except for PM only marginally increased the explained variance in OI to R^2 = 0.52. The results indicate a preference for flexible soles and uppers, and a tendency towards softer cushioned soles in business footwear. Furthermore, linear regression results confirm the importance of FIT on OI, and the complexity of assessing subjective comfort-related parameters in footwear settings. It is still unclear whether OI, comfort, and fit perceptions are based on the same semantic construct. Ergonomic comfort models provide theoretical frameworks to increase predictability of comfort, e. g. by including expectations, which were not considered in our study.

Keywords: Comfort, Fit, Flexibility, Subjective Ratings, Business Footwear

1 Introduction

Besides mechanical and biomechanical tests, subjective comfort perception is an important parameter in footwear development, as it may impact customers' purchasing decision and satisfaction with the shoe [1]. Comfort is an individually defined construct, which emerges as an interaction of subjective perceptions (e. g. physical, physiological or psychological) with environmental factors [2].

There are many theoretical frameworks in human factors that focus on the genesis of comfort and discomfort perception [3–7]. The comfort model of van Veen und Vink [6] illustrates the interaction of environmental factors, previous sensations, and expectations in generating comfort perception outcomes (Fig. 1). 'The expectations of the user and the human body effects result in the perception of the product or environment. These perceived effects influence the interpretation of the experiences as 'feeling comfortable', 'no feeling' or 'feelings of discomfort'.' [6].

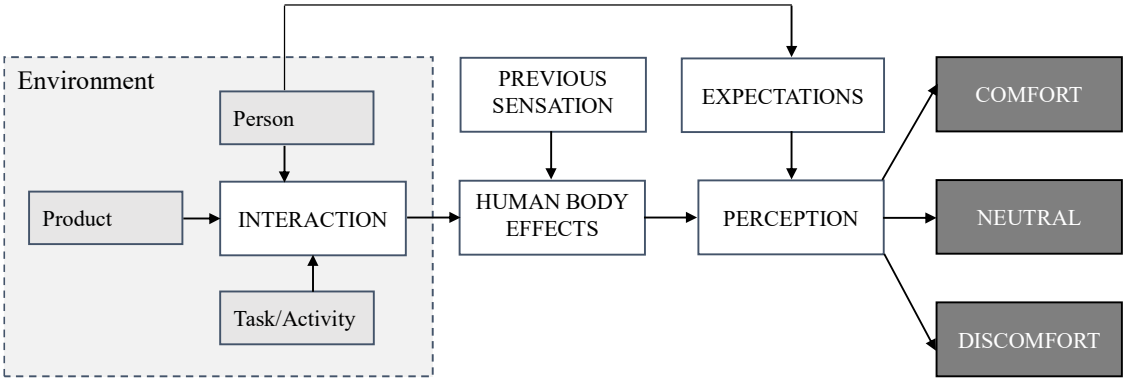


Fig. 1. Comfort model according to van Veen & Vink [6]

However, it is of particular interest and still unclear whether the global construct 'comfort' can be dissected analytically into a set of specific product characteristics and perceptive sub-categories. If so, analytical approaches to footwear comfort prediction based on specific shoe features could be used for product development as well as mass customization of footwear.

For athletic footwear (e. g. running shoes), fit, cushioning/shock absorption, (arch) support, stability, and/or pronation behaviour are typical items considered to be relevant for subjective footwear evaluation [8, 9]. A more generic approach to footwear characteristics includes overall comfort, thermal comfort (e. g. humidity sensation, foot ventilation), aesthetics, flexibility, ease of use, belief (brand, reputation), waterproofness, sole hardness, weight, flexibility, lacing, design, and different sub-characteristics of fit (e. g. heel fit, toe box volume, and length) [10–13].

To our knowledge, there are no studies on the comfort perception of business footwear. Unlike with athletic footwear, business footwear is still designed in a gender specific way to accommodate fashion stereotypes. Heel height in women's business footwear is an additional parameter that most likely has a massive influence on comfort perception. In order to eliminate this factor, the present study was designed in the context of men's business footwear.

A literature search on footwear comfort perception and its potential sub-categories reveals a lack of publications in this area. Only few studies are available, that provide insight on possible associations of footwear features, sub-categories of comfort and overall comfort perception. Tay et al. [8] reported a good predictability of overall preference in running shoes (between 77.7 % and 81.6 %) by using the footwear perception factors fit, cushioning, arch support, and stability in a multiple regression model. In another study on trekking boots, thermal comfort was not associated with overall/general comfort [10]. Studies relating footwear comfort to footwear biomechanics were considered irrelevant for our study, since our focus was put on predicting overall comfort from its sub-categories, not from objective measurements (e. g. of pressures or forces).

With Tay et al. [8] being the only usable approach for our purpose, we used a similar study design with a modified set of variables to assess the predictability of overall impression of men's business footwear.

2 Methods

The study was carried out in shoe stores in six different cities across Germany. 187 male subjects (age: 39.1 ± 13.7 years, height: 180.7 ±6.7 cm, weight: 82.0 ± 15.3 kg) were asked to evaluate business shoes the same way they would if they were to buy a new pair of business shoes. Any form of orthopaedic foot disease was considered as an exclusion criterion.

Study participants were requested to choose their best fitting model out of a set of identical business shoes in different sizes (US 7-10). Subjects were given some time to evaluate the shoes (e. g. walking in the store) before they gave their subjective ratings on specific characteristics of the shoe using an electronic questionnaire presented on a tablet computer.
The questionnaire was subdivided into a general and a specific section. In the general section, subjects were asked about their perceived importance of footwear characteristics like visual appearance, upper flexibility (UpFlex), cushioning (Cush), sole flexibility (SoleFlex), breathability, weight, waterproofness, and price, regardless of the shoe model they chose for testing.
In the specific section, subjects were asked to rate overall impression (OI), overall fit (FIT), pressure marks (PM), Cush, UpFlex, and SoleFlex of the test shoe. These functional parameters were considered relevant as they can be modified during the footwear development process by variation of mechanical properties of materials, construction features, or last shape. Cush, UpFlex, and SoleFlex were rated regarding their perceived magnitude and liking. FIT was omitted from importance ratings since it has already been confirmed as a very important factor in footwear comfort perception [1]. All ratings except for PM were given on visual analogue scales (VAS), which are sensitive to small changes of subjective perception [14, 15] and can be implemented using digital questionnaires. Subjects were asked to mark the VAS according to their perception of the item in question (Fig. 2Fig. 1)

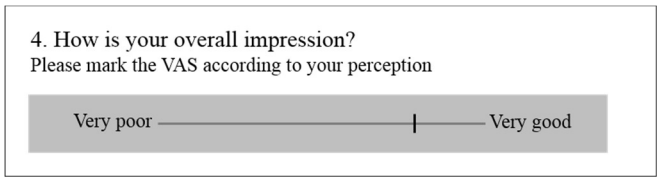


Fig. 2. VAS used in the questionnaire

Tapping the horizontal bar activated the slider, which was invisible initially. Subjects were then allowed to fine tune the slider position as often as necessary.
VAS scales comprised 101 datapoints inbetween the extreme values (0-100). End points were verbalized using 'unimportant' to 'important' for general importance of shoe features, 'poor' to 'excellent' for OI and FIT, 'soft' to 'hard' for magnitude of Cush, 'rigid' to 'flexible' for magnitude of UpFlex and SoleFlex, and 'unpleasant' to 'pleasant' for liking.
The location and frequency of pressure marks (PM) was assessed within the specific section of the questionnaire using a graphic representation of the foot. Subjects were asked to mark all pressure sites on their feet in a dichotomous fashion. Within-subject accumulated PM frequencies were used for analysis.

2.1 Statistical analysis

IBM® SPSS® Statistics Version 24 and MATLAB R2013a (V8.1) were used for data analysis. VAS were assumed to produce skewed data distributions due to their ceiling effects and unipolar design, which was true for OI and FIT. As a conservative strategy, Median and IRQ were used to describe sample data, and Spearman's Rho (r_s) was used to assess the relationships between magnitude and liking of the variables Cush, UpFlex, and SoleFlex, as well as their relationship with FIT and OI. Linear regression was used for analysis of multivariate predictability of OI using FIT, PM, and liking of Cush, UpFlex, and SoleFlex as predictor variables.

3 Results

Fig. 3 depicts the general importance of footwear features of business shoes. Visual appearance is the most important characteristic (median: 90, IQR: 15), followed by Cush, UpFlex, SoleFlex and breathability with slightly lower ratings (median: 79 to 81, IQR: 20 to 24). Weight, waterproofness and price show larger variances

(median: 56 to 68, IQR: 33.5 to 39) and are considered less important. There is no item clearly rated as being unimportant.

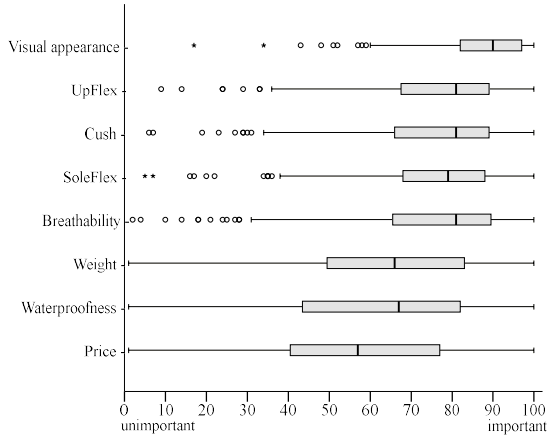


Fig. 3. Importance of business footwear characteristics in general

In general, subjects gave positive ratings about the shoes used in the study. FIT and OI displayed smaller variance (median 60 to 65, IQR 30 to 31) than SoleFlex, UpFlex and Cush (median 56 to 63, IQR 34 to 41). We found slightly stronger relationships between magnitude and liking for SoleFlex ($r_s = 0.69$) and UpFlex ($r_s = 0.77$) than for Cush ($r_s = -0.53$) (Fig. 4).

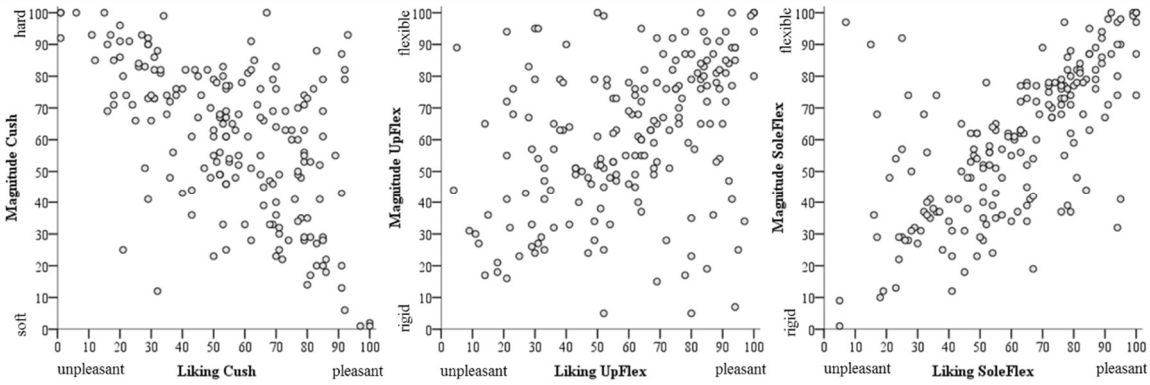


Fig. 4. Scatterplots of liking and magnitude

44.5 % of subjects indicated PM on at least one region in the shoe, with heel (n = 41) and instep (n = 29) being the most affected areas.

Spearman's Rho for liking of Cush, SoleFlex, UpFlex, OI and FIT are illustrated in Table 1. OI and FIT ($r_s = 0.64$) as well as SoleFlex and Cush ($r_s = 0.56$) show the strongest associations. With respect to the linear regression model, FIT, liking of Cush, SoleFlex, and UpFlex qualify as potential predictors of OI, since their intercorrelations are moderate and none of the variables appear to be either too closely related or totally unrelated to OI.

Table 1. Spearman's Rho (r_s) for OI and its potential predictor variables

r_s	*OI*	*FIT*	*Cush*	*SoleFlex*	*UpFlex*
OI	1.00	0.64	0.48	0.44	0.44
FIT	0.64	1.00	0.43	0.34	0.39
Cush	0.48	0.43	1.00	0.56	0.28
SoleFlex	0.44	0.34	0.56	1.00	0.42
UpFlex	0.44	0.39	0.28	0.42	1.00

In univariate regression models, FIT was able to explain the largest proportion of OI variance (adjusted $R^2 = 0.48$) among the variables listed in Table 1. Table 2 contains the results for this particular regression model.

Table 2. Regression coefficients for FIT on OI

Model component	*β*	*SE*	*t*	*p*
1 Intercept	16.31	3.50	4.66	0.01
2 FIT	0.68	0.05	13.10	0.01

A multivariate stepwise regression model including all variables (including PM) indicated that PM was excluded from the best-fit model, and interactions were only of spurious magnitude. However, a robust linear regression model (bisquare weight method) with FIT, and liking of Cush, SoleFlex and UpFlex and no interactions only marginally increased the explained variance in OI to an adjusted $R^2 = 0.52$.

Table 3. Regression coefficients for stepwise analysis

Model component	*β*	*SE*	*t*	*p*
1 Intercept	5.53	4.00	1.38	0.16
2 Cush	0.10	0.06	1.79	0.08
3 SoleFlex	0.09	0.06	1.64	0.10
4 UpFlex	0.18	0.05	3.68	< 0.01
5 FIT	0.49	0.06	8.62	< 0.01

5 Discussion

This study aimed to investigate the relevance of shoe characteristics in business footwear and their impact on overall impression. Visual appearance was rated as the most important aspect in business footwear. SoleFlex, UpFlex, Cush and breathability were rated as being less relevant, although only by a small margin. Weight, waterproofness, and price produced the most variable ratings across subjects and seem to be less important on average.
Subjects preferred flexible over rigid business shoes, as indicated by correlations between liking and magnitude of SoleFlex and UpFlex. However, in contrast to other shoe types (e. g. running shoes) the preference of more cushioned footwear was less pronounced in business shoes.

Almost half of the subjects indicated the presence of PM when evaluating their test shoes. Despite the large number of subjects indicating PM, participants still gave predominantly positive ratings for FIT. The most frequent location of PM was found in the instep area, a portion of the shoe with greatest adaptability to the foot. In summary, PM did not contribute as much to OI as the authors initially expected. One reason for this may be the way PM was assessed (dichotomous variable, no magnitude). Another reason might be the fact that PM are probably more related to discomfort than to comfort perception. Neither discomfort nor any interaction of PM and pre-existing subjective expectations of business footwear fit were included in our study, and thus we were unable to uncover any potential relationships between those variables. It is for future studies to examine the distinct relationship between PM, (dis-)comfort perception, and subjective expectations of business footwear.

Based on the results of this study, FIT seems to be the best univariate predictor for comfort perception in business footwear. Multiple regression results including SoleFlex, UpFlex and Cush only marginally improved the overall proportion of explained variance in OI. While SoleFlex, UpFlex, and Cush can be easily modified in shoe design but demonstrate a lack of impact on OI, the semantically fuzzy construct of FIT explains most of the OI variance, but is hard to causally attribute to modifications in shoe design. Future studies should investigate the nature of FIT, its sub-categories and the influence of specific shoe characteristics on the perception of FIT.

Summarizing our results, the following aspects are proposed to improve the predictability of OI in future studies:

1. The most important variable in business footwear – **visual appearance/aesthetics** – was not included in the specific part of our study where subjects were able to rate the test shoes. Other studies propose a relationship between aesthetic aspects and comfort perception [7, 16]. In order to assess and explain possible interaction effects of aesthetics with other shoe features (e. g. flex characteristics), it is recommended to include visual aspects/aesthetics in future studies of footwear comfort perception.
2. For a reliable assessment of any subjective comfort-related variable, **long-term measurements** should be carried out in realistic task-specific settings to employ the 'task/activity' dimension of the comfort model from van Veen & Vink [6]. 'Even though visual and tactile perceptions can give rise to point of sale comfort, it does not guarantee long-term comfort.' [11]. Aesthetic aspects are presumed to be time-invariant, whereas several comfort descriptors and most discomfort descriptors vary over time [17]. Even though these findings are based on evaluations of chairs, they may be transferable to evaluations of footwear.
3. Any previous experience, which might have triggered certain **expectations** [4, 5] about the footwear to be rated, may have played an important role in subjects' ratings in our study. Since we did not assess expectations with regard to business footwear, we were unable to assess any effect of expectations on actual comfort perception. In other shoe types (e. g. athletic footwear), functional aspects might override pre-existing expectations. For business footwear, expectations might play a more important role and future studies should include expectations as a possible predictor for OI.
4. It is still unclear whether OI, comfort, and fit perceptions are based on the same **semantic construct**. Given the rather moderate correlation between FIT and OI in our data ($r_s = 0.64$), our subjects presumably used distinct definitions for FIT and OI. However, we cannot provide any data on whether OI and comfort perception are considered to be semantically identical. Unpublished findings of the authors suggest a highly subjective definition of footwear-related comfort. It may be beneficial to put the focus of analysis on **discomfort** rather than comfort perception since it may be easier to verbalize (with fewer semantic variation), and thus easier to link to specific shoe-related factors or perceptions related to footwear evaluation, e. g. fatigue [17].

6 Conclusions

A linear model incorporating the variables FIT, Cush, SoleFlex, and UpFlex only resulted in moderate predictability of OI of business footwear. FIT provided the largest explanatory power of all variables, but may suffer from semantic fuzziness. Visual appearance and pre-existing expectations should be included in future studies on footwear related comfort to potentially increase the predictability of OI and check for interactions with other (functional) footwear-related factors. Future studies may examine how geometric variations in last shape, variations in material properties of the shoe upper, and different lacing systems affect FIT and comfort-related variables to further identify their relevance, e. g. for mass customization of business footwear.

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References

[1] Reinschmidt C, Nigg BM. Current issues in the design of running and court shoes. Sportverletz Sportschaden 2000; 14(3): 71–81
[2] de Looze MP, Kuijt-Evers LFM, van Dieën J. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics 2003; 46(10): 985–97
[3] Moes NC. Analysis of sitting discomfort, a review. In: Bust PD, McCabe PT, editors. Contemporary ergonomics 2005. London: Taylor & Francis 2005; 200–4.
[4] Vink P, Hallbeck S. Editorial: Comfort and discomfort studies demonstrate the need for a new model. Applied Ergonomics 2012; 43(2): 271–6
[5] Naddeo A, Cappetti N, Califano R, Vallone M. The Role of Expectation in Comfort Perception: The Mattresses' Evaluation Experience. Procedia Manufacturing 2015; 3: 4784–91

[6] Veen S van, Vink P. Can Prior Experience Influence Seating Comfort Ratings? Ergonomics in Design: The Quarterly of Human Factors Applications 2016; 24(2): 16–20
[7] Liu R, Little T. The 5Ps Model to Optimize Compression Athletic Wear Comfort in Sports. Journal of Fiber Bioengineering and Informatics 2009; 2(1): 41–52
[8] Tay CS, Sterzing T, Lim CY, Ding R, Kong PW. Overall Preference of Running Shoes Can Be Predicted by Suitable Perception Factors Using a Multiple Regression Model. Human Factors 2017; 38: 001872081668114
[9] Hennig E, Schulz J. Subjective evaluation of biomechanical shoe properties during blinded and non-blinded running. Footwear Science 2011; 3(sup1): S75-S76
[10] Arezes PM, Neves MM, Teixeira SF, Leão CP, Cunha JL. Testing thermal comfort of trekking boots: An objective and subjective evaluation. Applied Ergonomics 2013; 44(4): 557–65
[11] Au EYL, Goonetilleke RS. A qualitative study on the comfort and fit of ladies' dress shoes. Applied Ergonomics 2007; 38(6): 687–96
[12] Deselnicu DC, Vasilescu AM, Mihai A, Purcarea AA, Militaru G. New Products Development Through Customized Design Based on Customers' Needs. Part 1: Footwear Comfort Parameters. Procedia Technology 2016; 22: 1043–50
[13] Branthwaite H, Chockalingam N, Greenhalgh A, Chatzistergos P. The impact of different footwear characteristics, of a ballet flat pump, on centre of pressure progression and perceived comfort. The Foot 2014; 24(3): 116–22
[14] Mündermann A, Nigg BM, Stefanyshyn DJ, Humble RN. Development of a reliable method to assess footwear comfort during running. Gait & Posture 2002; 16(1): 38–45
[15] Schomacher J. Gütekriterien der visuellen Analogskala zur Schmerzbewertung. physioscience 2008; 4(3): 125–33.
[16] Zhang L, Helander MG, Drury CG. Identifying Factors of Comfort and Discomfort in Sitting. Human Factors: The Journal of the Human Factors and Ergonomics Society 1996; 38(3): 377–89
[17] Helander MG, Zhang L. Field studies of comfort and discomfort in sitting. Ergonomics 1997; 40(9): 895–915

The First International Comfort Congress, 7-8 June 2017, Salerno (Italy)

The future of comfort … a future beyond foam?

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ABSTRACT

Humans have been using support materials for cushioning throughout the ages. Natural materials, like straw, sheepskin etc., provided a combination of pressure relief as well as a breathable support, that cooled and removed moisture (sweat). Since the industrial revolution, novel high tech materials have taken their place, with a variety of specialized foams being the workhorse. Versatile as these materials are, they can be tuned to provide impact resistance as well as mould themselves perfectly around the body, like for instance memory foams do.

Yet there is a price to this: the breathability is mostly lost. Despite developments creating open cell structures, foams are only slightly more breathable and ventilating, as the natural fibrous materials are.

With ever increasing customer expectations, arising from both a more active population, as well as an aging group with increased medical support needs, is foam as a material still the best choice in future comfort cushioning applications?

Recent developments in a variety of industries show that the dominant position of foams in these applications could become challenged. Open structure seating concepts for offices as well as novel car-seat designs, 3D-printing of open structures as well as developments in 3D knitted spacer textiles, 3D nonwovens and 3D extruded filament mat structures now form new alternatives to fulfill the pressure relief demands while maintaining excellent breathability and ventilation, enabling solutions with advanced and improved climate control. We see these concepts appearing in many applications, for example different car seat designs personalized shoe sole technologies and medical cushioning applications. Whilst some of these developments are still more expensive in comparison to foams, innovations are taking place rapidly and more cost-effective solutions are being proposed.

An example is given in the developments of the 3D entangled thermoplastic filament products from Low & Bonar, for which new generations are now being developed with alternative polymers that enable resilient structures with a variety of compression resistance levels. Even at high compression these structures retain their open space and therefore provide comfort in pressure relief as well as in local climate control.

An interesting feature of these structures is their broad design window, which means they can be optimized using state of the art computative techniques to finetune their performance.

A very important advantage of these materials also lies in their polymeric building blocks, which can be bio-based and are molecules of a much more friendly nature than the toxic, often carcinogenic chemicals that for example PU foams are made of.

The approach enables the creation of better comfortable solutions that improve the quality of life, while contributing to a more sustainable world.

KEYWORDS: Cushioning, Innovative materials, Entangled filament structures, Lightweight materials

Now is the time for a comfort congress

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Comfort is in our daily lives

When buying a bed, a chair or a car, taking the train, holding a hand tool or flying across the ocean, comfort comes into play. Users interact with products and rate their experience. Therefore, designers and manufacturers of products such as seats, cars, beds, hand tools, and production lines strive for optimal comfort. If we look at some trends like “attention to health”, “ageing workforce (and population)”, “environmental awareness and sustainability” and “attention to well-being”, (dis)comfort is an important consideration (Vink & Hallbeck, 2012). This means that in our daily lives we are confronted with comfort.

Only the user decides whether it is comfortable

A difficulty in studying comfort is that a product in itself can never be comfortable (Vink, 2005). It becomes comfortable (or not) in its use. Despite an ongoing debate in the literature on the meaning of comfort (de Looze et al., 2003), it is generally accepted that comfort is a construct of a subjectively defined personal nature. The user decides whether or not a product is comfortable, or leads to discomfort, by using the product. Some have defined loose ‘comfort’ boundaries as an experience where pain receptors are not active (e.g. Mansfield et al., 2014) but even this is a difficult working boundary in some situations such as healthcare where comfort and pain can occur simultaneously. This makes designing a comfortable product difficult. On the other hand it is not impossible to design comfortable products. Efforts are being made to understand the genesis of the holistic comfort impression and to define the different aspects of comfort and corresponding test methodology for using human beings as measurement tools (Frohriep, 2009). One aspect is that the comfort experience cannot be better than its weakest aspect. On the other hand, several studies show that paying attention to a better product or service lead to more comfort, or less discomfort (Vink, 2005). However, there is certainly room for knowledge development supporting the design of more comfortable experiences.

Challenge for companies

The main challenge for companies that spend money and time for launching more appealing products on the market is to understand which mental/physical/physiological/environmental mechanisms act in creating a (dis)comfort perception. Thus, in product design, designers and engineers, supported by Psychologists, Physiologists, Ergonomists, posture experts and so on.., try to work towards defining a comfort-driven step to take into account the improvement of comfort (or the decrease of discomfort) as new, mandatory, functional requirements of a new product (Cappetti, 2017). Nevertheless, they still do not have methods and instruments, nor models or experience, to optimize products for comfort. As tools and knowledge for the early stages in the design process are missing, much is done in a late phase of the design. (Dis)comfort assessments have to be done as an "evaluation" step in the design process with higher costs and few possibilities to make changes for improvement.

Comfort in scientific literature

In the scientific domain the word comfort is often mentioned. Vink & Hallbeck (2012) report 104,794 double reviewed papers in 30 years (between 1980 and 2010) including the term discomfort or comfort. Most of these studies refer to temperature related discomfort or patient comfort. Bazley et al. (2015) showed more recently that in the scientific literature between 2003 and 2013 more papers are focused on discomfort than on comfort. Also in this study, patient (dis)comfort is the most mentioned within these 10 years. Other studies mention visual comfort, musculoskeletal discomfort, thermal comfort and discomfort, vibration and comfort related to products. The latter concerned only 5% of the papers. So, arguably, the most important application of comfort research into product design is a low priority in the literature.

Papers on theories related to comfort are rather underdeveloped. There are papers explaining more about the concept of comfort. Helander and Zhang (1997) describe terms underlying the concept of comfort and discomfort and De Looze et al. (2003), Kuijt-Evers et al. (2004), Vink & Hallbeck (2012) and Naddeo et al., (2014) made models to explain and describe (dis)comfort. In addition, comfort and discomfort in relation to products is studied (e.g. Mansfield et al., 2014; Sammonds et al., 2017; Hiemstra-van Mastrigt et al, 2015, Naddeo et al., 2015)). Most of these studies concern sitting. Even models that attempt a multi-factorial approach including, for example, dynamics, static, fatigue and temporal factors (Ebe and Griffin, 1998; Mansfield, 2005) tend to use a 'black box' to describe the components building these factors rather than building from the fundamental biomechanics, physiology and neurology.

This means that the theoretical foundations for comfort research remain underdeveloped, but the number of papers touching comfort knowledge continues to expand.

The Comfort Congress

So, more knowledge is coming available and it could mean that interest in comfort is growing. This made us (the authors) decide in 2016 to organize a congress on the topic comfort in 2017.

The aim of the comfort congress is to create a platform for product comfort research. It will provide an opportunity to discuss comfort definitions and models, methods and methodology of assessing and quantifying comfort, system science approaches, and application examples. Importantly we want to build bridges between those who use comfort models to design products and researchers who are motivated to improve the understanding of human comfort.

Researchers will share studies, theories, methods and technologies in the realm of comfort, encompassing all human-machine interfaces. Research fields include body support systems, such as seats and bedding, vehicle and aircraft seats and interiors, consumer products, environmental factors and the tools to research them. Research topics cover the wide range of physical, physiological and psychological human-product interaction, among them product usability, fit and hold analysis, visual comfort, thermo-physiology, well-being, and perceived product quality.

The papers

The papers submitted are organized is two parallel sessions. Session A papers concern comfort theory and human perception in the clusters methodology, modelling, psychophysics, and dynamics. Session B papers are dedicated to measurement and products in the clusters tools, thermal comfort, seating, and other applications.

The presenting researchers represent a broad array of research institutions and countries, from our host country Italy, over Great Britain, The Netherlands and Germany, to France, the United States of America, and Japan.

The Aim

The aim is to form a knowledge base, start an exchange, present and advance comfort research. The best participating papers will be published in a special issue of a scientific journal based on the congress proceedings to disseminate current comfort research. The future of comfort begins in Salerno in June 2017, and we welcome you: Make yourselves comfortable.

References

1. Bazley, C.M.,. 2015. Beyond Comfort in Built Environments. PhD thesis, TU-Delft.
2. Cappetti, N., A. Naddeo, R. Califano, and M. Vallone. 2017. Using Axiomatic Design to Identify the Elements that Affect the Evaluation of comfort/discomfort Perception. Advances in Intelligent Systems and Computing. Vol. 487. doi:10.1007/978-3-319-41688-5_21. www.scopus.com.
3. Ebe, K., Griffin, M. J., 2001. Factors affecting static seat cushion comfort. Ergonomics, 44(10), 901–921.
4. Frohriep, S., 2009. „Comfort Evaluation in Simulations: Meaningful Use of Virtual Comfort,“ Proceedings of Digital Process Management and the Digital Factory, June 16 – 18, 2009, pp. 179 – 184, Magdeburg.….
5. Helander MG, Zhang L. 1997. Field studies of comfort and discomfort in sitting. Ergonomics 40; 895–915.
6. Hiemstra-van Mastrigt, S., 2015. Comfortable passenger seats. Recommendations for design and research. PhD thesis, TU-Delft.
7. Kuijt-Evers LFM, Groenesteijn L, Looze MP de, Vink P. Identifying factors of comfort in using hand tools. Applied Ergonomics 2004;35(5):453-458. 02

8. de Looze, M. P., Kuijt-Evers, L. F. M., Dieën, J. van, 2003. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics, 46(10), 985–997. doi:10.1080/0014013031000121977.
9. Mansfield, N.J., 2005.Human Response to Vibration, CRC Press, London, UK, 2005.
10. Mansfield, N.J., Mackrill, J., Rimell, A.N. and MacMull, S.J., 2014. Combined effects of long-term sitting and whole-body vibration on discomfort onset for vehicle occupants. ISRN automotive engineering, 2014.
11. Naddeo, A., Cappetti, N., D'Oria, C., 2015. Proposal of a new quantitative method for postural comfort evaluation. International Journal of Industrial Ergonomics, 48, 25–35. doi:10.1016/j.ergon.2015.03.008
12. Naddeo, A., Cappetti, N., Vallone, M., Califano, R., 2014. New trend line of re-search about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions. In T. Ahram, W. Karwowski, & T. Marek (Eds.), AHFE 2014, Krakow, Poland, 19-23 July 2014
13. Sammonds, G.M., Fray, M. and Mansfield, N.J., 2017. Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs). Applied Ergonomics, 58, pp.119-127.
14. Vink, P. (ed), 2005, Comfort and Design: Principles and Good Practice, Boca Raton: CRC Press
15. Vink, P., Hallbeck, S., 2012. Editorial: Comfort and discomfort studies demonstrate the need for a new model. Applied Ergonomics, 43(2), 271–276. doi:10.1016/j.apergo.2011.06.001.

From Measurement to Meaning: Methods of Comfort Assessment and Corresponding Ergo-Lab Functions

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Abstract This plenary presentation will explore comfort assessment from the view of an operator systems supplier's comfort definition and present corresponding internal and external capabilities. Grammer AG as a manufacturer supplies a global market with diversified requirements with operator systems (encompassing seats and HMI controls) for offroad vehicles such as agricultural vehicles, construction equipment, and fork-lift trucks, as well as truck, rail and bus seats and automotive components. Application examples from seat and interiors development leveraging in-house research and a research partner network will be discussed.

Keywords: operator comfort, perceived quality, ergolab functions, HMI, research partner network

1 Introduction: Products Developed for Human Use

The interface of human and product needs to be understood on a system level. Human beings interact with products and process their impressions to form an opinion. The foundation for developing successful products for human use is insight on three levels: Understanding the human being, understanding the product, and understanding their system interaction. Research areas resulting from this are firstly, mental and physical human traits, secondly, technical product attributes, and thirdly, functionality, usability and comfort of the configured product. GUX (= Grammer user experience) provides the guideline for achieving a positive user interaction.

1.1 Perceived Quality

The product development process at Grammer AG has defined “perceived quality” as its guiding theme. Products are developed and optimized on the foundation of understanding their users and the range of use cases, from which design requirements are deducted. The definition of *perceived quality* is here “a positive user interaction with the product in all relevant use cases”. For achieving this, the areas design, ergonomics and application comfort contribute and cooperate. The Design department creates and refines product design concerning styling, visual comfort, and design for use. Ergonomics handles perceived quality methods development and the complete scope of comfort related testing. Application comfort refers to the configuration of the product to the specific use case(s). Targets of the product development process concerning perceived quality are to provide a positive product interaction in all details, user comfort and to minimize driver / passenger stress and strain by good product design.

1.2 Comfort Definition

Experiencing comfort in user-product interaction is the result of internal human computing of sensory input into a holistic impression in a fluid process over interaction time. Human beings compute this holistic interaction rating with little conscious effort, and generally with low awareness for its components. When an aspect comes to the attention of the user and becomes prevalent within the overall impression, it will dominate the comfort rating. This can occur in either direction: The negative occurrence has been named "limiting comfort factor", entailing that the holistic comfort experience cannot be better than its weakest aspect. The positive occurrence can be referred to as the "wow-factor" of a product, exceeding the expectation of the user. Thus, experiencing comfort encompasses all human senses and can be defined as "*an overall positive user interaction experience with a product".*

2 Ergonomics and Innovation Lab Targets and Functions

The field of ergonomics provides the compendium for analyzing and rating the interaction between user and product. Its goal is to understand the system fully and optimize this interaction. In order to be able to do this, human beings in their variation are the foundation. They are assessed concerning their perception, anthropometry, biomechanics and physiology (see fig. 1).

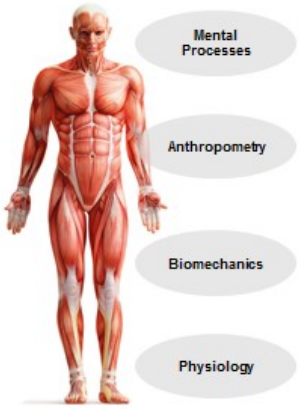


Fig. 1. Research Areas

Perception refers to the human senses, their information processing and rating of the sensory input. Anthropometry applies human dimensions in their global diversity. Biomechanics analyzes human movement, body structures and their kinematics. Human physiology respects the equilibrium of the functioning body, for example in breathing, blood flow, temperature, biochemical processes. All of these fields provide information for understanding and configuring specific test panels.

Internal specifications have been developed at Grammer AG for the parameters of perceived quality and associated test methods, looking at test methodology, interpretation and data aggregation. The scope of the Ergo-Innovationlab goes beyond offering comfort assessment and analyses e.g. by providing basic knowledge, performing innovation verification, and expanding internal and external capabilities (see table 1).

Table 1. Targets and Functions of Grammer Ergo-Innovationlab

Target	*Function*
Provide knowledge base for Grammer AG products	Basic research and data aggregation
Rate and optimize products	Provide analysis methods, innovation verification
Expand internal capabilities	Test according to Grammer Specifications, continuous methodology development
Build and upkeep global Grammer research network	Visualization of comfort research, Eye-level communication
Positioning of Grammer Brand	Branding by ErgoLab capabilities and research results

In order to ensure user comfort, an overall positive user interaction experience with a product, the Ergo-Innovationlab supports product development with its six domains: anthropometrics, ergomechanics®, perception, thermal comfort, seat comfort testing and variable environments.

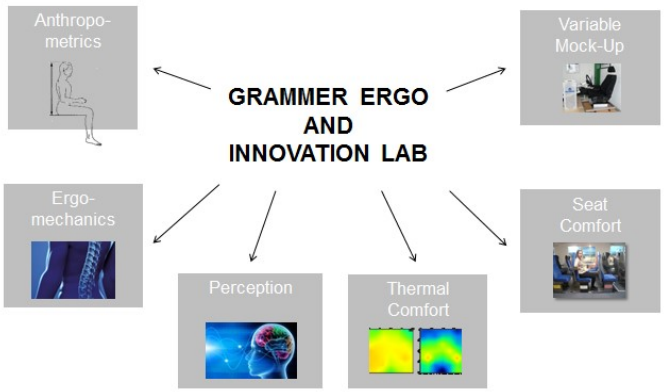


Fig. 2. Ergo-Innovationlab Domains

The domain of anthropometrics provides global body measures for defining and verifying product dimensions. An internal test subject panel with assessed body measures and preferences is being continuously updated, to provide test subject pools where applicable. Testing with external research partners is planned and coordinated. User typology also falls into this domain. The ergomechanics® domain is concerned with ergonomics research and biomechanics. It incorporates current research on spine physiology for developing product details in its application.

The domain of perception is concerned with visual comfort, cognitive ergonomics, and mental workload. It evaluates the interaction experience of operator systems including HMI. Cognitive assessment and functional mapping of use cases form the basis of operator workload and user experience.

In the thermal comfort domain, human thermophysiology is analyzed and rated. By measuring temperature and humidity in the human-seat interface in combination with subjective thermal comfort assessment, the effectiveness of active and passive climate systems is verified.

For assessing seat comfort, the standardized Grammer methodology defines procedure and analysis. The physical interface is rated, as well as cognitive ergonomics in the aspects of product consistency, intuitiveness, and functionality. Depending on the respective application, testing is performed either with lay persons, professional users, or expert panels.

The flexible mock-ups provide vehicle environments for giving the user orientation as to elements such as steering wheel, pedal plane, roofline, and vehicle interior dimensions, in order to be able to test seats and

components with test subjects. For higher external validity, vehicle field testing is also available with the respective defined test procedures.

3 Research Partner Network and Ergonomic Hub

Complimenting Grammer AG in-house capabilities, international research partners are available for additional content and capacity. For example, human models for developing products for a global market, experimental biomechanical procedures and simulated dynamic environments are accessible through a range of research partners. Specialized partners have been identified for researching the diverse user groups of products in the automotive, truck, agriculture, construction equipment, material handling, bus and rail driver and passenger applications. Throughout product development, research towards understanding and meeting user needs is performed by internal and external laboratory and field testing. The ergonomics department serves an *ergonomic hub* function by planning and distributing all ergonomics content as applicable.

The complexity of the human spinal system is currently not completely understood by science. In order to develop products for human use according to comfort and health principles, it is necessary to further invest efforts into advancing this knowledge. The Grammer AG has strategic partners in spine research and has been supporting basic research leading to a more comprehensive understanding of the human spine for the past two decades. This research spans a wide range and furthers understanding in methods development, alleviation of spinal disease, and healing, advancing a deeper understanding of the multi-factorial topic back pain. Topics of the past years were a better understanding of the human spinal system, spine modelling, and spinal therapies. The results at the Berlin Charité in 2011 help vehicle users to regain full use of their vehicles quicker after spinal surgery. 2016, new methods for visualizing disk nutrition deficiency were found by the Medical College of Wisconsin that can contribute to identifying causes for back pain more quickly. This advancing scientific knowledge is continuously being integrated into human interface products for the global market.

4 Application Examples

Ergonomics facilitates translating research results into products according to their specific application and use cases. The human spine is challenged in the vehicle work place by static loading and enforced postures due to work tasks and long-term exposure. Research of the *Institute of Orthopaedic Research and Biomechanics* at the Trauma Research Center Ulm has shown that the slouch posture alternated with upright posture positively influences all spinal structures. This insight has been incorporated into seats by Grammer AG. They enable body position change according to the ergomechanics® principle, i.e. the spine can assume different positions in seat contact.

4.1 Fork lift synchro seat

The synchro seat's functionality has been developed for specific applications, such as high stack fork lift trucks and work in backward facing positions. The high stack fork lift truck poses an extreme situation for the cervical spine by the required overhead view control of the operator. In this use case, the cervical spine is subjected to high stress and strain through its flexibility, the weight of the head, and the necessary body posture.

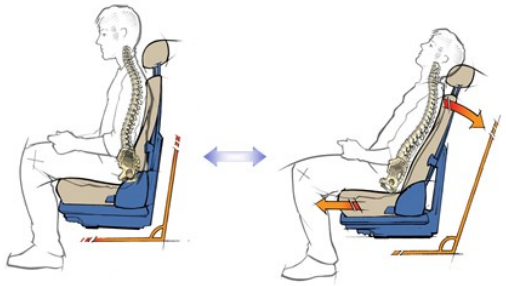


Fig. 3. Synchro-Mechanic Adjustment

In order to minimize the load on the body, a seat was developed that allows for a biomechanical support of the cervical spine (see fig. 3). In this application, the ergomechanics® principle is respected in allowing for lumbar spine travel in a synchronous movement of seatback and seat cushion. Also, by providing a high seatback with recline travel, the cervical spine is supported throughout overhead view control.

4.2 Dual Motion

Research on the thoracic spine during backward facing driving shows that the back of the driver typically loses contact with the seatback and is unsupported in this prevalent posture, causing muscular strain. The presence of vibrations further exacerbates this effect.



Fig. 4. Dualmotion Seat

In order to reduce driver load and strain, the Dualmotion seat has been developed (see fig. 4). In front facing driving position, the upper part of the Dualmotion backrest remains parallel to the lower part. To accommodate a backward facing driving posture, it can be rotated to the left on a defined trajectory. In this way, it provides support to the spine in rotated position, thus reducing muscle load. The effectiveness of the Dualmotion principle has been shown with EMG measurements and joint angle modeling of associated postures. Its functionality was proven in field trials with tractor drivers.

4.3 MFA Multifunctional Armrests

Position and travel windows of HMI controls and entire seat systems need to be tested and adapted based on global user populations of current products. The layout of a multifunctional armrest for the global market was developed 2016 in cooperation with the *Institute for Technical Logistics and Work Systems* at the TU Dresden. In order to represent global users, the human model was configured in global extreme percentiles and different proportions. Typical body postures for work situations in commercial vehicles were defined and researched (see fig. 5).

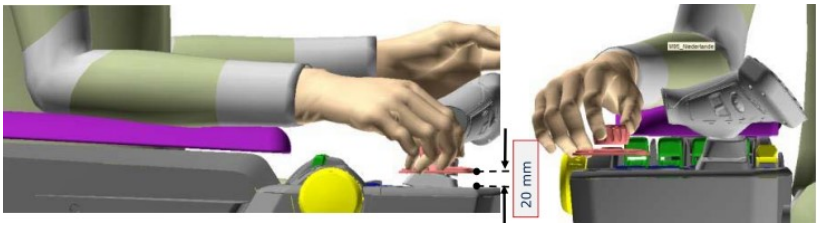


Fig. 5. Multi-Functional Armrest Layout with Human Model

The results defined the position of the multifunctional armrest in relation to the seat index point and its optimal travel window for comfortable use of the global user group. Furthermore, the position and layout of HMI controls was assessed and optimized with respect to the manipulation task at hand and compliant with global hand measures. Quick mock-up prototypes are then built to cross check and verify workable use cases of the suggested Virtual Geometry Data in the Ergolab. The data is available in CAD format in the knowledge base and serves as orientation for layouts of armrests for global users.

5 Conclusions

Research fields of Grammer AG ergonomics are use case dependent user typology, spinal health and load reduction for drivers and passengers, and comprehensive understanding of the human product system interaction. The development of associated ergonomic tools and methods is a continuous process. It is connected to permanently changing parameters („moving targets“), such as new technologies that influence vehicles and workplaces, e.g.: autonomous driving, connectivity and smart products. User expectations rise with the modernization of their surroundings. The parameters of perceived quality also underlie this change process and are kept current by internal and external Grammer AG research that also incorporates advances in research findings.

Acknowledgments The research work reported here was made possible by Grammer AG.

References

1. Bubb, H., Bengler, K., Grünen, R. and M. Vollrath, 2015.Automobilergonomie. Springer, Wiesbaden.
2. Bundesamt für Wehrtechnik und Beschaffung (ed.), 1989. Handbuch der Ergonomie. Koblenz.
3. Frohriep, S., 2017. „Funktionsbasierte Nutzfahrzeugentwicklung bei der Grammer AG,“ Proceedings Forum Technische Logistik und Arbeitssysteme 2017, pp 33 – 41, Dresden.
4. Frohriep, S., 2009. „Comfort Evaluation in Simulations: Meaningful Use of *Virtual Comfort*,“ Proceedings of Digital Process Management and the Digital Factory, June 16 – 18, 2009, pp. 179 – 184, Magdeburg.
5. Hatzfeld, C. and T.A. Kern, 2009. Engineering Haptic Devices. Springer, Berlin / Heidelberg.
6. Schmauder, M. and B. Spanner-Ulmer, 2014. Ergonomie. REFA Bundesverband, Dortmund.
7. Vink, P., 2016. Vehicle Seat Comfort and Design. Delft.
8. Wilke, H.-J. (ed), 2004. Ergomechanics. Shaker, Aachen.
9. Wilke, H.-J. (ed), 2006. Ergomechanics 2. Shaker, Aachen.
10. Winner, H., Hakuli, S. and G. Wolf (eds.), 2014. Handbuch Fahrerassistenzsysteme. Vieweg+Teubner, Wiesbaden.

Vibration and shock in vehicles: new challenges, new methods, new solutions.

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Abstract There are many components that contribute to the overall feeling of comfort in a vehicle. One of the important components in the exposure to vibration. Vibration can cause an acute increase in discomfort. Furthermore, the presence of vibration accelerates the onset of discomfort for long duration exposures. It is therefore important that vibration remains a key consideration in the development of vehicle seats. There are currently two opportunities for vibration research in vehicles. The development of autonomous cars means that the assumptions relating to driving task and posture are no longer valid and therefore new seats will need to be developed that allow for the variety of tasks that an autonomous occupant will need to complete. Small fast boats can expose their occupants to significant vibration and shock affecting the comfort, performance and health of the crew. There are a multitude of potential control measures that can be implemented as part of a control strategy including design of boat and seat, and operational design.

Keywords: Whole-body vibration, seating, marine, boats, autonomous, polyurethane foam

1 Introduction

'Human Response to Vibration' has been a well-established discipline within vehicle system research for many years. Classic texts include those from Griffin (1990) which summarised the field at that time, and Mansfield (2004) which was designed to be more introductory and accessible in nature but covering all core knowledge required for the practitioner. The discipline comprises three key words (Figure 1):

- *Human* : it is necessary to understand many aspects of human biology, physiology, and anatomy in order to grasp the discipline,
- *Response* : it is necessary to consider how the human responds in the context of vibration including their biomechanics, performance, psychology and potential health effects from chronic or acute exposures to vibration,
- *Vibration* : it is necessary to understand the physics and engineering of the vibration environment in order to understand control measures necessary to optimise the vibration environment.

Many of the greatest challenges in the study of Human Response to Vibration lie in the interactions between these key areas.

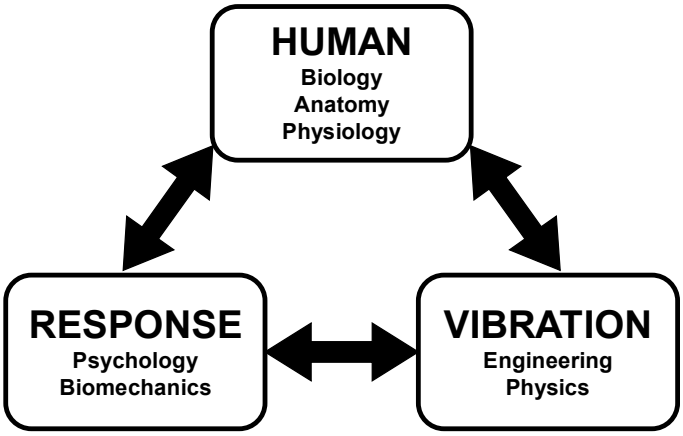


Fig. 1. Key elements of the study of human response to vibration (Mansfield 2004).

It is possible for vibration to exist at magnitudes that are measurable but are unperceivable. For example, seismic measurement apparatus will measure motion in the ground that humans cannot detect; once the vibration of the ground exceeds perception thresholds an earthquake occurs that could potentially damage structures. In this case the effects on the human are indirect (i.e. it is not the vibration that poses the greatest danger but the effects of the vibration on other structures). In vehicles the vibration is usually above a perception threshold. For the majority of kilometres travelled in modern society, the vibration poses minimal direct health risk but could be distracting, fatiguing or uncomfortable. If the exposure magnitudes and exposure durations are long enough the vibration could pose a chronic health risk. For example, a professional worker operating an earth-moving machine could be exposed to vibration for many hours each day with their discomfort levels gradually increasing as they fatigue. Over time, these exposures have been associated with an increased prevalence of health effects (e.g. Bovenzi et al. 2006). In the most extreme environments it is possible for vibration and shock to cause acute health effects such as spinal compression fractures or disc herniation (e.g. Johanning, 2015).

The effects of vibration depend on the frequency of the vibration, the magnitude of the vibration, the waveform and direction, and the application site. Broadly, the response to vibration can be categorised into three application areas (Figure 2):

- *Motion Sickness* : Very low frequency motion of the whole body, with effects including lethargy, nausea, loss of well-being and ultimately vomiting.
- *Whole-body vibration* : Vibration usually between about 1 and 50 Hz, typically experienced in vehicles and affects the whole body.
- *Hand-arm vibration* : High frequency vibration potentially into the kHz range, typically experienced through the use of power tools with effects including hand-arm vibration syndrome / vibration-white finger.

Research has led to the development of standards, directives and regulations for vibration exposure. For vehicle environments, the key document is ISO2631-1 (1997) : Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration: Part 1 - General requirements. This standard includes guidance on the evaluation of vibration in terms of perception, comfort and health. The key process for evaluation involves measurement of the vibration on the seat surface in the three orthogonal axes (x-, y-, and z-). These data are frequency weighted, providing an indication of the effect of the vibration on a human seat occupant. This can be compared to criteria for predicted levels of human response. Further measurements and calculations are required in order to generate an overall daily dose (A(8)) that can be used for basic risk assessments (Figure 3). The standard provides more complex methods of data analysis including guidance on how to assess vibration at the floor and backrest; how to assess rotational motions; how to evaluate motion sickness; how to use alternative risk metrics such at the vibration dose value (VDV).

Whilst the basic evaluation of whole-body vibration has been established for some years, there remain several areas that constitute a significant challenge and the focus for future research. This paper seeks to reflect on contemporary challenges in the field of human-response to vibration in the context of vehicles and transport systems.

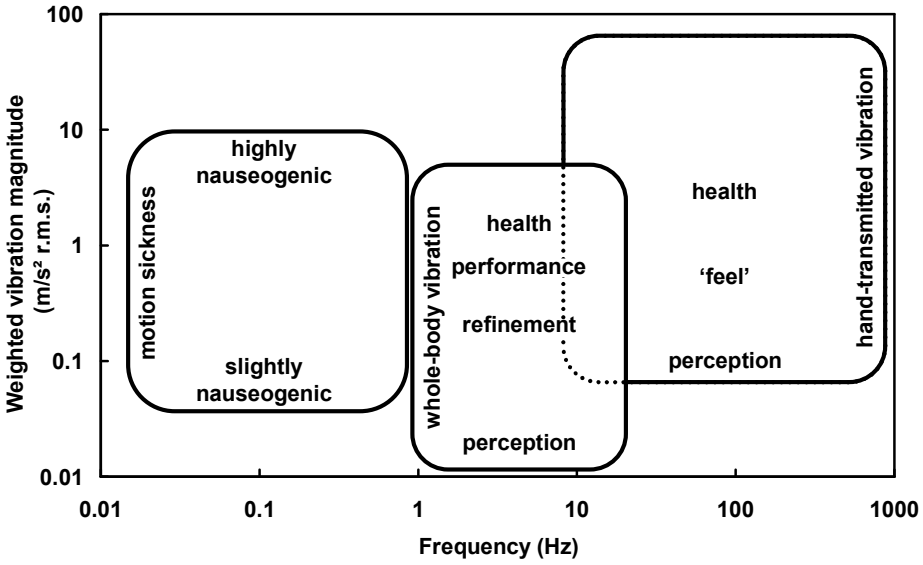


Fig. 2. Typical frequency ranges and effects of vibration on the body (Mansfield 2004).

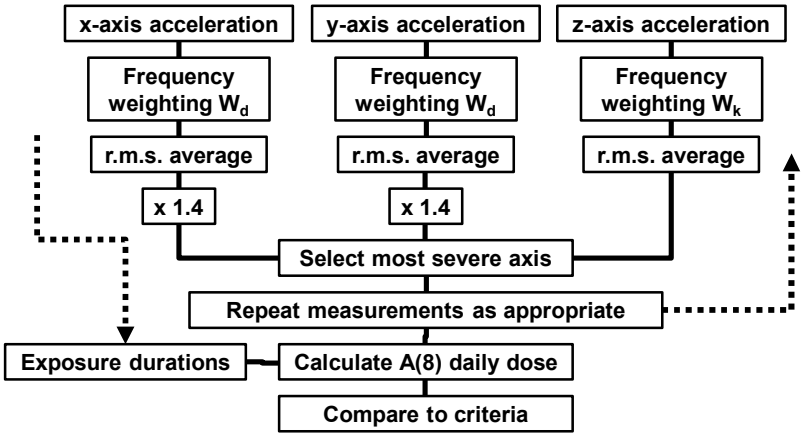


Fig. 3. Simplified schematic showing the process of evaluation of vibration according to ISO 2631-1.

2 Seat design for long-term vibrational comfort

Over the past two decades, seat technologies have progressed. Improved manufacturing methods and the drive for more sustainable transport has motivated development of lighter seats, many of which have maintained the requirements for comfort. In some sectors the seat requirements have significantly changed. For industrial machines, agriculture and forestry the cab was previously not seen as a priority in terms of marketing and development. However, this has changed such that owners now also prioritise the vehicle interior de-

sign and the associated comfort. Hence, there is great opportunity for development of comfort technologies including better seat design. After-market products have become viable; e.g. BOSE developed and market their 'ride' seat, acknowledging that it is a premium product with an associated premium pricing. This is marketed at holistic well-being of drivers after driving for long periods of time. Mansfield et al. (2016) showed how after extended periods of time the benefit of an improved foam composition become more important, especially where there is vibration (Figure 4). This interaction of vibration / comfort / duration has been developed into a multi-factorial model that allows for the prediction of discomfort over extended periods of time, and with different levels of vibration (Figure 5). Importantly, the model shows how the presence of vibration accelerates the onset of discomfort (Mansfield et al. 2014).

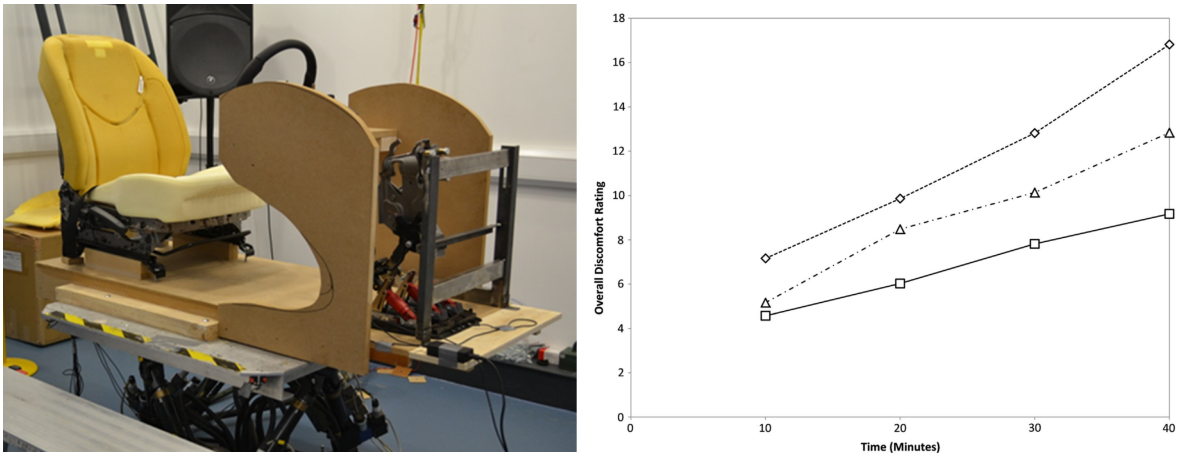


Fig. 4. Study of discomfort in car seat for Foam 'A' (no vibration -[]- ; with vibration --<>--) and improved Foam 'B' (with vibration - - Δ - -). Data from Mansfield et al. (2016).

3 New challenges for vibration discomfort in autonomous transport

With the unrelenting development of autonomous vehicles the context of use for automotive transport is changing. Whereas historically design guidelines have assumed that the driver is in a very constrained posture dictated by the position of the pedals, steering wheel and eye-point, autonomous driving no longer needs these constraints. For the foreseeable future even the most technologically advanced cars will need to switch between what are effectively alternative driving modes. Autonomous modes of driving would be possible at slow speed in urban centres where the speeds are low. On highways the car could also be in fully autonomous mode whilst driving at higher speeds in contexts where the traffic and road is predictable. For less predictable urban roads with a mixed transport economy, manual driving will be necessary. Whilst travelling a long distance on a highway the driver will inevitably want to carry out a variety of tasks including resting/sleeping, working, making calls, or engaging in entertainment activities. Therefore the posture in which the driver sits may need to be very different to efficiently perform these tasks in the same seat in which they were previously driving. Research shows that it is possible to have a radically different driving posture was maintaining comfort (Smith et al., 2105) but there is still significant research needed to be completed in order to establish the requirements and objectives of the necessary seat design for future vehicles.

It could be argued that many vehicles already consider the multiple postures that are necessary for autonomous automobiles. For example the vast majority of occupants in aircraft and trains are passengers rather than the driver. There are clearly synergies possible between the automotive industry and the passenger transport sectors.

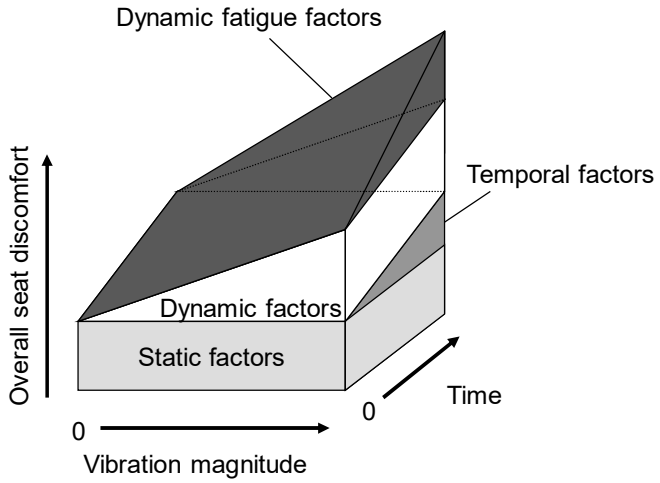


Fig. 5. Multi-factorial model of overall seat discomfort (Mansfield (2012)).

The secondary concern for autonomous vehicles is the discomfort that will come from motion sickness. Some have been argued that the effect of motion sickness could be a terminal problem for autonomous vehicles, significantly constraining their widespread use (e.g. Diels et al., 2016). For many occupants habituation will occur, where the symptoms decline with repeated exposures, but many may self-select and choose not to travel in that mode due to the motion sickness problem (Mansfield, 2004). There are opportunities for acceleration and routing algorithms for autonomous cars that could minimize the effects of motion sickness, especially in the context where time of travel shifts from being 'wasted' time to a useful part of the day due to opportunities for carrying out alternative tasks.

4 Marine environments: the problem of small fast boats

Small fast boats remain a challenge in terms of whole-body vibration exposure control. This type of craft includes search and rescue (e.g. RNLI in the UK), Coast Guard patrol boats, windfarm maintenance craft, leisure and thrill rides, military craft, and pilot boats. A pilot boat is the craft that is used to transfer a helmsman who has local knowledge (the 'pilot') that is required to direct a large vessel into a sea port. Whilst the large vessel may be able to adequately cope with rough sea conditions, if the pilot boat cannot transfer the pilot to the larger vessel the port is effectively closed with no vessels able to enter or depart. Military special forces have a requirement to transport personnel at high speed and potentially stealthily. Upon arrival at the destination the personnel may need to be immediately vigilant and able to perform at their best in order to succeed in their mission. The vibration exposure can reduce performance, increase fatigue and cause great discomfort. Search and rescue is a special case in which many crew members are civilian volunteers who may not have the seamanship experience and skill of a professional. The crews' role is to rescue those whose lives may be in danger in high seas and therefore if they receive an emergency call they do not have a choice but to set to sea.

The nature of the vibration and shock that small craft are exposed to its characterised by two components. There is a steady-state element as the craft moves with the sea. This is the most common component for non-planing craft. For planing craft, superimposed on the top of steady-state motion are repeated shocks. The boat will leave one wave crest at high-speed and move into freefall before it makes contact with the water again. The vibration profile is characterized by repeated impulses in the vibration signals (e.g. Rantaharju et al. 2015; Figure 6). In very high seas it is possible for free-fall to extent to 1-2s and the boat hits the trough of the next wave at high speed inducing what is known as a wave slam. These shocks can be significant and are the highest known shocks that workers are regularly exposed to in any industry (e.g. 10g; Haynes 2016).

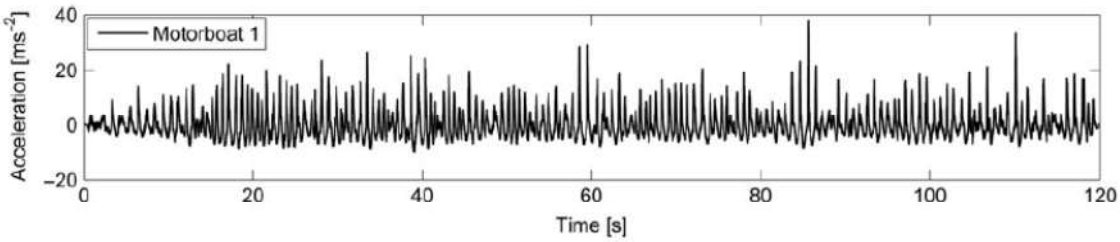


Fig. 6. Typical vibration profile on the seat of a high-speed motorboat without significant wave-slam. Data from Rantaharju et al. (2015).

Control measures for improving the comfort and well-being of occupants of small fast boats do exist. These include:

- *Avoid travel* : limiting use below certain sea states,
- *Hull design* : improving hull form to optimized 'v' rather than flatter bottom,
- *Coxwain skills* : skilled coxwains can drive the craft in a manner that minimizes shocks,
- *Reduce speed* : minimization of the free-fall component of the vibration,
- *Minimise operation time* : controlling the exposures of crews to ensure that minimal exposure occurs in high sea states,
- *Suspension decking* : the floor can be isolated directly or surface coatings can be used to minimize impacts,
- *Seat design* : new optimized marine suspension seats can be effective in minimizing the shock exposure.

In order to improve the comfort well-being and health of crewmembers the seats can be optimised to absorb the energy in each of the wave slams. These require sophisticated and reliable suspensions with a long displacement and with progressive damping to ensure that the motion of the seat is smooth and that end-stop impacts do not occur. New test methods have been developed for the seats but are as yet not established. The test method requires a drop tower where the seat being tested is mounted on to a sled which drops from a specific height. Beneath the sled a shaped probe impacts into a sand box. This provides a well-defined deceleration profile that can be used for repeatable seat testing.

5 Conclusions

The vibration performance of vehicle seats remains important. Research has shown that improvement in the dynamic environment to which a seat occupant is exposed will directly affect the comfort, not only acutely but also over long periods of time. Looking forwards, there are new challenges that face the discipline particularly in the development of mass market autonomous vehicles, and the specific challenges facing the niche of small fast boats.

References

Bovenzi, M., Rui, F., Negro, C., D'Agostin, F., Angotzi, G., Bianchi, S., Bramanti, L., Festa, G., Gatti, S., Pinto, I. and Rondina, L., 2006. An epidemiological study of low back pain in professional drivers. Journal of Sound and Vibration, 298(3), pp.514-539.

Diels, C., Bos, J.E., Hottelart, K. and Reilhac, P., 2016. Motion Sickness in Automated Vehicles: The Elephant in the Room. In Road Vehicle Automation 3 (pp. 121-129). Springer International Publishing.

Griffin, M.J., 2012. Handbook of human vibration. Academic press.

Haynes, J., 2016. Developing a holistic strategy for shock mitigation on fast boats. Proceedings of *Human Response to Vibration*, held at Institute of Naval Medicine, September 2016.

International Organization for Standardization. (1997). Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration: Part 1 - General requirements. ISO2631-1.

Johanning E, 2015. Whole-body vibration-related health disorders in occupational medicine – an international comparison, Ergonomics, 58:7, 1239-1252, DOI:10.1080/00140139.2015.1005170

Mansfield N.J. (2012). Human response to vehicle vibration. In: *Gkikas, N., 2012. Automotive ergonomics: driver-vehicle interaction. CRC Press.*

Mansfield, N. J., Mackrill, J., Rimell, A. N., & MacMull, S. J. (2014). Combined effects of long-term sitting and whole-body vibration on discomfort onset for vehicle occupants. ISRN automotive engineering, 2014.

Mansfield, N., Sammonds, G., & Nguyen, L. (2015). Driver discomfort in vehicle seats–Effect of changing road conditions and seat foam composition. Applied ergonomics, 50, 153-159.

Mansfield, N.J., 2004. Human response to vibration. CRC press.

Rantaharju, T., Mansfield, N.J., Ala-Hiiro, J.M. and Gunston, T.P., 2015. Predicting the health risks related to whole-body vibration and shock: a comparison of alternative assessment methods for high-acceleration events in vehicles. Ergonomics, 58(7), pp.1071-1087.

Smith, J., Mansfield, N., Gyi, D., Pagett, M. and Bateman, B., 2015. Driving performance and driver discomfort in an elevated and standard driving position during a driving simulation. Applied ergonomics, 49, pp.25-33.

Comfort-driven target setting

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Abstract Since the first appearance of hand-tools, artisans and engineers have attempted to make handwork as comfortable as possible. In the second half of twentieth century, awareness raising by industrialists about ergonomics and safety made the preventive evaluation of workplace ergonomics/comfort an essential element of product/process design. ISO 11228 provided guidelines for improving overall operator performance, as well as reducing the risk of muscle-skeletal disease. Companies, designers and engineers use their knowledge to improve work environments and artefacts to enhance worker performance and improve user safety. In the digital era (since the 1990s) new virtual prototyping (VP) techniques and their development and deployment in industrial environments have allowed products, processes and workplaces to be designed and redesigned in a virtual environment. Similarly, Digital Human Modelling (DHM) techniques and instruments allow designers and engineers to virtualise the human/machine interaction (HMI) and to preventively assess ergonomic elements, resulting in an improved appeal to the market. Nevertheless, the 'comfort' issue is still an open problem due to the subjectivity of performances and to the difficulty in developing a 'model' of perception that is both easily integrated in VP and can be used for designing new products/processes/workplaces. The introduction of comfort-driven design into the product/process development plan remains a challenge for scientists, engineers, designers and others. This paper gives an overview of the state of the art concerning ergonomic-driven and comfort-driven design in companies' innovation activities. It also proposes a general 'comfort model' and a general 'design framework' for introducing a comfort-driven step to product target setting.

Keywords: Comfort-driven design, (dis)comfort model, objectifying comfort, virtual prototyping, target setting.

1 Introduction

Since the first appearance of hand-tools, artisans and engineers have attempted to make handwork as comfortable as possible. In the second half of twentieth century, awareness raising by industrialists about ergonomics and safety made the preventive evaluation of workplace ergonomics/comfort an essential element of product/process design. Nowadays, designers and engineers know that a comfortable and ergonomic workplace can improve overall operator performance, as well as reducing the risk of muscle-skeletal diseases and subsequent absence periods and/or insurance issues. Nevertheless, this knowledge is not always easily applied, due to its economic cost and its resultant time to market (TTM) increase.
However, the 'comfort issue' is not strictly related to workplace design. 'Ergonomics' is a Greek term (ἔργον, meaning 'work', and νόμος, meaning 'natural law') whose original meaning is 'the natural law of work'. The first time that this term was used for describing work-related activity was in an 1857 article by the Polish scientist Wojciech Jastrzębowski [1]. Its first English usage is generally attributed to British psychologist Hywel

Murrell at the 1949 meeting at the UK Admiralty, which led to the foundation of The Ergonomics Society, with his famous phrase Ergonomics is: 'to fit the job to workers'.
After the Second World War, the concept of 'fitting something to humans' (not only to workers) became a central component of both user-centred design (that defines humans as 'users') (UCD) and human-centred design (that takes the term 'human' to include all the elements that can interact with humans, even independently of their will, e.g. the environment or emotions) (HCD). UCD is a broad term used to describe design processes in which end-users influence the way that a design takes shape [2]. It is both a broad philosophy and a method, both of which involve users during the design process. The term 'user-centred design' itself originated in Donald Norman's research laboratory at the University of California San Diego (UCSD) in the 1980s (Norman & Draper, 1986, [3]) following the publication of the seminal book *The Psychology of Everyday Things* (Norman, 1988, [4]). This book contains several suggestions about the design process by those directly involved. In the UCD approach, the 'comfort' variable is intrinsically taken into account by a method that requires several sessions of 'testing with users'. Both usability and comprehensibility tests are utilised to improve users' direct experience; however, no specific comfort-driven design methods were ever set down. In 1987, Ben Shneiderman articulated a similar set of principles in the form of eight golden rules (Shneiderman, 1987, [5]). These were later adapted and popularised by Jakob Nielsen in his heuristics for usability engineering (Nielsen, 1993, 2001, [6], [7]). The involvement of users in the design process seems to provide designers and manufacturers with instruments that lead to more effective, more efficient and safer products, as well as contributing to their commercial acceptance and success (Preece, Rogers, & Sharp, 2002, [8]). Nevertheless, the user-centred approach is too limiting and experience-related to allow for the development of a real comfort-driven design method.
The natural landing point of this design issue was hence the human-centred approach. As stated above, HCD techniques place humans (and their wellbeing) at the centre of the design process. Their main aim is to improve products, processes and the environment to give users a better interactive experience. Both in the fields of health [9] and human rights [10], HCD helps companies and industries to support the development of product/process strategies that improve wellbeing. Recently, HCD artefacts have also become part of companies' development and improvement strategies [11]. Finally, HCD is defined in ISO 9241-210 [12] as 'an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, usability knowledge, and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance'.
While the Standard was developed for VDT workers, this description goes beyond the concept of ergonomics to include theoretical and practical ideas relating to human wellbeing. In Stavrakos 2015 [13], we find the notion that companies' needs translate into business targets. To stay ahead of the competition, industry aims for products that are comfortable or that can drive the user by means of a comfortable experience. This is especially true for products that are either worn or which come into contact with the human body. In addition, discomfort should be prevented in order to reduce pain in the long term (Hamberg et al, 2008,[14]) or reduce dissatisfaction with the product. Scientists, researchers and private companies thus began to consider comfort/discomfort as important factors in their businesses. Simply stated: **user comfort has translated into revenue targets.** This in turn, demands that comfort requirements, seen as functional requirements, are incorporated into products' design parameters – the most significant design challenge of the last twenty year. And this paper seeks to play a part in meeting this challenge.

2 State of the art

Ergonomics and comfort in design development began with HCD/UCD, as the first requirements of human-machine interface (HMI) design are the guarantee of good safety levels and the avoidance of health problems such as muscular-skeletal disease in users. During the last two decades, the market has been impacted by several laws that work both as new constraints and as new challenges for designers:

- EN ISO (International Organization for Standardization) 14738, September 2002 "Safety of machinery – anthropometric requirements for the design of workstations at machinery" [15];
- ISO 11226/2000 – "Ergonomics – evaluation of static working posture" [16];

– EN 1005-3/2009 “Safety of machinery – human physical performance – part 3: recommended force limits for machinery operation” [17].

ISO 11228 [18] was the first ISO Standard that gave us a good reference on ergonomics evaluation mainly based on a “Postural Load Index” that represents the Ergonomics level of examined posture [19][20], even if does not give us information about the perceived well-being. ISO 11228-3 deals with evaluation of risk in cases that require repetitive movements. Risk evaluation is based on two procedures: first, an initial screening of the check list proposed by ISO Standards; second, a detailed evaluation procedure based on International standard methods of Ergonomic analysis like RULA [21], REBA [22], LUBA [23], STRAIN INDEX [24]; OCRA [25], OREGE [25], NIOSH [27,28,29]and others, with a preference given to the OCRA [19,20]. In the first decade of 2000, these methods have been widely used to check and verify the existing workplaces and HMI in order to propose an ergonomic driven re-design of them. The literature contains many papers addressing ergonomics. Nevertheless, ergonomics concepts are frequently developed and used in relation to a specific product or process. Few papers present a systematic approach to product/process/interaction design under the rubric of ergonomic-driven design. In Caputo et al [30], ergonomics were applied to car-interior design using augmented reality devices; in Bordegoni et al [31], VR haptic devices were used to perform ergonomic analyses in two cases of ergonomic-driven design; in Di Gironimo et al [32], the Kano model was used to formulate an ergonomics-driven design method; while in Di Gironimo et al [33], a Virtual OWAS/RULA analysis was performed to re-design the cabin cockpit of a train in a completely digital environment.

In the second part of the first decade, we begin to find papers dealing with the application of ergonomic principles for designing products, processes, workplaces and other general interactions between humans and artefacts. Nevertheless, the standard methods currently available are not able to identify and quantify the necessary parameters to perform a comfort analysis, also because the wellbeing of users/humans is a very ‘slim’ subrange of the ergonomic safety-range in the HMI domain.

Looking back over the last 30 years, there are many papers dealing with (dis)comfort and general well-being in the literature. The majority have tried to demonstrate and quantify the relationship between environmental and physiological factors and perceived comfort (Galinsky et al., 2000 [34]; Hamberg-van Reenen et al., 2008 [35]; Naddeo and Memoli, 2009 [35]). Papers that explicitly address the concept of comfort are those by Helander and Zhang (1997) [37], De Looze et al. (2003) [37], Moes (2005) [38] and Kuijt-Evers et al. (2004) [39]. However, most of the others concern the relationship between subjective perception of comfort/discomfort and factors relating to the product/process/interaction/environment/users. Many papers focus on a specific interaction between humans and artefacts (HAI) in order to understand the mechanism of (dis)comfort perception and identify the artefacts’ parameters that influence that perception. A search for papers whose keywords (and abstracts) contain “Comfort”AND“Design” or “Discomfort”AND”Design” in the main scientific databases reveals several papers written in the last 20 years. In Taptagaporn et al. [40] and Sisay et al [41], a VDT workstation was designed using guidelines based on the physiological resting states of the eye, and on postural analysis; Lai et al. [42], address perceived comfort due to lateral acceleration in motorcycle design; in Wijaya et al. [43], Menegon et al. [44] and Yang et al.,[45], derive guidelines for designing new comfortable seats from experiments concerning vibration perception; Corradi et al. [46], Hasan [47], Nejlaoui et al. [48] and Li et al. [49] give proposals for estimating the comfort indexes of a rail vehicle at the design stage based on lateral acceleration; Dainoff et al. [50] present a design approach based on ecological comfort/ergonomics; Vlaovic et al. [51] give the results of subjective comfort analysis for new materials for chairs; Albers et al. [52] adopt a systematic approach to train design using tools for human comfort; Allocca et al. [53] present a noise-comfort approach for regional aircraft design; Webster et al. [54] provide a study of cricket leg guard comfort by incorporating subjective end-user perceptions in the design process; Chen et al. [55] and Mohamad et al. [56] take comfort as one of their design targets in seat design; Sharma et al. [57] and Xiang-Rong et al. [58] link subjects’ comfort to their behaviour in a crowd; Shen et al. [59] and Tan et al. [60] relate thermal comfort during sleep to mattress characteristics; Pei et al. [61] and Wang et al. [62] relate environmental comfort to the controlled air quality perceived by subjects; and Vink et al. [63] define some seat adjustability guidelines by examining the differences in pressure sensitivity for areas of the human body in contact with the seat pan and backrest of a vehicle seat.

The main purpose of these papers is to produce guidelines for designers seeking to create more comfortable products and drive their development and innovation. The problem of defining a comfort-driven design method has been explicitly addressed by several papers. For example, Pandharipande et al. [64] examine the user-comfort-driven design of indoor LED lighting control systems via spatial illumination rendering; Vallone et al. [65] propose the redesign of a manufacturing plant’s workstation to improve operators’ perceived comfort.

Each of these authors seeks to extrapolate or synthetize a general rule for assessing a comfort evaluation and, ultimately, to provide initial guidelines for a comfort-driven design method.
Nevertheless the need of a more suitable and complete comfort model, shown in Fig.2, has come in the second decade of the 2000 and was highlighted in the work of Vink and Hallbeck (2012)[66]. In this work an exhaustive analysis of the state of the art about the comfort in HMI has been performed by authors and starting from the Moes' (2005) [38] model represented in Fig.1.

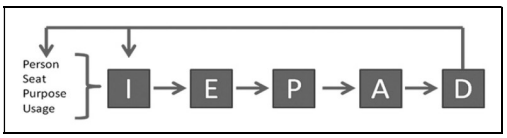


Figure 1. Moes model of discomfort perception

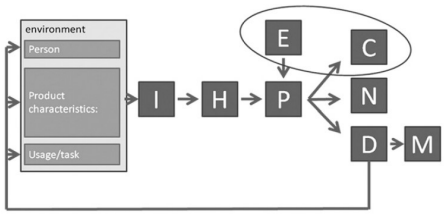


Figure 2. Vink-Hallbeck model of comfort/discomfort perception

They start from the following main topics individuated in a wide literature overview, for introducing their model:

1) Sensory input (De Korte et al.[67], 2012; Vink et al., 2012[66]);
2) Activities conducted during the measurement with an influence on comfort (Groenesteijn et al., 2012[68]; Ellegast et al., 2012[69]);
3) Different bodily regions (Franz et al., 2012[70]; Kong et al., 2012[71]);
4) Effect of the product' contour on comfort (Kamp, 2012[72]; Naddeo et al. 2010[20]; Noro et al., 2012[73]);
5) Physical loading (Borg, 1982[74]; Lee et al., 2012[75], Di Pardo et al. 2008[76]; Zenk et al., 2012[77]).

Moes (2005) [38] deals about a specific case on the topic of "seat-design" and describes that if a person uses a seat with a specific purpose, the interaction (I) arises. For example, this interaction can consist of the pressure distribution of the contact area between the subject and seat. An interaction results in internal body effects (E), such as tissue deformation or the compression of nerves and blood vessels. These effects can be perceived (P) and interpreted, for instance as pain. The next phase is the appreciation (A) of the perception. If these factors are not appreciated, it can lead to feelings of discomfort (D).
Vink and Hallbeck (2012)[66] have modified this model (Fig.2); in their opinion, the interaction (I) with an environment is caused by the contact (could also be a non-physical contact, like a signal in the study of De Korte et al. [67]) between the human and the product and its usage. This can result in internal human body effects (H), such as tactile sensations, body posture change and muscle activation. The perceived effects (P) are influenced by the human body effects, but also by expectations (E). These are interpreted as comfortable (C), you feel nothing (N), or it can lead to feelings of discomfort (D) [2] and the Discomfort could result in musculoskeletal complaints (M).
In 2014 Naddeo et al. [78] proposed the following model in Fig.3:

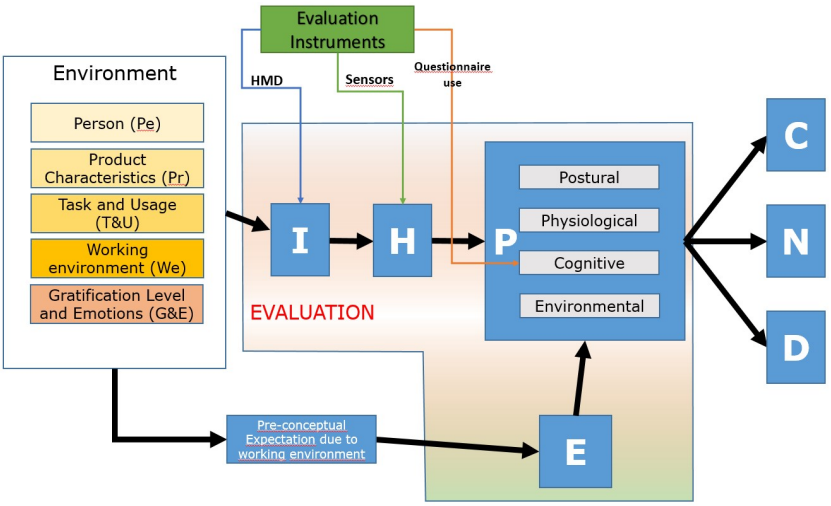


Figure 3. New proposal for comfort perception model

In this model, the Environment is represented by the logic sum of five main aspects that contribute to HMI description and classification:

- Person (Pe): represent the whole body geometric and personal characteristics of human involved in tasks;
- Product (Pr): represent all geometric and non-geometric characteristics that describe the element that come in contact with the human body during task execution (shape, materials, colour, surfaces' treatment and so on…);
- Task/Usage (T&U): represent all the task or the use that humans can do during HMI experience (kind of contact, timing, kind of interaction);
- Working environment (We): represent the set of parameters that characterizes the working environment, both under climate and under layout point of view (temperature, humidity, lighting, working seat, kind of workspace);
- Satisfaction/Gratification level and emotions (G&E): represent the set of work characteristics and the emotional state that contribute to the satisfaction/dissatisfaction of worker (job position in organization chart, working shifts, gratification, salary and so on) and is widely related to the general environment.

The Vink/Hallbeck model (2012) [66] is integrated with a relation that directly connects the Environment in which the comfort/discomfort is experienced with the expectation through the coding of several pre-conceptual aspects due to not only the same environment but also to the cultural/experience background of the worker. An aspect that cannot be underestimated because it is always present when a comfort/discomfort evaluation is performed also integrates this model: the perception modification due to experimental devices needed to evaluate comfort. These "devices" can modify most of contributes to the formation of the comfort/discomfort perception.

For example, a HMD (Head mounted display) used for VR (Virtual Reality) application in HMI evaluation can modify the Postural Comfort Perception (Interaction – I); the use of markers/sensors on the naked body to perform pressure/temperature/movement data acquisition can change the Physiological Comfort Perception (Human Body effect – H); the use of questionnaire can annoy the workers and directly modify his Cognitive Comfort perception (Perceived effects – P).

In the same paper, Naddeo et al. propose a mathematical/functional model of comfort/discomfort that includes all the aspects discussed in the cited papers, which may be summarised as follows:

$$C_i = Mod_C * P_C(h(Pe, Pr, T\&U, We, G\&E) - E$$
$$D_i = Mod_D * P_D(h(Pe, Pr, T\&U, We, G\&E) + E \quad (1)$$

In which:
Mod = Modifier of **P** (Perception) of the **h** = Human body effect due to:
Pe = Personal characteristics
Pr = Product characteristics
T&U = Task and usage
We = Working environment
G&E = Gratification level and emotions
E = Expectations

It is quite difficult to find other general models for (dis)comfort perceptions that are explained or expressed by a mathematical/logical formulation. However, several other comfort models have been proposed in different terms in recent decades. Most of these addresses a specific, context-related issue. Many papers have been written about thermal comfort, and these generally adopt human thermal models (e.g. the Fanger model) to describe perceptions of comfort/discomfort. All the other aspects are addressed in the following papers:
Looking for "Comfort"AND"Model" in the main scientific databases, the following papers deal with Comfort models. In [66], [78] and [79], a conceptual model of Comfort perception that takes into account physical, psychological, object, context and environment have been presented.
In [80], a comfort index for seat has been modelled through Artificial Neural Networks (ANN) and Step-wise Linear Regression (SLR) on several heterogeneous data. In [81] the driving posture comfort is modelled through a function obtained by Support Vector Machine (SVM) regression analysis methods and in [82] and [83] a Multiple Linear Regression (MLR) is used for fusing subjective and objective information.
In [84], [85], [86], [87], [88], [79] and [89], an algorithmic approach is used for optimizing a comfort function based on simulations' results. In [90], a Nested Logit Model is developed for predicting Subway system comfort. In [91] a Genetic Algorithm is used for describing the postural comfort related to the Human joints' position. In [92], Fuzzy Key Means (FKM) is used for defining a comfort model for sleep comfort, while in [93],[94] and in [95] a Sugeno Fuzzy inference system is used for defining a comfort model for car passengers and for products. In [96], Machine Learning techniques have been used for developing a predictive comfort model for HVAC. In [97], a Multilayered Model Based on Situated Multi-agent Systems has been developed for assessing people comfort into a crowd. In [98] a Probabilistic model for human comfort is presented.
Looking for "Discomfort"AND"Model" in the main scientific databases, the following papers seal with Discomfort models.
In [85], [99], [100] and [101], an algorithmic approach is used fusing subjective and objective information in order to obtain a predictive discomfort function. In [102] a Multiple Linear Regression (MLR) is used for fusing subjective and objective information about perceived discomfort. In [103], [104], [105], [106], [107] and [108], a predictive postural discomfort model has been developed through experimental function's extrapolation and fusion. In [109], [110] and [111] a database modelling approach is used to describe the dis-comfort related to a position.
All of these may be seen as a part of the general model expressed in the above formula by Naddeo et al. However, this formula has no possibility to be used, as it requires that the function describing the relation between a factor influencing (dis)comfort perception and the perception itself be deployed. This is the real challenge that scientists must face when implementing a model that allows them to perform a preventive analysis of (dis)comfort in the virtual design process.

3 Simulation in Engineering and Design

The use of both mathematical and engineering models in engineering design allows designers to speed up the design process and to improve and optimise their results from different perspectives. The use of models that describe the 'behaviour' of a product (artefact) in terms of a human-artefact interface (HAI) can help de-

signers include HCD optimisation as a step in the design cycle. The design cycle can be summarised by the following diagram in Fig.4:

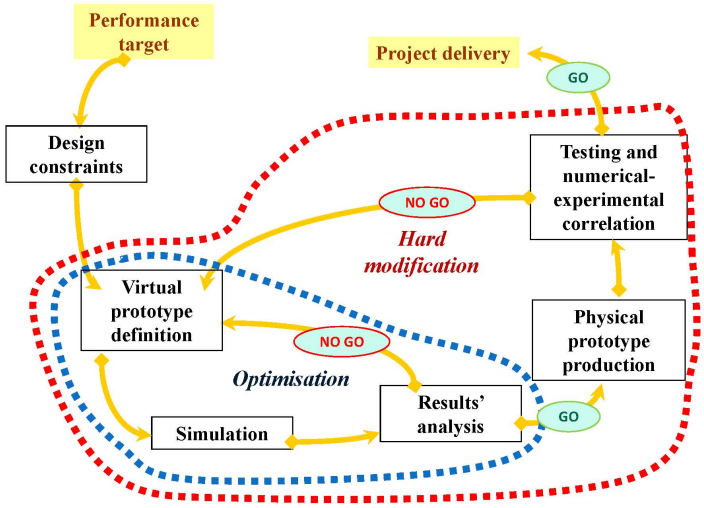


Figure 4. Product design and development diagram in digital era

In this process, target setting generally begins with customer needs and the functional requirements of the final artefact. When introducing HCD to the artefact development plan, we require models that describe the HAI in the very early phase of the design. Contrarily, (dis)comfort performances can be discovered and evaluated only after the production of a physical prototype. Due to the subjectivity of comfort perception, it is difficult to objectivise this kind of performance via a model, and integrating these models into the artefact development plan is even more challenging. To achieve this requires the integration of the standard or non-standard design methods and the techniques for modelling the (dis)comfort behaviour. Simply stated, we need to create a comfort-driven design method that can be applied to the early phase of the design process and that can help designers and engineers optimise the product by introducing comfort-related issues in the target-setting phase.

4 Comfort-driven target setting: an axiomatic approach

From the panorama of different design methods, we have selected Axiomatic Design. As stated in the previous paragraph, the factors that contribute to perceptions of (dis)comfort can be classified and in [112]. This classification has been used for the axiomatic approach to artefact design.
In 1990, Suh [113] proposed the use of axioms as the scientific foundations of design. From these twelve initial axioms, Suh arrived the following two basic axioms, along with six corollaries, that a design must satisfy:

Axiom 1 - The Independence Axiom: Maintain the independence of the functional requirements
Axiom 2 - The Information Axiom: Minimise the information content in a design

In Axiomatic Design [114], the engineering design process is described as in Fig. 5. Here, the array of functional requirements (FRs) is the minimum set of independent requirements that completely characterise the design objective based on customer attributes (CAs). Design is defined as the creation of a synthesised solution that satisfies perceived needs via the mapping between the FRs in the functional domain and the design

parameters (DPs) in the physical domain, and via the mapping between the DPs and the process variables (PVs) in the process domain.

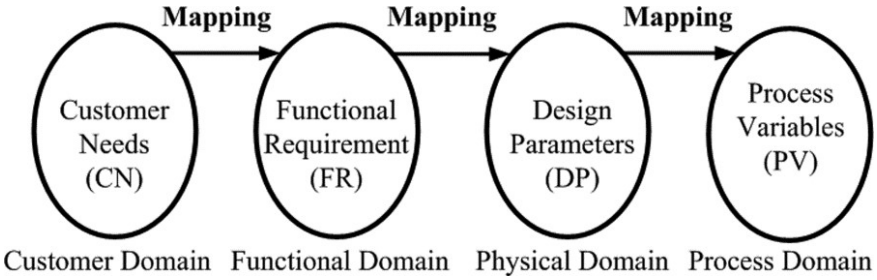


Fig. 5. The Axiomatic Design Framework

The physical and process mappings can be expressed mathematically as

$$\{FR\}_{mx1} = [A]_{mxr}\ \{DP\}_{rx1} \tag{2}$$

$$\{DP\}_{rx1} = [B]_{rxn}\ \{PV\}_{nx1}$$

where $\{FR\}_{mx1}$ is the vector of independent functional requirements with **m** components, $\{DP\}_{rx1}$ is the vector of design parameters with **r** components, $\{PV\}_{nx1}$ is the vector of process variables with **n** components, $[A]_{mxr}$ is the physical design matrix, and $[B]_{rxn}$ is the process design matrix.
Axiom 1 implies that [A] should be either a diagonal matrix or a triangular matrix.
After satisfying Axiom 1, design simplicity is pursued by minimizing the information contents for Axiom 2, where the information content is defined as a measure of complexity. One popular measure of information content is entropy [115]. FRs' entropy is related to the probability of satisfying its specification in the physical mapping (the DP in the process mapping) [116] [117] [118].
Entropy and information content can be mathematically expressed in different ways. The more useful measures are those that evaluate the probability of meeting design specifications, which is the area of intersection between the design range (dr) (design specifications) and the system range (sr) (process capability). The overlap between design range and system range is called the common range (cr); an example is shown in Fig.6.

Information in probability = $\log_2 (1/p)$
Fuzzy information = $\log_2 [1/mf(x)]$
General function information = $\log_2 [1/f(x)]$

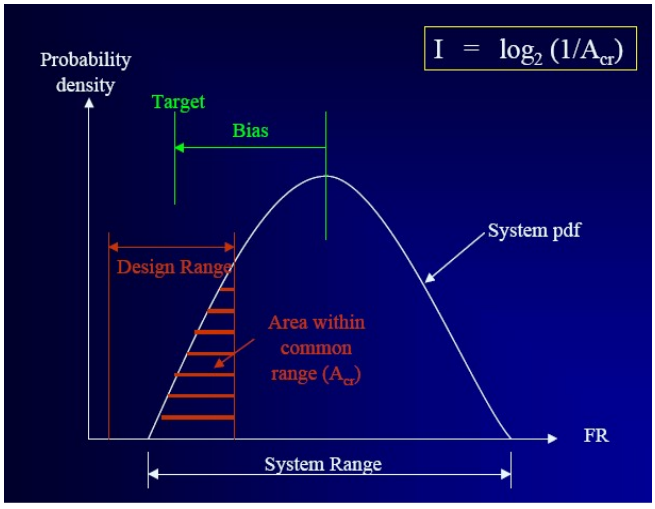


Fig. 6. Design/System/Common Range in Axiomatic Design Framework

The probability of success is defined as the area (probability) ratio of the common range to the system range, i.e. the common measures are based on the logarithmic function. In terms of probability, the information related to an event of probability p is I = log2 (1/p). In addition, our information content evaluation is based on this concept [116] [118]. The power of this method is that the probability function can be expressed, for example, through:

- statistical curves
- fuzzy membership functions
- artificial neural network based curves
- genetic algorithms curves
- fitting curves (with different fitting methods)

In this way, all results from the literature can be integrated in a design process when it is based on the axiomatic approach. In particular, the target-setting step in the artefacts development process fits perfectly with the first mapping operation in which customer needs must be translated into functional requirements. In this mapping operation, the comfort guidelines from the literature and/or the comfort models used both for modelling and for simulations can be translated into functions to which design principles can be applied.
In a target-setting operation, all comfort related issues, formulated as user perceptions, can be considered as customer needs. The model can help translate these needs into artefact functional requirements that are fulfilled by means of the right decisional process in the definition and assessment of design parameters. The power of the axiomatic approach may also be seen in the possibility to clarify and quantify all the interdependencies among customers' needs or among functional requirements, which are always formulated in terms of comfort perception.
Finally, virtual simulations allow for an axiomatic-design-driven multi-variate optimisation in which both the guidelines and the (dis)comfort models are used to create and implement the required functions. Clearly, this optimisation can also be made in terms of Suh's axioms, allowing 'human comfort' to be become a new and vital functional requirement.

5 Case studies: dashboard command positioning and mattress comfort

The following two case studies have been reported.
The first of these, published in SAE proceedings [119] by the author, presents a example of comfort-driven target setting and the consequent comfort-driven re-design of a car-dashboard, whose functional requirements were expressed by the phrase: 'the HVAC regulation bolt has to be reached in a comfortable way by a car driver whose anthropometrics data are among the 5th female and the 95th male European percentiles.'
In this case study, a method for objectifying the postural comfort [120] of the upper limbs was used to determine the positioning of automotive HVAC controls (see Fig.7). The objectivised perceived postural comfort for the reachability and visibility of the controls were merged into an overall comfort function that was optimised in terms of 'easiness to use', using a fuzzy/axiomatic approach. The results were a series of iso-comfort curves and surfaces that allowed the commands to be positioned to maximise predicted comfort. An example application on an FCA car was provided.



Fig. 7. The Virtual/Experimental Comfort evaluation: (A) Delmia Simulation, (B) Experimental analysis, (C) Solidworks multi-body simulation, (D) CaMAN Software for postural comfort rating

The second case study, currently awaiting publication, comes from the field of mattress comfort evaluation. Three years in development, it is the result of a cooperation with Rinaldi Group, Srl., a company that designs and produces mattresses for a worldwide market.

Here, a new foam-layered mattress was designed by defining product targets in terms of manufacturing technologies, general layout, final price, final user characteristics (BMI, height, and gender) and perceived comfort. The design development process was driven by the final user characteristics (BMI, height, and gender) and perceived comfort, while the general layout, manufacturing technologies and final price were considered in the same way as design constraints.

The design flow begins with the definition of the target in terms of perceived comfort, to be developed for several kinds of opportunely clustered final users. For marketing reasons, a general layout was imposed by the mattress company, and the design process was developed in terms of material choice (several materials were available) and geometric features.

The main target for the product was expressed by the following two phrases:

1) The product must be comfortable for all users between the 50th female percentile and the 99th male percentile. The comfort rating must be more than 7.5 in a scale of 0-10.
2) The product must be comfortable in a supine position for the duration of a 15-minute test (the maximum test time for users seeking to buy a mattress)

A comfort scale and a comfort rating system was then developed based on the following parameters:

- Ratio between the surface in contact with the human body and the total surface, to take the 'wrapping' effect into account;
- Average pressure on the body compared with the ideal pressure cited in the literature;
- Maximum pressure: a good indicator of body parts that are prone to local discomfort;
- Median value and variance of the pressure: these give an idea about the distribution and the differences between perception by different body parts;
- Qualitative pressure distribution, evaluated by an expert;
- Values and distribution of the pressure in the shoulder/spine area, to take account of the discomfort in those body parts that are more sensitive when a person lies down on a mattress [121,122,123,124];
- Qualitative index about the load transfer between the layers, to evaluate how each mattress layer works.

To improve the mattress, cylinder-shaped holes were filled with three different types of foam. To account for differences between users, the layout of the foam was chosen on the basis of the users' gender, percentile (height), and BMI. The first choice of layout was overseen by marketing experts and mattress designers. After that, several simulated tests were performed to understand what changes were needed to optimise the mattress for the user. The experience of researchers and experts involved in the process, as well as the limited number of possible layouts due to technological limitations, allowed these optimisation steps to be performed using a 'trial and error' method.

The final product resulting from this comfort-driven innovation process is shown below in Fig. 8.

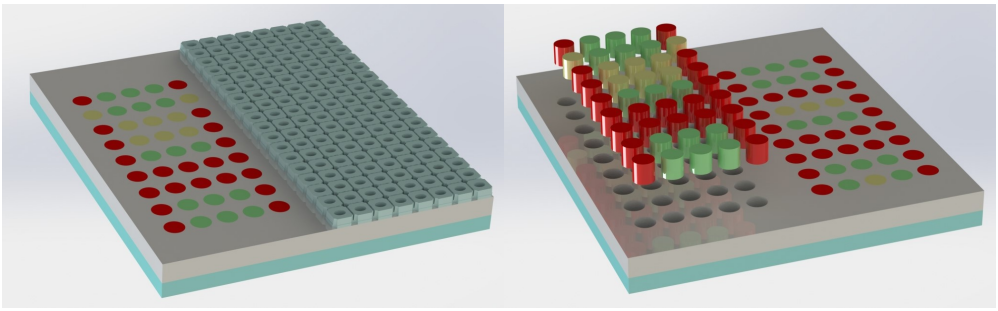


Fig. 8. The innovative Mattress named Ergon

6 Conclusions

Companies and scientists are converging towards a common goal: to include (dis)comfort performance evaluation into the early stage of product development plans via the objectification of the performance using virtual prototyping techniques. The challenge is to develop a general model, and to discover the relationship that links subjective comfort perception to objective parameters that can be measured and/or controlled. This paper presents a scheme for the (dis)comfort perception based on the effects experienced by the subjects and the types of interaction, taking into account all the external factors that may affect perception. The proposed general model can be framed under the Axiomatic Design approach, in which the links between customer needs and functional requirements, and functional requirements and design parameters, can be expressed in terms of statistical function, fuzzy function, empirical function, and so on. These functions can be optimised via the first two axioms of the Axiomatic Design approach, which also allow the results from the literature to be formulated in the proper way. As this approach is applicable from the concept design phase onwards, comfort performance can be included in the target-setting framework and, as such, become the main element in the overall evaluation, allowing for real comfort-driven target setting to be achieved.
Future developments may proceed in a number of different ways. Nevertheless, the main challenges remain the same:

- To understand which functions describe the links between (dis)comfort perception and the characteristics of user interactions;
- To understand which interactions are present in these requirements and optimise them accordingly.

All of us are working on.

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REFERENCES

1. Jastrzębowski Wojciech. 1857, Rys ergonomji czyli nauki o pracy, opartej na prawdach poczerpniętych z Nauki Przyrody (The Outline of Ergonomics; i.e. Science of Work, Based on the Truths Taken from the Natural Science).
2. Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-centered design. Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications, 37(4), 445-456
3. Norman, D. A. & Draper, S. W. (Editors) (1986) User-Centered System Design: New Perspectives on Human-Computer Interaction. Lawrence Earlbaum Associates, Hillsdale , NJ, USA, ISBN:0898597811.
4. Norman, D. (1988) POET: "psychology of everyday things' in The Design of Everyday Things, Doubleday Publishing, 1540 bradway, New York 10036. ISBN 0-385-26774-4
5. Shneiderman, B. (1987) Designing the User Interface: Strategies for Effective Human-Computer Interaction. Reading, MA: Addison-Wesley Publishing Co. Reading, MA, USA. ISBN:0-201-16505-8
6. Nielsen, J. (1993) Usability Engineering. San Francisco: Morgan Kaufmann. ISBN 0-12-518405-0.
7. Nielsen, J. (2001) Ten Usability Heuristics, www.useit.com/papers/heuristic

8. Preece, J.; Rogers, Y., & Sharp, H. (2002) Interaction design: Beyond human-computer interaction. New York: John Wiley & Sons, Inc. ISBN 0471492787
9. Matheson, G. O., Pacione, C., Shultz, R. K., & Klügl, M. (2015). Leveraging human-centered design in chronic disease prevention. American Journal of Preventive Medicine, 48(4), 472-479.
10. Buchanan, R. (2001). Human dignity and human rights: Thoughts on the principles of human-centered design. Design issues, 17(3), 35-39.
11. Giacomin, J. (2014). What Is Human Centered Design? The Design Journal, 17(4), 606-623.
12. ISO 9241-210:2010 – 'Ergonomics of human-centred system interaction'
13. Stavrakos, S-K., Ahmed-Kristensen, S., & Goldman, T. (2015). Assessment methods for comfort of consumer products at early stages of the development process. Department of Management Engineering, Technical University of Denmark.
14. Hamberg-van Reenen, H.H., Van der Beek, A.J., Blatter, B.M., Van der Grinten, M.P., Van Mechelen, W., Bongers, P.M., 2008. Does musculoskeletal discomfort at work predict future musculoskeletal pain?, Ergonomics 51, 637648.
15. UNI EN ISO 14738:2009, Safety of machinery – anthropometric requirements for the design of workstations at machinery
16. ISO 11226:2000, Ergonomics - Evaluation of static working postures
17. UNI EN 1005-3:2009, Safety of machinery – Human physical performance – part3: Recommended force limits for machinery operation
18. ISO 11228-1, Ergonomics - Manual handling - Part 1: Lifting and carrying
19. Annarumma M, Pappalardo M, Naddeo A, Methodology development of human task simulation as PLM solution related to OCRA ergonomic analysis, IFIP International Federation for Information Processing, Volume 277, 2008, Pages 19-29
20. Naddeo A., D'Oria C., N. Cappetti, M. Pappalardo. Postural analysis in HMI design: an extension of OCRA standard to evaluate discomfort level. Journal of achievements in materials and manufacturing engineering. Vol. 39. Pag.60-70.
21. McAtamney L. and E.N. Corlett, "RULA: a survey method for the investigation of work-related upper limb disorders", Applied Ergonomics. 24(2), doi:10.1016/0003-6870(93)90080-S, 1993.
22. Hignett S. and L. McAtamney, "Rapid Entire Body Assessment (REBA)", Applied Ergonomics. 31, Issue 2, 201-205, doi:10.1016/S0003-6870(99)00039-3, 2000.
23. Kee D. and Karwowski W., "LUBA: an assessment technique for postural loading on the upper body based on joint motion discomfort and maximum holding time", Applied Ergonomics. 32, doi:10.1016/S0003-6870(01)00006-0, 2001.
24. Moore J.S. and Garg A., "The strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders", Am Ind Hyg Assoc J. 56(5):443-58, 1995.
25. Occhipinti E. and Colombini D., "Proposta di un indice sintetico per la valutazione dell'esposizione a movimenti ripetitivi degli arti superiori (Ocra index)", Medicina del Lavoro, vol. 87, n. 6, 1996, pp. 526-548.
26. Valentin L., Gerling A. and. Aptel M., "Validité opérationnelle d'OREGE (Outil de Repérage et d'Evaluation des Gestes)", Laboratoire de Biomécanique et d'Ergonomie: Département Homme au Travail, Université Henri Poincaré Nancy(FR), 2004.
27. Konz, S., NIOSH lifting guidelines, (1982) American Industrial Hygiene Association Journal, 43 (12), pp. 931-933. doi: 10.1080/152986682914108
28. Sauter, S. L., Gottlieb, M. S., Jones, K. C., Dodson, V. N., & Rohrer, K. M. (1983). Job and health implications of VDT use: Initial results of the wisconsin-NIOSH study. Communications of the ACM, 26(4), 284-294. doi:10.1145/2163.358098
29. Waters, T. R., Putz-Anderson, V., Garg, A., & Fine, L. J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics, 36(7), 749-776. doi:10.1080/00140139308967940
30. Caputo F., De Amicis R., Di Gironimo G., Stork A., 2003. ERGONOMIC DRIVEN DESIGN IN AUGMENTED REALITY. XIII ADM – XV INGEGRAF International Conference.
31. Bordegoni M., Colombo G., Formentini L., 2006. Haptic technologies for the conceptual and validation phases of product design. Computers & Graphics 30 377–390. doi:10.1016/j.cag.2006.02.012.
32. Di Gironimo G., Lanzotti A., Vanacore A., 2006. Concept design for quality in virtual environment. Computers & Graphics 30 1011–1019. doi:10.1016/j.cag.2006.08.002.
33. Di Gironimo G., Patalano S., 2008. Re-design of a railway locomotive in virtual environment for ergonomic requirements. Int J Interact Des Manuf 2:47–57. DOI 10.1007/s12008-007-0035-z.
34. T.L. Galinsky, N.G. Swanson, S.L. Sauter, J.J. Hurrell and L.M. Schleifer, "A field study of supplementary rest breaks for data entry operators", Ergonomics. 43, 622-638, doi:10.1080/001401300184297, 2000.
35. Naddeo A. and Memoli S., "Postural Comfort Inside a Car: Development of an Innovative Model to Evaluate the Discomfort Level", SAE Int. J. Passeng. Cars - Mech. Syst.. 2(1):1065-1070, 2009, doi:10.4271/2009-01-1163, 2009.
36. Helander M.G. and Zhang L., "Field studies of comfort and discomfort in sitting", Ergonomics. 40, 895-915, doi:10.1080/001401397187739, 1997.
37. De Looze M.P., Kuijt-Evers L.F.M. and Van Dien J.H., "Sitting comfort and discomfort and the relationships with objective measures", Ergonomics. 46, 985-997, doi:10.1080/00140130310001219 77,2003.
38. Moes N.C.C.M., "Analysis of sitting discomfort, a review", in: Bust, P.D., McCabe, P.T., Contemporary Ergonomics 2005. London: Taylor & Francis, 200-204.
39. Kuijt-Evers L.F.M., Groenesteijn L., De Looze M.P. and Vink P., "Identifying factors of comfort in using hand tools", Applied Ergonomics. 35, 453-458, doi:10.1016/j.apergo.2004.04.001,2004.
40. Taptagaporn, S., Sotoyama, M., Saito, S., Suzuki, T., Saito, S., 1995. Visual comfort in VDT workstation design. (Article). Journal of human ergology. Volume 24, Issue 1.
41. Workineh S.A., Yamaura H., 2016. Multi-position ergonomic computer workstation design to increase comfort of computer work. International Journal of Industrial Ergonomics 53 1e9. doi.org/10.1016/j.ergon.2015.
42. Lai H., Liu J., Lee D.T., Wang L., 2003. Design parameters study on the stability and perception of riding comfort of the electrical motorcycles under rider leaning. Mechatronics 13 49–76.

43. Wijaya A. R., Jönsson P. & Johansson Ö., 2003. The Effect of Seat Design on Vibration Comfort. International Journal of Occupational Safety and Ergonomics. DOI: 10.1080/10803548.2003.11076563.
44. Menegon L. da S, Vincenzi S. L, De Andrade D. F, Barbetta P. A., Merino E. A. D., Vink P.,2017. Design and validation of an aircraft seat comfort scale using item response theory. Applied Ergonomics 62 216-226. doi: org/10.1016/j.apergo.2017.03.005.
45. Yang, Z., Sun, S., Chen, G., 2009. Evaluating sitting comfort with questionnaire and body pressure distribution: Overview and design (Conference Paper). Proceeding 2009 IEEE 10th International Conference on Computer Aided Industrial Design and Conceptual Design: E-Business Creative Design, Manufacturing CAID and CD'2009. DOI: 10.1109/CAIDCD.2009.537535.
46. Corradi, R., Melzi, S., Ripamonti, F., Romani, M., 2006. Estimation of the comfort indexes of a rail vehicle at design stage (Conference Paper). 8th Biennial ASME Conference on Engineering Systems Design and Analysis, ESDA2006; Torino; Italy; 4 July 2006 through 7 July 2006.
47. Nazmul Hasan, 2011 Passenger Track Curve Design Criteria: Comfort Criteria, Equivalent Comfort Criteria, and Application. 2011 Joint Rail Conference. doi:10.1115/JRC201156012.
48. Nejlaoui M., Houidi A., Affi Z., Romdhane L., 2013. Multiobjective robust design optimization of rail vehicle moving in short radius curved tracks based on the safety and comfort criteria. Simulation Modelling Practice and Theory 30 21–34. doi.org/10.1016/j.simpat.2012.07.012.
49. Li, T., Li, G., Gu, J., Dong, L., 2012. Multidisciplinary design optimization of passenger compartment safety and comfort. Jixie Gongcheng Xuebao/Journal of Mechanical Engineering. Volume 48, Issue 2. DOI: 10.3901/JME.2012.02.138.
50. Dainoff, M., Mark, L., Ye, L., Petrovic, M., 2007. Forget about aesthetics in chair design: Ergonomics should provide the basis for comfort (Conference Paper). International Conference on Ergonomics and Health Aspects of Work with Computers, EHAWC 2007; Beijing; China; 22 July 2007.
51. Vlaović, Z., Bogner, A., Grbac, I., 2008. Comfort evaluation as the example of anthropotechnical furniture design (Article). Collegium Antropologicum. Volume 32, Issue 1.
52. Albers, A., Lerspalungsanti, S., Düser, T., Ott, S., Wang, J., 2008. A systematic approach to support drive train design using tools for human comfort evaluation and customer classification (Conference Paper). 2008 Proceedings of the ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC 2008.
53. Allocca, M.C.a, Paonessa, A.a, Marulo, F.b, Polito, T.b, Noise comfort design approaches for next Regional Aircraft generation, Volume 31, Issue PART 3, 2009, 8th European Conference on Noise Control 2009, EURONOISE 2009; Edinburgh; United Kingdom; 26 October 2009 through 28 October 2009;
54. Webster, J.M., Roberts, J., 2009. Incorporating subjective end-user perceptions in the design process: A study of leg guard comfort in cricket (Article). Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology. DOI: 10.1243/17543371JSET31.
55. Chen, K.M., Shyr, Y.H., Lee, H., 2010. Study of prediction model of seat comfort in seat design (Conference Paper). 9th PanPacific. Conference on Ergonomics, PPCOE 2010.
56. Mohamad, D., Md Deros, B., Wahab, D.A., Daruis, D.D.I., Ismail, A.R., 2010. Integration of comfort into a driver's car seat design using image analysis (Article). American Journal of Applied Sciences. Volume 7, Issue 7.
57. Sharma S. and Fisher A., 2013 Simulating the User Experience Design Optimisation for Visitor Comfort.
58. Xiang-rong C. and Shuo-xian W., 2013. Study on Seat Density based on comfort Analysis and optimization design. Fourth International Conference on Intelligent Systems Design and Engineering Applications. DOI 10.1109/ISDEA.2013.150.
59. Shen T. Y., Tan S. H., Wu F. G., 2015 Comparison of Sleep Quality and Thermal Comfort for Innovative Mattress Design. Procedia Manufacturing 3 5874 – 5880. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015.
60. Tan S. H., Shen T. Y., Wu F. G., 2015. Design of an innovative mattress to improve sleep thermal comfort based on sleep positions. Procedia Manufacturing 3 5838 – 5844. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015.
61. Pei J, Sun Y., 2016. Special issue on built environment design for health and comfort with energy efficiency. Energy and Buildings 133 359. doi.org/10.1016/j.enbuild.2016.
62. Wang L., Zhang J., Li C., Qian D, and Zhang G., 2016. Data and Knowledge Driven Design of SIRMs Connected Fuzzy Inference System with Application to Thermal Comfort Prediction. World Congress on Intelligent Control and Automation (WCICA).
63. Vink P., Lips D., 2017. Sensitivity of the human back and buttocks: The missing link in comfort seat design. Applied Ergonomics 58 287e292. doi.org/10.1016/j.apergo.2016.07.004
64. Pandharipande A., Senior Member, IEEE, and Caicedo D., 2013. Adaptive Illumination Rendering in LED Lighting Systems. IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS, VOL. 43.
65. Vallone, M., Naddeo, A., Cappetti, N., & Califano, R. (2015). Comfort driven redesign methods: An application to mattresses production systems. Open Mechanical Engineering Journal, 9(1), 492-507. doi:10.2174/1874155X01509010492
66. Vink P. and Hallbeck S., "Editorial: Comfort and discomfort studies demonstrate the need for a new model", Applied Ergonomics. 43, 271-276, doi:10.1016/j.apergo.2011.06.001, 2012.
67. De Korte E.M., Huysmans M.A., De Jong A.M., Van de Ven J.G.M. and Ruijsendaal M."Effects of four types of non-obtrusive feedback on computer behavior, task performance and comfort", Applied ergonomics. 43, 344-353, doi:10.1016/j.apergo.2011.06.010,2012.
68. Groenesteijn L., Ellegast R.P., Keller K., Krause F., Berger H. and De Looze M.P., "Office task effects on comfort and body dynamics in five dynamic office chairs", Applied ergonomics. 43, 320-328, doi:10.1016/j.apergo.2011.06.007, 2012.

69. Ellegast R.P., Keller K., Groenesteijn L., Krause F., Berger H. and Vink P., "Comparison of four specific dynamic office chairs with a conventional office chair: impact upon muscle activation, physical activity and posture", Applied ergonomics. 43, 296-307, doi:10.1016/j.apergo.2011.06.005,2012.
70. Franz M.M., Durta A., Zenk R. and Desmet P.M.A., "Comfort effects of a new car headrest with neck support", Applied ergonomics. 43, 336-343, doi:10.1016/j.apergo.2011.06.009,2012.
71. Kong Y.U., Kim D.M., Lee K.S. and Jung M.C, "Comparison of comfort, discomfort, and continuum ratings of force levels and hand regions during gripping exertions", Applied Ergonomics. 43, 283-289, doi:10.1016/j.apergo.2011.06.003, 2012.
72. Kamp I., "The influence of car seat design on its character experience", Applied Ergonomics. 43, 329-335, doi:10.1016/j.apergo.2011.06.008, 2012.
73. Noro K., Naruse T., Lueder R., Nao N. and Kozawa M., "Application of Zen sitting principles to microscopic surgery seating", Applied Ergonomics. 43, 308-319, doi:10.1016/j.apergo.2011.06.006, 2012.
74. Borg G., "Psychophysical Bases of Perceived Exertion", Medicine and Science in Sports and Exercise. (14), 377-381, 1982.
75. Kee D. and Lee I., "Relationships between subjective and objective measures in assessing postural stresses", Applied Ergonomics. 43, 277-282, doi:10.1016/j.apergo.2011.06.002, 2012.
76. Di Pardo M., Riccio A., Sessa F., Naddeo A. and Talamo L., "Methodology development for ergonomic analysis of workcells in virtual environment", SAE Technical Papers. doi: 10.4271/2008-01-1481, 2008.
77. Zenk R., Franz M., Bubb H. and Vink P., "Spine loading in automotive seating", Applied Ergonomics. 43, 290-295, doi:10.1016/j.apergo.2011.06.004, 2012.
78. Naddeo, A., Cappetti, N., Vallone, M., Califano, R., 2014. New trend line of research about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions. In Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE, edited by T. Ahram, W. Karwowski and T. Marek.
79. Da Silva L., Ligia S., Bortolotti V., Carolina I., Campos M. and Merina A.E.D., 2012. Comfort model for automobile seat. Work 41 295-302.DOI: 10.3233/WOR-2012-0172-295.
80. Kolich M., Seal N., Taboun S., 2004. Automobile seat comfort prediction: statistical model vs.artificial neural network. Applied Ergonomics 35 275–284. doi:10.1016/j.apergo.2004.01.007.
81. Zou N., Sun S., Tang M., Chai C., Dong Z., 2008. A Comfort Analysis Model based on SVM Computation. Fourth International Conference on Natural Computation. doi 10.1109/ICNC.2008.518.
82. Zi-min Jin, 2009. STUDY ON THE PREDICTION MODEL OF PRESSURE COMFORT OF MEN'S SEAMLESS UNDERWEAR'S UNDERPART. Supported by The Importance Item of Science and Technology Department of Zhejiang Province.
83. Zhongliang Y., Shouqian S., Zenggui G., Yumiao C.,2010. Correlation Model of Overall and local Sitting Comfort based on Rating Scales.
84. Guo L., Dong R., Zhang M., 2016. Effect of lumbar support on seating comfort predicted by a whole human body-seat model. International Journal of Industrial Ergonomics 53 319-327. doi.org/10.1016/j.ergon.2016.03.004.
85. Pinkelman, B., 2014. A Consumer Utility Model of Automotive Seating Comfort: Discomfort, Comfort Character, and Expectations. SAE Technical Paper 2014010454, 2014, doi:10.4271/2014010454.
86. Pir F., Albak E., Öztürk F., Kaya N., Korkmaz I., 2016. Integrated model-based approach for the optimisation of vehicle ride comfort and handling characteristics: integrated vehicle dynamics model design. International Journal of Vehicle Design (IJVD), Vol. 71.
87. Obi, B.E., Leyva, E., Miyazaki, Y., Walia, P., Minnikanti, V., 2012. Model validation for predicting comfort in automotive seating polyurethane foams (Conference Paper). 70th Annual Technical Conference of the Society of Plastics Engineers, ANTEC; Orlando, FL; United States.
88. Jacobson I. D., Martinez J., 2017. The Comfort and Satisfaction of Air Travelers-Basis for a Descriptive Model. HFES International Annual Meeting.
89. Jia N., Yu L., Yang K., Wang R., Luo X., and Xu Q., A Novel Exercise Thermophysiology Comfort Prediction Model with Fuzzy Logic. Hindawi Publishing Corporation Mobile Information Systems Volume 2016.
90. Zheng Y., Guo W., Zhang Y., and Hu J., 2014. Generalized Comfort Function of Subway Systems Based on a Nested Logit Model. TSINGHUA SCIENCE AND TECHNOLOGY. Volume 19.
91. Deng L., Wang G. and Chen B., 2015. Operating Comfort Prediction Model of Human-Machine Interface Layout for Cabin Based on GEP. Hindawi Publishing Corporation Computational Intelligence and Neuroscience Volume 2015.doi.org/10.1155/2015/896072.
92. Su L., Xu M., 2017. Sleep comfort analysis using a part-based mixture model with night time infrared video. Neurocomputing 0 0 0 1–10. dx.doi.org/10.1016/j.neucom.2016.08.128.
93. Ng A.K., Ölc-er A._I., 2012. A new human comfort model onboard a vessel based on Sugeno type fuzzy inference system. Ocean Engineering 55 116–124. .doi.org/10.1016/j.oceaneng.2012.07.023.
94. Xingfang Lu, 2014. Study of Fuzzy Comprehensive Evaluation Model for Shoes Comfort. 11th International Conference on Fuzzy Systems and Knowledge Discovery.
95. PENG B., YANG Y., HUANG L., 2009. Analysis for the Impact of the Geometric Parameters of Train Seat on Riding Comfort Based on Human Body CAD Models. 2009 International Conference on Measuring Technology and Mechatronics Automation. DOI 10.1109/ICMTMA.2009.428.
96. Zhou Y., Li D., Spanos C.J., 2015. Learning Optimization Friendly Comfort Model for HVAC Model Predictive Control. 2015 IEEE 15th International Conference on Data Mining Workshops. DOI 10.1109/ICDMW.2015.119.
97. Lembo P., Manenti L., and Manzoni S., 2010. Towards Patterns of Comfort: A Multilayered Model Based on Situated Multiagent Systems. ACRI 2010, LNCS 6350.

98. Laier, J.E., 2013. Probabilistic model for human comfort (Conference Paper). 11th International Conference on Structural Safety and Reliability, ICOSSAR 2013; New York, NY; United States.
99. Korhan O., Mackieh A., 2010. A model for occupational injury risk assessment of musculoskeletal discomfort and their frequencies in computer users. Safety Science 48 868–877. doi:10.1016/j.ssci.2010.03.010.
100. Kim T., Lee S., Senior Member, IEEE, and Conrad Bovik A., Fellow, IEEE, 2015. Transfer Function Model of Physiological Mechanisms Underlying Temporal Visual Discomfort Experienced When Viewing Stereoscopic 3D Images. IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 24. DOI 10.1109/TIP.2015.2462026.
101. Oh H., Lee S., Senior Member, IEEE, and Conrad Bovik A., Fellow, IEEE,2016. Stereoscopic 3D Visual Discomfort Prediction: A Dynamic Accommodation and Vergence Interaction Model. IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 25. DOI 10.1109/TIP.2015.2506340.
102. De Lapparent M., Koning M., 2016. Analyzing time sensitivity to discomfort in the Paris subway: an interval data model approach. Transportation 43:913–933. DOI 10.1007/s11116-015-9629-7.
103. Fritzsche, F. and Bubb, H., 2008. Discomfort Model for Arm Movements. SAE Technical Paper 2008011872. doi:10.4271/2008011872.
104. Lin Y., Liu Y.,Sun Y., Zhu X., Lai J., and Heynderickx I., 2014. Model predicting discomfort glare caused by LED road lights. Optical Society of America.
105. Daruis, D.D.I., Nor, M.J.M., Deros, B.M., Fouladi, M.H., 2011. A psychophysics model of predicting car seat static and dynamic discomfort (Conference Paper). 18th International Congress on Sound and Vibration 2011, ICSV 2011.
106. Zacher, I., Bubb, H., 2004. Strength based discomfort model of posture and movement (Conference Paper). Digital Human Modeling for Design and Engineering Symposium; Rochester, MI; United States.
107. Shen, Wenqi, Galer, Ian A.R., 1993. Development of a pressure related assessment model of seating discomfort (Conference Paper). Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society; Seattle, WA, USA.
108. Pintakham K., Siriwong W., 2016. Effectiveness of the multidimensional ergonomic intervention model to reduce musculoskeletal discomfort among street sweepers in Chiang Rai Province, Thailand. Jounal Risk Management and Healthcare Policy.
109. Wang, X., Chateauroux, E., Chevalot, N., 2007. A databased modeling approach of reach capacity and discomfort for digital human models (Conference Paper). 1st International Conference on Digital Human Modeling, ICDHM 2007; Beijing; China.
110. Ebe, K., Griffin, M.J., 2000. Qualitative models of seat discomfort including static and dynamic factors (Article). Ergonomics Volume 43.
111. Seitz, T., Recluta, D., Zimmermann, D., Wirsching, H.J., 2005. FOCOPP An approach for a human posture prediction model using internal/external forces and discomfort (Conference Paper). Digital Human Modeling for Design and Engineering Symposium; Iowa City, IA; United States.
112. Cappetti N., Naddeo A., Califano R. and Vallone M., 2016. Using Axiomatic Design to Identify the Elements That Affect the Evaluation of Comfort/Discomfort Perception. Advances in Human Factors and Ergonomics 2016.
113. Suh, N.P.: Axiomatic Design, Advances and applications. Oxford University press Inc. (2001).
114. Suh, N.P.: The Principles of Design. Oxford University Press Inc. (1990).
115. Donnarumma, A., Cappetti, N., Santoro, E.: Application of fuzzy measure to doxastic design process. In: Proceedings of 11th ICED'97, pp. 3, 115–118 (1997).
116. Naddeo, A.: Axiomatic design of a car bonnet: a new decoupling method based on fuzzy logic application. Int. J. Appl. Eng. Res. 10(9), 23859–23870 (2015).
117. Naddeo, A., Pappalardo, M.: Failure mode analysis using axiomatic design and non-probabilistic information. J. Mater. Process. Technol. 164–165, 1423–1429 (2005).
118. Naddeo, A.: Optimization and solution approximation of design problems formulated by axiomatic design and paracomplete logic. Int. J. Appl. Eng. Res. 10(16), 38058–38064 (2015).
119. Naddeo, A., Apicella, M., & Galluzzi, D. (2015). Comfort-driven design of car interiors: A method to trace iso-comfort surfaces for P ositioning the dashboard commands. SAE Technical Papers, 2015-April(April) doi:10.4271/2015-01-1394
120. Naddeo, A., Cappetti, N., & D'Oria, C. (2015). Proposal of a new quantitative method for postural comfort evaluation. International Journal of Industrial Ergonomics, 48, 25-35. doi:10.1016/j.ergon.2015.03.008
121. DeVocht J.W.,Wilder D.G.,Bandstra E. R.,Spratt K.F., 2006. Biomechanical evaluation of four different mattresses. Applied Ergonomics 37 (2006) 297–304. doi:10.1016/j.apergo.2005.07.002.
122. Liu W., Lian Z., Deng Q., Liu Y., 2011. Evaluation of calculation methods of mean skin temperature for use in thermal comfort study. Building and Environment 46 (2011) 478e488. doi:10.1016/j.buildenv.2010.08.011.
123. VERHAERT V., DRUYTS H., VAN DEUN D., BERCKMANS D., VERBRAECKEN J., VANDEKERCKHOVE M., HAEX B., VANDER SLOTEN J. The use of a generic human model to personalize bed design. Vincent Verhaert, Human modeling in bed design.
124. Park S. J., Kim J. S., Kim C., 2009. Comfort Evaluation and Bed Adjustment According to Sleeping Positions. Human Factors and Ergonomics in Manufacturing, Vol. 19 (2) 145–157 (2009). DOI: 10.1002/hfm.20142.

Comfort and discomfort effects over time: the sweetness of discomfort and the pleasure towards of the end

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Abstract

In this paper the influence of effects over time on comfort and discomfort are studied. The principle of the the sweetness of discomfort at the beginning and the pleasure towards of the end is studied. An unpleasant experience could make a person more aware of the comfort in the next event: the sweetness of discomfort. In this paper literature has been found that supports this phenomenon.

Also, near the end of an event the expectation of what will happen could influence the comfort or discomfort. The hypothesis is that a situation with discomfort could result in less discomfort near the end due to the fact that the participant becomes aware of the fact that the situation will end soon. A secondary analysis of six studies where comfort in time is studied showed some support for the hypothesis. Three studies show a reduction in discomfort near the end, the others were difficult to interpret. Further research is needed to affirm the hypothesis.

Keywords: comfort, time, sweetness of discomfort, experience

1 Introduction

There is at least one thing on which passengers or end-users have more knowledge than comfort researchers and comfort designers (Vink & Brauer, 2009). That is the passengers' own sense of comfort or the end-users' own sense of comfort. Researchers and designers can't predict exactly whether a particular passenger feels comfortable in an airplane or whether an end-user will feel comfortable using the product. This is due to the fact that apart from the product or system that is designed many factors influence comfort. The mood of the participant has its influence, but also factors that are not always influenced by the product or system itself (Vink, 2014). A low office temperature due to a malfunctioning climate system will be appreciated coming from a cold freezing windy environment (Vink, 2014). And, a nice flight attendant can create comfort and passengers forget about the hard seat (Vink et al., 2012). Even a VR system with an attractive game can reduce the discomfort caused by limited leg space (Lewis et al., 2016). This seems a bit frustrating for designers of products and systems focused on more comfort.

However, on group level effects can be predicted and a good design will have its effects. The study of 10,000 passengers reported in Vink et al. (2012) showed that newer planes are regarded significantly better with respect to comfort than are older planes. These findings should give those involved in the airline industry a sense of satisfaction with regard to the job they have done in improving comfort. They have shown that it is possible to improve the comfort experience. Another more specific example that comfort can be influenced is the study of Bronkhorst & Krause (2005). They studied the whole train journey and determined which activities are done in the train seat. They adapted the train seat to the activities to create a comfortable experience. These activity supporting train seats were designed for the commuter train 'Long Island Railroad' bringing

passengers from Long Island to New York (Bronkhorst & Krause, 2005). It appeared that 83% of the passengers preferred the resulting seat to current seats and the comfort was higher.

There is another opportunity to improve the comfort experience. That is making use of the principle of the 'sweetness of discomfort' (Vink, 2014). The sense of the softness of a seat is dependent on the hardness of the previous seat (Veen & Vink, 2016). Veen and Vink (2016) showed that after sitting on a hard wooden stool, a test seat feels significantly softer than sitting in a comfortable chair and then sitting on a test seat. In this experiment the test seat was covered with a white blanket and the subjects were told that the seat differences would not be shown. In fact the seat was not changed. This information was not relayed to the test subjects. Before the test, subjects were instructed to sit on the stool and the luxury chair to become accustomed to the environment. Half of the subjects began with the 'hard stool' conditions and the other half began in the 'luxury soft chair' condition. At the same time the next day the subjects arrived to test the 'second seat' and the pre-condition was changed again. The results show for the pre-condition "stool" (the chair feels soft: 1 = I don't agree, 9 = I agree) a rating of 6,75 ± 1,94 on a 9-point scale and for the pre-condition "luxury chair" a rating of 4,96 ± 2,46 which was significantly different. So, the theoretical assumption is that precondition influences the sensation appears to be true. This can be applied in seat design for instance by starting with a hard surface and by pushing a button the seat becomes softer. This can be done by using the Vitamaterials air/foam cushion. This cushion is filled with air and rather hard. At the touch of a button the valve design allows the passenger's weight to exhaust the air from the cushion and provide a personalized contoured seat. This distributes weight evenly and it could be more comfortable than the previous hard state. It would be interesting to study if this is affirmed by research. So, sitting on a hard surface in the precondition could make the tested seat feel softer. For other sensors the principle of influence by the previous experience is described as well. Temperature is experienced differently when coming into an interior from a cold environment as opposed to coming in from a warm environment (De Dear & Brager, 2002). Retreating in and out of dark and light spaces influences our sensors. Our senses see the interior of an airplane differently when emerging from a dark jet way than when entering the airplane by stairs in open air (Vink, 2014). Konieczny (2001) found that comfort during the flight correlated most with the comfort preceding the flight ($r = 0.407$), fear of flying ($r = 0.492$), and attitude toward flying ($r = 0.367$). Correlations to other factors were weaker. This study infers that situations or experiences before the flight could influence the experience during the flight.

Making all steps in the journey highly comfortable probably does not automatically make the whole journey comfortable, because the human sensors record differences better than absolute values. Perhaps phases of discomfort or low comfort should be alternated with more comfortable phases to stimulate more awareness of high comfort or low discomfort levels: "the sweetness of discomfort". Of course the discomfort should not be so high that it makes the whole journey a terrible experience. Introducing a bed of sharp nails or introducing sounds above the pain level is not advised as an object of study. The challenge is to find the ideal balance between comfort and discomfort experiences for the entire travel journey.

Apart from the influence of the phase at the beginning of the comfort experience the end phase also has opportunities for comfort increase. An old study of Kahneman et al. (1993) showed that the end of a pain period the human experience can be improved by adding a phase where the pain is slowly reduced. This resulted in a better experience then when the situation was immediately ended. The study also showed the discomfort experience reduced towards the end in both situations, while the condition was the same. The question is whether the findings of this pain experiment are valid for long term comfort and discomfort studies as well. Therefore, in this paper a few recent studies were taken from the literature where long term comfort experiments were done and where data in time were gathered. The hypotheses is that in a situation where comfort is low or discomfort is high the discomfort reduces towards the end of the experiment or the comfort increases near the end.

2 Methods

To test the hypotheses a secondary analysis was performed on six studies mentioned in five journal papers with data on comfort or discomfort in time. A study of De Lille et al (2016) on comfort during the flight, a study of Sammonds et al. (2017) on discomfort sitting 140 minutes in a car seat, a study of Smulders et al. (2016) sitting 90 minutes in a business class seat, a study of Wenhua Li et al. (2017) on sitting 3 hours on a seat simulating a 28", 30" and 32" pitch and two studies of Bazley et al. (2015) on discomfort during the workweek. De Lille et al (2016) asked 149 travelers on the comfort of their last flight on a scale from 1-10 10 being the maximum comfort and they calculated the average. Sammonds et al. (2017) used the discomfort

scale defined in ISO 2631-1 and studied 10 subjects in the driving positions in a driving simulator and calculated the average. Smulders et al. (2016) studied 12 subjects sitting 90 minutes in two types of business class seats. In the secondary analysis the average discomfort is calculated over the 12 subjects and the 2 conditions of the Smulders' study. In the study of Wenhua Li et al. (2017) the discomfort was recorded in 18 healthy subjects seated for three hours in three different seat pitches (32 inches, 30 inches and 28 inches). A seat pitch is the distance from a point on a seat to the exact same point on the seat in front. A 28 inch pitch is usually a situation where there is limited legroom although that is dependent on the thickness of the backrest as well. The Body Part Discomfort Scale described by Corlett and Bishop (1976) was used in this study. Bazley et al. (2015) studied the discomfort in a workweek in two professions: 16 engineering professionals located in the USA with a workweek of 4 days and 18 plasterers located in Ireland both with five days' workweek. The comfort was recorded 3 times a day for the engineers and one time (after lunch) for the plasterers and the values of the different subjects were averaged.

3 Results and Discussion

Based on the hypothesis the comfort would raise near the end of the activity or the discomfort would reduce. Out of the six figures based on the five afore mentioned papers describing the discomfort pattern in time three affirm the hypothesis. In the other three it is less clear. In figure 1 the comfort increases at the end where passengers know that they approach the destination. In figure 5 the discomfort reduces during the last work day and figure 6 also shows after lunch a reduction knowing that the end of the week is approaching. One figure (figure 2) does not affirm the hypothesis. Figure 2 shows that the discomfort increases also near the end. Figure 3 and 4 could be seen in different ways. Figure 3 shows no further reduction in discomfort, which could affirm the hypothesis, but it could also be that the minimum in comfort is reached which will not further decrease in this business class seat. The discomfort in figure 4 continues to increase for the 28 inch seat, which is very narrow having very little leg room, for the 30 and 32 inch the increase in discomfort is grows less, which could be caused by the fact that end is near.

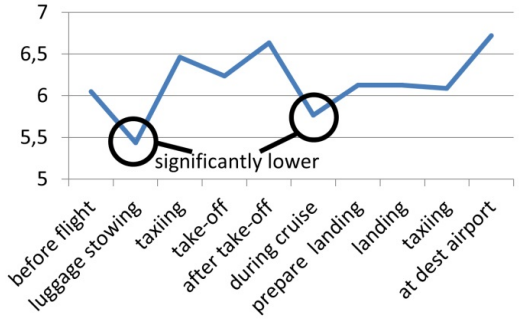


Fig. 1. Comfort during a flight (Lille et al, 2016)

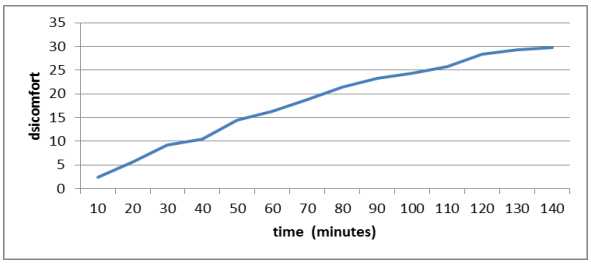


Fig. 2. Driving discomfort (Sammonds et al., 2017)

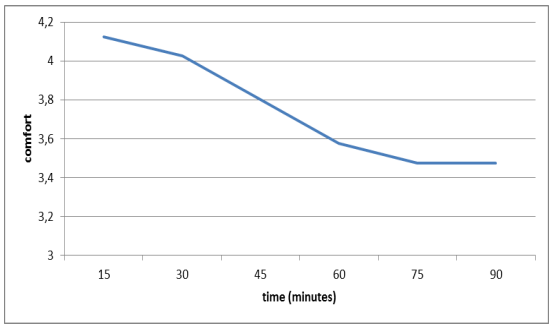


Fig. 3. Business class comfort (Smulders et a., 2016)

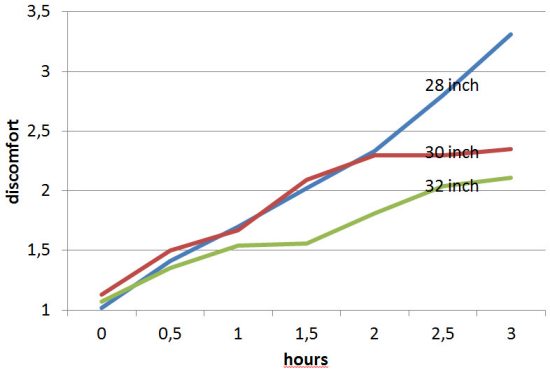


Fig. 4. Discomfort in 3 pitches (Wenhua Li et al., 2017)

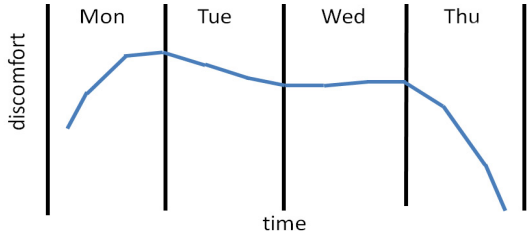


Fig. 5. Discomfort for engineers (Bazley et al., 2015)

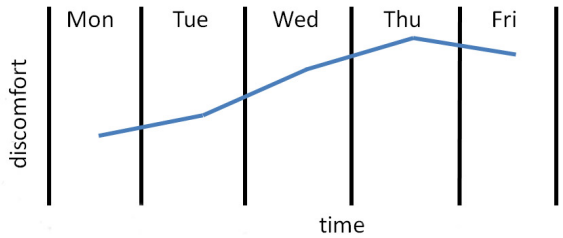


Fig. 6. Discomfort for plasterers (Bazley et al., 2015)

Drawing a conclusion from these six studies should be done with care. Statistics on significance is missing and it is not sure whether the subjects were aware of the fact that the experiment was almost done near the end. In the case of the workweek and the flight it is clear that participants knew that end is near. However, in the other papers nothing is reported on the fact that people could see a watch or have other information about the end of the test. The fact that the end of an experience is important has been described before (e.g. Fredrickson, 2010). Kahneman et al. (1993) also describe the positive affect associated with hope for a good outcome. Also, regarding comfort the phenomenon has been described before. Bazley & Vink (2016) describe that for students on Friday, before the weekend, the comfort levels were significantly higher than Thursday, the day before (t-test for paired comparison, $p < 0.05$).

So, this paper is only an indication that the hypothesis could be true. More research is needed in which different endings should be compared. The comfort in time could be studied of endings where participants are aware of the end compared with those who are not aware of the time the experiment or experience stops. This should have its influence on the comfort experience. Even a condition could be added as described in Kahneman et al. (1993) in which the discomfort is slowly reduces instead of immedialtely. If the hypothesis is true this has implications for the journey design. In long rows informing the participants on the end could reduce discomfort and in travelling more information on the time to go could be useful as well. Also slowly reducing the discomfort like in the experiement of Kahnemann et al (1993) could be added. It could be applied in a taxI ride as well. For instance, being in a foreign taxi could create uncertainty of the travel time and create discomfort. This discomfort could perhaps be improved near the end by showing the expected arrival time or the expected travel time. Also, for research this has implications. Preferably the ending time should not be mentioned as it could influence the comfort or discomfort scores.

4 Conclusion

Comfort and discomfort are influenced by previous experiences and effects over time. There are indications that when a person enters an event the comfort levels are dependent on where a person has been and what the comfort experience was. An unpleasant experience could make a person more aware of the comfort in the next event. Also, the end of the event (e.g. an experiment or a happening in daily life) could be influenced by the expectation of what will happen. A situation with discomfort could result in a less discomfort near the end due to the fact that the participant becomes aware of the fact that the situation will end soon and the comfort will become better (or the discomfort will become less). The hypothesis is that for a situation where comfort is low the comfort increases near the end. Or in a situation where discomfort is high the discomfort reduces towards the end. There are indications that the hypothesis is supported by a few studies, but further research is needed to affirm this.

References

1. Bazley, C., Nugent, R., Vink, P., 2015 Patterns of Discomfort. J of Ergonomics 5:1, http://dx.doi.org/10.4172/2165-7556.1000136
2. Bazley, C., Vink, P. 2016. Don't forget time in environmental design. Work 54, 1025–1029

3. Bronkhorst, R.E., Krause, F. Designing comfortable passenger seats. in: Vink, P., ed. Comfort and Design: Principles and Good Practice. Boca Raton: CRC Press, 2005: 155-168.
4. Corlett, E.N., Bishop, R.P., 1976. A technique for assessing postural discomfort. Ergonomics 19, 175-182.
5. De Dear, R.J., Brager, G.S., 2002. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. Energy and Buildings 34: 549-561.
6. Fredrickson, B.L., 2010. Extracting meaning from past affective experiences: The importance of peaks, ends, and specific emotions Cognition and emotion 14, 577-606.
7. Kahneman, D., Fredrickson B.L., Schreiber, C.A., Redelmeier , D.A., When more pain is preferred to less: Adding a Better End. Psychological Science 4(6), 401-405.
8. Konieczny G. Die Messung und steigerung der Qualität von Dienstleistungen in der Flugzeugcabine: ein Beitrag zur Kundenorientierten Flugzeugentwicklung. Technische Universität, Berlin. Dissertation, 2001
9. Lewis, L., Patel, H., Cobb, S., D'Cruz, M., Bues, M., Stefani, O., Grobler, T., 2016 Distracting people from sources of discomfort in a simulated aircraft environment. Work 54, 963–979.
10. Lille, C. de, Santema, S., Bouwens, J., Schultheis, U., Vink, P. 2016. Designing the cabin interior knowing high and low peaks in a passenger flight. AEGATS conference, AEGATS2016_48 on stick.
11. Sammonds, G. M., Fray, M., Mansfield, N., 2017. Effect of long term driving on driver discomfort and its rela tionship with seat fidgets and movements (SFMs). Applied Ergonomics 58, 119-127.
12. Smulders, M., Berghman, K., Koenraads, M., Kane, J.A., Krishna, K., Carter, T.K., Schultheis, U. 2016. Comfort and pressure distribution in a human contour shaped aircraft seat (developed with 3d scans of the human body). Work 54, 925–940.
13. Veen, S. van, Vink, P., 2016. Can Prior Experience Influence Seating Comfort Ratings? Ergonomics in Design 24: 16-20.
14. Vink, P, The sweetness of discomfort. Delft: TU-Delft, 2014
15. Vink, P., Bazley, C., Kamp, I., Blok, M., 2012. Possibilities to improve the aircraft interior comfort experience. Applied Ergonomics 43, 354-359.
16. Vink, P., Brauer, K. Aircraft interior comfort and design. Boca Raton: CRC Press, 2011.
17. Wenhua Li, Yu, S., Yang, H., Pei, H., Zhao, C., 2017. Effects of long-duration sitting with limited space on discomfort, body flexibility, and surface pressure. International Journal of Industrial Ergonomics 58, 12-24.