Comfort Congress 2021

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Nottingham Trent University

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Preface

Welcome to the 3rd International Comfort Congress!

Following the successful conferences of the Salerno Congress in 2017 and Delft Congress in 2019, the 2021 Congress organisers are delighted to welcome you to Nottingham Trent University… even if it is occurring via videoconferencing. Since the last Congress in Delft the global pandemic has meant that there have been enormous changes in our experiences of working life, our expectations when travelling on public transport, and our experimentation methods and constraints. More than ever, experts still seek to share their latest ideas and to learn from others. Through the presentations and discussion that will occur at the 2021 ICC we hope that you will engage in these discussions and be enriched and inspired.

The extended abstracts in these proceedings give details of research that is presented across 10 sessions:

Thermal
Motion 1
Motion 2
Commercial vehicles
Methods, models and standards
Future vehicles
Posture and pressure methods
Comfort assessment
Clothing
Aviation

Presenters represent institutions from across the world, including Europe, USA, Japan, Iran and Canada; the presenters themselves represent an even greater diversity of nationalities. At previous Congress, delegates have enjoyed exchanging ideas with those applying their work in different industries and so we encourage you to explore beyond your usual sector to allow you to broaden your knowledge.

The conference is being organised in partnership with the Chartered Institute of Ergonomics and Human Factors (www.ergonomics.org.uk), and with the support of the EU-funded ComfDemo research project (www.comfdemo.com).

We hope that you enjoy reading these abstracts and contributing to ICC 2021.

The organizing committee:

Prof Neil Mansfield
Dr Susanne Frohriep
Prof Alessandro Naddeo
Prof Dr Peter Vink
Dr Anna West

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Thermal

Ethnic differences: The influence of relative humidity on thermal perception

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ABSTRACT

Field studies have shown that populations from tropical climates are better able to tolerate high humidity (>80%) conditions. This finding is contrary to physiology literature, which indicates no genotypic differences between ethnicities exist. The extent to which ethnicity influences thermal perception in humid environments remains unknown. To determine a definitive standpoint is challenging, given the various methodologies, environmental conditions and metrics used in previous studies. Here, we compare thermal perception between two ethnic groups in highly-controlled steady-state conditions at multiple relative humidities. Twelve body-matched Chinese (from central and southern China) and white-British males completed five 30-minute climatic chamber trials (25°C 35%; 25°C 85%; 29°C 35%; 29°C 65% and 29°C 85%). Metabolic rate and clothing insulation remained constant. Thermal perception was measured using a battery of psychological scales. Physiological responses were monitored throughout each trial. After 30-minutes, there were no significant between-group differences in the physiological responses and most psychological results obtained. A difference in wetness sensation was observed for the warm-high humidity (29°C, 85% RH) condition only, where Chinese males rated approximately one scale-unit higher (*wet*) than British males (*slightly wet*). The results indicate British and Chinese males respond predominantly in the same way to their thermal environment. Although, Chinese males did perceive the warm, humid environment as being wetter. Given the lack of human hygroreceptors, it is unclear what is driving this increased perception of wetness. It could be linked to thermal history and behavioural expectations; both considered responsible for differences observed between field and controlled laboratory studies.

KEYWORDS

Thermal perception, ethnicity, humidity

Introduction

Field studies comparing ethnic differences in thermal sensation responses have reported that populations from warm, humid climates better tolerate high humidity conditions (Mom et al. 1947; Ellis 1950, 1953; Knez and Thorsson 2006). Ellis (1953) sought to examine preferred levels of warmth between Europeans and Asians in Singapore. Thermal comfort surveys were distributed to individuals with European ancestry (British and Australian nationals) who had resided in Singapore for at least six months and individuals from across multiple Asian countries (e.g., China, India, and Malaysia). Participants were required to record indoor dry and wet-bulb temperatures and their corresponding thermal comfort level at any time of day. The European group were less tolerant of the warm, humid comfort zone conditions overall, and were most comfortable in these conditions whilst sedentary and wearing light clothing. Knez and Thorsson (2006) conducted a quasi-experimental study to examine ethnic differences in thermal perception between Japanese and Swedish citizens in public squares located in Göteborg, Sweden (mean air temperature: 20.3°C; mean air velocity: 1.6 $ms^{-}1$) and Matsudo, Japan (20.7°C; 1.0 ms^{-1}). Swedish individuals reported an almost neutral thermal sensation, while Japanese volunteers were closer to feeling slightly warm. The Japanese inhabitants were thermally less comfortable, although they estimated the weather as being warmer.

One major drawback of using field studies as an approach to exploring ethnic differences in thermal perception is the potential variation in confounding factors. The studies have attempted to account for these by obtaining details on clothing worn, food consumption, time of day and activity level (Ellis 1953; Ballantyne et al. 1979), but individual differences such as age and sex, as well as body size and composition, have also been implicated in thermal perception responses (Shipworth et al. 2016; Wang et al. 2018). However, several laboratory studies support the existence of ethnic differences in various thermal perceptual responses (Lee et al. 2011; Maiti 2013; Havenith et al. 2020). Remarkably, support for ethnic differences contradicts physiology literature, which indicates no genotypic differences between ethnicities exist (Taylor 2006). Thus, the extent to which ethnicity influences thermal perception in humid environments remains unknown.

Given the various methodologies, environmental conditions and metrics used in previous studies, it is difficult to draw a definitive conclusion. Although previous research has been conducted to explore human thermal responses in various air temperature and relative humidity combinations, no single study has directly compared different ethnic groups in highly-controlled body-matched climatic chamber trials. Such methodology would confirm any presence of physiological and psychological differences in thermal perception between ethnic groups. The study aimed to determine the influence of ethnicity on thermal perception at various relative humidities. In highly controlled laboratory conditions, physiological and psychological responses from two ethnically homologous groups were examined.

Methods

Six Chinese and six white-British males were body-matched by body mass index (BMI) within ±1kg. All recruits were required to have lived in the United Kingdom, without overseas travel, for three months before the study. Limitations on activity level and food consumption were imposed prior each trial. A set clothing ensemble, equal to an insulation value of 0.5 clo (short-sleeved t-shirt, trousers, socks, running shoes) was worn. Five experimental conditions were examined in a counter-balanced order: neutral-low (25°C 35% RH), neutral-high (25°C 85% RH), warm-low (29°C 35% RH), warm-moderate (29°C 65% RH) and warm-high (29°C 85% RH), with each trial lasting sixty minutes.

Participants spent thirty minutes in a thermoneutral room to physiologically stabilise. At the end of the stabilisation period, physiological (Local skin temperatures, mean skin temperature, tympanic temperature, heart rate and skin hydration) and psychological (thermal sensation, thermal comfort, thermal preference, pleasantness, stickiness and wetness sensation) measurements were taken. The participants then moved into a climate-controlled environmental chamber and exposed to the experimental conditions for thirty minutes. To maintain a steady activity level during the trial, participants remain seated. Physiological and psychological responses were repeated immediately upon entry to the chamber and every five minutes until the end of the thirty-minute trial.

Results

The environmental conditions were highly-controlled across all experimental conditions, as shown in Table 1 below. Physiological and psychological measurements taken throughout the 30-minute exposure to the experimental conditions. The 30-minute end values are presented in Table 2.

Table 1: Mean environmental conditions and standard deviations.

	Condition	T_a (°C)	RH (%)	Measured T_a (°C)	Measured RH (%)
1	neutral-low	25	35	25.3 ± 0.0	34.8 ± 0.8
2	neutral-high	25	85	25.1 ± 0.4	85.1 ± 0.9
3	warm-low	29	35	29.3 ± 0.3	35.0 ± 0.7
4	warm-mod	29	65	29.2 ± 0.2	64.9 ± 0.4
5	warm-high	29	85	29.3 ± 0.1	85.3 ± 0.4

Table 2: Summary of mean physiological and psychological measurements taken after 30-minutes for British males (Br) and Chinese males (Ch).

	25°C				29°C					
	Low		High		Low		Moderate		High	
	Br	Ch	Br	Ch	Br	Ch	Br	Ch	Br	Ch
Mean Skin Temperature (°C)	33.8	33.6	33.9	33.9	34.7	34.4	34.5	34.6	34.6	35.0
Skin Hydration: Forehead (PWC)	52.2	57.2	58.5	61.2	56.5	59.3	59.0	61.0	62.5	68.0
Skin Hydration: Forehead (TDC)	38.2	28.5	61.7	64.8	47.2	38.8	64.2	76.3	103.8	119.5
Thermal Sensation*	1.7	7.3	5.0	5.0	11.7	16.7	25.0	15.0	21.7	21.7
Thermal Comfort	0.2	0.5	1.0	0.7	0.8	1.2	1.8	2.0	2.8	3.5
Thermal Preference	0.2	-0.5	-0.2	-0.2	-1.0	-0.8	-1.2	-1.3	-1.8	-1.5
Stickiness	0.2	0.3	1.0	1.0	0.2	0.5	2.5	1.7	3.0	3.8
Wetness	0.2	0.5	0.8	1.0	0.3	0.5	1.8	2.0	2.3	3.8
Pleasantness	0.7	0.5	-0.2	0.0	0.2	-0.6	-1.2	-1.0	-1.3	-1.7

*To provide greater sensitivity for the ratings of Thermal Sensation the scale was increased by 10, so 2 Warm = 20 Warm

Physiological measurements

There were no significant differences in physiological responses between the experimental groups, across conditions. The Chinese males did repeatedly demonstrate higher skin hydration across all environmental conditions. Figure 2 presents the percentage water content (PWC) and tissue dielectric constant (TDC, an arbitrary unit) skin hydration results for the forehead in the warm-high condition. Chinese males had higher forehead PWC (Br: 62.5 ± 5.6; Ch: 68.0 ± 2.6; $P = 0.053$) and TDC (Br: 103.8 ± 30.2; Ch: 119.5 ± 24.9; $P = 0.350$) than British males. However, these effects were not statistically significant.

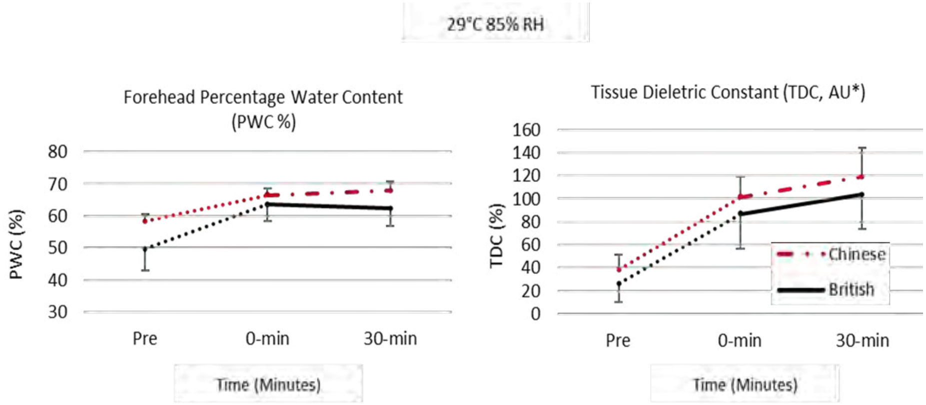

Figure 1: Skin hydration results for the warm-high humidity condition (29°C, 85% RH) for the 30-minute trial duration.

Psychological measurements

After thirty minutes of exposure, no significant differences ($P > 0.05$) were found between each ethnic group for the following psychological metrics: thermal sensation, thermal comfort, thermal preference, stickiness or pleasantness, for any condition. A notable difference in wetness sensation level was observed at multiple time points in the warm-high condition only, as illustrated in Figure 2. For example, at 10-minutes, Chinese males reported a '*wet*' sensation (3.7 ± 1.6), while British males reported feeling '*slightly wet*' (1.7 ± 0.8; $P = 0.042$).

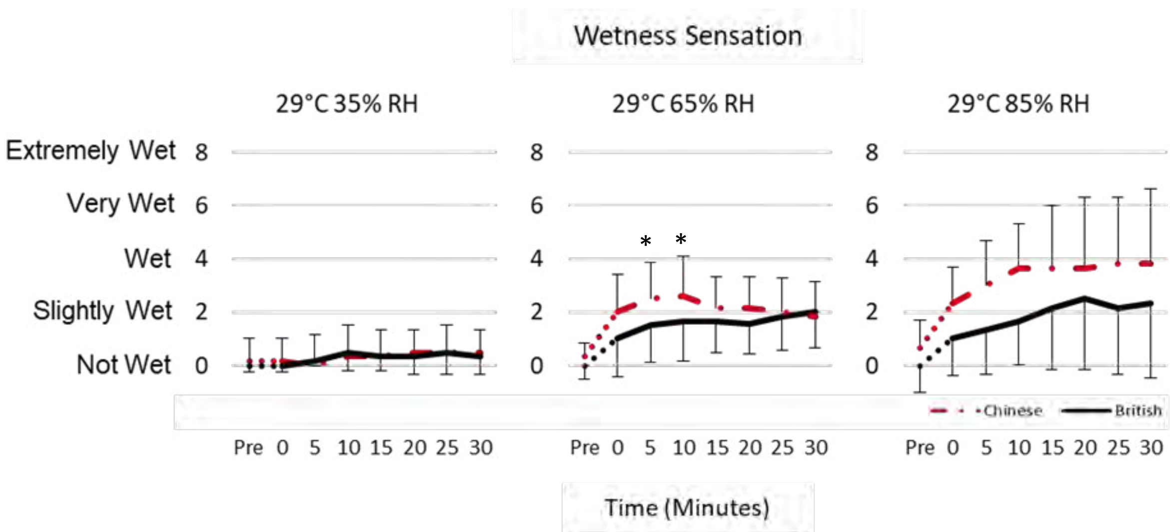

Figure 2: Wetness sensation response obtained at intervals during the trial for the warm trials (warm-low, warm-moderate and warm-high). *Significance P < 0.05.

Discussion

The principal research question was to determine the influence of ethnic differences on thermal perception and how it changes with relative humidity level. The diversity of research methodologies used in the past to investigate this phenomenon make it difficult to determine the basis for the observed differences. This study took a highly controlled experimental approach to systematically examine this concept using a wide range of physiological and psychological measurements. The main finding in the study is that no significant differences between each ethnic group for the following psychological metrics: thermal sensation, thermal comfort, thermal preference, stickiness or pleasantness, for any condition. This finding shows that when body-matched individuals in controlled environments, clothing and metabolic activity levels, there is minimal difference in most subjective thermal perception metrics.

The one subjective factor that where there was a difference between ethnicities was wetness. The Chinese group reported stronger wetness sensation responses than for the British group across all conditions. Immediately upon exposure to the test conditions, the Chinese reported a statistically higher wetness rating than the British group for all conditions. Although, significant differences were only identified in the warm-high humidity condition (29°C, 85% RH). The underlying mechanisms of sensing skin wetness (i.e. hygrosensation) was examined in Filingeri et al. (2014) and (Filingeri and Havenith 2015). Humans lack skin humidity receptors (hygroreceptors) to discern wetness and humidity cutaneous sensations, but do so successfully, as demonstrated in the current and in previous studies (e.g., (McIntyre 1978; Jin et al. 2017). It is proposed that the ability to detect wetness is a learned response based on prior sensory experience, derived from a complex integration of somatosensory cues (e.g., from thermoreceptors and mechanoreceptors) (Bergmann Tiest et al. 2012; Filingeri et al. 2014; Filingeri and Havenith 2015).

Ethnic differences in wetness sensation appears to have not previously been reported in the literature. A possible explanation for this finding is the notion of perceptual inference, a top-down Bayesian approach in which deductions about external sensory stimuli are predicted from a bank of stored neural representations (Filingeri et al. 2014; Aggelopoulos 2015). Neural representations are developed via long-term associations from previous experiences, and as described by operant conditioning (Skinner 1963), are involuntarily stimulated when evoked by external stimuli. The two ethnic groups used in the current study were born and raised in distinctly different climates. According to the Köppen climate classification system (Kottek et al. 2006; Waycott et al. 2014), the white British group would be accustomed to a temperate oceanic climate (Cfb).

In comparison, being from regions across central and southern China, the Chinese group would be familiar with a hot summer, humid continental climate (e.g., Beijing: Dwa; Shanghai: Cfa). Therefore, it may be that these two ethnic groups have attuned long-term neural representations based on their respective typical thermal environments. For the Chinese group, stronger, rapid onset sensations could result from a more honed response due to frequent exposure to high humidity conditions.

Overall, the study shows that minimal differences in physiological and psychological responses (except for wetness sensation) exist between ethnicities when physical, environmental and personal factors are controlled. However, this finding conflicts with the notable difference in preferred air temperatures between British and Chinese groups (Havenith et al. 2020). Thus, the disparity may be explained by the ability to control the environment, in which aspects that are influenced by ethnic background (e.g., thermal history and thermal expectation) may influence the choices made.

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Impact of different radiation types on thermal comfort modelling

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ABSTRACT

Different radiation types are present in everyday environments, and have a major impact on human thermal perception and ultimately on comfort. In a study with participants, we found that humans perceive long-wave radiation (e.g. a warm wall) differently from short-wave radiation (e.g. sunlight). Straightforward comfort models do not directly account for this difference. In more complex thermal simulations, it is possible to consider such different radiation types. To evaluate this modelling approach, the experimental conditions are recreated and assessed in simulations. In analogy to the study with participants, in the simulation a human manikin with a comfort model predicts human thermal perception. Then, participants' responses are contrasted to the comfort model predictions. Comparison of simulated and participant-reported results allow identification of deviations between the model and the actual perception, and thereby suggestions for further enhancements of simulations are derived.

KEYWORDS

Human Comfort Model, Radiation, Simulation, Thermal Comfort, Thermal Management

Introduction

In environments as vehicles or buildings, the human thermal perception is a key aspect of overall comfort. Thermal perception is correlated to air temperature, air movement and other factors [Gen19]. Here, a major aspect of thermal perception is the radiative heat exchange between a human body and its environment. Typically, different kinds of radiation – for example sunlight, radiative heaters and enclosing surfaces (walls) – can be of significance.

Conventional comfort models, for instance the *Predicted Mean Vote* (PMV) model developed by Fanger [Fan72], allow for a straightforward assessment of thermal environments. To account for radiation, such conventional models summarize different kinds of radiation to a single *mean radiant temperature*. However, this conventional approach drastically simplifies the radiation's characteristics [Hir21].

In recent decades, the understanding of human thermal perception advanced significantly. Several investigations focused on the *transient* thermal evaluation in *non-uniform environments* [Che12]. In contrast to straightforward, conventional comfort models, advanced comfort simulations typically include three components [Gua03]:

- Firstly, a physical model simulates the heat transfer (e.g. convection, radiation) between the human body and its environment. By modelling heat transfer in an exact way, such an approach might better account for the actual radiative heat exchange than the *mean radiant temperature*-approach of conventional models.

- Secondly, a physiological model represents the active and passive thermal behavior of the human body. For instance, the model by Fiala et. al. simulates the physiological behavior of a human body, considering the passive thermal system (e.g. temperatures at various body parts and layers) as well as active thermoregulation (e.g. shivering) [Fia99, Fia01].
- Thirdly, the psychological perception of thermal sensation and thermal comfort is predicted. [Gua03]. Such an assessment of human thermal sensation and thermal comfort at various body segments (e.g. thermal sensation at hands, face, etc.) might be carried out with the *Berkeley Comfort Model* by Zhang et. al. [Zha10a, Zha10b, Zha10c].

Considerations on modelling radiation's effect on thermal perception require a basic understanding of radiation. Different kinds of radiation are distinguished by their respective wavelength λ [Iso07]. There is typically an exchange of long-wave infrared radiation (IR-C with $\lambda \geq 3$ µm) between a human body and the enclosing surfaces. Furthermore, sunlight or certain heaters provide additional short-wave irradiation (IR-A radiation with λ 0.78 µm to 1.4 µm, as well as visible light). [Hir21]

The radiation properties of human skin are highly depending on the radiation wavelength. In several measurements, it was confirmed that human skin absorbs more than 90 % of incident long-wave radiation [Pia10, Ter86, San09]. In contrast, 30 to 70 % of incident short-wave radiation are reflected and not absorbed by human skin [Pia10, Jaq55, Ter86]. Concerning clothing, a very similar trend was observed for a cotton fabric specimen [Car97]. Notably, only absorbed shares of incident radiation contribute to the human heat balance, and conclusively to the thermal perception.

Radiation of different wavelength differs also by its penetration depth into human skin. Long-wave radiation penetrates only the outermost skin layer, while short-waves' penetration depth partially exceeds skin depth [Pia10, Ter86, Hir21]. As human thermal sensation is based on thermoreceptors in the upper skin region [Str11], the penetration depth of radiation supposedly has an effect on the thermoreceptors' response and ultimately on human thermal perception [Hir21].

The authors previously investigated the effects of different radiation types on human thermal perception [Hir21] on the basis of a study with participants [Gen19]. To integrate observations of this study into comfort modelling, it is intended to recreate and investigate the experimental conditions in thermal simulations.

Materials and Methods

In the first part of this section, the experimental setup is briefly recapitulated. For a detailed description, the reader is referred to the original publications [Gen19, Hir21] on the experiment. The second part comprehensively outlines the simulation approach.

As Gentner et. al [Gen19] describe, participants in a study were exposed to short-wave infrared A radiation and to long-wave infrared C radiation and rated their thermal sensation and their thermal comfort. On this behalf, the thermo-acoustic chamber at the Institute for Automotive Engineering (RWTH Aachen University) was equipped with a setup of radiant heaters. Short-wave radiation lamps (peak wavelength 1.2 µm) as well as long-wave radiative heaters (peak wavelength ~ 8 µm) were installed at different locations. The chamber provided defined thermal conditions, and the study was carried out at approximate air temperatures of 16°C and 22°C. Participants were positioned on a movable automotive seat. Two irradiance levels (100 W/m² and 200 W/m²), each at two air temperatures (16°C and 22°C), were investigated and compared to baselines (no additional irradiance). Participants were exposed to every condition for about 10 minutes, while they repeatedly reported their thermal sensation and their thermal comfort. Thermal sensation was rated on a scale from cold (-3) over cool (-2), slightly cool (-1), neutral (0), slightly warm (+1), warm (+2) to hot (+3). Thermal comfort was assessed on a scale from very uncomfortable (1) to very comfortable (10). [Gen19] For demonstrative purposes, the result section presents arithmetic means of the participant-reported thermal sensation. More details, including statistical parameters and boxplots, are provided in the publication on the experiment [Hir21].

In addition to the participant study, extensive measurements were conducted in the thermo-acoustic chamber to fully capture the thermal environment within every experimental condition. Local irradiance was measured at a reference plane, located at the participant positions. Furthermore, the air temperature, air velocity, air humidity, and globe temperature within every experimental condition was measured. These measurements provide sufficient input to Fanger's PMV model. Thereby it is possible to predict thermal sensation within every experimental condition in a very straightforward way. [Hir21]

For the purpose of the present investigation, the experimental conditions at an air temperature of 16°C are addressed. The analysis will thereby focus on five conditions, which are presented in Table 1.

Table 1: Experimental conditions (adapted from [Hir21])

Spectrum	**Short-wave (IR-A)**		**Long-wave (IR-C)**		**-**
Irradiance	**200 W/m²**	**100 W/m²**	**200 W/m²**	**100 W/m²**	**0 W/m²**
Reference Number	C3	C4	C5	C6	C7 (Baseline)

Based on the study with participants, the experimental conditions were recreated and assessed in simulations. Firstly, a three-dimensional geometric model of the thermo-acoustic chamber was set up. Geometric models of the radiation sources and of the participant seat were added to the chamber model. Derived from anthropometric data, the geometry of a sitting woman (50 % percentile, female European) was defined. All geometry was imported into the thermal simulation software *TAItherm* (Version 2021.1.1).

To allow for an accurate simulation of the radiative heat transfer, a detailed model of the radiation sources is eminent. In the experiment, long-wave radiation sources (modified Digel CL-900 heaters) consisted of large heated surfaces. The temperature distribution on these surfaces is known from thermographic measurements. This temperature distribution was accordingly implemented into the simulation model. On the other hand, the employed short-wave radiators (Optron IRE 380L) behave similar to certain incandescent lamps. Data on the intensity distribution of these radiation lamps was provided by the manufacturer. This distribution data was implemented into the *TAItherm* simulation model. In analogy to the experiments, where irradiance was measured at reference planes, comparable simulations were carried out. The irradiance on the simulated reference plane was contrasted to irradiance measurements in the actual experimental setup. This step ensured that the simulation model correctly predicted the rather complex radiative heat transfer situation.

Within the simulation software, the model was further prepared for simulations. Thermal properties (e.g. material characteristics) as well as boundary conditions (air velocity, air temperature) obtained from measurements were implemented into the simulation model. The manikin geometry was placed on the participant seat, and clothing was added in alignment with the actual participant's clothing. With this configuration, the software is able to compute the heat transfer (radiation, convection and conduction) between the manikin and the thermal environment including radiation sources. The wavelength-depended properties of human skin and clothing were implemented into the simulation model by separately accounting for short- and long-wave radiation. For long-wave radiation, an absorptivity of 0.98 (skin) and 0.95 (clothing) was specified. In contrast, the short-wave absorptivity of skin was adjusted to 0.65, and of clothing to 0.60. These values are also default values in the used software [Tai21].

Beside heat exchange with the environment, also thermal properties within the human body were of interest. The *Human Modeling Extension* allows to simulate the physiological behaviour of a human body within TAItherm. The model considers 19 body segments (e.g. head, hands, …) and their typical layered structure (bones, muscles, tissue). The blood flow, as well as active and passive thermoregulation is considered as well. Thereby, metrics as skin and core temperatures, and various heat rates can be predicted. [Tai21] We assigned the manikin geometry to the Human Modelling Extension, and thereby obtained a complete model of the thermal properties within the manikin.

On the basis of physiological metrics of the manikin, also human thermal sensation can be predicted. A model developed at UC Berkeley correlates skin temperatures and other physiological data to predict thermal sensation and comfort [Zha10a, Zha10b, Zha10c]. This *Berkeley Comfort Model* is used for the simulations, to predict thermal sensation within the experimental conditions.

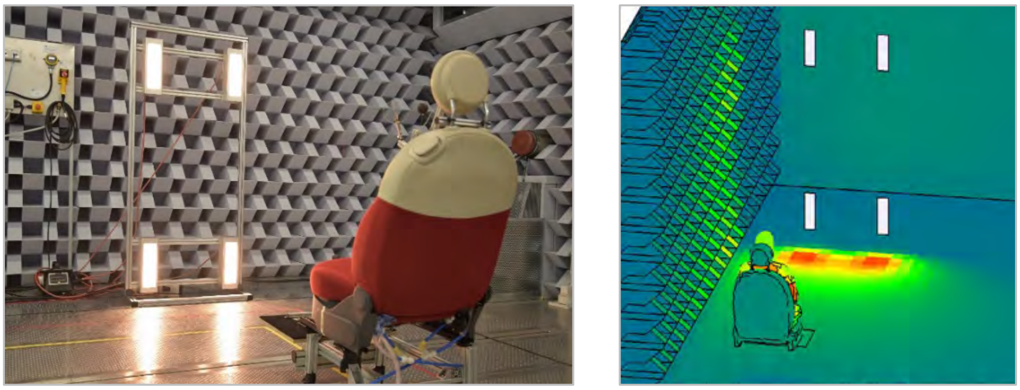

Figure 1: Experimental setup of condition C4 with short-wave heaters and the participant seat. On the left, a photo depicts the actual setup [Gen19]. On the right, the respective simulation is presented.

Summarizing, the heat exchange between manikin and environment is simulated in a first step. A software extension allows to simultaneously simulate the physiological behaviour of the manikin itself. On that basis, a further model predicts human thermal sensation. With these three components, the aforementioned typical composition of advanced comfort simulations is complete. Figure 1 illustrates this complete simulation setup for one experimental condition. All simulations are transient, and the simulated timing matches the actual durations of the experiment.

To compare experimental results to model predictions, overall thermal sensations are contrasted for the five experimental conditions. Participant-reported sensations are thereby compared to simulation output. All comparisons are carried out for the thermal sensation at five minutes of exposure to the specific experimental condition. Two different predicted thermal sensations are evaluated: Firstly, we considered PMV predictions obtained with the straightforward Fanger model. Secondly, rather complex predictions were derived from 3D-simulations and on the basis of the Berkeley comfort model. Regarding thermal sensation, two different scales are commonly used and are depicted in Figure 2. Participants reported their thermal sensation on a scale that is identical to the PMV model scale (Figure 2, a). On the other hand, the Berkeley comfort model uses a similar scale, but with extensions for very extreme conditions (Figure 2, b). It should be noted, that a direct comparison of values at different scales might be misleading. The interpretation of thermal sensation scales is a current focus of research (for instance [Schw17]). For a first interpretation however, the deviation between the two scales is neglected in our analysis.

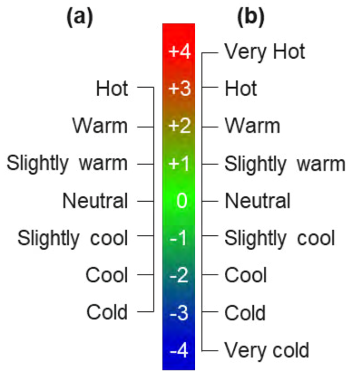

Figure 2: Thermal sensation scales. Participants reported their perception on scale (a), which is also used by the PMV model. The Berkeley comfort model uses a slightly different scale (b).

Results and Analysis

When comparing irradiation at the reference planes, the simulated irradiation distribution closely matched the measurement results. Exemplarily, results from measurement and simulation of condition C4 (short-wave radiation at 100 W/m²) are depicted in Figure 3. A similar accordance between simulation and measurement was observed in the other conditions as well.

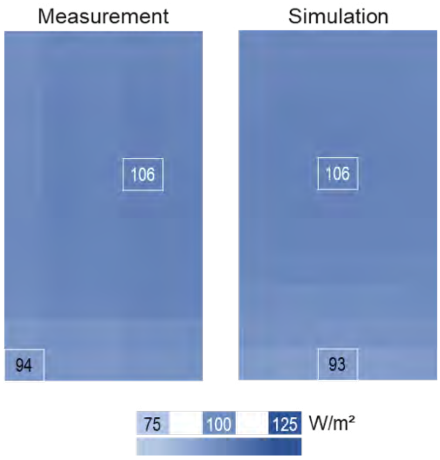

Figure 3: Irradiance distribution for experimental condition C4, from measurement [Hir21] and from simulation. Minimum and maximum values are indicated.

For the five investigated conditions, the respective thermal sensations are comprehensively illustrated in Figure 4. The dots (●) represent mean values of the participant's perception after five minutes of exposure to a condition. From the participants' responses, it was confirmed that any irradiation induced a warmer thermal sensation [Hir21]. A further outcome of the original study is linked to the radiation wavelength. The perception of condition C4 and C6 was almost identical, while condition C3 and C5 were perceived differently. Notably, this difference is statistical significant [Hir21], so in this rather moderate condition, the both radiation types are perceived differently. As potential cause for this observation, the wavelength-dependent skin reflectance and skin penetration were discussed [Hir21].

As can be seen from Figure 4, predictions on the basis of Fanger's PMV model (▲) are in some cases very close to the actual perceptions. Especially for the baseline C7, where the radiation sources were deactivated, the model predictions are rather accurate. While additional irradiation leads to higher PMV values, this straightforward model underestimated the effect magnitude. When pairwisely comparing situations distinguished only by the radiation type (e.g. C4 – C6), the PMV values are very close to each other. Apparently, the PMV model does not directly account for the diverging human perception of short-wave and long-wave radiation [Hir21]. In principle, it would be feasible to integrate such effects into the calculation method of the mean radiant temperature.

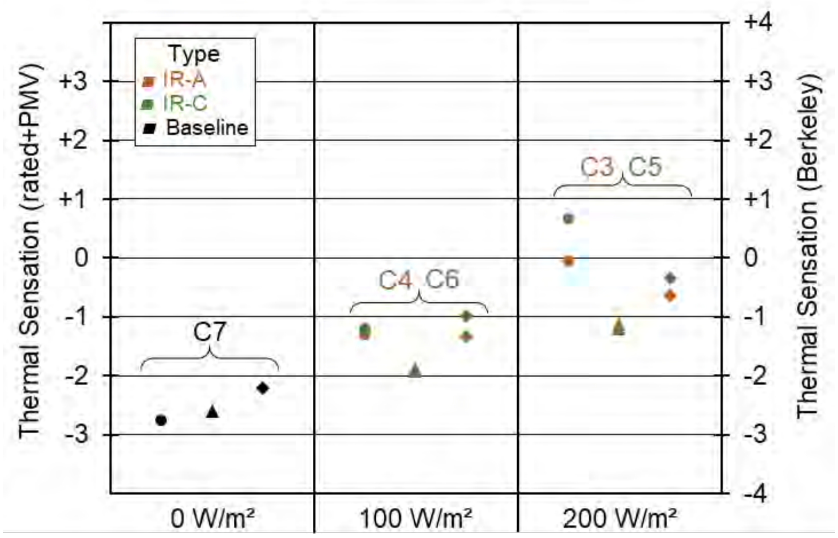

Figure 4: Thermal sensation within the five experimental conditions. Participant-reported mean thermal sensations are plotted as dots ●, predictions from Fanger's PMV model as triangles ▲, and predictions from a simulation with the Berkeley Comfort Model as diamonds ◆.
Participant responses and PMV values from [Hir21].

Figure 4 furthermore presents predictions based on elaborate 3D-simulations and the Berkeley Comfort Model (plotted as diamonds ◆). The predicted thermal sensation of the baseline situation C7 is near the actual perception. With increased irradiation, the Berkeley model predicts a warmer thermal sensation. However, apparently for the conditions with an irradiation of 200 W/m² (C3, C5), the magnitude of the simulated increase appears to be smaller than the actual effect.

Furthermore, the two different kinds of radiation show a different effect in the Berkeley comfort simulations. In analogy to the actual responses, long-wave radiation (conditions C5, C6) effected a warmer thermal sensation than the respective short-wave counterpart (conditions C3, C4). Thereby the 3D simulations appropriately considered the diverging human perception of different kinds of radiation.

The general agreement between actual and simulated thermal sensation might require further fine-tuning. Firstly, transient effects might play a role. The exposure time of five minutes might not be sufficient for obtaining a steady-state response. While transient simulations (Berkeley model) show that a nearly constant level of thermal sensation is reached after 3 to 5 minutes, the actual perception of the participants might not have settled at a constant level after 5 minutes. Furthermore, as mentioned in Figure 2, the different scaling might lead to a misconception when directly comparing simulated and actual thermal sensation. Some deviation might also result from an approximate model of convective heat transfer (based on [Fia99]), which was implemented in the simulations.

Concluding, the experimental situations with two kinds of radiation sources were accurately recreated in 3D simulations. The actual human perception, as well as elaborate simulations with the Berkeley comfort model, did confirm that short-wave and long-wave radiation diverge in their effect on human thermal sensation. The simulated prediction of thermal sensation might be further improved by considering also transient effects on thermal sensation, by enhanced modelling of convective heat transfer, and by taking different scales of thermal sensation into account.

Acknowledgements

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An investigation of three theoretical assumptions associated with thermosensory testing

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ABSTRACT

The goal of the study was to explore three theoretical assumptions associated with thermosensory testing, using the local application of thermal stimuli. The first assumption we addressed was that relationship between thermal sensation and physical contact temperature is linear. We also examined the assumption that local thermal discomfort is more sensitive to cold, than it is to heat. Lastly, we examined the assumption that participants exhibit high levels of confidence in repeated thermal sensation ratings, across a wide range of contact temperatures. In nine female, and eight male volunteers, thermal sensation, thermal discomfort, and the confidence in thermal sensation scores, were measured in response to seventeen physical contact temperature stimuli, ranging from 18 to 42°C, applied to the dorsal forearm. Our findings demonstrated that the first theoretical assumption, that local thermal sensations are linearly related to the stimulus temperature, is true. This indicates that the distance between the thermal sensation anchors is close to equal in terms of physical temperatures changes, across the range tested presented. On the contrary, the second assumption, that participants experience local cold as more uncomfortable than local heat stimuli, was not supported by the present data. Rather participants rated a similar thermal discomfort level to both cold and hot thermal stimuli. Indeed, the last assumption presented was also contraindicated by the present study, in which the average confidence of thermal sensation was less than 100% (87.5%). Interestingly, the similar levels uncertainty was observed across the range of physical contact temperature tested.

KEYWORDS

Thermal sensation. Thermal discomfort. Thermosensory

Introduction

A protocol was developed to test theoretical assumptions associated with the interrelationship between thermal sensation, thermal discomfort, and physical contact temperatures in humans. To achieve this, perceptual responses (thermal sensation and thermal discomfort) to the application of seventeen absolute physical temperatures, ranging from cold to hot (18 - 42°C) were examined. In addition, the present study tested the confidence of participants in their thermal sensation ratings also, across a wide spectrum of thermal stimuli. Seventeen Western European university students volunteered and consented to participate in the study. The location of the application of the probe was marked on their skin, ensuring consistent application across temperatures, and all participants were blinded to the environment conditions, as well as the temperature of thermal probe controller unit, to avoid expectation bias. Physical temperatures were applied with a conductive thermal probe

(Physitemp Instruments Inc., USA) consisting of a 25 cm^2 metal surface, applied with a pressure of 4 kPa, in a mixed counterbalanced order. The probe was applied to the skin for 10 seconds for all applications, at the end of which participants rated their local thermal sensation, the confidence of thermal sensation, and local thermal discomfort. A recovery time between thermal probe applications of at least 20 seconds was used. Local skin temperature has been reported to have returned to its baseline value using a single spot infrared thermometer (FLUKE 566, Fluke Corporation, USA) prior to each subsequent thermal probe application.

Findings

A positive linear and sigmoidal fit at forearm described the thermal sensation to physical temperature relationships (r^2 = 0.91 and r^2 = 0.91, respectively). While the sigmoidal model offers an improved relation, the difference between the models was limited. For this reason, it may be concluded that the physical temperature distance between the thermal sensation anchors for the range studied is close and is largely explained by a linear model as shown in Figure 1.

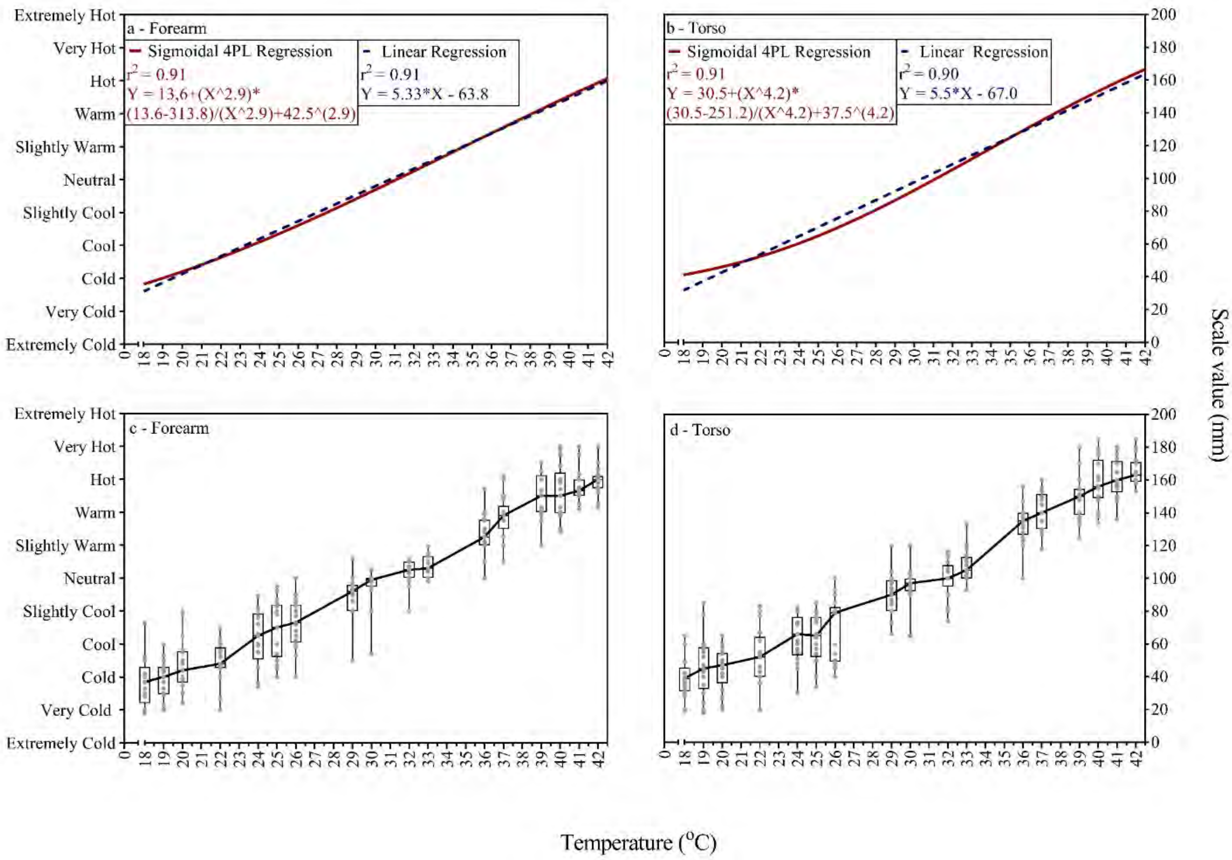

Figure 1: Relationship between applied physical temperature and thermal sensation

The second and third-order fits in the forearm described the thermal discomfort to physical temperature relationships, however predictive value was limited by inter-individual variability (r^2 = 0.33 and r^2 = 0.34, respectively). The data and the degree of discomfort was comparable in both cold and hot for a given increase or decrease in physical contact temperature or thermal sensation (Figure 2).

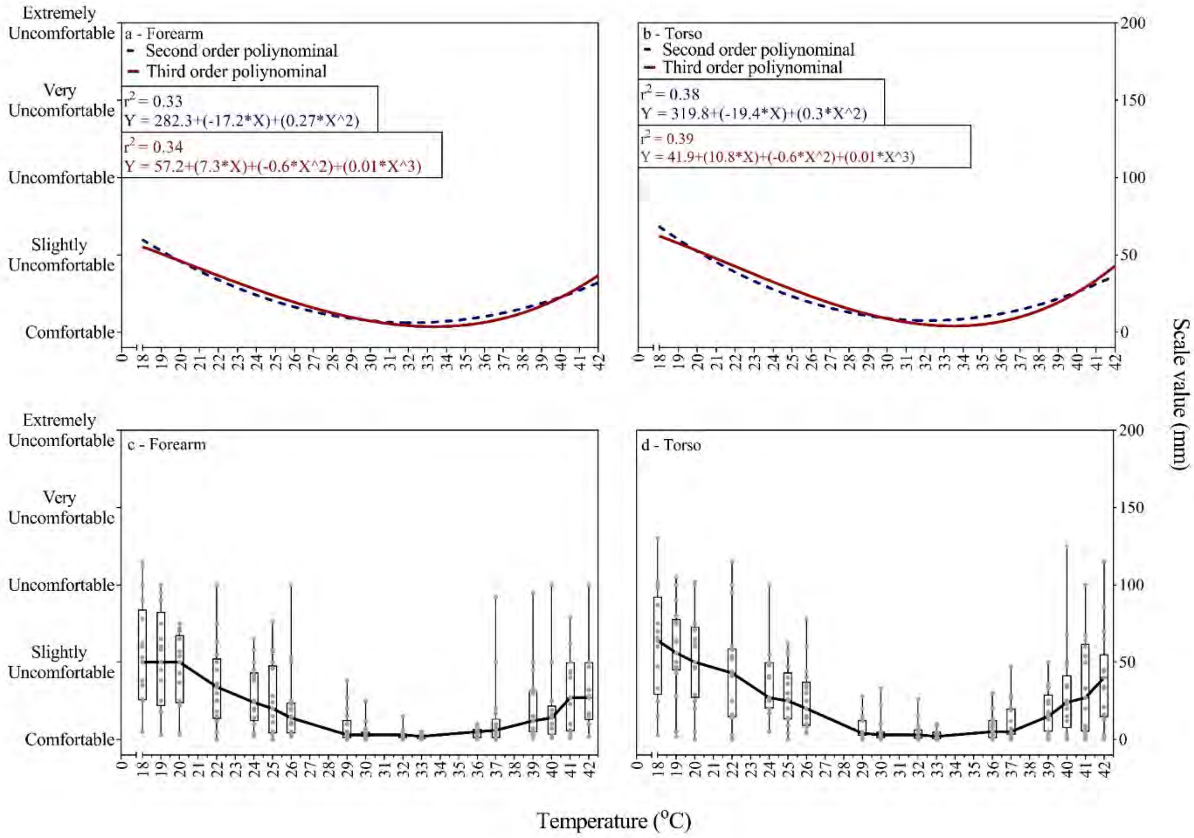

Figure 2: Relationship between applied physical temperature and thermal discomfort

Lately, the results also showed that the confidence in thermal sensation ratings did not depend on the temperature of the physical contact, and that none of the participants rated their thermal sensation with 100% certainty across all contact temperatures tested. The median confidence in the thermal sensation rating of a person was 86%, varying from approximately 40% to 100% (Figure 3).

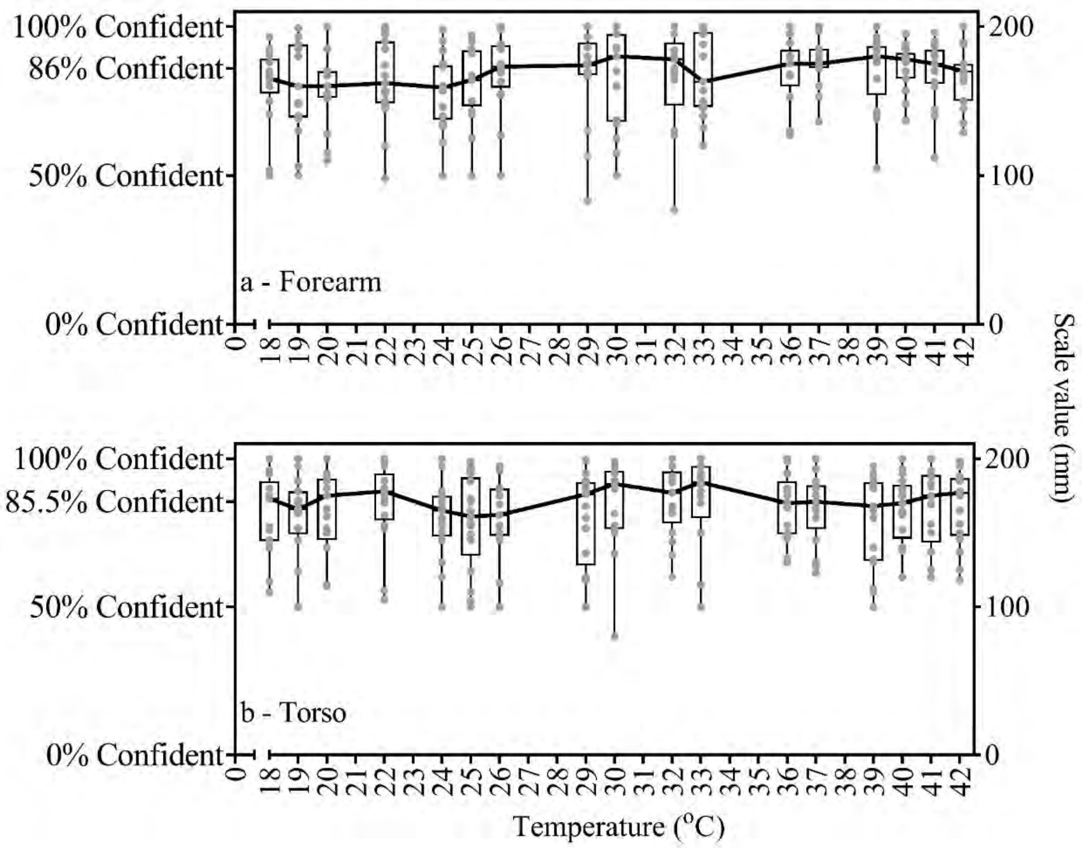

Figure 3: Individual data and box and whiskers with median connection line of the confidence of thermal sensation ratings in forearm (a), and in torso (b)

Thermophysiological comfort of duvets in consideration of the bed cave

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ABSTRACT

Sleep is a fundamental need for humans. On average 1/3 of the lifetime is spent in bed. Important for a healthy sleep is the duvet. This should have sufficient heat insulation and should ensure a dry bed climate at the same time. The thermophysiological comfort of classic duvets can be rated via skin model and thermal manikin. The simultaneous detection of dry and moist heat flux of duvets is now not possible. The lecture presents results of the German funded project AiF 19522 N "Bed Cave and Comfort". Within the project the interaction of thermophysiological comfort during sleeping and the bed cave was investigated. Duvets with different filling materials (down and feathers, polyester, animal hair as well as new developments) were examined according the classical, thermophysiological evaluation method for sleep comfort. Furthermore, a new evaluation method for duvets with the sweating, thermal manikin Sherlock (Newton type, Thermetrics) was developed. During the measurement, a realistic sleep situation can be reconstructed with the sweating, thermal manikin. All measured data were validated by monitored sleep test within a climatic chamber.

KEYWORDS

Thermophysiological comfort, duvets, sweating, thermal manikin

Introduction

Sleep is a fundamental an underestimated basic need of humans. On average 1/3 of the lifetime is spent in bed. After 48 hours without sleep the concentration for simplest tasks is lost (Zulley, 2011). Restful sleep is very important for human regeneration and health maintenance (Hobson, 1989). During sleep a comfortable warm bed climate, night movements and a lowering of body temperature of 0.5 °C with subsequent rise should be possible. Therefore, produced body heat is dissipated by the skin by radiation, conduction, and convection. Further sweating can occur to cool down the human body. To avoid moisture in the bed system sweat should be transported through the system during sleep (Zulley, 2011). Studies show that about one fifth of the produced heat and moisture produced during sleep is released to the mattress. The majority of 80 % is released to the duvet (Caps & Umbach, 1988). Other components like mattress, linen or nightwear play a tangential role. So, the duvet should be able to transport the produced sweat to the ambient. Further the human body should not cool down during sleeping. Duvets must therefore have adequate thermal insulation.

In the 1990s a method and model to characterize the comfort of duvets was invented at Hohenstein, which is still used today (Umbach, 2003). This evaluation system is based on two methods: dry heat insulation of ready-made duvets measured with the thermal manikin and the material-specific characteristics of heat and moisture transport determined with the Hohenstein skin model. The measurement of dry and wet heat flow of ready-made duvets in consideration of the bed cave is until now not possible. Further, the insulation of the duvet depends on the draping of the duvet and the so formed bed cave between human and duvet. This draping ability of the duvet depends on the material, the rigidity, the filling quantity, and the packaging. Within a German funded research project AiF 19522 N a new measuring and evaluation method for traditional and new ready-made duvets in consideration of the bed cave was investigated. In addition, the influence of the bed cave and the enclosed air layer on the thermal insulation and sleeping comfort was researched.

Materials and Methods

Within the project more than 40 duvets with different cover materials and fillings e. g. polyester (PES), down and feathers, wool (WO), camel hair, cotton (CO) were investigated. Screening tests showed that 18 duvets represent state of the art of German duvets. These duvets were used for further investigation.

Sweating, thermal manikin

A new method was invented to characterize the thermophysiological comfort of duvets in consideration of surface coverage, snugness and the microclimate within the bed cave using the sweating, thermal manikin Sherlock (type Newton, Thermetrics). The sweating, thermal manikin Sherlock has the anatomical shape of a human standard man (height 1.75 m, body surface 1.85 m², clothing size 50). The skin surface of the manikin was regulated to a constant temperature T_s of 31 °C. The required electrical heating power H_c for the constant surface temperature was the measured value, for the determination of the thermal resistance R_c of duvets. The measurement was set in a climate chamber at temperature of T_a = 15 ° C and relative humidity of RH_a = 50% rh.

To create a realistic sleeping condition, the measurement took place with the sweating, thermal manikin Sherlock lying down, wearing a two-piece pyjama (CO). The head rest on a pillow. The duvet itself was measured without a cover. To record the microclimate of the bed cave, ten additional temperature and humidity sensors were attached to the sweating, thermal Manikin Sherlock, and the duvet. The duvet was draped uniformly around the manikin. Care was taken to ensure that the duvet lies loosely so that there is enough air volume in the bed cave. A standard bed construction consisting of a tubular steel bed frame with a one-piece foam mattress (180 mm thick), which is covered with a cotton sheet, was chosen for the investigation. In addition to these investigations of the thermal resistance R_c, realistic sweating during sleep was simulated with Sherlock to determine the water vapor resistance R_e of duvets. The same measurement setup was used for this. Sweating is achieved with the help of a tight sweat suit and sweat nozzles, which are distributed over the body. The sweat suit has the function of distributing the sweat (water) from the sweat nozzles evenly over the body. The sweat nozzles can be controlled individually, so different sweating rates can be set. The used sweating rate are based on Park et al. (Park & Tamura, 1992) and simulate vapours sweating. These sweating rates reproduce a realistic sleeping situation and leads to reproducible measurement results for duvets.

Subject trial

To validate the results with the thermal, sweating manikin subject trials with selected duvets M5, M14 and M32 were done. Five, healthy male subjects performed monitored sleep experiments in the climate chamber. The monitored sleeping experiments were performed at 20 °C, 50% RH in a climatic chamber with air movement 0.3 m/s. To create comparable conditions to the experiments with the sweating, thermal manikin Sherlock, identical experimental conditions were implemented in the subject trials (clothing, bed construction). The subjects slept for at least 6 hours in the climate chamber, whereby the bed cover was tested without a cover and five temperature and humidity sensors recorded the microclimate in the bed cavity. The objective body data were recorded using various sensors. The heart rate was recorded using a chest strap (Polar WearLink). Temperature sensors (T) for the skin temperature as well as combined temperature-humidity sensors (T, RH;

MSR Electronics GmbH) for recording the microclimate were distributed on the body surface in accordance with ISO 9886. In addition, the subject's subjective sensations after the sleep were queried and recorded using a questionnaire. Before sleeping experiments, the test subjects were equipped with the sensors and get dressed. This process took at least 30 minutes to also acclimatize the subjects. The individual experiments each lasted at least 6 hours, during which the test subjects slept in a bed under the respective duvet. Furthermore, the change in weight of the test subjects and the sweat absorption of the individual items of clothing and the duvet were determined by weighing before and after the sleep experiment.

Results and Discussion

Sweating, thermal manikin

The investigations with the sweating, thermal manikin Sherlock indicate that it is possible to determine the thermal resistance R_c and water vapor permeability R_e of duvets. Table 1 shows the results of these characterizations. Regarding the thermal resistance R_c the values are in the rage 0.56 – 1.00 m²K/W. M28 shows the lowest thermal resistance with 0.56 m²K/W (Table 1). Therefore, this duvet is less insulating and should be used as summer duvet. Duvets M5, M8, M17, M18, M20 and M32 have Rc-values in the middle range between 0.61 – 0.72 m²K/W. The residual duvets M3, M4, M6, M7, M11, M12, M13, M14, M21, M25, M29 show high thermal resistance values in the range 0.75 – 1.00 m²K/W (Table 1). So, the thermal insulation of these duvets can be rated as high, and they should be used in winter when the ambient temperature in bedrooms is low.

Table 1: Thermal resistance R_c and water vapor resistance R_e of different duvets measured with sweating, thermal manikin Sherlock.

Sample	Thermal resistance R_c [m²K/W]	Water vapor resistance R_e [m²Pa/W]	Sample	Thermal resistance R_c [m²K/W]	Water vapor resistance R_e [m²Pa/W]
M3	0.77	98.78	M14	0.75	73.33
M4	0.76	82.93	M17	0.65	66.85
M5	0.61	64.86	M18	0.69	68.23
M6	0.96	104.84	M20	0.71	84.74
M7	1.00	102.54	M21	-	61.54
M8	0.72	73.98	M25	0.95	92.48
M11	0.87	100.09	M28	0.56	51.89
M12	-	54.09	M29	0.87	84.69
M13	0.77	83.13	M32	0.62	60.15

The results of water vapor resistance R_e are in the range 51.89 – 104.84 m²Pa/W. Especially duvet M28 and M12 has low R_e-values, which means these duvets have a good breathability and during sleep produced sweat can be transported through the duvet to the ambient. The highest water vapor permeabilities have the duvets M6 and M7 with values in the range 102.54 – 104.84 m²Pa/W. This can be explained, among other things, by the high thickness of the duvet. The by human produced sweat (water vapor) must pass through more material before it can be released into the ambient. The results show no correlation between the R_e-value and the filling or stitching design of the duvets.

In addition, the microclimate in the bed cave was determined during the measurements of the water vapor resistance by ten temperature and humidity sensors. Figure 2 shows the average temperature (orange, left) and relative humidity (blue, right) in the bed cave during the measurements of the water vapor resistance R_e using the sweating, thermal manikin Sherlock. There are slight differences in the microclimate of the bed cave for different duvets. The temperature is between 25.67 - 28.89 °C. The lowest temperatures in the bed cave were achieved for duvet M3 and M28, for duvets M11, 21 the highest. In the case of relative humidity in the bed cave, the values are in the range of 54.43 - 67.43% RH. From a clothing physiological point of view, the relative humidity should be below 60% RH, because at higher relative humidity's no differentiation can be made by humans and it is sensed as unpleasant wet. The duvets M14 and M28 have the lowest relative humidity in the bed cave during the determination of the water vapor resistance. The duvets M7 and M11 the highest relative air humidity in the bed cave. There are no apparent correlations between water vapor resistance R_e measured with the sweating, thermal Manikin Sherlock, and the climate in the bed cave.

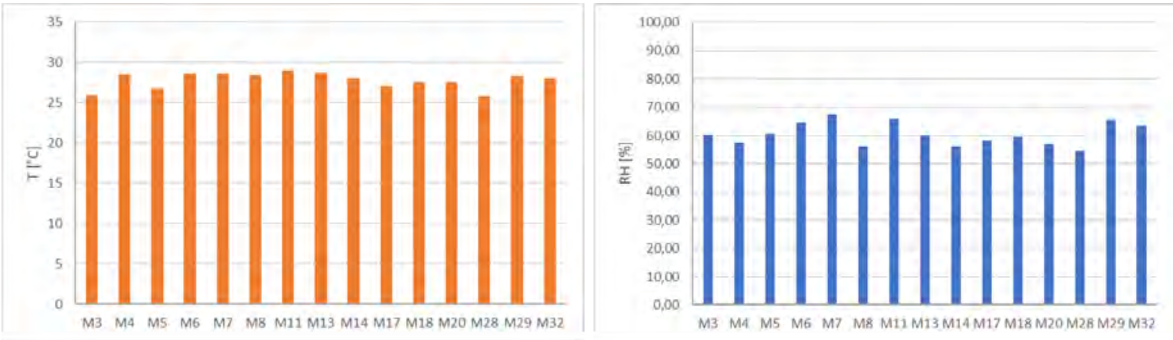

Figure 2: Temperature T (left) and relative humidity RH (right) in the bed cave during the measurements of the water vapor resistance R_e using sweating, thermal manikin Sherlock.

Subject Trial

During the monitored sleeping experiments the test subjects produced a small amount of sweat between 275 g and 490 g (Table 2). Most of the produced sweat P evaporates, i.e., 95.54% (M32) - 97.27% (M14) (ratio evaporated sweat E/produced sweat P) were transported through the duvet and released into the environment. In the duvets themselves, 1.31 g (M5), 1.62 g (M14) and 3.91 g (M32) remain over the entire monitored sleeping experiment (Table 2). This means that only very small amounts of sweat remain in the duvets. The results show clearly that while sleeping under the duvet M32, which has climatic zones, the subjects produce less sweat. Simultaneous duvet M32 absorbs the highest amount of sweat. The results of the individual monitored sleeping experiments were evaluated. The data was analysed subject-specific and product-specific. The mean values across all subjects were calculated. Due to the large number of data, the following results are limited to mean values of the recorded objective data (skin temperature, temperature in the microclimate, humidity in the microclimate) for all duvets on lower back right position.

Table 2: Produced and evaporated sweat amount during subject trial.

	Amount of sweat [g]		
	M5	**M14**	**M32**
Produced Sweat P [g]	490.00	461.11	275.00
Evaporated sweat E [g]	476.46	448.50	262.74
E/P [%]	97.24	97.27	95.54

Figure 3 shows the relative humidity (right) in the microclimate above the skin of the subject on lower back right position. All three duvets M5 (grey curve), M14 (orange curve) and M32 (blue curve) show the same curve progression with minor differences for the individual duvets. Towards the end of the sleep period of six hours, however, trends can be seen. M32 tends to have the lowest moisture in the microclimate above the skin, M14 the highest. This confirms the measurements with the sweating, thermal Manikin Sherlock. Here M14 has the highest water vapor resistance Re compared to the duvets M5 and M32. Low water vapor resistance R_e means produced sweat is transported through the duvet to the ambient. In case of higher values this transport is less efficient and the relative humidity in the microclimate above the skin rises. By comparing the temperature in the microclimate (Figure 3, right) above the skin of the subject on lower back right position of the three duvets similar curve progression can be seen, too. This is not surprising considering that these duvets have slightly differences in the thermal resistance Rc (Table 1). The measurement fluctuations within curve M14 on the lower back right can be explained by averaging over all subjects. M14 has the highest thermal resistance, which means thermal insulation, of these three samples. It is therefore not surprising that the temperature in the microclimate of the bed cave is higher in the case of M14 than in the other duvets. Duvet M14 has the higher Re-value compared to M5 and M32, but the relative humidity in the microclimate is almost the same for these three duvets during the subject trail. Furthermore, the subject produced 461.11 g of sweat in case of M14, which is greater than M32 and a little bit lower than M5. That implies that M14 puffers more sweat than M5 and M32.

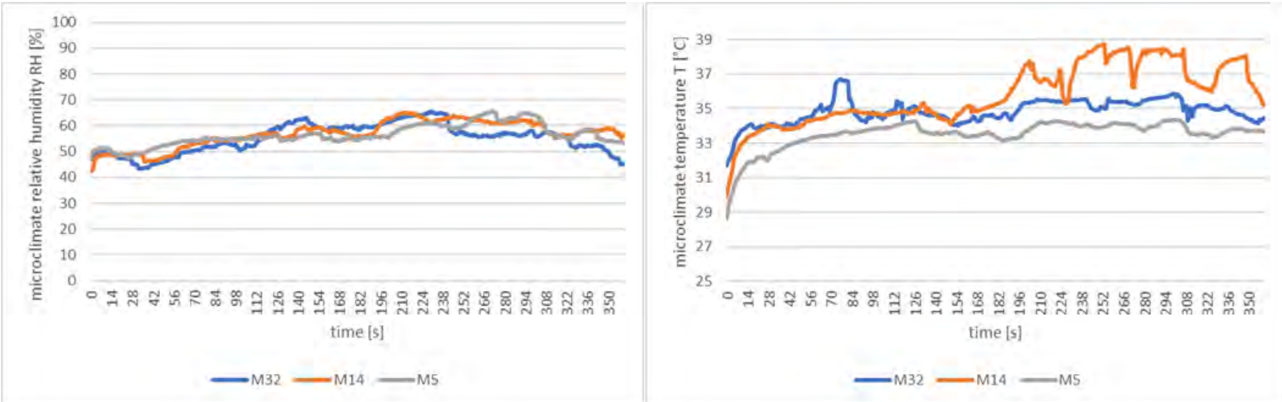

Figure 3: Relative humidity RH (top) and Temperature T (bottom) in the microclimate above the skin on lower back right position during monitored sleeping experiment with subjects.

Figure 4 shows the skin temperature on lower back right position during the monitored sleeping experiment. The values show, as before the temperature in the microclimate, that the three duvets slightly differ in their thermal resistance. It can be said that the lowest skin temperatures occur while sleeping under the duvet M32. Compared to M5 and M14, this duvet also has the lowest thermal resistance (Table 1).

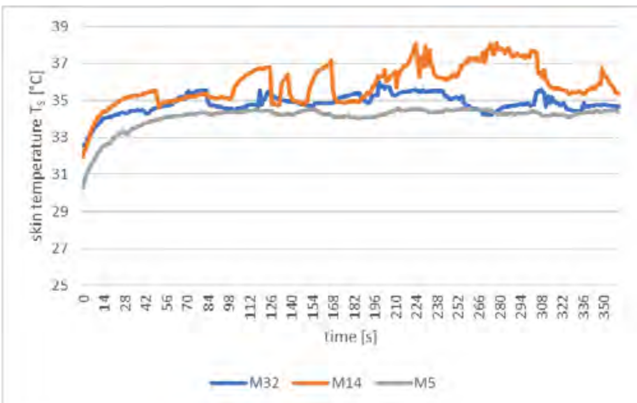

Figure 4: Skin temperature Ts on lower back right position during monitored sleeping experiment with subjects.

After each individual sleeping experiments, the subjects filled out a detailed standardized questionnaire. This questionnaire includes questions about the feeling and comfort of the duvets, as well as the overall comfort. These detailed questions are relevant for the overall evaluation, to be able to classify the thermophysiological properties of duvets and the measurements with the sweating, thermal manikin Sherlock.

Conclusions

Within the German funded IGF research project AiF 19522 N "Bed Cave and Comfort", a new system for characterizing the thermophysiological comfort of duvets should be developed, which can objectively assess the heat and moisture management of duvets considering the shape and size of the bed cave. For this purpose, a suitable measuring method was developed to characterize the thermal resistance Rc (thermal insulation) and the water vapor resistance Re (breathability) with the sweating, thermal manikin Sherlock. It became apparent that in manikin measurements by considering the bed cave a higher information content for characterizing the clothing-physiological comfort of duvets is obtained. Based on sleep tests with subjects, these thermophysiological indicators as well as the measurement method for the sweating, thermal manikin Sherlock could be validated. The new measurement method with the sweating, thermal manikin Sherlock is suitable for characterization of the thermophysiological comfort of duvets. Here, classic as well as innovative duvets can be assessed regardless of the filling used, and the construction and manufacture of the duvets. Conventional clothing physiological characterizations with the Hohenstein skin model do not have to be carried out and there is no loss of information in accuracy and significance.

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Future Vehicles

Chaise Longue: Passenger perception of more spacious economy class seats in the same pitch

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ABSTRACT

Usually, the economy class has limited space and limited recline possibilities causing discomfort, especially on long haul flights. In this paper, a seat was developed creating more space by using the vertical space in the aircraft. The design is described and 59% preferred this seat based on visual impression, which is promising. Further prototyping, certification studies and manufacturability research is needed to check the feasibility further.

KEYWORDS

Seat pitch, Passenger Density, Passenger Comfort, Spacious Aircraft Seats

Introduction

To increase the income airlines want as much passengers on board as possible. However, if space is too limited it could mean that passengers choose for another airline with more space. Depending on the length of the flight, 20-40% of passengers mention the cabin interior as the most important factor in their choice of an airline (Brauer, 2004). Vink et al. (2012) also found a strong correlation (r=0.73) between aircraft interior comfort and "fly again with the same airline". Ahmadpour et al. (2014) found that the seat is an important aspect in relation to aircraft passengers' comfort perception. Rankin et al. (2000) suggested that seat comfort is the best predictor of overall flight comfort (r=0.77, n=3630, p<0.01). Bouwens (2018) studied which seat related elements are important for passengers from Asia, Europe and the USA. The top five of most important seat related elements was the same in all three regions, only the order differs slightly. These were Legroom, Foot space, Hygiene, Bottom Cushion and Overall Space. Three of the five elements concern space and are influenced by the pitch if traditional seats are used. Seat pitch is the distance from any point on one seat to the exact same point on the seat in front or behind it (Vink, 2017). Anjani et al. (2020) found that comfort increases significantly when the seat pitch increases. Some airlines try to create space by developing a thin backrest (Vink, 2017) and some have a curved seatback instead of a flat one and if the passenger splays his legs (https://www.sfgate.com/travel/article/Spirit-Airlines-new-seat-pitch-14426008.php) a bit, the knees will have more room than before. Another possibility is to use the vertical space. This principle is applied in the Flying V (see fig.1). In a study among 1692 participants visiting the interior of the Flying V (Vink et al., 2020) it was shown that, the majority (36%) preferred this 'chaise longue' out of 4 possibilities. This seat (see fig. 1) uses the vertical space in the airplane and creates more legroom, more foot space and more overall space within the 32" seat pitch. A problem in aircraft seats is the limited variation of posture. In this 'chaise longue', it is possible to change the position of the human body. There is an upright position for eating and working with the laptop and a more reclined or lounge position for relaxing and sleeping.

Figure 1: The chaise longue seat of the Flying V using the vertical space in the aircraft cabin.

However, this seat needs further development. It was now made in a 1:1 mock-up and passengers could not sit on it. In addition, the moving mechanism was not functioning and was not designed in detail yet. The question remains whether this type of seat is feasible and accepted by passengers. In this paper, the seat is further engineered to see how the structure of this seat can be made and renderings are made of a more detailed aircraft seat and shown to potential travellers to get an impression on whether passengers are able to see the advantages and disadvantages. The research question of the paper is: 'are potential future aircraft seat users able to see advantages and disadvantages of the 'chaise longue' of a more detailed design?'

Engineering and detailed design

In detailing the design of the current 'lounge seat' of figure 1, it became clear that the construction will be heavy and hanging the construction on the ceiling is not feasible. Therefore, an alternative design was made and detailed. To make this seat as comfortable and minimalistic each piece of the Chaise Longue Design was engineered separately and optimised to reduce its weight while trying to keep comfort. The intention of the design is to keep the shape of the top and bottom rows as similar as possible so that in case of manufacturing those, the same moulds and machines could be used.

Figure 2: Exploded view of 6 seats indicating its modularity. The seat pan of the lower row can disappear under the back rest enabling in- and egress.

The design is modular, and pieces can easily be replaced without having to disassemble the whole seat structure (see fig.2). The headrests and the backrest are almost equal, except for an extra feature that enables the seat pan to be hidden under the backrest to improve in- and egress.

Figure 3: The headrest in the position with neck support and in the position with freedom for the neck.

Figure 4: the design of the back rest

The headrest has a U-shaped chin/neck rest that can rotate and has soft foam (see fig. 3). Franz et al. (2012) showed the importance of a difference between a neck rest and a headrest. The headrest is of harder foam. The length of the backrest (see figure 4) can be changed to create free shoulder space, which is important according to Goossens et al., (2003). The contour is based on the ideal shape found of Nijholt et al. (2016).

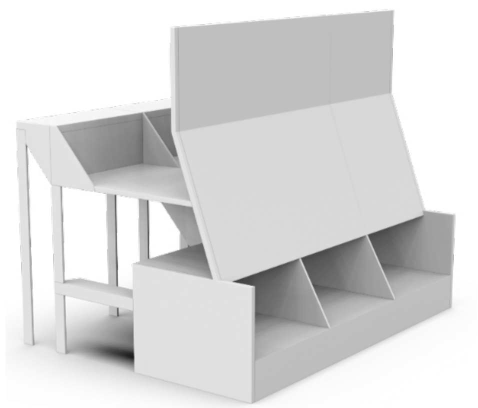

Figure 5: the seat pan

Figure 6: the basic structure

The seat pan was designed taking into account the human contour (Hiemstra-van Mastrigt, 2015). It has a soft front, which is inflatable as behind the knees the human is very sensitive (Vink & Lips, 2016) and because this area has the most variation if we overlay the various 3d scans of different humans (Hiemstra-van Mastrigt, 2015). For this reason the seat has a convex dent right at the back. Having designed the headrest, backrest and seat pan a supporting construction had to be designed.

This Double Decker Structure design took a long time because the calculation process was complicated. It should be safe and strong enough to withstand 15G (see fig 6).

How it works

The functioning of the Chaise Longue concept is divided into two main parts. The top row has a recline mechanism that is currently in use for the recline of aircraft seats (see figure 7). The backrest can be tilted backwards without taking knee space from the passenger behind it. The lower row mechanism is composed by two different mechanisms that have not been used yet in travel seats.

Figure 7: the top recline mechanism

Figure 8: The lower row sliding mechanism

Figure 8 shows the lower row seat sliding mechanism. For the seat pan, a telescopic or sliding mechanism is chosen that acts as a drawer. The passenger can change the position of the seat pan by pressing a button while pushing or pulling the seat to take it into the next position.

Method

To check the impression of passengers on these lounge seats an online questionnaire was sent to 49 participants. The participants had to rate the comfort of the lower and upper seat on a scale from 1-9, the impression for the in- and egress and the neck rest on the same scale. Additionally, they were asked to compare this seat to the current economy class seats (which was shown in a picture) and mention positive and negative points of the seats. A t-test was used to check statistical differences ($p<.05$).

Results

The comfort scores are not that high. The unreclined lower row scores on average 5.02 (stdv 1.70) and the unreclined upper row 5.46 (stdv 1.90). The difference is not significant ($p=0.23$). Both reclining positions score rather good. The reclined lower row scores on average 5.98 (stdv 2.22) and the reclined upper row 6.73 (stdv 1.45). The difference is significant ($p=0.05$). The difference between the lower row upright and reclined is significant ($p=0.018$; $t=2.40$) and for the upper row as well ($p=0.0004$; $t=3.68$). The in- and egress also show score that are not that high (5.02, stdv 1.74). The questionnaire also showed that 59.2% of the public would choose the Chaise Longue design while 32.7% would still prefer the current economy class seats. Others did not score a preference. The top row is chosen by most participants above the lower row (79.6%). This was surprising as the lower position has a more comfortable position for sleeping (see fig. 9), which is beneficial for a long haul flight.

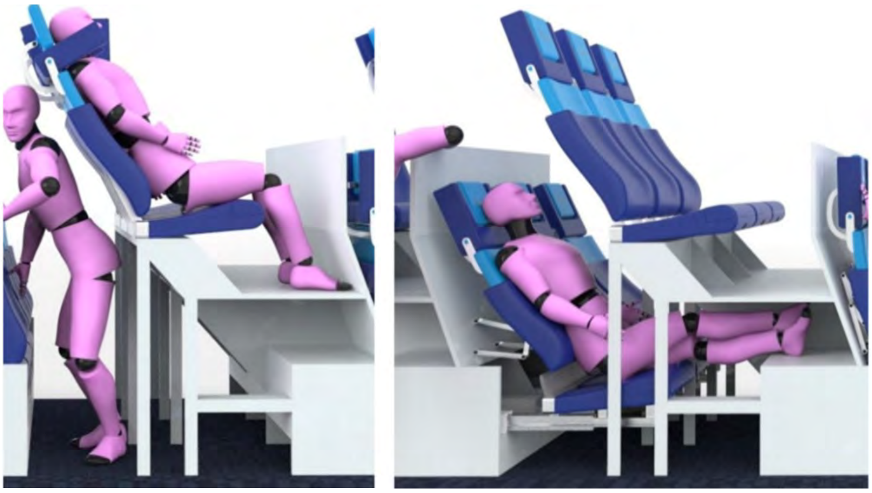

Figure 9: the reclined position in the top row (left) and lower row (right)

Discussion

This study indicates that the majority of end users did see the advantage of this new type of seat. In a previous version of the seat (Vink et al., 2020) the reactions were also positive. Although that version was hard to realize. The idea of using the vertical space is not new. An interior developed by Skift (2020) and one by Jacobs (2020) also use this space. These ideas are all conceptual and not flying. In this project, also, mechanisms and dimensions are defined, and calculations are made on strength and safety and human models are placed into the seats to check the anthropometric fit. However, also, in this case, further development is needed and prototypes are needed to check its feasibility. In addition, the passengers now rated the comfort based on visual impression. A working mock-up, which passengers could feel and experience, might give other outcomes and is in preparation.

The concept has new ideas that should be studied further, but they could have impact in the future of aircraft interior designs and comfort experience of passengers. Another advantage of this new modular concept where elements could be taken out, could be that passenger cabins could be used as small and medium cargo storage compartments (which is relevant in pandemic times). Although the modularity indicates an efficient manufacturing process, further prototyping is needed to check its manufacturability. Additionally, certification studies and research with participants is needed to check the feasibility further. Perhaps the main advantage and reason why this seat needs to be further developed is that the seat has been designed for the economy class on long-haul flights, which are more spacious, but take the same space as current economy class seats.

Conclusion

A seat using the vertical space in an aircraft has been developed, which seems to have potential. The first engineering step shows that it is still possible to make the seats. 59% of passengers preferred this seat based on visual impression. However, further prototyping is needed to check its feasibility

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Experimental investigation of preferred seating positions and postures in reclined seating configurations

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ABSTRACT

In highly automated vehicles, new activities such as working, relaxing, or sleeping may be allowed for all occupants including drivers. Vehicle interiors will likely need to be adapted to accommodate these activities, and current interior concepts include reclining seats. To design these new seats, some knowledge of the preferred occupant postures in reclined seating conditions would be valuable. However, past studies mainly focused on preferred postures for driving. When reclining the seatback to adopt a relaxed position, occupants may also desire to modify the seat pan angle. Therefore, the present study aimed to investigate the preferred seat pan angle and occupant posture in reclined configurations. Two test experiments were performed. The first one focused on the preferred minimal and maximal seat pan angles selected by 18 volunteers for three seatback angles (21, 40, and 60 degrees from the vertical). The second one evaluated the seating postures of 13 participants corresponding to 11 seating configurations by combining 3 seatback angles (21, 40, and 60 degrees) and 4 seat pan angles (14, 27, 40 degrees from the horizontal, and self-selected). Results suggested that the preferred seat pan angles increased when reclining the seatback, especially for the preferred maximal seat pan angles. Concerning the occupant posture, the pelvis angle was influenced by both seat pan and seatback angles; but the pelvic angle variations were smaller than the seatback and seat pan angle variations.

KEYWORDS

Preferred seating position, Relaxing, Reclined seat, Highly automated vehicles

Introduction

In highly automated vehicles (HAVs), i.e. automation level 3 or above, the occupants are no longer driving. This may allow new activities, such as conversing, relaxing, or sleeping (Pfleging et al., 2016). A new vehicle interior will likely be needed to accommodate these activities. Reclined seats were found desirable (e.g. Bohrmann and Bengler, 2020). Some knowledge of the preferred postures in reclined seating conditions would be valuable to design new vehicle interiors and seating conditions. However, past studies were mainly focused on driving posture (Schmidt et al., 2014; Peng et al., 2017). It is only in recent years that researchers started to investigate postures other than for driving (Reed et al., 2018; Yang et al., 2018). Concerning reclined seating, these studies quantified the occupant posture for seatback angles up to 60 degrees. They used an existing seat designed for the driving position, with a fixed seat pan angle (set to around 14 degrees). However, biomechanical investigations revealed that such reclined configurations with a low seat pan angle could be challenging for the occupant restraint in case of an accident, especially for the pelvis (Richardson et al., 2020). Occupant pelvis restraint could be improved by increasing the seat pan angle (Grébonval et al., 2019). A more reclined seat pan could also improve comfort for sleeping (Stanglmeier et al., 2020). Grébonval et al. (2019) also observed that the pelvic angle (slouched or upright) could affect the pelvic restraint. However, little data are currently available concerning comfortable seating configurations considering both the seat pan and seatback angles (Stanglmeier et al., 2020), and the corresponding body postures were not analysed. To address that gap, the current study aims to quantify the preferred seat pan angles for reclined seatback ranging from 21 to 60 degrees and the corresponding occupant postures.

Materials and methods

Multi-adjustable experimental seat

The experimental seat was composed of three main structural components: the seatback, the seat pan, and the foot support (Figure 1A). The seatback was articulated with the supporting frame around a lateral axis passing through the reference point of the experimental seat (PRC). The backrest was composed of three back supports, mounted on the seatback frame. A wooden triangular block was added to the seat pan support so that the seat pan could be tilted from 9 to 45 degrees. The foot support was composed of a flat rectangular surface with an office footrest mounted on it. Twelve adjustable parameters of the experimental seat were used in this study (Figure 1B). They could be controlled either by an experimenter via a computer or directly by participants via a tablet. Adjustable features included the forward (x) and vertical position (z) of the three back supports, the seat pan, and the foot support; as well as the backrest and seat pan inclinations. Two armrests were also used and their positions could be adjusted manually. The foot support, the seat pan, the two armrests, and the three back supports were equipped with force sensors to measure the contact forces in the XZ plane. A more detailed description of the experimental seat can be found in Beurier et al. (2017).

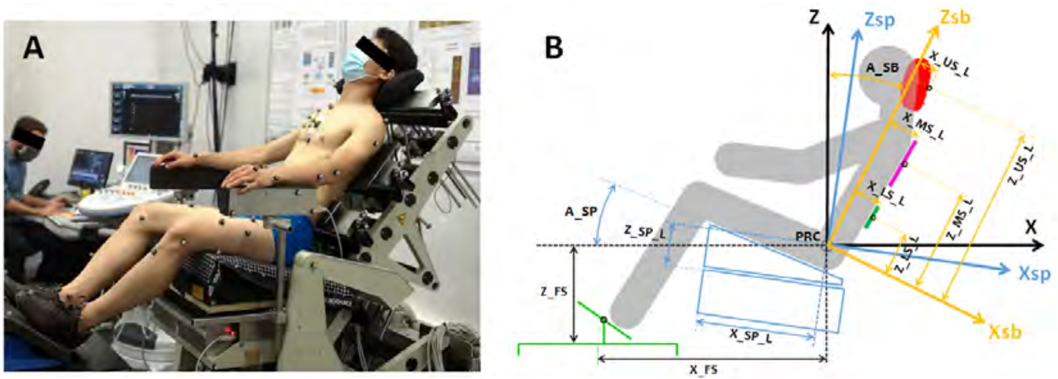

Figure 1: A view of a participant sitting on the experimental seat (A) and illustration of adjustable seat parameters (B)

Preferred seat configurations

The first experimental investigation (EXP_SEAT) aimed to quantify the preferred seat pan angles for a given back angle (A_SB). Nine males (Stature: 176±8cm; BMI: 24.3±3.7kg/m²) and nine females (Stature: 167±4cm; BMI: 21.3±1.2kg/m²) participated in the experiment. The experimental protocol was approved by the Université Gustave Eiffel Committee for research involving human subjects (CRPH). Three seatback angles (A_SB) were tested: 21, 40, and 60 degrees from the vertical. As the initial seat pan orientation could influence the self-selected seat pan angle (Theodorakos et al., 2018), two initial seat pan angles (A_SP) were tested. For each seatback angle, the seat pan could either set to 10 degrees to determine the minimal preferred seat pan angle or 40 degrees to determine the maximal preferred seat pan angle.

For each configuration, an experimenter positioned the middle and lower back supports approximatively at the height of the T9 and L3 vertebrae of the participant, respectively. The three back supports were initially aligned along the seatback z-axis (Zsb, Figure 1B). The seat pan length (X_SP_L, Figure 1B) was set to have a margin of approximately 50 mm between the popliteal fossa and the front of the seat pan while participants were asked to keep their back in contact with the lower and middle supports. Then, the foot support was adjusted (X_FS and Z_FS) until the thighs were in contact with the seat pan, and the knee angles were set to 110 degrees approximately.

After these preliminary adjustments, to adopt a comfortable relaxing position the participants were instructed to self-adjust head support position (X_US_L and Z_US_L), lower back support protrusion (X_LS_L), seat pan inclination (A_SP). They could also re-adjust seat pan length (X_SP_L) and foot support position (X_FS and Z_FS) if desired. Once a comfortable position reached, participants were asked to step off the seat in order to zero all the force sensors. Then, they were instructed to reposition themselves back on the seat and adopt a relaxed position. Preferred seat parameters were recorded at 20 Hz for 1.25 sec. Statistical analyses were performed using STATGRAPHICS Centurion 18 and statistic tests were considered significant if $p < 0.05$.

Occupant posture in reclined configurations

The second experiment (EXP_POST) aimed to quantify the occupant posture for a reclined seating configuration. Seven males (Stature: 177±6cm; BMI: 21.6±2kg/m^2) and six females (Stature: 170±5cm; BMI: 21.5±0.6kg/m^2) participated in the experiment. Among these thirteen participants, nine were also included in the first experiment (EXP_SEAT). The two experiments were separated by seven months.

Eleven seating configurations were defined by combining three seatback angles (A_SB: 21, 40, and 60 degrees from the vertical) and four seat pan angles (A_SP: 14, 27, 40 degrees from the horizontal, and self-selected initially set to 10 degrees). The combination (A_SB=21, A_SP=40) was considered unrealistic thus not used. The preferred seating procedure was similar to the one used for the EXP_SEAT trials, except that the participants could not change seat pan angle if it was predefined. In addition, the Vicon motion capture system was used to measure the position of 45 markers attached to the body for each trial. To better locate pelvis position, three landmarks (left and right anterior superior iliac spine, pubis symphysis) were also manually palpated.

Prior to the experiment, participants were scanned in a standing position to locate the spine joint centres using the method by Nerot et al. (2016). From the standing position, a personalized kinematic model including thighs, pelvis and spine was defined. Joint angles were defined as illustrated in Figure 2. To estimate the pelvic and spinal joint location once seated, an inverse kinematic algorithm was used to match the position of the markers attached on the trunk and thighs as well as the three manually palpated pelvic landmarks. The joint centre for the lower extremities and the head were estimated using external landmarks position as described in Reed et al. (1999).

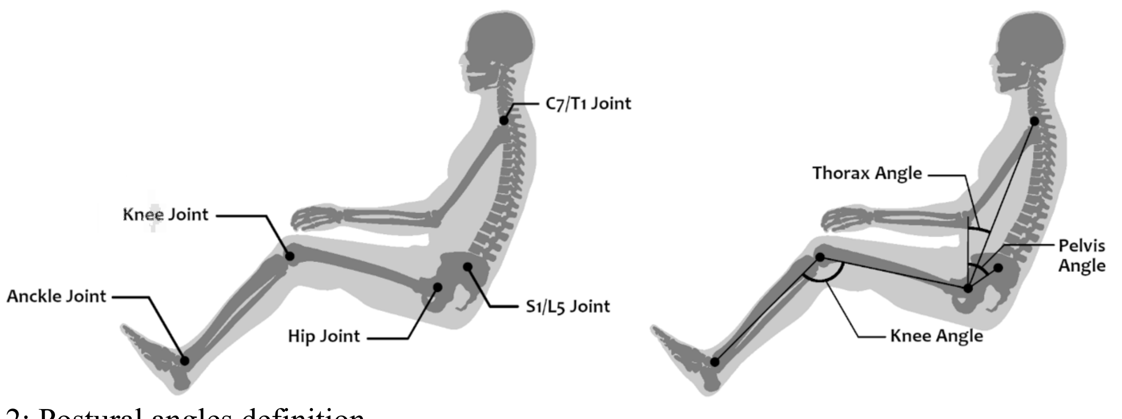

Figure 2: Postural angles definition

Results

Preferred seating configurations

The minimal preferred seat pan angle (i.e. self-selected, initially set to 10 degrees) were 12.2±2.1, 13.4±3.8, and 13.7±4.8 degrees for A_SB of 21, 40, and 60 degrees, respectively. The differences between the three were not significant (Figure 3A). The maximal seat pan angle (i.e. self-selected, initially set to 40 degrees) was significantly higher for the two reclined configurations (A_SB=40 and 60) than for the condition with a normal seatback inclination (Figure 3B). The maximal preferred seat pan angles were 30.8±6.8, 38.2±3.7, and 39.5±2.7 degrees for A_SB of 21, 40, and 60 degrees, respectively. Furthermore, the range of preferred seat pan angle (i.e. the interval defined by the minimal and maximal preferred seat pan angles) was significantly higher for the two reclined configurations (Figure 3C).

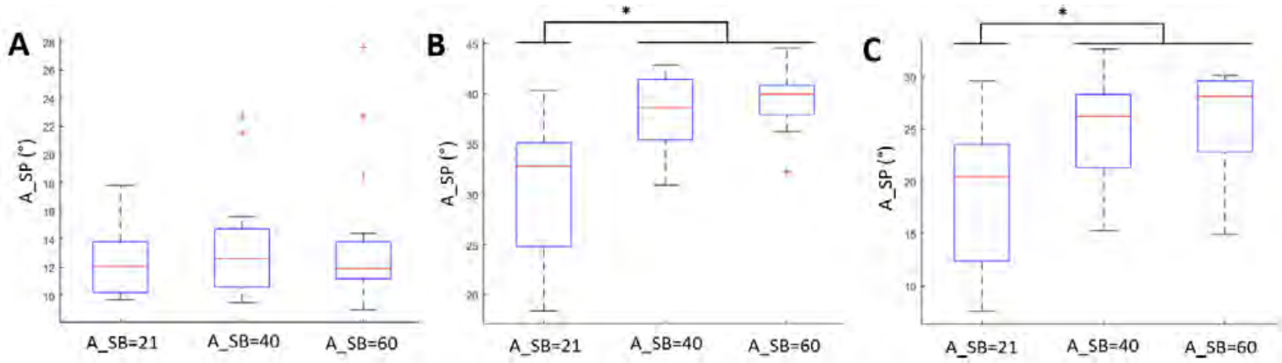

Figure 3: Minimal preferred seat pan angles (A), maximal preferred seat pan angles (B), and range of preferred seat pan angle (C) for each seatback angle (EXP_SEAT, n=18). Significant differences (p<0.05) are denoted with *.

As the lower back support protrusion (X_LS_L, Figure 1B) could be adjusted by the participant, the seatback profile angle (i.e. middle and lower back support line relative to vertical) could differ from the A_SB (backrest frame angle, which corresponds to the seatback profile angle if the back supports are aligned along the Zsb-axis). The seatback profile angles were 20.9±3.7, 38.3±2.4, and 55.1±4.2 degrees for A_SB being 21, 40, and 60 degrees, respectively.

In addition, as nine participants were included in both experiments, the reproducibility of both the minimal preferred seat pan and the seatback profile angles was analysed (Table 1). The seatback profile angles were similar and not statistically different between the two experiments. However, the minimal preferred seat pan angles were significantly higher in the second test campaign (Table 1).

Table 1: Reproducibility of the seat preferred configurations between the EXP_SEAT and EXP_POST trials (n=9). A_BackProfil: Seatback profile angle; A_SP_min: Minimal preferred seat pan angle.

Variable	**A_SB=21**		**A_SB=40**		**A_SB=60**	
(°)	EXP_SEAT	EXP_POST	EXP_SEAT	EXP_POST	EXP_SEAT	EXP_POST
A_BackProfil	20.6±1.4	20.5±1.5	38.5±2.4	38.5±1.6	55.5±3.7	56.8±6.2
A_SP_min	12.9±2.4	13.4±3.5	15.1±4.5	21.0±6.5	15.6±6.1	20.7±6.5

Occupant posture in reclined configurations

Table 2 summarizes the means and standard deviations of the body segment angles for the EXP_POST trials. The pelvis rotated more rearward when increasing either the seatback or the seat pan angle. As expected, a more reclined seatback increased the trunk angle (A_Trunk), which seemed not to be affected by the seat pan angle.

Table 2: Occupant posture in reclined configurations. Data from all EXP_POST trials were analysed. A_SB: Seatback angle; A_SP: Seat pan angle.

Variable	**A_SB=21**		**A_SB=40**			**A_SB=60**		
(°)	**A_SP=14**	**A_SP=27**	**A_SP=14**	**A_SP=27**	**A_SP=40**	**A_SP=14**	**A_SP=27**	**A_SP=40**
A_BackProfil	21.6±2.0	21.7±2.6	39.6±1.4	40.5±2.5	39.7±3.4	57.0±3.9	56.4±2.3	54.9±5.6
A_Trunk	24.9±2.4	24.6±2.0	39.6±2.9	42.2±3.7	41.3±3.9	56.0±3.7	55.5±2.3	53.9±5.8
A_Pelvis	61.3±5.3	67.6±5.9	67.2±4.8	75.3±10.0	79.0±6.7	73.7±5.3	78.0±5.5	81.4±7.2
A_Knee	118.6±9.7	113.5±6.9	122.4±8.8	113.9±7.6	110.2±10.6	120.7±5.8	114.4±7.1	112.4±12.3

Discussion and conclusions

The current study aimed to quantify both the preferred seat parameters and corresponding occupant postures in reclined seatback conditions. Results showed that the preferred seat pan angle highly depended on the initial seat pan inclination, as already observed by Theodorakos et al. (2018) using the same experimental seat. This finding suggests that a range of 23 degrees for A_SP could be considered as 'preferred' for a given back angle. Furthermore, current results indicate that reclining the seatback increased the range of preferred sitting configurations. The minimal preferred A_SP was around 13 degrees for A_SB of 21 and slightly higher for two other A_SB angles, but the maximal preferred SPA increased while reclining the seatback (31, 38, and 40 degrees for A_SB being 21, 40, and 60 degrees, respectively).

Postural results indicated that the pelvis rotated rearward when increasing either the seat pan or the seatback angles, but the pelvis angle variations were much smaller than the ones of seat angles. Using a current front vehicle seat (A_SB: 23, 33, 43, and 53 degrees), Reed et al. (2018) also observed that the pelvis rotated rearward when increasing A_SB.

Concerning the future vehicle interior, results suggest that the seat pan inclination seems not to be critical from point of view of seating comfort as a large range of seat pan angles may accommodate sitters in a more reclined seat. However, from a safety perspective, a more reclined seat pan may improve the pelvis restraint and reduce the submarining risk (Grébonval et al., 2019) but could also increase the spinal load and lead to lumbar spine fracture. Therefore, additional biomechanical investigations should be carried to establish if a safe range of sitting configurations (combination of A_SB and A_SP) exists within the range of comfortable positions. This is one of the aims of the ongoing ENOP Project in which the current postural results will be used to help position the occupant.

The present study has some limitations that should be addressed in future work. As an experimental seat with rigid contact surfaces was used, possible effects of soft cushion may need to be investigated. The preferred seating configurations were obtained during a short duration sitting session, effects of long-term sitting were not considered.

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Urban Mobility: Airtaxi Cabin from a Passengers Point of View

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ABSTRACT

Within German Aerospace Center (DLR), a project called HorizonUAM was launched in July 2020. Its main goal is to develop and design an aerial vehicle which would support the infrastructure of the ever-growing cities and strengthening the connection between as well the big cities as cities with their suburban areas. The vehicle will be designed for the four different scenarios: airport shuttle, intracity transport, intercity transport and suburban connection. This paper shows the research concerning the potential users of the vehicle including their requirements and shows a possible design solution for an airtaxi cabin. The process has followed the Design Thinking Method, ensuring a central role for the users. To determine whether there are potential passengers willing to use such a vehicle, in-depth research has been done. Data found in previously done research has been compared with results of the in-house research, consisting of a number of workshops with representatives of German population as well as results form questionnaires sent out to a different group of German population. During the workshops, the subjects were asked not only to indicate their opinion on the airtaxis, but also to create their own version of it. This was done following the so-called Disney method, creating the solution in three stages: dreamer, realist and critic. Based on this data, different fictive personas are created, to aid in understanding of the user's needs. In addition, trend analysis on how the urban mobility is developing, has also been executed. The state-of-the-art solutions available are analyzed and their strengths and weaknesses determined. The entire research has resulted in an extensive list of requirements for the design of the cabin. To address such a complex design challenge, a morphological chart has been created, systematically deconstructing the main function into subfunctions. This has been done by multiple workshops with a constant team.

Introduction

The human population is ever-growing. At the moment this paper is being written, this planet is a home to over 7,8 billion people (1). More people means more homes, and inadvertently, more/bigger settlements. Whereas new (mega)cities are built in Asia and Africa (2), Europe for example does not have that possibility. This has as a consequence that it is rather complicated and complex to built a new city to satisfy the needs of growing population, such as more efficient means of transportation. However, the existing cities still retain their attractive power and therefore grow in size (3). This leads to densification of urban areas, which in its turn, increases the demand for (public) transport possibilities. To answer that demand does not come easy for an already established city; the roads are often already as wide as they could be and can therefore process only a certain number of vehicles on a given moment. Public on-road transport is mostly dependant on the capacity of those same roads and can therefore be easily affected by the congested traffic. Subways and trams have their own network and therefore are not dependable on the traffic congestion. Unfortunately, they are not available in every city, have also a limited capacity and

often connect only the bigger traffic knots. In addition, suburban and rural areas are often times weakly connected to the larger urban areas, which makes them unattractive to live in, considering prolongated commute time. Another key component of reliable urban transport is reaching the connecting trips on time. Especially when connecting the city with and airport, a major improvement can be gained.
End of 2019, the world has been struck by a pandemic of a fast spreading virus with severe consequences. As the pandemic is slowly ebbing away, the urge to keep distance, high hygiene standards and private space remains. The consequences of the pandemic will not fully determine the results of the project, their influence however cannot and must not be ignored.

Within the scope of the project "HorizonUAM –Urban Air Mobility Research at the German Aerospace Center (DLR)", focus lies on one of the possible solutions to the future demands on urban mobility, namely the air transport within populated areas. As stated in the Raison d'Être of the project plan, efficiency, safety, feasibility, sustainability and affordability are the key characteristics of future urban mobility (4). HorizonUAM combines the research about UAM vehicles, the corresponding infrastructure, the operation of UAM services, as well as the public acceptance of future urban air transportation, including market scenarios up until 2050. The aforementioned issues have led to creation of four different scenarios for which the vehicle needs to provide a solution. The cabin design team is tasked with creating a travelling environment for a passenger of the future, fulfilling not only their demands, but also demands of other stakeholders as well.

This paper will demonstrate the level of acceptance among alleged passengers and their vision on how a cabin of such a vehicle should look like and what it should focus on, by following the user centred design. In addition, it will show how the different scenarios influence the cabin design and will establish whether it is possible to serve multiple scenarios with a single cabin, from a passenger's point of view. Furthermore, it will display how the results of previously committed research are translated into first ideas, sketched as well as 2D as 3D. As a wrap up, an insight in the next steps in the project will be given.

Design Approach

At the Institute of System Architectures in Aeronautics at German Aerospace Center (DLR), a cabin design team has been established beginning of 2016. Over the past couple of years, the team has developed a characteristic way of working, based on the Design Thinking Method. The choice to base the design approach on this particular method was due to the ultimate goal of the design team, to ensure the needs of the users (in this case, passengers) are met. This way, progress in the field of aircraft cabin design can be enabled. Being a user- centric design approach, Design Thinking Method provides the team with the possibility of including the end user into the design process in its earliest stages (5).

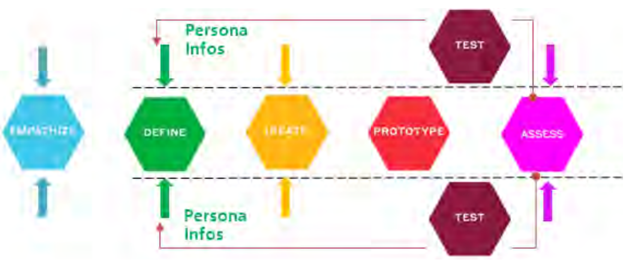

Figure 1: Graphic representation of Design Thinking Method, source: Fabian, DLRK2020

This method has proven to be of great value in the previous projects, which can be seen in the design study cases of (6), (7) and (8). Figure 1 shows the main phases of the design process according to the Design Thinking Method. In the course of the project HorizonUAM, all five phases of the design process will be completed. The Prototyping and Testing phase will be done by means of a Virtual Reality model which will be lifelike and high in detail. As the project has started in July 2020, only the first two phases, namely Empathise and Define have been completed, while the third phase, Ideate, is in its early stages. Accordingly, this paper will demonstrate the progress achieved so far, showing the results made in the aforementioned phases.

To fly or not to fly: Empathise phase

To design cabin concepts for UAM vehicles, awareness of the current state of technology and research is vital. Thorough background research has been done to gain an overview concerning new and conceptual urban mobility (air) vehicle interior concepts. Numerous factors have been considered during the research: user spectrum, storage options, distances, layout, number of seats, type of seat, interior in general, storage options, light, security systems, comfort aspects, aesthetics. The acceptance of the passengers has a major influence on the feasibility of new types of air taxis. Accordingly, different cabin concepts that are already being used successfully are examined in more detail. When looking at the automotive sector and the innovation within this particular market, there are several notable observations to be made. For example, strong colour contrasts are very present in the most innovative models (dark brown/grey tones for a noble look; white/cream tones for cleanliness and high quality). In addition, green tones and wood optics attempt to represent durability and environmental awareness. By means of bionic forms in the storage compartments or the ceiling columns, the design of the vehicle tries to mimic the nature and confirm the connection to sustainable design. The connection to the nature is also sought through large windows which allow the passenger to have a clear view of the surroundings. One of the important goals in automotive innovation being the first impression, the door concepts are very different from todays common vehicles. Designed in a unique way, a door is used to wow the potential customers. Vehicle designs are an extremely important indicator of feasible innovations in the UAM area. People are familiar with automobile design, so distinctive features from this sector certainly need to be factored in to be able to create recognition value and herewith form sense of familiarity and security.

Figure 2: representative current UAM Vehicles, concept design. Focus on the panorama view can be seen here as well.

Research on the existing UAM vehicles shows that this branch has learned from the innovation in the automotive sector. A lot of the companies developing a UAM vehicle is still in the early stages of the design process and has not revealed the cabin concepts yet. Those who have, show large overlap with creations of most modern cars (figure 2). The interiors are based on strong colour contrasts and minimalistic design, conveying a sense of connection to the automotive sector. Clarity in the design is here as well achieved through bionic window shapes and large windows, meant to enhance the flight experience. Seats are most often arranged according the automotive standard, creating recognition value.

According to the results of the state-of-the-art research, UAM vehicles are supposed to be modern, spacious, safe means of transportations for the near future. However, it is very difficult to say whether the broad public shares this view. Considering the fact that at the time of the writing of this paper no vehicles have been used by intended passengers on a regular basis, it is rather safe to say

that the reaction of the public to this particular product is yet barely known. In order to counter this effect, an acceptance study was organized within the scope of this project. Goal of this study was to find out what the general public thinks of this vehicle and its utilization. The study focused solely on the acceptance of such a means of transportation and has taken the factors such as pricing not into consideration. It consisted of a number of focus group with representatives of German population as well as results from questionnaires sent out to a different group of German population. During the gatherings, the subjects were asked not only to indicate their opinion on the air taxis, but also to create their own version of it. This was done following the so-called Disney method, creating the solution in three stages: dreamer, realist and critic (9). In her paper "A User-Centered Cabin Design Approach to Investigate Peoples Preferences on the Interior Design of Future Air Taxis", Maria Stolz goes into detail on the size, depth and significance of this study (10). The results of the study are encouraging. Most of the people have indicated readiness to use such a means of transportation at least every once in a while, thereby considering the factors like hygiene, safety, comfort, accessibility. When conducting the focus groups, participants were divided into different groups, once according to their age range and once according to the nature of their residence. The results showed clear differences in the requirements they set on a passenger's cabin of such a vehicle. When looking at the participants divided according the age range, all of them expressed a desire for certain technological features, such as augmented reality technologies. However, the participants from the younger group put a much lower focus on the on the aspects of comfort, privacy and accessibility than participants in the older group. Within the participants divided according the nature of their residence there also were quite distinguished differences. Where the inhabitants of a city were inclined to individualizing the cabin (modularity, adaptable seating), the residents of rural areas are more focussed on including the minority groups, such as families and physically impaired passengers. However, for both these groups comfort and privacy were of vital importance.
The research conducted in the Empathize phase has laid the foundations needed to understand not only the potential user of the final design but also the context in which the design will be used. All these findings are used as a direct input in the forming of the next phase in the design process, namely the Design phase.

Who is flying where and why: Define phase

The results gained in the previous phase have directly led to forming of the personas. Building a fictive personality, aka persona, helps the designer to understand the potential users better, which in its turn, ensures the development of a product that truly suits the user's needs (11).

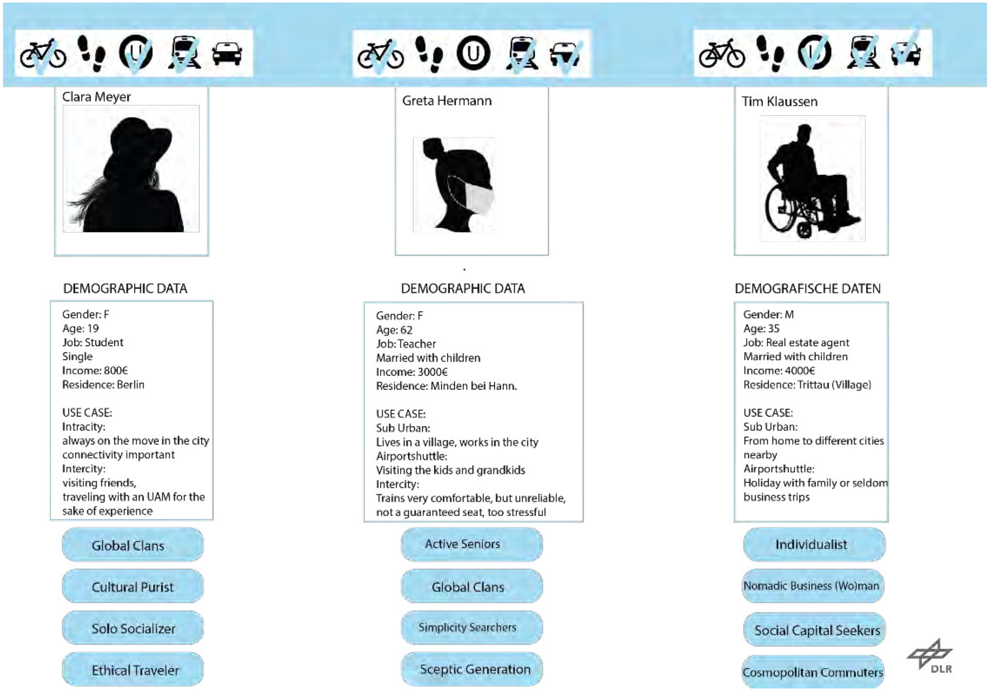

Figure 3: Persona overview

As it can be seen from figure 3, the discussions resulted in three different personas. Each of these personae have provided a set of requirements on the factors important to the particular user group the respective persona is representing.

When compiling the project plan, the decision was made that there were four different use cases that needed to be researched. An airport shuttle is supposed to pick up the passengers through out the city and bring them to the airport for their outbound flight. The Intracity vehicle should circumvent the traffic and bring the people from A to B as a taxi would. Where the Sub-Urban Commuter connects the rural areas with the bigger cities close by, the Inter-City should connect the cities themselves. Each of the use cases brings a different set of requirements to the design table.

Not only different users can be expected in the different use cases, but those utilizations bring along versatile boundary conditions. For a longer flight, more entertainment is expected; an airport shuttle has to provide ample luggage space. Sub-Urban-Commuter can expect more families (often meaning small children, their strollers and a vast amount of accompanying luggage for a day trip) and elderly people visiting the big city. These passengers are slower in their movements, need more space and an easily accessible and understandable cabin. Intra-City vehicle will probably serve passengers for a quick commute, business people going from one appointment to another. Combining the results from the state-of-the-art research with the requirements forth flowing from the personae and the use cases set by the project plan, list of requirements is compiled (available upon request at the main author). This list serves as a direct input in the next phase of the design process, where the solutions are created for the established problems.

How to fly: Ideation phase

At the time of writing this paper, the HorizonUAM project is still in its first out of three years. Based on the list of requirements compiled in the previous phase of the design process, first ideas have been created that might prove to be a partial solution to the established problems. Figure 4 shows a grasp out of the wide spectrum of different design solutions.

Figure 4: first ideas, rough sketches in 2D and 3D

To be able to solve the issues like privacy, a design study has been done on the installation of (retractable/collapsible) partition walls, which can be seen in the top left sketch. The 3D sketch in the upper middle shows an idea of pivoting seat, what can ease boarding and deboarding of physically challenged passengers (PRM, pregnant women, elderly people). Lower left 3D sketch demonstrates a possible luggage stowage in an airport shuttle or an Inter-City vehicle. Sketch on the lower right is an artist impression of a possible cabin, used as an inspiration. Last row of grey sketches is a top view of the cabin, each representing a different seating arrangement. These arrangements will be presented to the public in a new series of workshops in order to find out what the preferences of potential users are. The results of those workshops will be incorporated in the next design iteration.

What's next: Discussion

The direct and immediate feedback from the alleged user has proven to be of a great value in this case. Bringing an innovative and game changing product like this one on the market carries a high risk. Acceptance is a major factor, defining the success of the vehicle. In order to ensure the acceptance, a continuous dialogue with the potential passengers is vital.

The next steps in the concept design will include the aspects such as colour scheme study, ergonomics study, inclusion of the new hygiene standards as well as providing a feeling of safe distance to the other travellers. In case of the colour scheme study, a suitable combination between emphasizing the design details and providing psychological comfort to the passengers needs to be found. Here, different perceptions coming from different age and gender groups have to be considered. Ergonomics study is necessary to make sure most of the people are provided access to the vehicle. With to high entry/exit, lack of handle bars or any other assistance, people with restricted mobility are directly excluded. Two out of four use cases require vast amount of space for different kinds of luggage. This poses an extra challenge when trying to make sure that one vehicle can be deployed in most if not all use cases.

Considering the time gap between delivering the final version of this paper and presenting it at the conference, an updated version of the paper including new results from the ongoing design studies and following concept designs will be presented at the conference.

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Space Utilisation and Comfort in Automated Vehicles: A Shift in Interior Car Design?

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ABSTRACT

Autonomous vehicles will provide an opportunity for a paradigm shift in interior car design in the next decade. For over 100 years the evolutionary development of cars with a focus on driving has created vehicle architectures unfit for the opportunities afforded by autonomy. Highly autonomous cars (L4) will allow occupants to engage in non-driving related tasks (NDRTs), such as working, reading, social media and watching films, which could potentially increase the value of time spent in the vehicle. This research concerns interior space requirements, design, comfort, and wellbeing for highly autonomous vehicles using a novel simulator-based methodology. The holistic approach taken provides an insight into how occupants choose to use space in the vehicle, what activities they might do and how comfortable they might be when engaging in NDRTs.

Sixteen participants (8 males, 8 females) aged between 20 and 47 (M = 31.8, SD = 8.14) took part in the study, which involved three 45-minute simulated drives to determine relative comfort and wellbeing across three different conditions. A bespoke simulator buck was designed and built, and a 270-degree simulated environment was used. Occupants were given freedom to position themselves in the vehicle within the physical restrictions of each condition (including seat rotation, recline and seat height adjustment). Condition 1 involved a current vehicle layout with a fixed passenger seat, centre console, steering wheel, and pedals; Condition 2 presented a customisable vehicle layout with a moveable centre console, steering wheel and pedals; and Condition 3 was a co-designed layout where additional features were added based on participant feedback. A questionnaire was used to assess comfort and wellbeing at two points during each trial (after 10 minutes, and after 35 minutes). Data were also captured on posture and the chosen NDRTs.

The seat was reported to be comfortable and supportive in all three user trials, but when comparing between sessions, Condition 3 represented a significant improvement over Condition 1 and 2 for backrest and headrest comfort. Overall wellbeing scored highly across all three conditions and no significant difference was found between sessions for this metric. In Condition 2, some actively looked for flat surfaces to carry out their tasks (e.g., using the dashboard, or using the arm rest). This led to several personalised features for the co-designed layout, such as lap tables, fixed tables, and door ledges. There were some interesting effects of the new layouts for example, some participants experienced feelings of claustrophobia due to the addition of such features decreasing their reported wellbeing; others reported feeling less vulnerable as they were able to move themselves further towards the centre of the car.

KEYWORDS

Vehicle Design, Comfort, Autonomy, Ergonomics, NDRTs

Introduction

Automotive comfort has traditionally encompassed air quality, sound and noise, temperature, and vibrations (da Silva 2002) as well as postural comfort through the seat design. Automotive seat design has also been driven primarily by the task of driving. With future ACES cars (Autonomous, Connected, Electric and Shared) the definition of automotive comfort could be broadened to include naturality, disturbances, apparent safety, and motion sickness (Elbanhawi et al. 2015). With autonomy allowing more cognitively and physically engaging Non-Driving Related Tasks (NDRTs), the need to design a suitable interior increases. One benefit of autonomy is the freedom given to occupants to re-adjust their posture that could reduce the levels of discomfort (Large et al. 2017) which will require an interior design that allows for movement.

Large et al. (2017) ran a study on conditionally automated vehicles in a simulated environment. Most participants used a smartphone (80%) followed by reading a book, magazine, or printed paper (25%). Participants in this study used a current production vehicle and so were not afforded the potential freedoms of autonomy. In an Australian survey of 5,089 participants Cunningham et al. (2019) found watching the road, interacting with passengers, and eating and drinking to be the most frequent activities. Still, 53.3% would use a personal device, and 37.2% would read. Activities such as reading and using a smart phone require a change in posture (compared to driving) and as such, ensuring the interior space is designed for these activities should be of importance. This study presents postural comfort and wellbeing results and qualitative feedback from a three-condition simulator study investigating NDRT and space requirements for highly autonomous vehicles.

Simulator and Vehicle Buck Setup

A bespoke interior buck was built to the internal dimensions of a current production vehicle. The occupant driving position was maintained, including the pedals, steering wheel and seat height with all adjustability operatable by study participants (seat height, recline, lumbar adjustment, steering wheel height). A central display was used to display a timeline of the journey showing key points and providing audio-visual prompts. A modular centre console was designed that could be fixed in place, moved around the cabin or optionally removed depending on the condition. The participants' seat was mounted to a frame that held four ball-transfer units in each corner giving them the freedom to position themselves in the cabin by pushing themselves with their feet and hands. The roof height was set to 870mm (SAE H61-1) and the H-point height was 316mm from the floor, which was flat, level and carpeted. The interior width was 1444mm, and the centre of the steering wheel and the H-point "Y" position was 369mm from the centre line of the buck. The aim was to provide more rearward space than would be needed with a dashboard to the back wall of the buck measuring 2480mm.

The buck was placed inside a 3-screen driving simulator providing a 270-degree field of view for the occupant. A front wide-angle camera was placed to capture the occupant activities and postures. The simulated environment (built with SCANeR Studio 1.9) showed a typical two-lane motorway with simulated traffic which was used to increase immersion and add a feeling of motion.

Method

Participants were recruited using a convenience sampling strategy and were staff and students at the university. All participants held a driver's licence and were screened for motion sickness susceptibility due to the possibility of motion sickness in the simulator. Each participant (N=16) took part in three 45-minute simulated drives during a three-week period (each user trial was roughly one week apart). Participants were reminded that they would be simulating a morning or evening autonomous commute before each session and were instructed to bring things to do with them during the user trial. In all three conditions the participant was free to move within the limitations of the condition. The differences between the three conditions are as outlined below.

- ***Condition 1 – Baseline:*** The front passenger seat and centre console (which contains a cup holder and an arm rest) are both fixed in place.
- ***Condition 2 – Customise:*** The front passenger seat is removed, and the participant can freely move the centre console to create more space or to use it as a surface or a footrest.
- ***Condition 3 – Co-design:*** Participants are given the same freedom as Condition 2. However more features have been added based on the feedback from the first two sessions. These features include lap tables, armrests and the ability to use the central display for their own tasks.

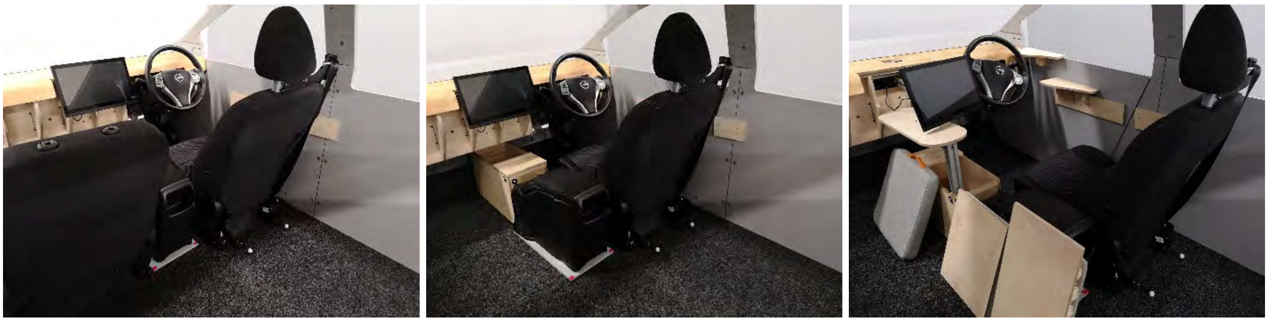

Figure 2: Photographs of the layout for Condition 1 (left), Condition 2 (middle), Condition 3 (right)

Participants were asked to complete both a comfort and wellbeing survey after 10 minutes, and again after 35 minutes. The comfort survey was adapted from Corlett and Bishop, (1976), and included eight areas of the body and a six-point Likert scale (from "not uncomfortable" to "extremely uncomfortable"). The wellbeing survey was adapted from Ahmadpour, Robert and Lindgaard, (2016) and included questions relating to feeling confined, feeling refreshed and feeling stiff using a five-point Likert scale (from "strongly agree" to "strongly disagree").

Participants postures were recorded using a posture reference guide (Table 1) adapted from Kamp, Kilincsoy and Vink, (2011). Postures were noted every time the participants settled on a new posture for more than 30 seconds. The observations were time-stamped so posture duration could be calculated, and the data correlated with other data sources. A short interview with the participants after each user trial was also conducted in the buck to gain some further understanding on their decisions.

Table 1: Posture reference guide

Head		**Trunk**	
Free of Support	1	Fully Supported	1
Against Headrest	2	Reclined	2
Looking Down	3	Upper Back Detached/Twisted	3
Legs		Slouching	4
Stretched	1	**Arms**	
Neutral	2	On Lap or Resting on Body	1
Close	3	Raised and Unsupported	2
Raised	R	Raised and Supported	3
Crossed	C	Extended/Stretched	E

To analyse the survey results, Wilcoxon signed-rank tests were performed for within condition analysis, and a repeated measures ANOVA was used for the between condition analysis. Chi-squared test with post-hoc analysis (Bonferroni correction) was used to analyse the posture data.

Results

Sixteen participants (8 males, 8 females) aged between 20 and 47 (M = 31.8, SD = 8.14) took part in the study and in total their where 48 simulator sessions. Eight of the participants were in full time work, six were doctoral researchers and two were undergraduate students. Table 2 presents the key measurements of the participants.

Table 2: Key measurements of the participants

	Total (n=16) (M ± SD)	**Male (n=8) (M ± SD)**	**Female (n=8) (M ± SD)**
Age (years)	31.8 ± 8.3	34 ± 11.2	29.6 ± 3.6
Stature (mm)	1706 ± 112	1785 ± 75	1628 ± 84
Sitting Height (mm)	889 ± 90	947 ± 43	830 ± 87
Buttock – sole of foot (mm)	1060 ± 78	1110 ± 59	1009 ± 60
Bi-deltoid (mm)	439 ± 35	463 ± 28	416 ± 24
Forward grip reach (mm)	650 ± 47	678 ± 38	623 ± 41

Figure 3: Images showing participants performing activities in different conditions.

For much of the total time (i.e., all participants) spent in autonomous mode, participants were using a device (73.6% of total time spent) split between using a laptop, mobile phone or tablet. Mobile phone use was highest in Condition 1 (34% of time spent) with laptop use the second most frequent activity (20% of time spent). In Condition 3 however, laptop use was the most frequent activity (46% of time spent) compared to mobile phone use (22% of time spent). In total, 22 unique primary activities were recorded throughout the user trial.

A common behaviour observed during the trial involved participants searching for flat surfaces during Condition 1 and Condition 2. This is most clearly shown in Figure 3 (Image B & C) where the participant rotated their seat to use the fixed-in-place armrest as a mouse rest. Other participants felt safer seated in the centre of the buck (Image A), and most participant carried out multiple activities at once as shown in image D (sketching & making a video call).

Discomfort and Wellbeing

Overall, the seats used were found to score low on the discomfort scales. Despite this, some statistically significant differences were still observed within and between conditions. Significant differences between conditions were found in the backrest and head contact area (p=0.012) (Figure 4). A significant increase in discomfort was also observed when analysing within condition 1 for the upper back (p=0.015) and condition 2 for the head/neck (p=0.008), upper back (p=0.006) and lower back (p=0.004). There was no significant increase in discomfort for other areas of the body within conditions or between conditions. Analysis of the wellbeing questionnaire found a significant difference for the "I am not feeling stiff" measure in condition 1 (p=0.046) and condition 2 (p=0.015). No other significant differences were found within conditions or between conditions.

Chosen Postures During Autonomy

The number of unique postures recorded increased from Condition 1 (43), Condition 2 (49) and in Condition 3 (53). In total 98 unique postures were recorded throughout all three conditions. Figure 4 shows the most observed postures during the user trial. Posture '3113' (head looking down, trunk against the backrest, arms resting on the body and legs close to the seat) was observed most with 12% of the total time spent across all three conditions. Posture '3112' (same as 3113 with legs in a neutral position) was the second most frequent posture with 7% of the time spent. Posture '1122' (head neutral, trunk against the backrest, arms raised and unsupported and legs in a neutral position).

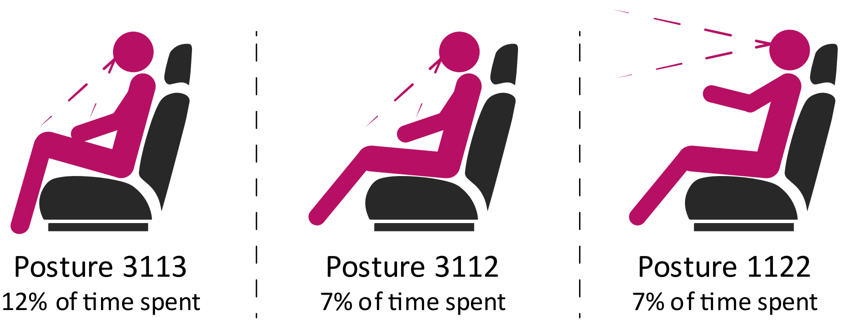

Figure 4: Illustration showing the top three chosen postures.

In Condition 1, 45% of session time was spent in neck flexion where a posture was held for longer than 10 minutes. This is significantly more than Condition 2 (36%, p = 0.04) and Condition 3 (27%, p < .001). There is also a significant difference between Condition 2 and 3 (p = .007).

Comparing results from the chi-squared tests, some chosen postures are significant when coupled with activities. Neck flexion is significantly more likely to occur with mobile phone use compared to laptop use (p < .001). There are also differences in leg position with laptop use more coupled with legs close to the seat (leg position 3) (p < .001) as well as raised and extended (leg position 1R) (p < .001). Extended legs (leg position 1) as well as extended, raised, and crossed (leg position 1RC) are significantly associated with mobile phone use (both p < .001).

Conclusions

This research has attempted to understand the journey comfort experience of highly autonomous vehicles by providing a simulated and adaptable environment for participants to use. From this research, several conclusions can be made:

- Using electronic devices such as laptops, mobile phones and tablets were found to be the most frequent activity carried out during the simulated journeys.
- Condition 3 (Co-designed interior space) resulted in less discomfort compared to Conditions 1 and 2. This could be because the added features and freedom of space provided the opportunity for participants to adopt a more comfortable posture.
- Time spent in neck flexion significantly reduced when features such as surfaces, armrests and footrests were added to the interior.

It has been believed that autonomous vehicles will improve the journey experience. However, autonomy could be a contributing factor for postural discomfort if no supporting features cabin, such as raised surfaces and arm rests are designed into the cabin. This research has shown that although providing more space, and hence freedom to adopt a more comfortable posture is desirable, there is still a possibility of postural discomfort.

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COMFORT CONGRESS 2021
Motion

Motion Sickness, Motivation, Workload and Task Performance in Automated Vehicles

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ABSTRACT

Previous literature has reported moderate losses in performance on cognitive tasks in the presence of mild motion sickness and concluded that motion sickness likely affected task motivation. These studies have used simple fundamental cognitive tasks, unlike the activities users of automated vehicles are expected to engage in. In this study we used a reading comprehension task with ecological relevance to automated driving. The study had a 2x2 within-subjects factorial design. The factors were the presence or the absence of motion and task incentive. We found no effect of motion nor incentive on task performance. We did however find a significant effect of motion sickness on subjective workload. This may mean that under more naturalistic conditions motion sickness may lead to task avoidance, which is of importance to the utility and acceptance of automated vehicles

KEYWORDS

Motion Sickness, Motivation, Task Performance, Workload

Introduction

The presence of automated vehicles on our roads is fast becoming feasible with fully automated SAE Level 5 vehicles being expected to reach 50% of market share between now and 2050 [1], [2]. Self-driving vehicles are envisioned by society as the embodiment of freedom, allowing its occupants to make use of otherwise unproductive travel time. Surveys reveal that approximately 40% of respondents would like to use this time to engage in cognitively demanding tasks such as working or reading [1]. However, a major expected impediment to performing these tasks, or indeed performing them in an optimal manner, is motion sickness.

Motion sickness is a syndrome whereby aggravating body motions trigger autonomic symptoms such as salivation, dizziness, headaches, panting, hot/cold flushes, stomach awareness, nausea and vomiting [3]. Exposure to sickening motions, such as those that may be encountered during daily traffic commutes, may in some individuals even lead to the Sopite syndrome, which is associated with lethargy, fatigue and drowsiness [4]. Indeed, it is known that around 2/3 of the population has experienced some car sickness during transport [5]. Therefore, fully quantifying the effects of motion sickness on task performance in an ecologically valid manner is an important step towards contextualising the detrimental effects of motion sickness on the adoption of automated vehicles.

Previous experiments on the effect of motion sickness on task performance reveal a small, but significant effect. One study notes a significant decrement for short term memory for the motion sick group over the not sick group -11% [6]. Another, notes a small correlation, with r = -0.21 between sickness ratings and task performance in a visual search task [7]. Likewise, [8] reported a small correlation of r = -0.15 for the case of a perception task, here an increase in the reaction time was also noted r = 0.11. Lastly, experiments on the combined effect of motion and sleep deprivation on task performance, noted a small correlation between sickness and task performance ρ = -0.19 [9]. Therefore, the consensus seems to support a small effect of motion sickness on task performance.

However, this small drop in performance may not be representative of the performance loss one might expect in more naturalistic settings. For the experiments described above, both the act of taking part in an experiment (i.e., the Hawthorne effect [10]) and the experimenter (i.e., the Observer-Expectancy effect [11]) may provide implicit motivation to the participant. This motivation may help the participant overcome the difficulties imposed by motion sickness. In [4] task performance was studied in two motion sessions. They observed a significant difference between the performance of symptomatic and asymptomatic participants, for memory and arithmetic tasks (ρ = -0.545 and ρ = -0.6 respectively), but only in the second motion session. This performance loss was attributed to the absence of implicit motivation provided by setting and task novelty. Moreover, this loss in performance was only observed for the more complex tasks of memory and arithmetic; not in simpler visual and auditory reaction tasks. It may thus be hypothesized that tasks that are complex and provide low implicit motivation are most affected by motivational losses.

Our work aims to address the following open questions: First, it is not clear how performance loss in abstract experimental tasks compares to performance loss for activities passengers may engage in when travelling in automated vehicles, such as reading and performing computer tasks. Therefore, a task that is more ecologically relevant, but still provides well defined performance criteria is needed. Second, the heave, roll and pitch motions used in the study by [4] are quite dissimilar to accelerations one would encounter when travelling in an automated vehicle. Therefore, the present study also aims to use motions that are more representative of autonomous vehicular transport. Thirdly, we directly manipulated and tested the hypothesis of an effect of motivation on motion sickness and task performance. Lastly, apart from motion sickness and motivation, task performance may affect perceived workload, and these variables may interact in complex ways. We will therefore also explore the relationship between motivation and perceived workload in the context of performing complex tasks whilst motion sick.

In this study we presented participants with a reading comprehension test derived from UKCAT verbal reasoning practice questions. The UKCAT is an exam taken by prospective medical students in the United Kingdom. The study had a 2x2 within-subjects factorial design. The factors were *motion*; where participants were either stationary or exposed to physical motions while performing the task, and *incentive*, where participants either competed for a monetary reward or not. Throughout each experimental session, participants' subjective sickness level was measured using the MISC scale [12], as well as after using the motion sickness assessment questionnaire (MSAQ) [13]. Moreover, we administered the NASA-TLX perceived workload questionnaire [14], and an adaptation of the Situational Intrinsic and Extrinsic Motivation questionnaire (SIMS) [15]. Task performance was quantified using the time-between-correct answers and accuracy of answers.

Methods

Participants

Participants were recruited amongst Bachelor and Master students of TU Delft. The limitation of the study to this demographic also meant that the incentive offered had a similar valence to each participant [16]. Efforts were also made to ensure that none of the participants knew or knew of the experimenters prior to the experiment. The recruitment was done by putting up flyers in notice boards and forwarding experiment adverts via the university intranet. The flyer stated the existence of a potential reward. Due to the stringency of the recruitment and corona restrictions only 8 participants could be recruited for this study (mean age = 26 years, STD = 2.87, 2 female, 6 male). The 8 participants had a mean motion sickness susceptibility questionnaire short form (MSSQ-Short) [17] score of 15.35 (STD = 13.72) indicating that they had above average susceptibility corresponding to the 63rd percentile.

Experimental Procedure

Participants came in to four sessions in total. All sessions were separated from each other by one week to prevent habituation effects. The experiment had four conditions evaluated in a within-subjects 2x2 full factorial design. The four conditions are; Motion-No Incentive, Motion-Incentive, No Motion-Incentive and No Motion-No Incentive.

Instructions to Participants

The participants were briefed at the start of each session. They were first told whether the session is a "graded" session with a ranking and monetary incentive or not. The monetary incentive gave 50 euros for the 1st , 30 for the 2nd and 20 for the 3rd highest scoring participants. The participants were then familiarized for a few minutes with the sickness scale to be used during the experiment. The participants were then placed in the driving simulator and asked to assume a natural posture. The seat belt was then secured around them. The participants were then given a laptop which presented to them the UKCAT verbal reasoning questions. Motion sickness ratings were queried after every other question. This was done by presenting a selectable MISC scale on the laptop screen. The questions were presented using psytoolkit [18]. The session lasted for 60 minutes, or the participant no longer wanted to continue due to motion sickness. The participants then filled out the SIMS, NASA-TLX and the MSAQ**.**

Apparatus & Motion

The experiment was performed using a driving simulator with hexapod motion platform. Bolted to the platform is the front half of a Toyota Yaris with the engine and other such components removed. The participants were seated on the passenger seat of the Yaris and belted in with the vehicles' own seat belt. During the experiment, participants wore an ear-enclosing headphone with embedded microphone which allowed for continuous two-way communication. The participants were subject to a multi-sine fore-aft and lateral accelerations, consisting of 4 sine waves at frequencies between 0.18-0.5 Hz with maximum amplitude of the final maximum acceleration value coming to 0.51 ms^{-2} for the longitudinal and 0.37 ms^{-2} for the lateral directions.

Task

As discussed in the introduction we are primarily interested in ecologically relevant tasks that can be more easily extrapolated to real work. Literature shows examples of "simulated" office work. This includes the operation of mouse and keyboard, writing, mental arithmetic but also quantitative and verbal reasoning [19]. We conducted a small pilot to determine that UKCAT was the most appropriate test for verbal reasoning for our purpose.

In our specific implementation, the task consisted of the presentation of a series of 15 written texts, with a length of approximately 200-300 words each, in one paragraph. For each paragraph, there were four multiple choice questions with three or four response categories, presented sequentially. All participants performed the task under four experimental conditions. To prevent them from answering questions on the basis of recollections from a previous session, we developed four variants of the task; one test-set for each experimental condition. The choice of test-set for a particular experimental condition was randomized between participants.

Results

For the motion conditions the mean MSAQ score for the motion condition was 34.2 (STD = 23.4) indicative of mild symptoms. Only 1 sessions out of the 16 total was cut short due to sickness. Lastly, participants obtained moderate accuracy of 64.2% in the task, exceeding pure guessing.

Evaluation of test-set difficulty

To counter confounding effects of task difficulty, we aimed to equalize the difficulty of the four test-sets used in the different experimental conditions based on pilot results. To validate this, we compared the score (#correct-#incorrect responses) and the reaction times between test-sets. There were no differences between these measures (score: F= 2.046, p=0.130; reaction time: F= 1.902, p=0.152).

Effect of Motion and Incentive

On the basis of a literature review, we formulated a series of hypotheses on the effects of motion and incentives on motion sickness ($y = MSAQ$), motivation ($y = SIMS$), workload ($y = TLX$) and task performance ($y = Score$). We evaluated these hypotheses by fitting linear mixed effects models of the following form (in Wilkinson notation):

$$y \sim motion * motivation + (1|id)$$

Here and represent effects for the factor variables described in the methods section, and the asterisk indicates fixed main effects and an interaction effect are included. The $(1|id)$ part specifies a random intercept for each individual, to account for individual differences in ability. There was a significant effect of motion on MSAQ (F = 5.97, p = 0.023) with a coefficient of 21.9 meaning an increase in the MSAQ level of 21.9 over the baseline (intercept) value of 12.8. All other differences between means did not reach statistical significance. We note however that, the effect of motion on motivation (p = 0.14) with an average decrease of 4.3, leads to a drop in SIMS that is 92% of baseline, this likely to become significant with more data. Similar consideration also applies to the effect of motion on workload ($p = 0.181$) with an average increase of 7.3, leading to a rise that is 113% of the baseline.

Motion Sickness, Task Performance, Workload and Motivation

The experimental conditions do not elicit a perfect manipulation of the dependent variables. Therefore, we also computed the influence of dependent variables measuring motivation, or a lack, of in the form of amotivation (this measure was based on the scores given to 6 items in the SIMS, example of one such item is *"I do this activity but I am not sure if it is worth it"*) and motion sickness using the MSAQ with task performance and workload. These dependent variables are better representations of the manipulation we attempted to do with our experimental conditions of incentive and motion.

Evaluating only the fixed effect of MSAQ and amotivation on performance (without interaction effects) we find that the effect of MSAQ on performance was not significant ($F = 0.618$, $p = 0.437$) however the effect of amotivation on performance was significant ($F = 5.97$, $p = 0.021$) with a coefficient of 0.33 relating the amotivation scores of the SIMS to task performance.

Evaluating only the fixed effect of MSAQ and amotivation on workload (without interaction effects) we find a significant effect of MSAQ on workload ($F = 14.2$, $p < 0.001$), with a coefficient of 0.38 relating MSAQ scores to NASA-TLX subjective workload scores. This corresponds to a 15% increase in subjective workload for mild motion sickness. Lastly, we find a non-significant effect of amotivation ($F = 0.797$, $p = 0.379$) on workload.

Discussion

The insignificant finding of the effect of motion and incentive likely owes itself to the small sample size of this study. In the case of motion, it may also be because the mean sickness level reached in this study was mild. There was also between participant variability in sickness, with some participants reaching high MSAQ scores, whilst others not getting sick at all. This in turn reduced the effect of motion.

Likewise, the incentive condition did not significantly increase the score of the participants. It is likely that despite our best efforts to motivate the participants motivation was not enough or that the implicit motivation provided by the experimental setup was. It is also possible that, despite the instruction, the participants did not uniquely attribute incentive to the incentive sessions, but to the overall experiment. This is a weakness of the within participants design.

We do, however, find a significant effect of amotivation on task performance in this experiment. It is unclear from the experiment whether it was a cause or an effect of performance. Administration of the SIMS prior to the experiment may clarify this.

Lastly, there was a significant effect of motion sickness on subjective workload. This to our knowledge, is the first quantification of an intuitive phenomena. Despite this increase in subjective workload, we did not find a significant effect of sickness on performance. This is likely because, in addition to the small sample size of the study, the participants likely employed more cognitive resources to complete the given task. However, in naturalistic settings it is possible that the higher workload can encourage maladaptive coping strategies such as task avoidance [20]. Such behaviours could be studied in particular in naturalistic settings giving participants freedom in task selection and pace exposed to realistic automated vehicle motion.

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Assessing (dis)comfort: measuring motion sickness progression

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ABSTRACT

Motion sickness has a dominant contribution to the broader concept of discomfort when self-motion is at issue, for example when travelling in a self-driving car. Recent studies are devoted to finding ways to mitigate motion sickness even though the relationship between the different types of scales used to measure motion sickness is largely overlooked. For this reason, we here compared two major types of self-report rating scales: those measuring general unpleasantness and those measuring specific symptomatology. For up to 30 minutes of ongoing motion stimulation, we found that 1) symptoms generally manifested in a fixed order, while unpleasantness seemed to increase non-monotonically, and 2) symptoms that manifested later were generally reported as more unpleasant, except for nausea onset. The onset of nausea was systematically rated less unpleasant than the preceding pre-nausea symptoms. This indicates that unpleasantness does not monotonically increase during the progression of motion sickness symptoms. Studies having used the two different types of scales can accordingly not directly be compared, particularly at nausea onset. Our results imply that rating how bad someone feels is not the equivalent of rating how close someone is to the point of vomiting.

KEYWORDS

Symptom progression, well-being, self-report

Introduction

The introduction of self-driving cars provides the prospect of a mode of transport with various societal benefits (Begg, 2014). However, their introduction is accompanied by an expected and observed increase in motion sickness (Diels & Bos, 2016; Iskander et al., 2019; Sivak & Schoettle, 2015). Motion sickness has a dominant contribution to the broader concept of discomfort when self-motion is at issue (Bos et al., 2007). Research on the mitigation of motion sickness is proliferating to ensure a successful embedding of these cars into society. However, to assess these countermeasures, it should be clear how we can measure motion sickness progression unambiguously with the use of self-report rating scales.

Motion sickness concerns a syndrome that is associated with discomfort. It encompasses several classes of symptoms that are suggested to progress in a fixed order over time. Bodily symptoms like flushing, stomach awareness, and dizziness often vary between people, but are typically followed by nausea, retching, and vomiting (Lawson, 2014; Reason & Brand, 1975). In parallel, motion sickness is recognised by its feelings of unpleasantness, that can vary from slight discomfort to absolute dreadfulness. One may observe that both symptomatology and unpleasantness lend itself for the use of a severity grading, typically rated using self-reports with label descriptions expressing a symptom or feeling in a single number. Despite their common usage, is the relationship between the two different types of scales still unclear.

Although some studies have reported positive correlations between measures of unpleasantness and symptomatology (Bos et al., 2005; D'Amour et al., 2017; Keshavarz & Hecht, 2011; Nooij, Pretto, Oberfeld, et al., 2017; Reason & Graybiel, 1970), exact knowledge on the development of unpleasantness with symptom progression is still missing. Correlational research can hide possible local deviations of a monotonic relationship, as also suggested by anecdotal evidence. To illustrate, vomiting is generally considered the final manifesting symptom, yet also reported to offer relief of misery (Dobie, 2019; Lackner, 2014; Leung & Hon, 2019). Moreover, despite finding an overall positive correlation, one study reported specific and temporary decreases in unpleasantness ratings midway the scale during ongoing motion stimulation (Reason & Graybiel, 1970).

Because we believe there is reason to assume that rating how bad someone feels may not be equivalent to rating how close someone is to the point of vomiting, we investigated whether one feels worse as symptoms progress. To that end, we first examined the temporal development of unpleasantness and symptomatology during ongoing motion stimulation (Part I), and secondly the development of unpleasantness during motion sickness symptom progression (Part II). These results have been reported partly in Reuten et al. (2020) and will be presented fully in a journal publication (Reuten et al., 2021).

Methods

Study characteristics

We reanalysed sickness ratings from seven previous and partly published experiments on motion sickness. These experiments exposed subjects to a 20- or 30-minute motion sickening stimulus using either virtual motion (Exp 1: Nooij et al., 2017; Exp 2: Nooij, Pretto, & Bülthoff, 2017; Exp 3: Nooij et al., 2021) or real motion (Exp 4: Bos et al., 2005; Exp 5: Bos, 2015; Exp 6-7: unpublished). Each experiment (except for Exp 3) consisted of multiple sessions presented on separate days. All experiments were approved by the ethical review board of the institution where the experiment took place.

Part I. The temporal development of unpleasantness and symptomatology

Our first goal was to obtain more insight in the temporal development of unpleasantness and symptomatology ratings during ongoing motion stimulation. We therefore analysed the transitions between consecutive ratings given on an unpleasantness scale, in this case the Fast Motion sickness Scale (FMS, Keshavarz & Hecht, 2011) in Exp 1-3, and consecutive ratings given on a symptomatology scale, in this case the MIsery SCale (MISC, Bos et al., 2005) in Exp 4-7. The FMS has endpoints varying from 0 (no sickness) to 20 (frank sickness) without intermediate anchoring. The MISC ranges from 0 (no symptoms) to 10 (vomiting), with each intermediate number referring to a specific class of symptoms (see Table 1).

Ratings were repeatedly obtained within each experimental session at two- to five-minute intervals until the session was completed, a stop-criterium was reached (FMS ≥ 15 or MISC ≥ 7, except for Exp 4 that used no stop-criterium), or a subject expressed the wish to stop (see also Table 2). We examined the FMS ratings of 132 sessions and the MISC ratings from 528 sessions with at least two ratings within each session. We analysed the difference in rated FMS or MISC class during consecutive ratings (i.e., transitions). We then first determined the number of observed transitions between two classes, and subsequently calculated the proportion of cases in which the rating after a certain class decreased (contradictive of a monotonic increase).

Table 1: The Motion Illness Symptoms Classification (MISC, Bos et al., 2005).

Class description		**MISC**
No problems		0
Some discomfort, but no specific symptoms		1
Dizziness, cold/warm, yawning, headache, tiredness, sweating,	vague	2
stomach/throat awareness, burping, blurred vision, salivation,	little	3
… but no nausea	rather	4
	severe	5
Nausea	little	6
	rather	7
	severe	8
	retching	9
Vomiting		10

Part II. The development of unpleasantness during symptom progression

We collected information on how unpleasantness corresponds with each of the MISC classes to assess the development of unpleasantness during motion sickness symptom progression. To that end, subjects performed a psychophysical rating task before and/or after the last motion sickness session in Exp 6-7 (see Table 2).

We asked subjects in Exp 6 to perform a magnitude estimation (MAG) task, in which we asked them to draw lines which lengths represented the level of unpleasantness they associated with each MISC class description (1 to 10). These drawings were made relative to a 10.5 cm reference line, which represented the unpleasantness for MISC 6 (i.e., MAG_6). To investigate whether the choice of reference was relevant, we let subjects perform these MAG ratings using MISC 4 as a reference in Exp 7 as well (i.e., MAG_4). To investigate whether the choice of task was relevant, we also added a two-alternative forced choice (2AFC) in Exp 7. We then asked subjects to compare 45 pairs of MISC class descriptions (1 to 10) and to choose which of the two symptoms they thought was most unpleasant. For all of these tasks, we only presented the class descriptions, without their corresponding class numbers. Note that these tasks were indirect comparisons of unpleasantness and symptomatology in which subjects needed to imagine how they would feel when experiencing the symptom. Therefore, subjects performed one additional measure directly after completion of each motion sickness session in Exp 6-7. In this task, we asked subjects to indicate their unpleasantness experienced during the session on a 12 cm visual analogue scale (VAS) with endpoints "very unpleasant" to "very pleasant". We compared this VAS rating to the highest rated MISC class during that session to allow for a more direct comparison of unpleasantness and symptom progression.

To compare the MAG with the 2AFC task, we normalised all ratings as follows. For the MAG task, we first measured all drawn line lengths (L) and subsequently determined the normalised ratings for each subject using their shortest and longest drawn line: $MAG = (L-L_{min})/(L_{max}-L_{min})$. For the 2AFC task, we first counted the number of times each MISC class was rated the most unpleasant (C) and subsequently determined the normalised ratings for each subject using their minimum and maximum counts: $2AFC = (C-C_{min})/(C_{max}-C_{min})$. For the VAS task, we first measured the distance up to the mark that each subject had drawn and subsequently determined an individual normalised rating by dividing this distance by the total line length. To promote a comparison between the unpleasantness rated using the FMS and the unpleasantness rated using the psychophysical tasks, we rescaled the FMS (further referred to as FMS') to values between 0 and 1.

Table 2: Overview of the used rating tasks and sample sizes.

Task	Exp	When	*n*
FMS	1-3	At 2-minute intervals during sessions	58
MISC	4-7	At 2- to 5-minute intervals during sessions	148
MAG_6	6	Before the first and after the last session	30
MAG_4	7	Counterbalanced before the first or after the last session	79
2AFC	7	Counterbalanced before the first or after the last session	83
VAS	6-7	After each session	107

Results

Part I. The temporal development of unpleasantness and symptomatology

The percentage and uniformity of decreases within the transitions of consecutive ratings on the FMS' and MISC will tell us whether these measures increase monotonically with the progression of motion sickness over time. Frequent and nonuniform decreases across classes then indicate the presence of a non-monotonic relationship. For unpleasantness, decreases in FMS' ratings were relatively frequent and non-uniformly distributed (Figure 1a) compared to the decreases in MISC ratings for symptomatology (Figure 1b). These results thus suggest that unpleasantness increases non-monotonically with time, whilst symptoms manifest in a fixed order over time.

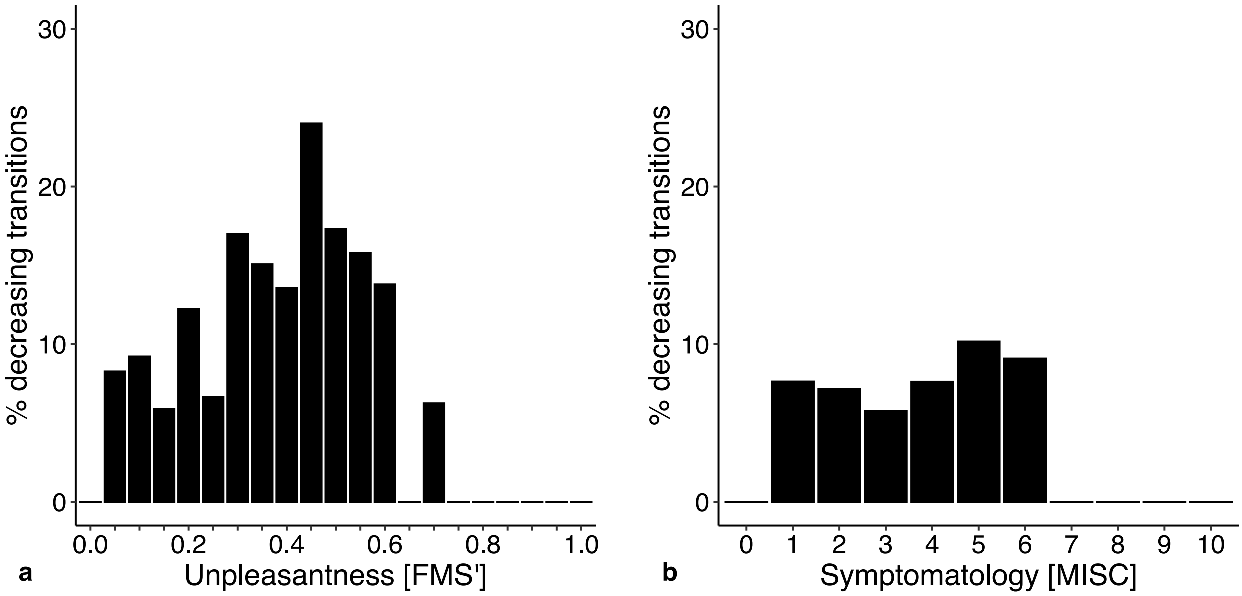

Figure 1: Overview of the percentage of decreasing transitions in consecutive ratings during ongoing motion stimulation using the FMS' (a) and MISC (b). Whereas the decreases for the MISC are uniformly distributed, the more frequent decreases for the FMS' peak in the central area of the scale, suggesting a non-monotonic increase of unpleasantness with time.

Part II. The development of unpleasantness during symptom progression

Median normalized values of the four psychophysical rating tasks (MAG6, MAG4, 2AFC, and VAS) demonstrate the development of unpleasantness with symptom progression in Figure 2. All ratings provided the same pattern of results: there is a positive correlation between unpleasantness and symptom progression, with a clear anomaly at MISC 6. This symptom, "feeling a little nauseated", systematically corresponded to feeling better compared to the preceding pre-nausea symptoms (MISC 5).

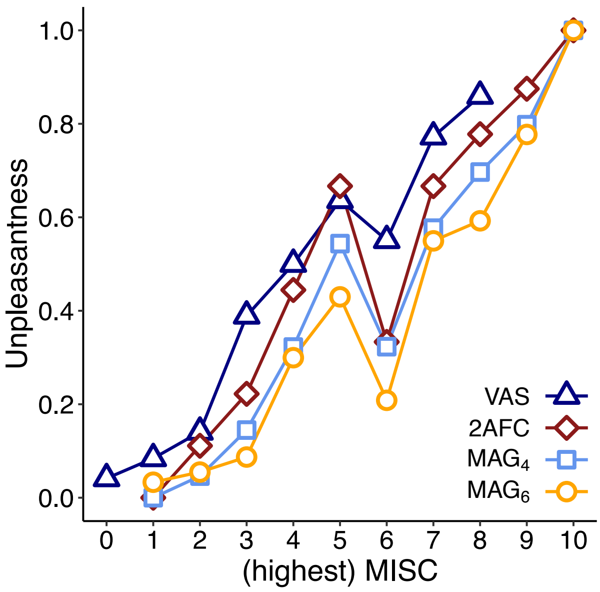

Figure 2: The unpleasantness associated or experienced with the MISC classes rated using magnitude estimations with MISC 6 (MAG_6) or MISC 4 as a reference (MAG_4), a two-alternative forced choice task (2AFC), or a visual analogue scale (VAS).

Discussion

To facilitate research on mitigating motion sickness, we focused on the question of how to unambiguously measure motion sickness progression using numerical self-report rating scales. When investigating the transitions between consecutive ratings given on an unpleasantness or symptomatology scale during ongoing motion stimulation, we observed that decreases in unpleasantness ratings occurred more frequently and peaked in the central area of the scale compared to symptomatology ratings. Based on those results, we suggested in Part I that symptoms manifest in a fixed order over time during ongoing motion stimulation, whilst unpleasantness increases non-monotonically. This interpretation is in accordance with the results of Part II, where we observed that later manifesting symptoms were generally judged as more unpleasant, apart from a clear exception at the onset of nausea. In four comparisons of a psychophysical task, nausea onset corresponded to feeling better compared to any other of the preceding pre-nausea symptoms.

Our results indicate that unpleasantness and symptomatology are positively correlated, but that there is an interval of relief at the onset of nausea. Because of this anomaly at nausea onset, we believe that caution is needed when comparing studies that have used the two different types of scales as ratings on these scales cannot one-to-one be compared in terms of motion sickness progression level. Rating symptomatology may be more relevant when it is important to prevent cleaning up the mess from vomiting, for example in car driving. Rating unpleasantness may be telling more about the (commercial) attractiveness of, for example, playing a game using virtual reality goggles, one game possibly evoking less unpleasantness than another. However, it is important to realize that rating how bad someone feels does not give an answer to the question how close someone is to the point of vomiting. We conclude that unpleasantness and symptomatology are non-equivalent constructs in the quantification of motion sickness progression and cover different aspects within the (dis)comfort spectrum.

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Human discomfort in aircraft cabins: effect of noise level and vibration magnitude

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ABSTRACT

In recent years, the air transport industry has made significant advancement in technology in context to fuel consumption, maintenance and performance. The most promising developments in terms of fuel efficiency and therefore minimisation of emissions is in future turboprop aircraft (i.e. those generating thrust from a propeller). The main drawback with propeller aircraft is that they tend to have noisier cabins, and there is an increased level of discomfort from vibration due to the tonality that is present. Human comfort perception is a key factor for aircraft manufacturers in the design of airframes and aircraft interiors; the aim of this research study is focused towards building a comfort model for aircraft to enable designers and engineers to optimise the passengers travelling experience. In this paper the authors demonstrate a laboratory experimental study in order to determine the relative importance of noise and vibration for the turboprop aircraft cabin. The results showed that with the increase in noise levels and vibration magnitudes the overall human discomfort also increased, indicating a cross- modal interaction.

KEYWORDS

Human comfort, Vibration discomfort, Noise

Introduction

The aviation industry is stepping towards innovative technologies to improve the human comfort in context to the discomfort to both the crew and passengers from noise and vibration inside the aircraft cabin. Future aircraft will be designed differently to make them more sustainable. They will be lighter and many more will be propeller driven to enable battery power and reduce environmental emissions (Babikian et al., 2002 and Schafer et al., 2019). Changes in design will mean that the noise and vibration experienced by passengers in the aircraft will be different to that experience in current aircraft.

Turboprop (propeller passenger aircraft) are more fuel efficient than jets but generate more noise and vibration inside the cabin resulting in discomfort amongst both crew members and passengers (Vink & Brauer, 2011). Optimisation of aircraft cabin noise levels and vibration magnitudes is essential to enhance the comfort of the passengers. The comfort perception of passengers in air vehicle environments should be taken into consideration during the aircraft cabin design, not only for wellbeing but also because a willingness to use similar aircraft again for travelling is influenced by the human comfort (Bellmann et al.,2004).

The aim of the present investigation was to map how individual comfort perception varies with different combinations of noise and vibration. Furthermore, we aim to build an overall comfort model in a vibro-acoustic environment for the aircraft passengers in order to enhance the travelling experience for the passengers.

Methods

18 volunteers (12 male, 6 female; 19-52 years) participated in a laboratory experiment at Nottingham Trent University, UK. Each volunteer was exposed to each combination of pairs of 10-15s stimuli comprising synthesized noise and vibration representative of those experienced in a turboprop. They were seated on a prototype aircraft seat which was mounted on a shaker platform (Figure 1). Noise was presented at each of 72, 78, 84 and 90 dB(A); vibration was presented at each of 0.50, 0.67, 0.83, 1.00 m/s^2 r.m.s. (r.s.s. bandlimited) comprising a multi-tonal signal. The order of stimuli was randomized. Participants were required to rate their perceived discomfort from noise, perceived discomfort from vibration, and their overall discomfort. Both noise and vibration ratings were based on the scale developed from ISO 2631-1 (Figure 2(a)), the overall discomfort was assessed using the Borg CR-100 scale (Figure 2(b)). They were also required to select whether they would choose to reduce the noise or the vibration to improve comfort. The study was approved by the NTU Research Ethics Committee.

Fig. 1. Aircraft seat mounted on a vibration simulator. The centre seat was used in the study. The image also shows amplifiers and positioning of loudspeakers.

2(a)

1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

1	Not uncomfortable
2	A little uncomfortable
3	Fairly uncomfortable
4	Uncomfortable
5	Very uncomfortable
6	Extremely uncomfortable

2(b)

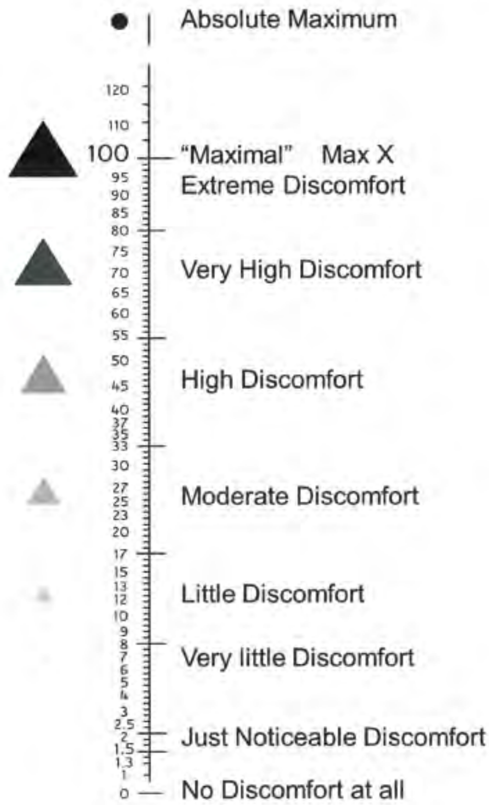

Fig.2. Subjective response scales. (a) Noise ratings and Vibration ratings based on scale from ISO 2631-1. (Sammonds et al., 2017 and Mansfield, N.J. 2004) (b) Borg CR100 scale for overcall discomfort ratings. Adapted from (Borg. E, 2002).

Results and Discussion

Participants were each exposed to 16 combinations of noise and vibration and gave 4 responses to each combination. Kolmogorov-Smirnov tests confirmed that parametric statistics could be used for data analysis ($p<0.0001$ for all 64 data sets).

Ratings of noise discomfort increased with noise level for each vibration magnitude (Figure 3). Two-way analysis of variance (ANOVA) showed a significant main effect of noise ($p<0.0001$) but no effect of vibration ($p=0.88$) and no interaction ($p=0.99$). Post-hoc t-tests confirmed a change in noise ratings at 72 dB and 90 dB for each of the vibration magnitudes ($p<0.0001$). There was no change in ratings of noise with vibration presented at 0.5 m/s^2 and 1.0 m/s^2 (p=0.38, 0.72, 1.00, 1.00) showing that there was no cross-modal effect observed.

Ratings of vibration discomfort increased with vibration magnitude for each noise level (Figure 4). Two-way analysis of variance (ANOVA) showed a main effect of vibration ($p<0.0001$) but no effect of noise ($p=0.76$) and no interaction ($p=0.98$). Post-hoc t-tests confirmed a change in vibration ratings at 0.5 m/s^2 and 1.0 m/s^2 for each of the noise levels ($p<0.0001$). There was no difference in ratings of vibration with noise presented at 72 dB and 90 dB (p=0.83, 1.00, 0.86, 0.17) showing that there was no cross-modal effect observed.

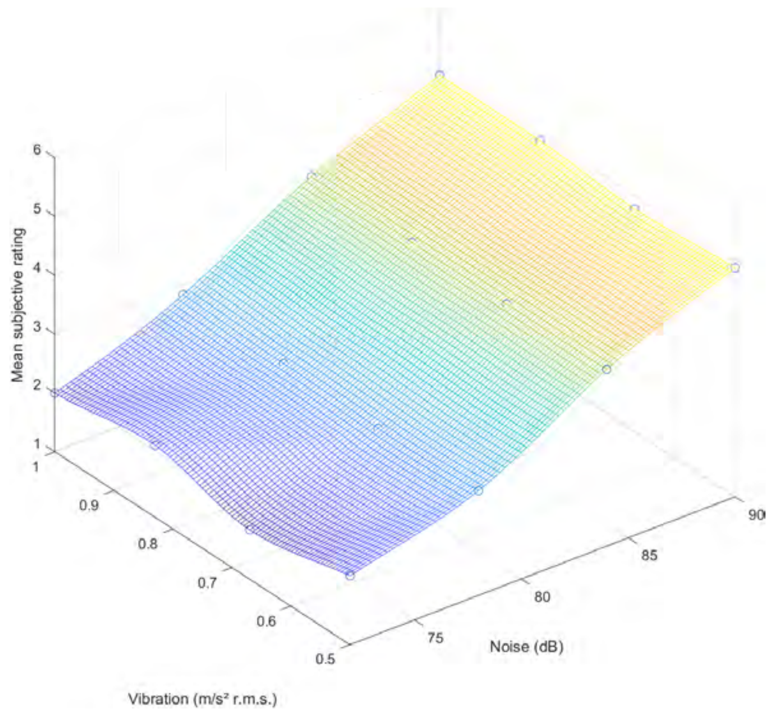

Fig.3. Mean subjective ratings of <u>noise</u> for all combinations of noise and vibration with cubic interpolated surface superimposed.

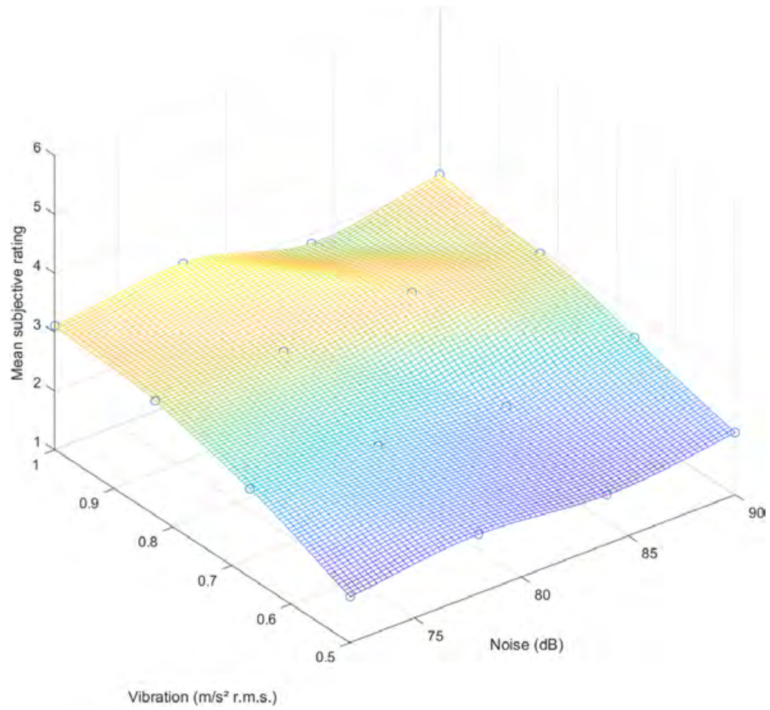

Fig.4. Mean subjective ratings of <u>vibration</u> for all combinations of noise and vibration with cubic interpolated surface superimposed.

Ratings of overall discomfort generally increased with both noise and vibration (Figure 5, Table 1). Whilst a two-way analysis of variance (ANOVA) showed a significant main effect of noise ($p<0.0001$) it did not reach significance for vibration ($p=0.23$) and no interaction ($p=0.99$). Post-hoc t-tests confirmed a significant change in overall ratings at 72 dB and 90 dB for each of the vibration magnitudes ($p<0.0001$). Overall ratings of discomfort significantly increased with vibration at 78 dB ($p<0.01$) but the trend did not reach significance at 72 dB ($p=0.04$), 84 dB ($p=0.02$), or 90 dB ($p=0.06$), despite systematic increases being apparent in mean data (Table 1).

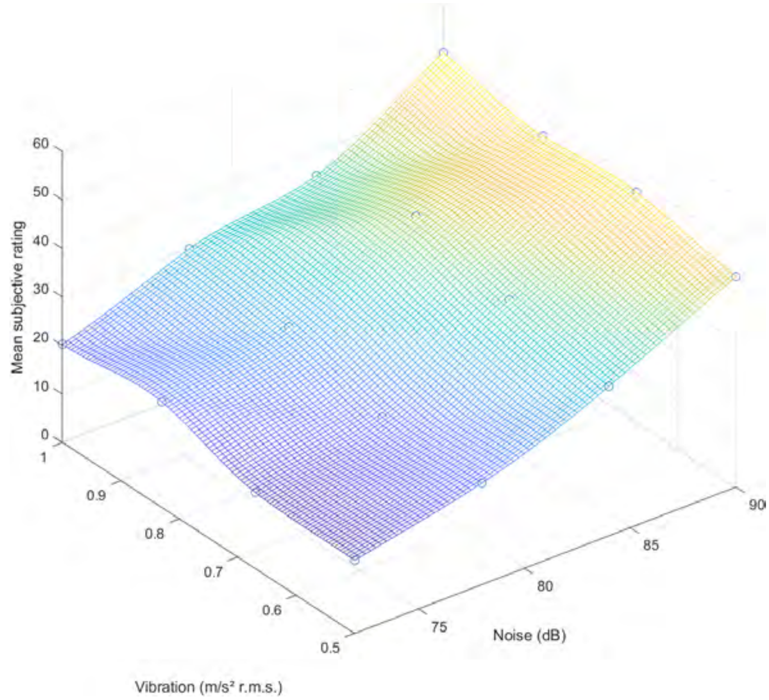

Fig.5. Mean subjective ratings of <u>overall discomfort</u> for all combinations of noise and vibration with cubic interpolated surface superimposed.

Table 1. Mean overall ratings of discomfort

	Vibration magnitude (m/s²)			
Noise level (dB)	**0.50**	**0.67**	**0.83**	**1.00**
72	15.00	15.64	21.75	20.28
78	20.89	21.11	27.11	29.89
84	30.78	35.25	39.94	34.94
90	43.33	47.39	46.42	50.22

These data show that the overall perception of discomfort was a function of both the noise and the vibration. Therefore, both variables need to be accounted for when evaluating aircraft cabin environments. Whilst the changes in responses to noise were greater than those to vibration, it should be noted that the power scaling of the two stimuli were not matched.

Conclusions

The study investigated human discomfort in an aircraft cabin in context to different noise levels and vibration magnitudes. The discomfort score ratings of the participants increased with the increase in noise level and vibration magnitude respectively. The overall discomfort rating for the participants also showed rise at higher combinations of noise levels and vibration magnitude. For the ranges of noise and vibration investigated, there were clearer trends observed for noise responses than for vibration responses.

Acknowledgement

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COMFORT CONGRESS 2021
Posture and Pressure Methods

Key factors of comfort pressure distribution - what we feel in sitting

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ABSTRACT

In the seating comfort research, it is known that the pressure distribution should not exceed a certain threshold from the viewpoint of tissue compression and should be widely distributed. However, its ideal distribution is not defined in past research. In this study, we focused on the pressure sensitivity of thighs and buttocks and performed an analysis assuming automotive seating. We determined the exponent of Steven's power law for seat pressure by measuring local perceived pressure load that felt the same pressure feeling at the reference load point, and the sensitivity distribution of 29 participants were measured and classified into 3 groups. The comfortable pressure distribution of 5 participants was measured using the experimental seat and converted into a perceived pressure distribution using the sensitivity distribution. The results show measured pressure distribution is not the same as perceived. Analysis of the perceived pressure distribution suggests that the comfortable perceived pressure distribution is a uniform distribution that falls within a certain range for the minimum pressure.

KEYWORDS

Seating comfort, Pressure distribution, Sensory sensitivity

Introduction

Pressure distribution is widely used in the analysis of body-chair interaction while sitting. It can be measured very easily by a commercial measuring system and is widely used in developments. Pressure distribution is very effective because it can visualize the contact state. It is known that pressure distribution that is widely dispersed and has no local concentration is good (Zemp et al., 2015), but no study showing what the optimal distribution is. In addition, although the upper limit of pressure is known from the viewpoint of blood flow inhibition due to tissue compression (Liu et al., 2020), no examples were shown about the distribution of appropriate values for comfort.

Vink et al. describe this lack of knowledge as a missing link, the effect of pressure sensitivity is linking the softness of product foam and seat, the contact area, and comfort caused by the interaction between the body and seat (Vink & Lips, 2017). It seems that individual differences, such as sensory organs, soft tissue thickness, etc., strongly affect pressure sensation. Therefore, we agreed on this model. Therefore, in this study, we focused on this pressure sensitivity.

To understand the sensory evaluation of the seating comfort, the sensitivity of thigh and buttock were measured by Hartung et al. (Hartung et al., 2004), Goossens et al. (Goossens et al., 2007), Vink et al. (Vink & Lips, 2017). No knowledge was shown about the relationship between sensitivity and pressure distribution.

In this study, we measure the pressure sensitivity distribution of the seated person. By defining this sensitivity as the conversion coefficient of the perceived pressure from the actual pressure, the purpose was to consider the perceived pressure felt by the seated person.

Sensitivity of thigh and buttock

Concept of the study

In this study, we calculate the perceived pressure felt by the seated person. Perceived pressure is obtained by multiplying the actual pressure by sensitivity.

$$Pressure_{Perceived} = Sensitivity \times Pressure_{Seat} \qquad \text{Equation (1)}$$

It is generally known that the relationship between sensation and stimulus follows Stevens' power law (Stevens, 1957). It is known that the relationship between the amount of sensation and the amount of stimulus is represented by using a power n that is unique to that sensation.

$$\emptyset = k \cdot S^n \qquad k\text{: Proportional constant} \qquad \text{Equation (2)}$$

Therefore, in this study, the reference point pressure P_1 was used as the stimulation S, and the measured pressure P_2 when a feeling of the same pressure was obtained as the sensation $\emptyset$, and the proportional constant k was defined as the sensitivity. Then, using the power law equation (2), the actual pressure is converted to the perceived pressure.

Measurement methods

Sensitivity measurement device

In this study, the sensitivity was defined by comparing the perceived pressure applied to a reference point with the pressure of the same pressure sensation at another measurement point. Figure 1 shows a pushing device for measuring sensory sensitivity. Pressurization of the thigh and buttock surfaces is performed with a contact by a rubber ball assuming pressure from the seat. The pressure was recorded using the load cell. The measurement seat shown in Figure 2 was used. The seat was cut out under the thigh area and a footrest and armrest were provided to maintain the sitting posture.

Procedure

The measurement point was defined as shown in Figure 3 using the ratio based on the femoral length L (distance between the lateral epicondyle of the femur and the greater trochanter). The sitting posture of the participant was adjusted to the same posture shown in Figure 4.

When two types of loads P_1, 20, and 40N with the contact area became a circle of Ø20 (converted to pressure, 1.59 N/cm^2), were applied to the reference point, the load P_2 that felt the same at each measurement point was measured. The measurement was performed at 6 points from 0.5 to 1.0L with 0.3 L as the reference point and from 0.3 to 0.5L with 1.0L as the reference point. The measurement was performed twice at each point.

The participants in the experiment were 32 adult males (Height 175.2 ± 4.2 cm, Weight 70.1 ± 8.9 kg) close to the American Male 50% tile.

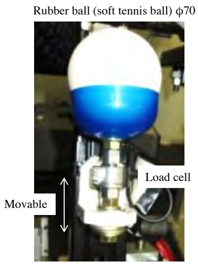


Figure 1: Pushing device

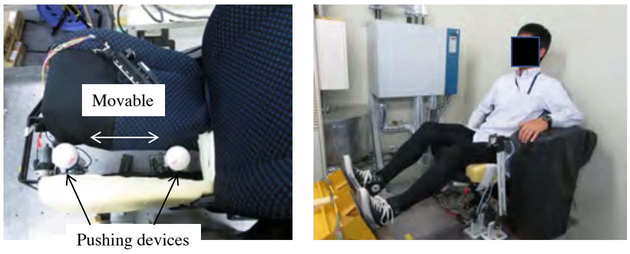


Figure 2: Sensitivity measurement seat

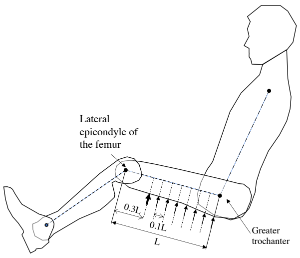


Figure 3: Measurement point at thig and buttock

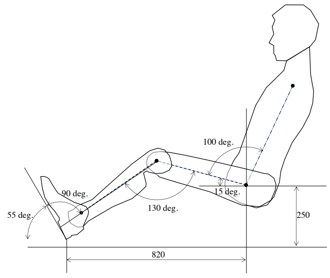


Figure 4: Sitting posture in the measurement

Determination of exponent of the power function

The slope of the regression line when plotting the four measured values P_1 and P_2 on the logarithmic axis corresponds to the exponent of the power function. The exponent was calculated for the data of 29 people, excluding 2 people who had the result that the magnitude relationship of the load could not be evaluated correctly and 1 person who had extremely poor reproducibility for two measurements.

From the results, no clear tendency was observed between the position at the thigh. The measurement points 0.9L and 1.0L at the buttock were significantly different from those of the thigh. Therefore, the exponents were determined using the average of each region as follows.

Thigh (0.3L~0.8L): 0.84 ± 0.36, Buttock (0.9L~1.0L): 1.11 ± 0.52.

Based on the above results, the sensitivity was defined as follows.

Sensitivity $k = \frac{P_1}{{P_2}^{0.84}}\ (Thigh),\ \frac{P_1}{{P_2}^{1.11}}\ (Buttock)$ Equation (3)

The perceived pressure equation (1) becomes the equation (4).

$Pressure_{Perceived} = k \times {Pressure_{Seat}}^{0.84}\ (Thigh), {Pressure_{Seat}}^{1.11}\ (Buttock)$ Equation (4)

Sensitivity calculations

Methods

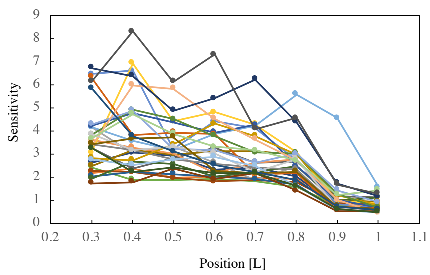
The sensitivity distribution of each participant was calculated from the same measurement data for the 29 participants. 20N (equivalent to 15.9 kPa), which is close to the seat pressure distribution value was used as the reference load. The measurement data are 6 points of 0.5 to 1.0L with 0.3L for the reference load point and 6 points of 0.3 to 0.5L with 1.0L for the reference load point. Both measured data were integrated into one distribution using calculating the value of 0.65L (midpoint of measurement area) with adjustment to fit the distribution. Then, the sensitivity distribution of each participant was calculated using equation (3).

Results

Figure 5 shows the sensitivity distribution of 29 participants.

Analysis of comfortable pressure distribution

Comfort pressure measurements



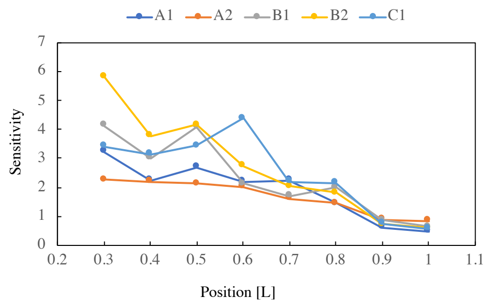


Figure 5: Sensitivity of participants   Figure 6: Sensitivity of the comfort test participants

Comfort pressure distribution was measured under the sitting posture shown in Figure 3 by adjusting the best seat shape for 5 adult males (Height 176.2 ± 5.1 cm, Weight 69.6 ± 9.6 kg). An experimental seat with variable shape in the two-dimensional sagittal plane (Hirao et al., 2006) was used. The sensitivity distribution of 5 participants was shown in Figure 6.

The pressure distribution at the seat cushion was measured by the pressure sensing mat (X-Sensor), and the skeletal coordinates of the femur were measured by the three-dimensional digitizer (FAROARM). From this comfortable pressure distribution, the sum of the pressure values in the lateral direction of the seat cushion from 0.3 L to 1.0L on the femur axis line was extracted as shown in Figure 7.

Calculation of perceived pressure

The comfortable pressure distributions of the five participants shown in Figure 7 were converted into perceived pressure distributions as shown in Figure 8 using the sensitivity distribution. Examples of measured and perceived comfortable pressure distribution were shown in Figure 9. There were the differences that measured one was relatively flat at the thigh but perceived one was more complex and sharper.

Discussion

Sensitivity distribution

From Figure 5, it was found that in most participants, the sensitivity of the buttocks was low in the range of 1 to 2, and the thigh was highly sensitive to the buttocks. From the tendency of the sensitivity distribution of each participant, 29 participants in the experiment were classified into

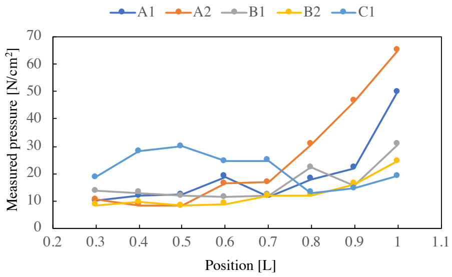


Figure 7: Measured comfort pressure

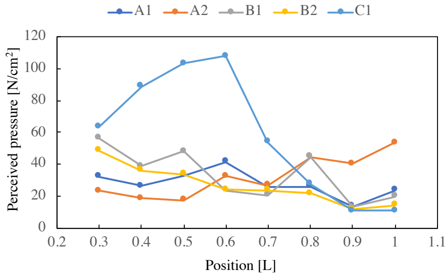


Figure 8: Perceived comfort pressure

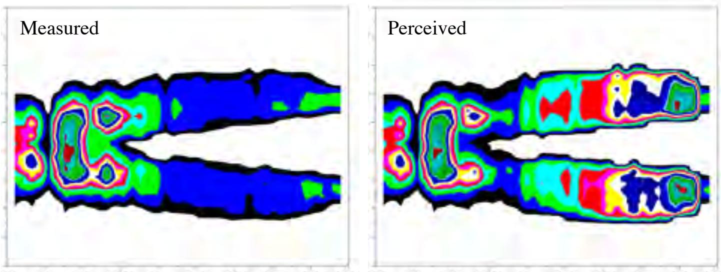


Figure 9: Example of measured and perceived pressure distribution

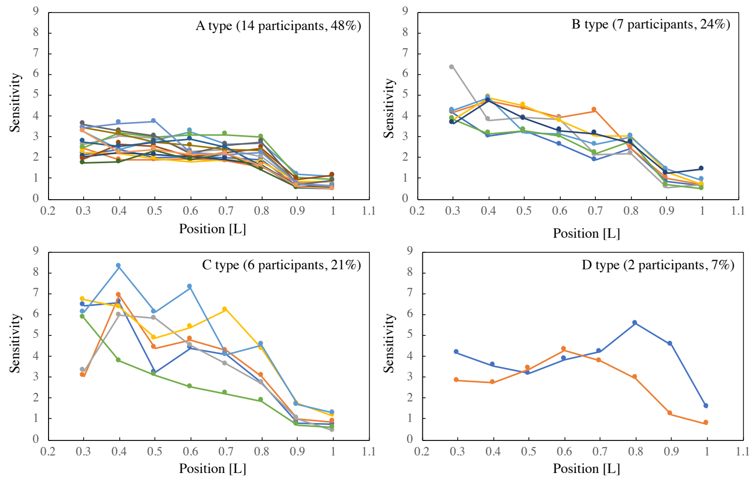


Figure 10: Four types of the sensitivity distribution

four types shown in Figure 10.

Perceptual mechanism of body pressure distribution

The sensitivity distribution shown in Figure 6 was A type 2 (Participant A1, A2) and B type 2 (B1, B2) and C type 1 (C1) in the classification described above.

The comfortable pressure distribution of the 5 participants was shown in Figure 7. The thighs are close to uniform and the buttocks have high-pressure values for 4 out of 5 participants and 2 of them tend to have particularly high pressure in the buttocks (A1, A2). In addition, one participant (C1) was significantly different, and the pressure in the thigh tended to be relatively high. In other words, two types were observed according to the tendency of the thigh and buttock respectively. Therefore, it is found that the optimal pressure distribution is not constant for all, which is consistent with the fact that no findings for optimal distribution have been shown.

The comfortable pressure distribution was converted to the perceived pressure distribution shown in Figure 8. In the perceived pressure distribution, the common tendency that a small value distribution from the thigh to the buttock within the range from 10 to 60 N/cm^2 was observed except for one participant (C1) with a large value at the thigh.

It is said that the pressure distribution is related to the feeling of fitness by feeling the continuity of pressure (Matsuoka, 1994). The perceived pressure ratio shown in Figure 11, a ratio to the minimum value of perceived pressure, was calculated as an index of continuity. Figure 12 shows the average and standard deviation of the perceived pressure ratio of each participant. It was found that the pressure distribution ratio was in the range of 1.8 to 2.5 ± 0.5 to 1.2, excluding participant C1. It means the pressure distribution was close to flat. In other words, it was found that perceived

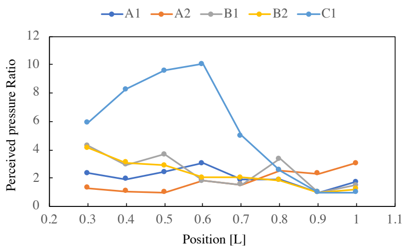


Figure 11: Perceived pressure ratio distribution

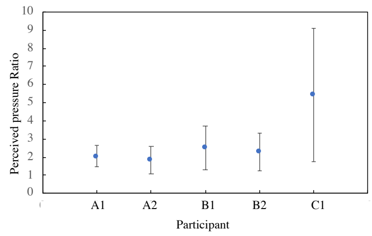


Figure 12: Average of the perceived pressure ratio

pressure distribution is within the range of about 2 times the minimum value may be preferred.

Reflection in seat design

As mentioned above, the sensitivity distribution can be roughly classified into 3 types. And the comfortable state may be two types of perceived pressure ratio distribution. Therefore, it is desirable to have a seat cushion shape or hardness adjustment mechanism that can absorb individual differences. In addition, since the sensitivity tends to increase, the seat should be made so that high pressure is not applied around the backside of the knee.

Conclusion

In this study, we determined the exponent of Steven's power law for seat pressure, and the sensory sensitivity distribution of 29 people was measured and classified into 3 groups.

The comfortable pressure distribution was measured using 5 participants and converted into a perceptual pressure distribution using the sensory sensitivity distribution. Analysis of the perceived pressure distribution suggests that the comfortable perceived pressure distribution is a uniform distribution that falls within a certain range for the minimum pressure.

The analysis of this study was limited only to the seat cushion. More detailed study and expansion to the backrest area and a three-dimensional analysis are also desired in the future.

In conducting all the experiments of this research, informed consent was obtained from the participants and Nissan's Human Subjects Research Ethics Committee approved the experiments.

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Use pressure data below seat cushions to evaluate comfort

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ABSTRACT

During a flight, passengers spend most of their time sitting in their seats. Studying the comfort and discomfort while passengers are sitting is helpful to improve the overall comfort during a flight. Pressure mats are commonly used in studies to collect pressure distribution in order to research sitting comfort. Different from most past studies, in which pressure mats are placed on the top of the cushions, the focus of this paper is to show the potential of placing pressure mat below the seat cushion. Three identical cushions differing in stiffness were prepared. The pressure distribution of 12 sitting postures was collected from 33 subjects both at the top as well as at the bottom of the foam in a randomized order. After sitting on each cushion, the participant was asked to leave the seat and complete a sitting comfort and discomfort questionnaire. The results show that the softest cushion got the highest rank in short-term comfort and lowest rank in short-term discomfort. The recorded pressure distributions both on the top and at the bottom of the foam can influence comfort and discomfort. This indicates the potential to use pressure distributions under the foam to evaluate the perceived comfort and discomfort in sitting, which might reduce the intrusive feeling of the participants in comfort studies.

KEYWORDS

Sitting comfort, aircraft seat, pressure distribution

Introduction

The air transport industry has been growing rapidly (Schaefer, 2012). Though in the period of 2020-2021, due to the influence of Covid-19, there was a massive drop in the number of passengers, it is expected that the demand will return to the pre-Covid-19 in about 2.4 years (Gudmundsson et al., 2021). Passengers' perceived comfort plays a vital role in creating a pleasant experience during flight. In 1980, Richards highlighted the importance of comfort as it has a substantial impact on passengers' decision to fly again with the same airline (Richards, 1980). Hiemstra-Van Mastrigt also identified that the perceived sitting comfort and discomfort are of significant importance for passengers when choosing an airline since they spend most of their time sitting in a constrained space (Hiemstra-Van Mastrigt et al., 2016). The prolonged sitting can cause discomfort in the body and severe complaints such as venous thromboembolism (Gavish & Brenner, 2011).

Vink and Hallbeck defined comfort and discomfort as "comfort is seen as a pleasant state or relaxed feeling of a human being in reaction to its environment" and "discomfort is seen as an unpleasant state of the human body in reaction to its physical environment"(Vink & Hallbeck, 2012). As these are two subjective and independent perceptions (Hiemstra-van Mastrigt et al., 2017), the presence of sitting comfort and discomfort can be simultaneous and they are not linearly correlated. For instance, the reduction in sitting discomfort does not necessarily increase the sitting comfort (Helander & Zhang, 1997). Besides, sitting duration also plays an important role in the evaluation of comfort and discomfort (Vink et al., 2017).

The pressure distribution has a clear relation with discomfort (De Looze et al., 2003). When people are sitting, the hip joints are fixed and the weight is mainly sustained by the bony structure (Floyd & Roberts, 1958). In an ideal situation, the maximum level of comfort can be achieved by a design which support the weight mainly around the ischial tuberosities (Lay & Fisher, 1940). Soft tissues on the buttock and thigh cannot support the sitting body for a prolonged duration (Akerblom, 1949), as when they are compressed, numbness and tingling can happen due to improper pressure load on nerves and blood vessels (Floyd & Roberts, 1958). To avoid the risks of blocking the blood flow in vessels, the pressure should stay below 60mm Hg (Conine et al., 1994). Therefore, the hypothesis is that human will consciously, or unconsciously, move the body in a prolonged sitting. Such movements often lead to the change pressures underneath the buttocks.

Pressure distributions of people sitting in automobiles are studied to guide the seating designs in order to improve comfort of passengers and reduce potential health risks (Hartung, 2006)(Zenk et al., 2012)(Kilincsoy, 2019). In the study of Ebe and Griffin, it was found that a 'bottoming feeling' and a 'foam hardness feeling' were the two main factors influencing cushion comfort of a seat (Ebe & Griffin, 2001). Zemp et al. (2015) showed that the less discomfort and higher comfort are related to the lower mean pressure, the lower peak pressure, and larger contact areas. Another study of automotive seats also indicated the correlations between perceived comfort and the peak and mean pressure on the seat pan (Akgunduz et al., 2014), which implicitly addressed the importance the geometry of the seat pans. Besides the geometry, interface pressure can be strongly influenced by other factors of the seats (Vos et al., 2006). For instance, Zemp et al. confirmed that pressure distribution under the buttock is highly related to the materials and the mechanical configuration of the seat (Zemp et al., 2016)(Wegner et al., 2019).

Most of the existing studies on the pressure distributions focus on office chairs and car seats. Only a few studies investigated the seat of the aircraft (Dangal et al., 2021). Also, it is confirmed in previous studies that features of both the top and bottom layer of a cushion could influence sitting comfort in the short and long term (Moon et al., 2020) but in most studies, only the pressure distribution of the top interface of the seats are investigated. However, the airtight and slippery material may cause extra discomfort in long duration experiments. When people are seated, the body surface in contact with the seat requires a different material than the body parts in contact with the environment (Ferreira & Tribess, 2009). Airtight material can make the process of heat and humidity transfer very difficult. Also, the pressure mat can be shifted slightly due to the movement of the participants.

In this study, the pressure distribution was recorded on the top as well as at the bottom of the seat. Three types of aircraft seat pans were used and effects on comfort and discomfort were studied. Our target is to investigate the potential of evaluating the perceived comfort of participants in sitting position using pressure (distributions) measurements at the bottom. This leads the to the research question: is it possible to evaluate the perceived comfort and discomfort using pressure and pressured distributions measured at the bottom of the seat cushion?

Methods

A within-subject experiment was designed based on two rows of aircraft seats. Subjects of this experiment were 18 males and 15 females, aging from 23 to 37 years old. BMI of the participants varied from 17.6 to 41.3. Three cushions with the same shape, but different in foam hardness were evaluated in a randomized order. All cushions were supported by a self-designed seat pan on the frame of a Recaro BL3520 economy class passenger seat. The inclination angle of the seat pan is 12 degrees and the angle between seat pan and backrest is 96 degree. During the experiment, each participant was asked to perform 12 postures pre-selected by the researchers on each seat pan. Each posture lasted for about one minute. The pressure distribution of each posture on the top surface and bottom surface of seat pans was recorded by pressure mats LX210:48.48.02 developed by XSENSOR Technology Corporation. Each mat consists of 48 by 48 sensing cells, and the dimension of each cell is 12.7 mm by 12.7 mm. Transparent adhesive tape was used to fix the pressure mat on the top. After each cushion participants left the seat and completed the questionnaires. This was done for 12 postures. The questionnaires used in this study consisted of a comfort and discomfort questionnaire and a local postural discomfort questionnaire. In the local discomfort questionnaire, eight regions selected from the regions used in Hartung's study (Hartung, 2006) regarding sitting postures was used. The sequence of postures and cushions were different for each participant based on a randomized order as well. To exclude bias of visual perception, the appearances of different cushions were made the same for the participants. The complete protocols of the experiment can be found in Fig.1. Figure 2 shows the inner-structure of three types of cushions. Different types of foams and the combination of foams can be observed. Among them, cushion A is the softest of the cushions, and cushion C is the stiffest one. The bottom materials (the black layer) of cushion B and Cushion C are the same.

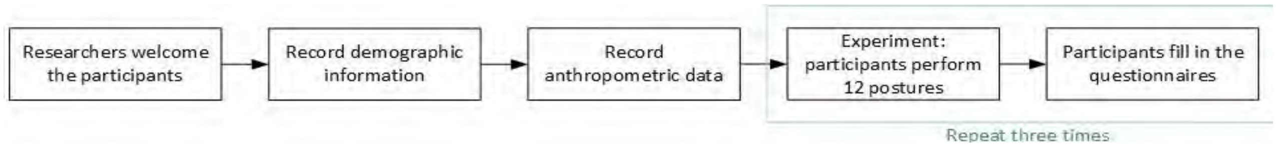


Figure 1:Experiment *protocols*

Cushion A Cushion B Cushion C

Figure 2: Three cushions used in the experiment

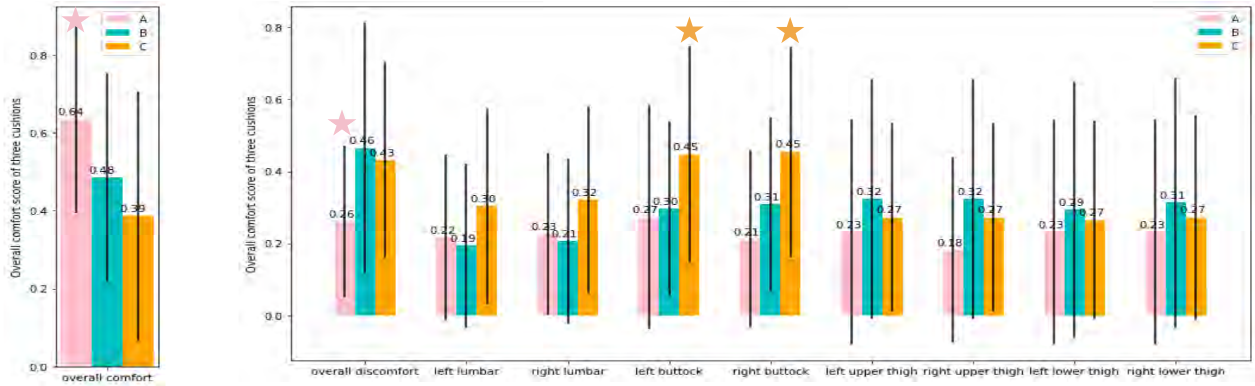
The data of the questionnaires were first normalized using the min-max scaler, and tested with a Shapiro Wilk test for normality. Since the results of questionnaires are not in the normal distribution, a Mann-Whitney U test was selected to find out the difference in perceived comfort and discomfort between the three cushions.

The missing data of the pressure mat were filled with the average value of its neighbours. The average pressure and contact area of each posture were calculated. To reduce noise, cells on the mat sensing less than 0.01 N/cm^2 were excluded.

Results

The mean values of the data regarding comfort and discomfort are presented in Fig.3. The items with a significant difference ($p<0.05$) from others are marked with a star. The softest cushion

(cushion A) scored the highest in comfort and the least in general discomfort. Regarding the different regions, the stiffest cushion (cushion C) showed most discomfort around the buttock regions. It also scored the lowest on perceived comfort. Significant differences were found between cushion A and other two cushions. There is also a significant difference between cushions with the same bottom layer materials. Though most of participants are right-handedness, we did not find difference between the left and the right regarding the subjective feelings.



(a) Comfort score

(b) Discomfort score

Figure 3: Scores of perceived comfort and discomfort (items with significant difference with other two cushions are marked with stars)

The mean pressures sensed by both pressure mats were calculated for each posture as presented in Fig.4 and Fig.5, respectively. The softest cushion has the smallest value regarding the mean pressure and the hardest cushion has the highest. Figure 6 and 7 show the average contact area of each cushion in different postures. The softer the cushion is, the larger the contact area between the human body and the cushion is. The mean pressures of three cushions were significantly different in most postures on the top layer, except for posture 5 (no significant difference between cushion B and cushion C) and posture 6 (significant difference were only found between cushion A and cushion C). For the bottom layer, the mean pressure of cushion A is significantly different from cushion B and cushion C. Significant differences between cushion B and cushion C were only found regarding posture 9 and 10. Contact areas on the top layer were different between all the cushions except for posture 11. In this posture, a significant difference was sensed between cushion A and the other two cushions on the bottom layer. A summary was made in Fig.8 to show whether significant differences are found both in pressure distribution, contact area and sitting comfort status regarding the top and the borrow layer.

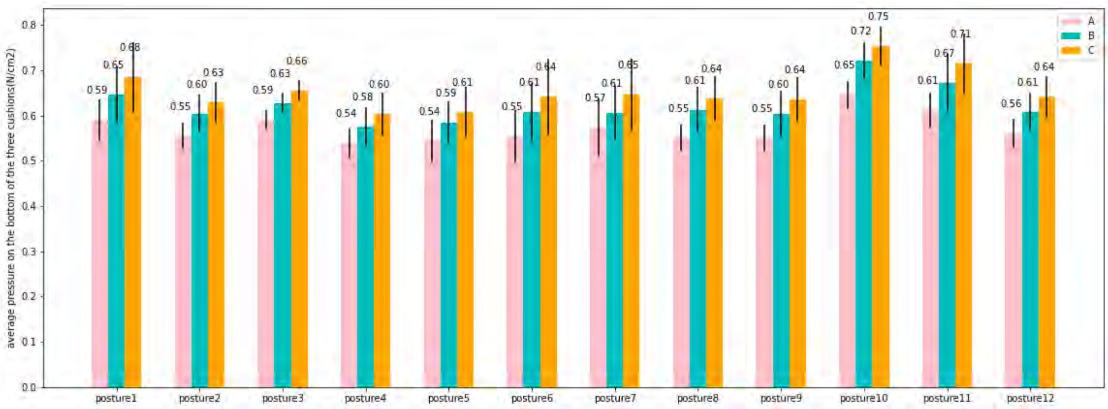


Figure 4: Mean pressure of each posture with different cushions(top layer)

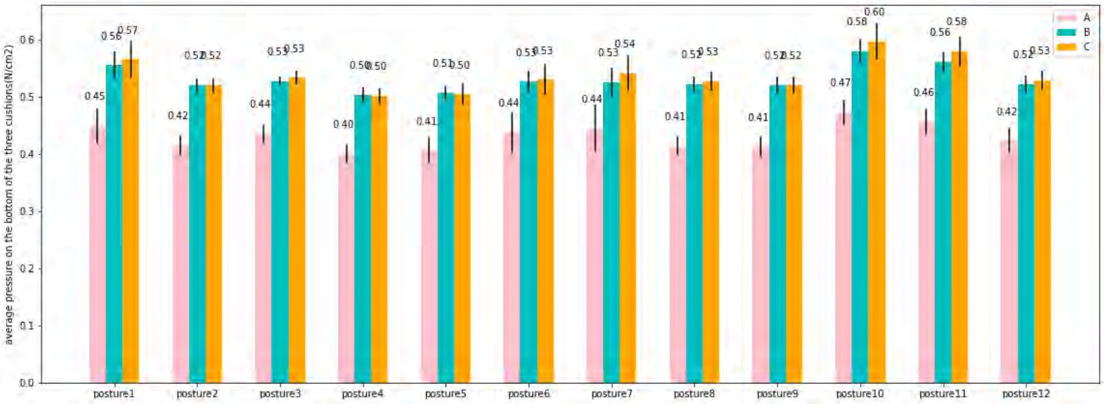


Figure 5: Mean pressure of each posture with different cushions (bottom layer)

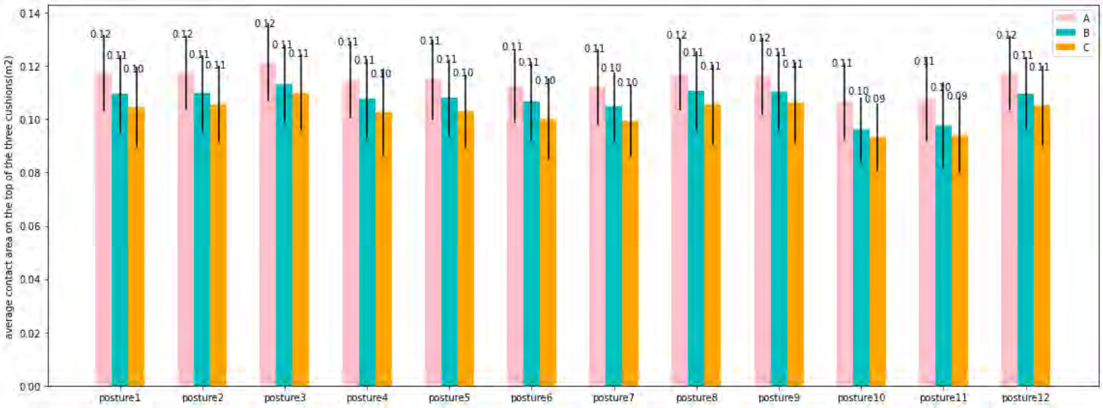


Figure 6: Mean contact area of each posture with different cushions(top layer)

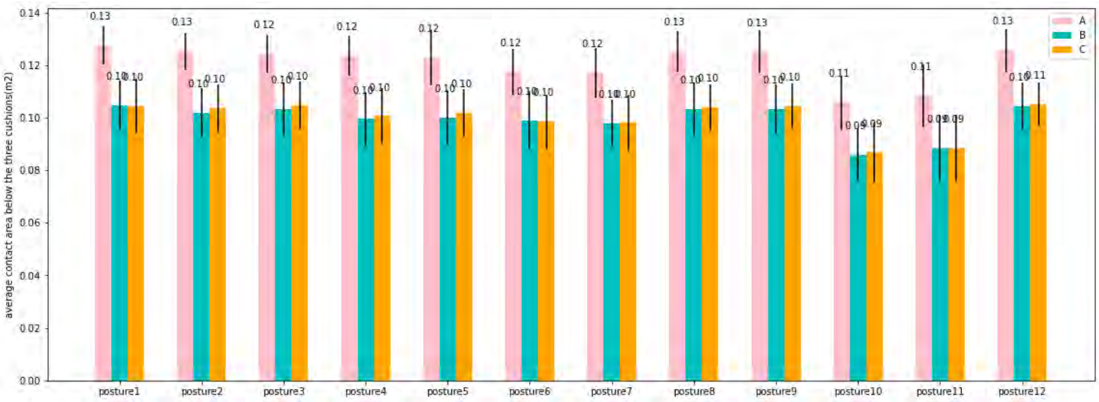


Figure 7: Mean contact area of each posture with different cushions (bottom layer)

Figure 8: cross comparison of significant difference found in pressure distribution, contact areas and the comfort status

Discussion

In this study, the softest cushion, which has the lowest mean pressure and the largest contact area performed best on perceived comfort. A similar result can be found in the study of Dangal et al. (Dangal et al., 2021). Ebe and Griffin also found that compared to seats that create high pressure under the buttock, the ones that create less pressure beneath the ischial bones are considered as more comfortable (Ebe & Griffin, 2001). This can be a result of associating softness with luxury (Kamp, 2012). The most significant differences in pressure distribution were found between cushion A and the other two cushions but still, cushion B and cushion C performed different on discomfort. With different materials both on the top and bottom, cushion A performed different on comfort and discomfort.

Figure 8 show the coherent performance of the pressure distributions at the top and the bottom, which indicate the potential of using either of them as an evaluation tool for comfort/discomfort. It is not validated whether the stiffness on the top layer mainly influences discomfort and the stiffness of the bottom layer has a bigger influence on comfort but it is clear that the features of both surfaces of a cushion can be associated to sitting comfort/discomfort. This is in accordance with the work of Moon et al. (2020).

According to Stevens's power law (Stevens, 1957), the exponent of tactual hardness regarding the perceived amplitude is 0.8, but the exact difference of hardness of different cushions was not measured in this study. It is not sure whether the difference in hardness of the three cushions can be sensed very well.

The population age of this study is between 23 and 37. Both young children and the elderly were not included. However, the preference of these groups should still be studied. Also, during the experiment, the position of pressure mats could be shifted due to participants' movement, which may cause noise.

Conclusion

This study using three cushions which differ in hardness, shows that pressure data at the bottom of a foam cushion and at the top of a cushion are linked to each other and have a relationship with experienced comfort and discomfort. The lowest mean pressure and the largest contact area performed best on perceived comfort and had the lowest discomfort. Although the impact of pressure on the two surfaces may not be equal, the potential of using pressure data under the foam to evaluate the perceived comfort and discomfort of the user in different sitting postures is verified.

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A parametric investigation of preferred pressure distribution on both seat pan and backrest cushions

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ABSTRACT

The present work aimed to investigate the preferred pressure distribution on both seat pan and backrest cushions using a reconfigurable experimental seat and 12 inflatable air cushions. Thirty-seven male and female volunteers participated in the experiment covering a large range of variation in stature (1.51 to 1.9 m) and BMI (18.6 to 43.8 kg/m²). Twelve seating configurations were defined by the combination of 4 back angles (10°; 20°, 30° and 40° from the vertical) and 3 seat pan angles (self-selected from an initial angle of 0°, from an initial angle of 25° and the average of the two previously selected angles). Self-selected pressure distributions were highly dependent on both anthropometric and seat parameters, even for the relative pressure proportion. Results suggest that there is no unique 'ideal' pressure distribution for all sitters and all seats. The parametric models from the present study will be useful for optimising cushion design.

KEYWORDS

Seating, Discomfort, Pressure distribution, Airplane

Introduction

Among objective methods for assessing seating discomfort, the pressure mapping system is the most widely used thanks to its relatively low cost and easy use (Zemp et al., 2015). It is generally recommended that peak pressures on the seat pan should be located under the ischial tuberosities and no other local maxima should be found (Reed et al, 1994). However, quantitative criteria are missing. Mergl et al. (2005) are among very few researchers who proposed criteria based on seat pressure parameters. However, their data were collected only from a sample of 10 young males and 10 young females selected by stature without considering BMI and only for automotive driving tasks. Only six different seat settings defined from two existing seats were tested. It is not clear whether the proposed criteria would be applicable to other seating conditions and populations. The present work aimed to investigate the preferred pressure distribution on both seat pan and backrest cushions using a reconfigurable experimental seat, which allows a sitter to change pressure distribution and seat parameters.

Materials and methods

Thirty-seven volunteers participated in the experiment (18 males, 19 females), aged from 19 to 65. They were recruited based on their body mass index (BMI) (healthy 18.5-25 kg/m², obese >30 kg/m²) and stature (1501-1903 mm). The experimental protocol was approved by the Univ-Effel ethics committee and informed prior consent was obtained for each participant.

The multi-adjustable experimental seat, recently developed at Univ-Eiffel (formerly ISFTTAR, Beurier et al, 2017) was used to simulate different seating configurations and to measure contact forces. A wooden plate was fixed on the seat pan support. Seven inflatable air cushions were attached to the plate using Velco bands, allowing the control of pressure distribution of

- the overall surface (support air cushion);
- the frontal and rear ischial areas. The four ischial cushions were put under the support air cushion and its centre was located at the peak pressure measured by a pressure map. The air pressure of the two frontal cushions was controlled by a same pump, while that of the two rear cushions was controlled by another one.
- the two lateral areas by two lateral air cushions, whose pressure was controlled by a same pump.

Similarly for the backrest, five air cushions were attached to a wooden plate which was fixed on the middle panel, allowing the control of pressure distribution of

- the overall surface (support air cushion);
- the upper and lower lumbar areas by two cushions, whose pressure was controlled separately. The mid point of the two cushions was positioned approximatively at the subject's third lumbar vertebra.
- the two lateral areas by two lateral air cushions, whose pressure was controlled by a same pump. They were positioned symmetrically and self-selected by participants.

Two Xsensor pressure-mapping systems (PX100.48.48.02) covered the cushions and were used to measure the contact pressures at the back and seat pan. They were carefully positioned with respect to the front and up edge respectively for the seat pan and backrest supports. Participants could increase or decrease the air pressure of these cushions using an intuitive user interface, specially developed for this study. Figure 1 shows the location of these inflatable cushions on the seat pan and back supports and an overview of the experimental setup.

Figure 1. Location of the inflatable air cushions on the seat pan and backrest (on the left) and an overview of the experimental set-up with a participant

Twelve seating configurations were defined by the combination of

- 4 seat back angles (A_SB): 10°; 20°, 30° and 40° from the vertical
- 3 seat pan angles (A_SP): self-selected from the initial angle of 0° (PRL) and 25°(PRH) and the average of the two previously selected angles (PRM).

Prior to test these 12 configurations, a reference pressure distribution was obtained at first at two reference seating configurations, upright seating with A_SP=0° and A_SB=20° for the seat pan and reclined seating with A_SP=14° and A_SB=40° for the backrest. For these two reference seating conditions, participants were instructed to be familiar with experimental facilities and to adjust seat height, seat pan length, and of course the pressure distribution by increasing and decreasing the air pressure of each cushion. As finding a preferred pressure distribution could be a long process (>10 minutes in general), the reference air pressure was saved and used as the initial adjustment for the 12 test conditions. Then for one of four backrest angles randomly selected, three seat pan angles (PRL, PRH and PRM) were tested. For each test configuration, participants were instructed to adjust seat height (and headrest position if used) at first and then air pressure of each cushion to find their preferred pressure distribution on the seat pan and backrest. Once preferred pressure distributions found, participants were instructed to adopt a comfortable position with the buttocks and back being in contact with the backrest and keep still so that the contact forces and pressures were measured.

It happed that some pressure cells failed. The missing pressures were interpolated with the measures of the surrounding cells at first. Then the pressures were smoothed using a moving average filter of 3 by 3. To visualize the main effects of anthropometric and seat parameters, a principal component analysis (PCA) of pressures on both seat pan and back was used to reduce the dimensionality in data. A linear regression was performed between the PC scores explaining 95% of variance and predictors. In the present work, seat pan angle (A_SP), backrest angle (A_SB), stature, BMI and sitting height to height ratio (SHRatio) are chosen as predictors.

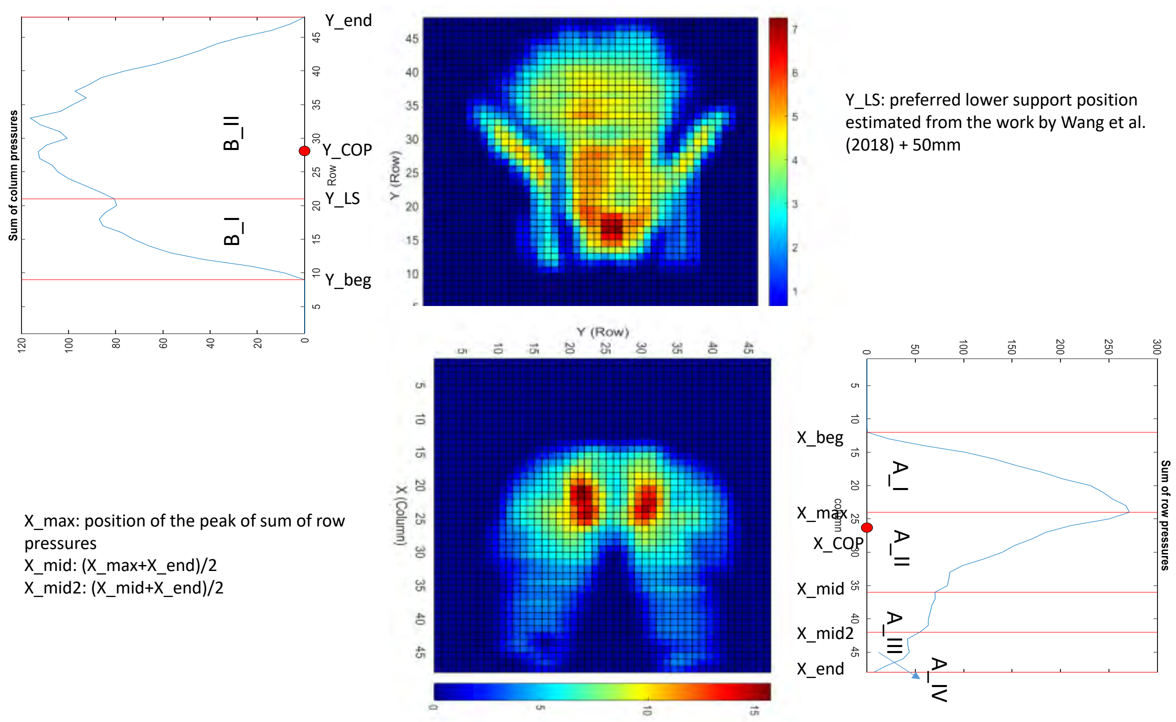


Figure 2. Definition of different contact areas for the seat pan and backrest.

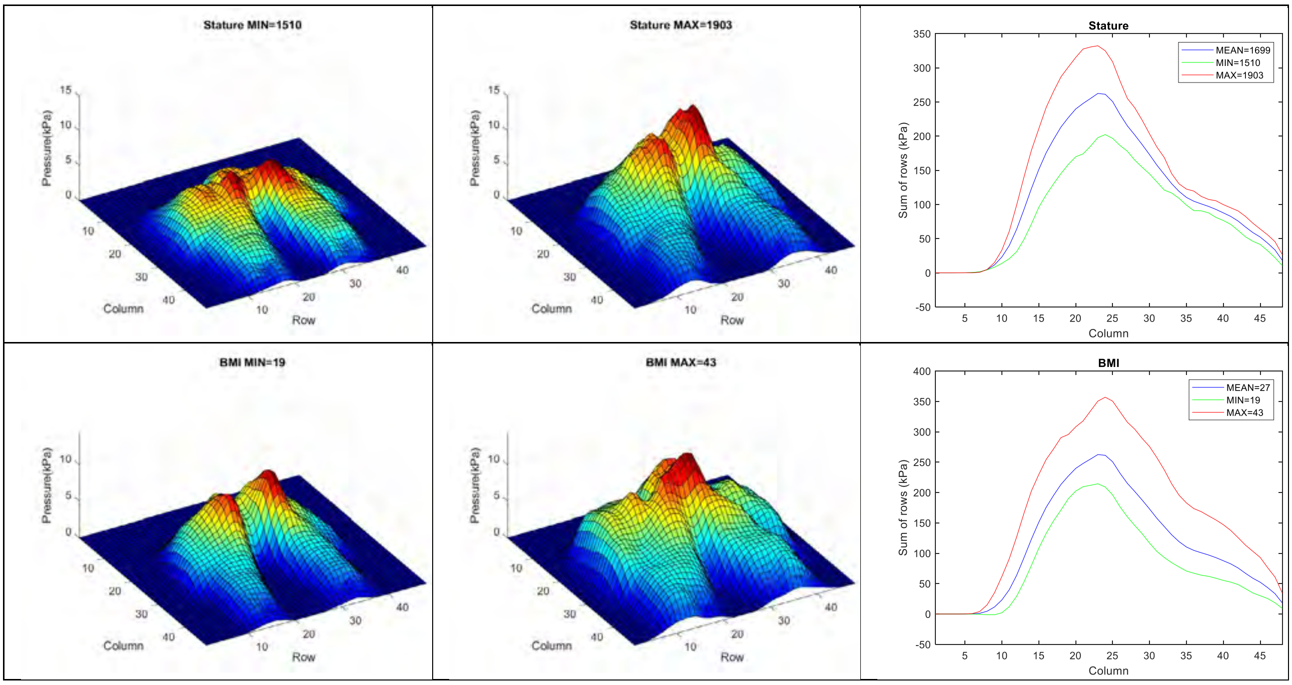
From the pressure profile as illustrated in Figure 2, three contact regions were defined for the seat pan representing buttock, rear and frontal thigh. For comparison purpose, the frontal thigh was further divided into two sub-regions and the one close to the knee was named 'IV'. For the backrest, two regions were defined representing lower and upper back support areas. They were separated by the line corresponding to the preferred lower support position, estimated using the regression equation from our previous work (Wang et al, 2018) taking into account the participant's height, BMI, seat pan angle and back angle. 50 mm was added to define the separation line considering the half width of the panel used in our previous study. As peak pressure and gradients are more sensitive to raw data noise and data processing, the load proportions applied at these sub-regions were preferred:

- A_I, A_II, A_III and A_IV: ratios of the sum of pressures in the sub-regions I to IV with respect to the total pressure applied on the seat pan contact surface
- B_I, B_II: ratios of the sum of pressures in the sub-regions I and II with respect to the total pressure applied on the backrest contact surface

Multifactor ANOVAs and multiple variable regressions were performed using STATGRAPHICS Centurion 18. Effects of independent variables were considered 'significant' when $p<0.05$.

Results

Pressure distributions on the seat pan and back were highly dependent on the sitter's anthropometric dimensions and seat parameters, as showed in Figure 3 and Figure 4. As expected, higher BMI and higher stature resulted in a larger contact area, while peak pressure was more sensitive to stature than to BMI. A more reclined backrest led to higher pressure on the back thus reducing the pressure on the seat pan. A more reclined seat pan led to higher pressure under the distal part of the thighs (near to the knees) and also increased the pressure on the back.



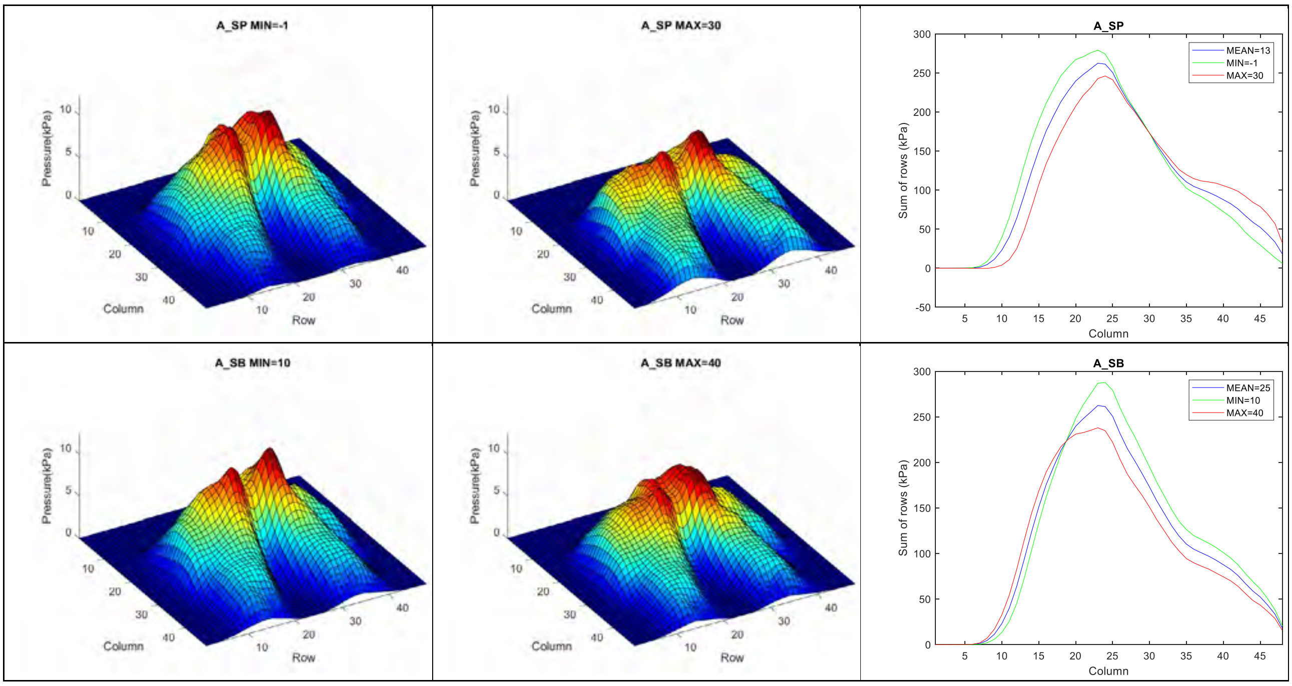
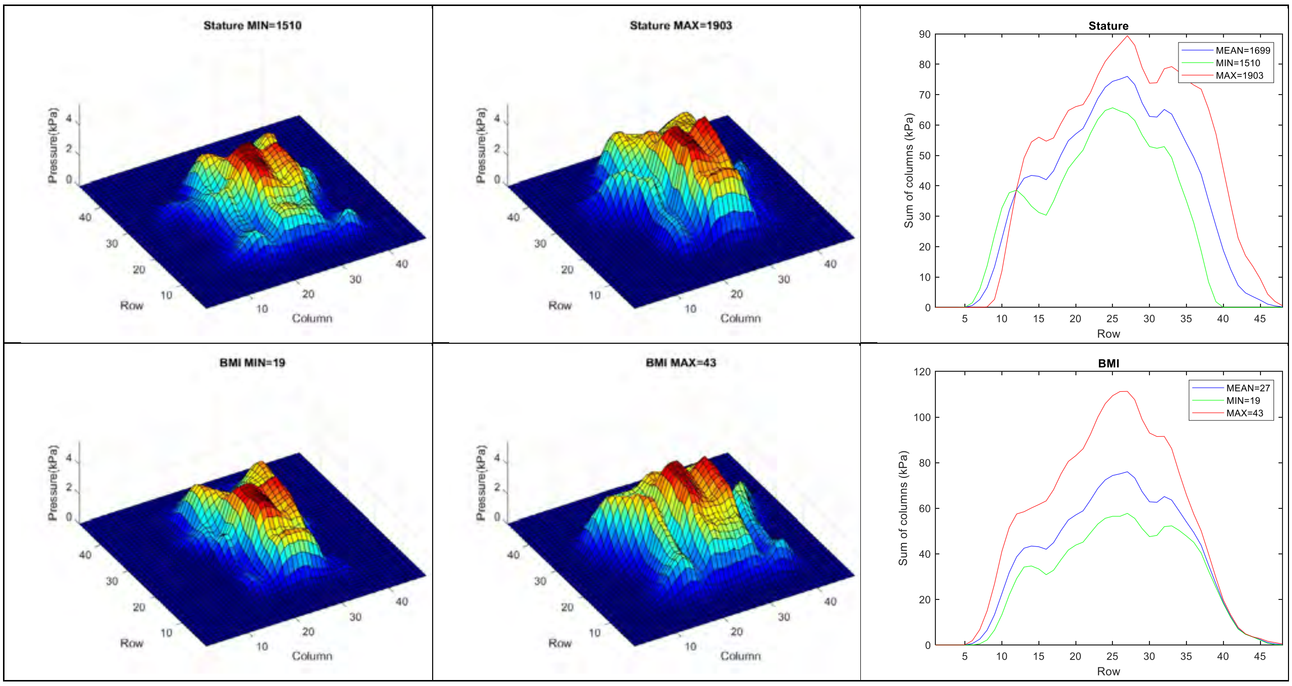


Figure 3. Main effects of stature, BMI, A_SP and A_SB on the pressure distribution on the seat pan. (Column 48, Row 0) represents the frontal right corner. Sum of the pressures by the sensors on the line perpendicular to the seat symmetry axis is on the right.



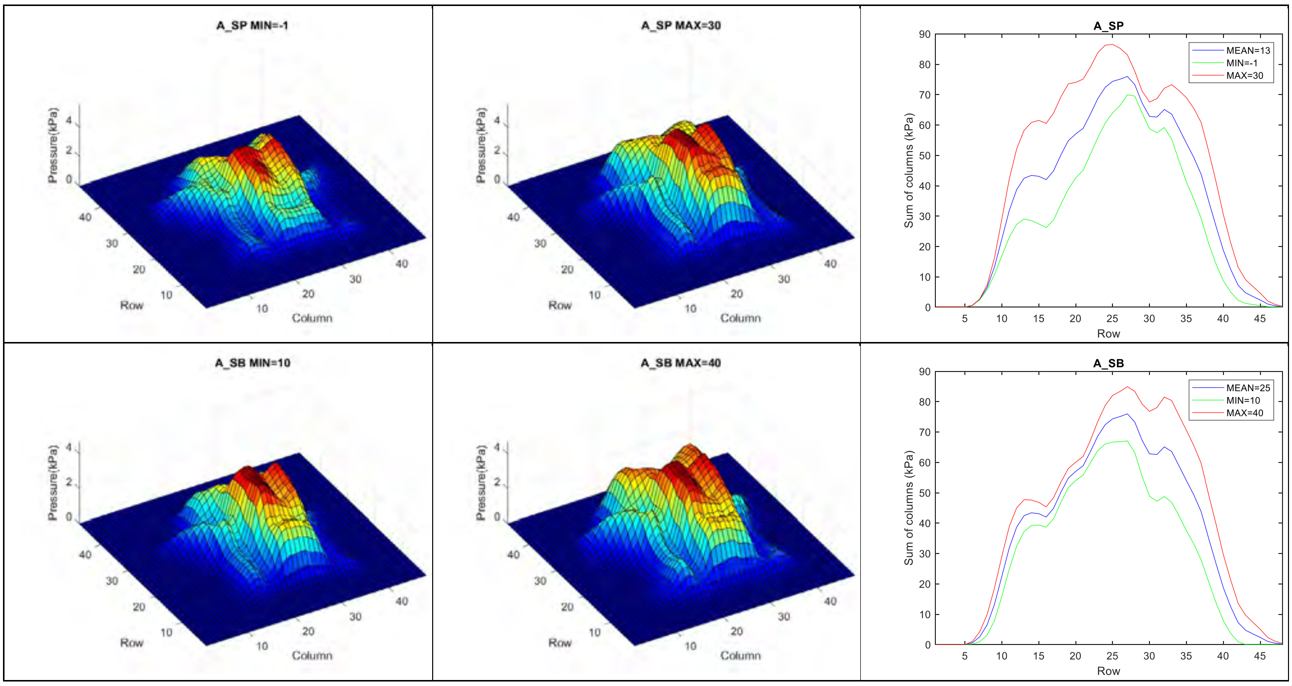


Figure 4. Main effects of stature, BMI, A_SP and A_SB on the pressure distribution on the seatback. (Column 0, Row 0) represents the bottom right corner. Sum of the pressures by the sensors on the line perpendicular to the seat symmetry axis is on the right.

Concerning the relative load proportions defined in Figure 2 (Table 1), BMI affected all of them, while stature only had a slight effect on back pressure distribution (B_I and B_II). A_SP only affected relative pressure proportions (A_I to A_IV) on the seat pan, while A_SB only changed back load proportions B_I and B_II.

Table 1. Regression equations of the load proportions for the sub contact areas defined in Figure 2.

Variable	Constant	A_SP (°)	A_SB (°)	Stature (mm)	BMI (Kg/m²)	SHRatio*	R^2_{adj} (%)	MSE
A_I	0.347	-	-	-	0.0015	-	1.65	0.0047
A_II	0.542	-0.0014	-	-	-0.00276	-	11.07	0.0028
A_III	0.103	0.0018	-	-	0.00133	-	9.85	0.0020
A_IV	-0.023	0.0012	-	0.000026	0.00065	-	13.07	0.0006
B_I	1.60958	-	0.00255	- 0.00021	0.00362	- 2.20169	17.65	0.0085
B_II	=1-B_I							

*SHRatio: ratio between head to seat height in sitting and body height

Discussion and conclusions

In the present work, we experimentally investigated the self-selected pressure distributions on both seat pan and back which using a reconfigurable experimental seat and 12 inflatable cushions. Results show that self-selected pressure distributions were highly dependent on both anthropometric and seat parameters, even for the relative load proportions. Mergl et al (2015) used a scalable grid over the pressure matrix of the seat pan to define different body parts. However, it is difficult to locate these sub contact areas accurately only from pressure distribution. In the present work, we used the peak location on the load profile, corresponding approximatively to the position of the ischial tuberosities, to define the sub contact regions on the seat pan. Due to the difference in contact area definition, we cannot compare the load proportions obtained in the present study with those by Mergl et al. However, our results suggest that the ‘ideal’ pressure distribution depends on body size and seat parameters.

To our knowledge, this study is the first to investigate the self-selected pressure distribution on both seat pan and backrest. The parametric models from the present study will be useful for optimising cushion design.

Acknowledgement

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Objective comparison of two cushions: pressure distribution and postural perceived discomfort

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ABSTRACT

Designing seats is crucial not only for health issues but also for the (dis)comfort perception. The seat pan design could be mainly influenced by two factors: pressure distribution and seat contour. For seat pan discomfort, the lower average pressure is accompanied by less discomfort. Moreover, a seat contour with a large contact area is correlated with more comfort. So, a shaped seat pan was accurately realized following the buttock-thigh shape of an international population (including P5 females and P95 males). For the comfort assessment, a comparison was made between this shaped seat pan (shaped cushion) and a standard aircraft seat pan (flat cushion). Twenty-two international participants (11 males and 11 females, with BMI between 16 and 30) took part in the blind experiment assuming six different postures. Subjective data were gained from questionnaires, whose results showed that the shaped cushion is better in terms of perceived postural comfort. Also, 64% of participants chose the shaped cushion as a preferred cushion because it was more comfortable and suitable for the buttock shape. Objective data were gathered with a pressure mat, and results showed a higher contact area and lower mean pressure distribution for shaped cushion. Significant correlations were calculated between objective and subjective data with Spearman Correlation coefficients.

KEYWORDS

Seat-pan, Human-centre-design, Pressure map

Introduction

Remaining seated for extended periods, such in long-haul flights, increases the risk of pressure ulcers development over the buttocks, as the soft tissue in this area is squashed between two surfaces, the seat and the bones of the pelvis (Stephens and Bartley 2017; Schubert, Perbeck, and Schubert 1994). Thus, it is crucial for designing the seat not only for the (dis)comfort perception but also for the health issues. The seat pan design could be mainly influenced by two factors: pressure distribution (Kilincsoy et al. 2016) and seat contour (Smulders et al. 2016). Pressure distributions are assumed to correlate with seat (dis)comfort because they are obtained with a real sitting person (Franz, Vink, and Bubb 2010; R. Fang, Gao, and Xie 2016; Fasulo, Naddeo, and Cappetti 2019). Indeed, the pressure mapping system is the most widely used to assess the perceived(dis)comfort thanks to its relatively low cost and easy use (Zemp, Taylor, and Lorenzetti 2015; Wang et al. 2020). Also, the pressure distribution presents more statistical correlations with discomfort (De Looze et al. 2003; Hiemstra-van Mastrigt et al. 2016). Moreover, interface pressure depends on postures, seat characteristics (also the shape), assumed postures, anthropometric measurements (Hiemstra-van Mastrigt et al. 2016). For seat pan discomfort, the lower average pressure is accompanied by less discomfort (Noro, Fujimaki, and Kishi 2004). Moreover, there are indications that a seat contour resulting in a large contact area is correlated to more comfort (F. Fang et al. 2016; Zemp, Taylor, and Lorenzetti 2016; Zenk et al. 2012). One way would be to use a shaped contour shell derived from the human body and handle fewer foams to fit a considered large population, including the P5 females and P95 males. Consequently, authors realized a so-called “shaped cushion” aiming to follow the buttock-thigh shape of an international population (including P5 females and P95 males). A comparison is then required to validate the hypothesis that states: the shaped cushion could have more benefits than the standard commonly used “flat cushion”.

Materials & Methods

Experiment protocol has been approved by the Ethical Committee at Delft University of Technology (TU Delft), in the Netherlands. Participants have been explained about the protocol and asked to fill the Informed Consent before experiments.

Seat-pan cushions

Aircraft seats with two different seat-pan cushions have been used: 1) “Flat cushion”, having a fixed foam thickness, as commonly used in standard aircraft seats; 2) Shaped cushion”, made by the same type of foam but with a different shape and contour that could be suitable for an international population. Seat pan’s contour and shape were based on a dataset of pressure maps, aiming to follow the buttock-thigh contour.

Pressure mat

The Pressure mat Xsensor LX210:48.48.02 has been used to evaluate the pressure distribution. The total sensing area is 24 inches x 24 inches (about 60.9 cm x 60.9 cm) with a very low thickness (0.03 inches, that is about 0.09 cm) allowed to detect a wide range of population without influencing perceived (dis)comfort.

Questionnaires

Questionnaires were used to gather subjective data after experiencing one cushion to detect participants’ sensations, overall perceived comfort and discomfort. Participants were asked to rate two questions: 1) Overall perceived discomfort (1=No discomfort, 2=Low Discomfort, 5=Discomfort, 7=High Discomfort, 9=Extreme Discomfort); 2) Overall perceived comfort (1=No Comfort, 2=Low Comfort, 5= Comfort, 7=High Comfort, 9=Extreme Comfort). Finally, at the end of the experiment, participants were asked to choose the preferred cushion (first or second cushion since it was a blind-test not to influence participant expectations (Naddeo et al. 2015)) and to explain the choice’s reasons of.

Postures

The cushion and posture orders have been planned for each participant adopting the Latin Square Method to randomize the order keeping the experiments repeatability (Fisher 1992; Fiorillo et al. 2019; Piro et al. 2019). The time assumed on each cushion was 44 minutes, supposing that inter-differences were more evident only after 40 minutes. The 5 planned postures were based on literature studies and are commonly assumed by passengers (Liu, Yu, and Chu 2019):1) upright; 2) bending forward with elbows on legs; 3) upright with leg crossed; 4) bending on the side with arm on armrest; 5) bending on the side with arm on armrest and crossing the legs. The last posture was always the desired posture, where participants could assume their comfortable posture freely during a flight.

Participants

Twenty-two participants (11 males and 11 females) were recruited through social channels of TU Delft, especially spreading emails, obtaining a large sample of the international population with high variability on age, height, weight, and body shape, as shown in Table 1.

Table 1. Demographic data of participants (n=22). BMI = Body Mass Index; WHR = Waist-Hip Ratio.

	Average	Median	Standard deviation	Max	Min
Age	28,73	27,50	5,55	48,00	24,00
Weight (kg)	64,64	62,50	13,00	95,00	48,00
Height (cm)	169,32	167,00	9,42	193,00	155,00
BMI (Kg/m2)	22,40	22,06	3,05	29,40	16,60
WHR	0,84	0,84	0,06	0,96	0,72

Experiments protocol

Once the participant came to the experiment lab, he/she has been briefed on the blinded experiment protocol. Then, the participant sat on the planned first cushion assuming for 7 minutes each given posture. Within 7 minutes, the pressure-mat recorded pressure distributions three times, for 30 seconds, at beginning, in the middle and at the end of this time slot. After 42 minutes on the first cushion, the participant was asked to fill the questionnaire. Then a break of 5 minutes was given before repeating the experiment on the second cushion. After experiencing both cushions, the participant has been asked to choose the preferred cushion and explain why.

Results & Discussions

Subjective data were gathered from questionnaires, while objective data were gathered from the pressure mat evaluating pressure distributions and contact areas. Statistical differences were calculated with the Wilcoxon Signed-Rank test, and significant Spearman's correlations with IBM® SPSS® Statistic 26 software.

Subjective data

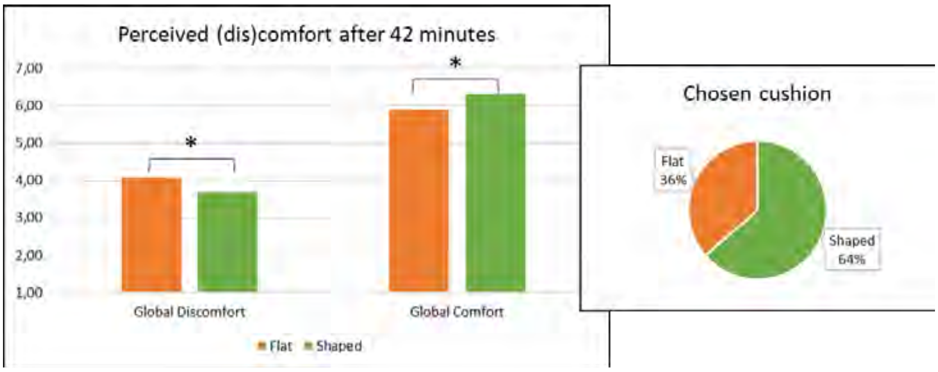

Figure 1: Results from questionnaires regarding the perceived postural discomfort and comfort rated on a 10-point scale. Significant differences are shown with *

Figure 1 shows results of Global Perceived Discomfort, Global Perceived Comfort and the percentages of the chosen cushion. Most participants chose the shaped cushion because they felt it softer, more comfortable and more adequate for their body shape. Instead, the flat cushion gave more support, but they felt more pressure on the lower body areas.

Table 2 shows significant correlations from Spearman Correlation analysis; in particular, the global comfort is negatively correlated with the global discomfort meaning that by reducing the discomfort, the perceived comfort could arise per each cushion.

Table 2: Significant Spearman Correlations for subjective data. LBD=Lower Body Discomfort

		Global Discomfort Flat	Global Comfort Flat	Global Discomfort Shaped	Global Comfort Shaped
Global Discomfort	Flat	-	-,750**	,762**	
	Shaped	,762**	-,614**	-	-,697**
Global Comfort	Flat	-,750**	-	-,614**	,668**
	Shaped		,668**	-,697**	-

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Objective data

The comparison among cushions was evaluated confronting pressure distributions and contact areas by differences: data from the shaped cushion have been subtracted with data from the flat one. Negative values of average pressure mean the pressure distribution on the shaped cushion is lower than the flat cushion; positive values of contact area mean the contact area on the shaped cushion is higher than the flat one. Figure 2 shows this comparison's results for each assumed posture, demonstrating that the shaped cushion presented less pressure and higher contact area than the flat cushion.

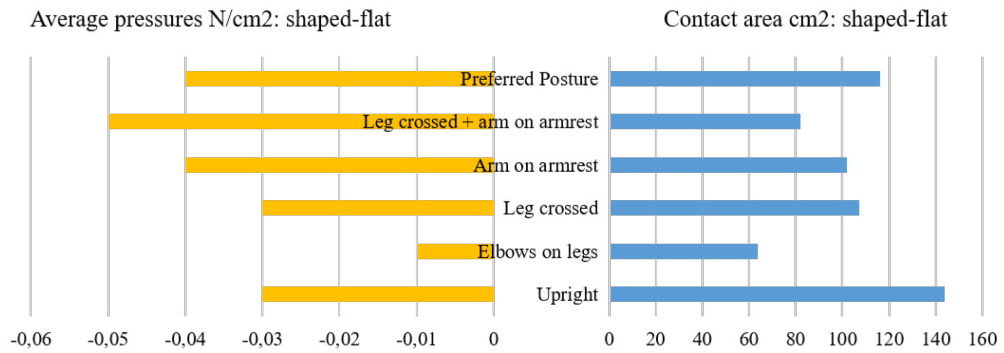

Figure 2: Result from the pressure mat: differences of average pressures and contact areas

Significant correlations have been calculated between objective data and subjective data with Spearman Correlation coefficients, as shown in Table 3. The presence of correlations between pressure distributions and perceived discomfort is aligned with literature studies. Moreover, pressure distributions and contact areas were strongly correlated with gender (p~0,6), indicating that these values were higher for men than women.

Table 3: Significant Spearman Correlations calculated between objective and subjective data for Flat and Shaped cushions (n=22).

		Average pressure					
		P1	P2	P3	P4	P5	P6
Global Discomfort	Flat	,770**	,503*	,432*		,656**	
	Shaped			,602**	,805**	,433*	,423*
Global Comfort	Flat	-,627**	-,597**		-,697**	-,556**	
	Shaped	-,433*		-,593**		-,457*	-,566**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Conclusions

Sitting is an everyday activity that for a prolonged amount of time could lead to discomfort or, in the worst case, health problems. For these reasons, it is essential to design a comfortable seat preventively. Less pressure distribution at the contact interface between the seat pan and buttock-thigh area could lead to higher perceived comfort or discomfort reduction. The blind experiments performed at TU Delft demonstrated a shaped seat-pan cushion (designed as the buttock-thigh shape) was more comfortable than the flat standard cushion considering mainly objective data of pressure distributions. The shown subjective data of (dis)comfort perceptions were rated after experiencing each cushion and considered for correlations' purpose. The blind test was meant not to influence participant expectations knowing the difference between cushions a priori. In particular, results showed that the flat cushion scored higher perceived global discomfort while the shaped higher perceived global comfort. Also, 64% of participants preferred the shaped cushion because it was more comfortable and suitable for the buttock shape. As far as the pressure distribution, the contact area was always higher on the shaped cushion, even for all postures. The average pressure distributions for the shaped cushion were always lower than the flat one. Thus, the shaped cushion, having a wider contact interface, was more comfortable and results confirmed literature studies. Since this study could obtain pressure distributions for each cushion and each assumed posture, the next step will be developing pressure distributions maps to study the ideal pressure distribution and contact interface for aircraft seats.

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The influence of the angle of attack on passenger comfort

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Abstract

The angle of attack (AOA) of an airplane changes the direction of the gravitational force on passengers and thereby might influence passengers' flying experience. However, the contribution of the AOA regarding comfort/discomfort is not fully explored. In this paper, we aim to fill this knowledge gap by identifying the relationships between the perceived comfort/ discomfort of passengers and the AOA of the plane during the take-off and climbing phases of a flight. An experiment is conducted in a Boeing 737 fuselage where 10 participants were recruited. Each participant experiences 3 setups of seats with different AOAs (3, 14 and 18 degrees) for 20 minutes, respectively. Participants were asked to complete several sets of questionnaires during each session, and their heart rate and the pressure on the seat and the backrest were recorded as well. Experiment results indicated that participants experienced 14-degree as the most comfortable angle with the lowest discomfort, which might be useful for airlines in setting up the take-off and climbing procedure.

Keywords

Seat inclination; comfort; take-off/climbing

Introduction

Passengers' comfort experience in flights is one of the key elements in selecting airlines (Balcombe et al., 2009). Previous studies have analysed factors influencing comfort/discomfort, e.g. space of the seat, in-flight service and noise (Brindisi & Concilio, 2008; Mellert et al., 2008)(Mellert et al., 2008). However, most discussions focused on the sitting comfort during the cruising stage of the flight, and only a few paid attentions to comfort of the passengers in the take-off and climbing phases. During these two phases, which may take up to 30 minutes, the plane has an inclination angle (angle of attack, AOA) to climb to the cruising height. According to the procedure recommended by Boeing, the AOA of a 737 plane varies between 15-18 degrees (Wakefield & Dubuque, 2009) in these phases. This angle changes the seat inclination angle with respect to the ground, and therefore changes the direction of the gravitational force of passengers' body against the seat. Furthermore, in these two phases, the backrest of the seat is put upright and the seat belt is often fastened, which might make it difficult for passengers to seek for a comfortable posture themselves.

The changed direction of the gravitational force may influence the pressure distribution between the body and the seat. Literature suggested that there is a relationship between pressure distributions and the discomfort experiences (Smulders et al., 2016). A large contact area between the seat pan and the human body often decreases discomfort. It is also confirmed that lower mean pressure and an even pressure distribution will create more comfort (Zemp et al., 2015). Besides, many studies have investigated that the inclination of the trunk may affect the physical state, muscular activities (Munoz & Rougier, 2011) as well as posture mobility (Cherng et al., 2009). However, these studies were mainly carried out in the clinical environment with the focus on patients. The combined effects on comfort/discomfort of healthy passengers in the take-off and climbing phases of a flight are still to be explored.

The aim of this research is to fill in the knowledge gap regarding the influence of inclination of the seat on comfort. The research question is: *What is the relationship between the comfort/discomfort experience of the passengers regarding the AOA of the plane during the take-off and climbing phases of a flight.*

Methods

Setup

An experiment was set up in the Boeing 737 fuselage at the Delft University of Technology (Fig.1). To simulate the scenario in a realistic context, two rows of seats were used in this experiment while participants sit in the middle of the second row. The seats were mounted to a large platform which can be adjusted to different inclination angles. The width of the seat was 17 inch and the pitch was 30 inches. Three inclination angles were tested in this experiment. The 3-degree was chosen to simulate the cruising stage, and the 14-degree and 18-degree were selected to simulate the minimal and maximal AOAs. The backrest was adjusted to the upright angle and the seat belt was always fastened as well. The experiment setup and the protocol were approved by the Human Research Ethical Committee (HREC) of Delft University of Technology.

Figure 1: Setup of the experiment

Figure 2: The measurement stool

Table 1: Anthropometric measurements of subjects

	Mean	SD
Age	25.9	1.81
Height	162.6	6.02
Weight	50	3.92
BMI	18.89	1.54
Hip breadth	368.1	21.64
Popliteal height	451.5	24.45
Buttock-popliteal depth	465.7	22.22

Participants & Measurements

Ten international participants (2 male and 8 female) joined the experiment. The mean age is 25.9±1.81. To acquire the anthropometric data, we used the measurement approach as described in DINED (Huysmans & Molenbroek, 2021) which includes the use of a stool (see Fig.2). Besides, the height and weight of participants were measured by a tape measure and a weighing scale, respectively. The measurement results and the calculated BMI values are presented in Table 1.

Two pressure mats (Brand: Xsensor) were put on the seat pan and backrest to measure pressure distribution data regarding the buttock and back of the subject, respectively. A pressure mat consists of 48 by 48 measuring cells; each has a size of 12.7 by 12.7 mm. Cameras were installed in the front and at the side of the subject to record the scenario as well as the movements of the subjects during the experiment. All participants wear a Scosche Rhythm24 armband at the left forearm. Their heart rate and the RR intervals were logged throughout the experiment.

A set of questionnaires, which includes a 10-likert scale overall comfort and discomfort questionnaire and a local postural discomfort (LPD) questionnaire was asked several times in the experiment (Anjani et al., 2021). In the comfort and discomfort questionnaire, participants are able to rate the perceived comfort and discomfort regarding the overall experience at a given time span. Using the LPD questionnaire, participants evaluate the perceived discomfort regarding different areas of body. In this experiment, besides all regions at the back of the body, participants are also able to rate the discomfort levels regarding different regions in the front of the body. For filling the questionnaire, participants were instructed that for a region(s) that she/he feels no discomfort, she/he can skip the question regarding this region(s). To avoid the effect on short term memory and to avoid the confusion of the word comfort and discomfort in different languages and cultures (Vink et al., 2021), we asked the question on comfort in the beginning, followed by the LPD questionnaire, and at the end of the questionnaire, we asked the question regarding the overall discomfort. Besides this set of questionnaires, participants were also asked to rank the 3 setups regarding comfort/discomfort levels after the experiment, i.e. after experiencing all setups.

Protocols

Two researchers hosted each experiment where they welcome the participants first. After a short introduction of the setup and the procedure of the experiment, the participants signed an informed consent. She/he then worn the Scosche Rhythm24 armband on the forearm, and sat on the seat with the first setup and fastened the safe belt. Before the start of the timer, the participant had several minutes to adapt to the setup as they did in the air travel. During this time, he/she completed questionnaire set 1 (incl. Comfort/discomfort questionnaire and LPD). As the AOA were adjusted to 3, 14 and 18 degrees in 3 setups, the sequence of the setups that the participant experienced was in a Latin square order. After finishing questionnaire 1, she/he sat for 20 minutes in total to simulate the duration of the take-off and climbing phases of a normal commercial flight. During this period, the participant completed questionnaire set 2 (same as the first set) after about 10 minutes. This took approximately 1 minute. Another 10 minutes after finishing the second set of questionnaires, she/he completed questionnaire set 3, which was the same as previous sets. In this period, the pressures on her/his buttock and the back were recorded in a 1 HZ frequency and her/his heart rate was continuously monitored and logged as well.

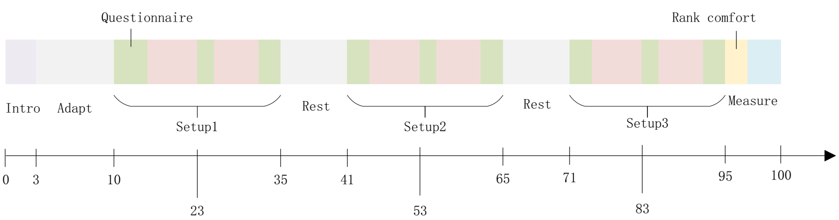

Figure 3: Experiment procedure

After finishing the first setup, he/she left the seat and took a 7-10 minutes break before experiencing the next setting. During the break, she/he was asked to walk along the aisle and had some water and snacks to “reset” the comfort/discomfort status. After a participant experienced all the 3 settings, her/his anthropometric data were measured by a researcher using the methods described in the previous section. Meanwhile, she/he was asked to rank the 3 setups regarding comfort/discomfort levels. Figure 3 illustrates the complete procedure of the experiment in a chronological order regarding a participant.

Data analysis

The collected data on heart rate, pressure (distributions), anthropometrics and results of the questionnaires were further analysed. For all logged RR intervals, a one-minute window was used to extract all HRV features using a self-developed Python program. The pressure recordings were processed by a self-developed program for calculating the mean pressure and the contact areas on the seat and the backrest, respectively.

All anthropometric data and the results of questionnaires were digitized in Excel where empty answers in the LPD questionnaires, they were filled in 0 by default. The mean values of the ratings of all subjects were calculated and the Wilcoxon signed rank test (using SPSS) was used ($P<.05$) to identify if there are differences between any two of the three conditions.

Results and discussion

Overall comfort/discomfort

Figure 4 presents the mean scores of overall comfort and discomfort of the 3 settings over time. Compared with the control group (3-degree), participants comfort levels decreased slightly in inclined settings. However, as the AOA gets larger, the perceived discomfort levels developed over time.

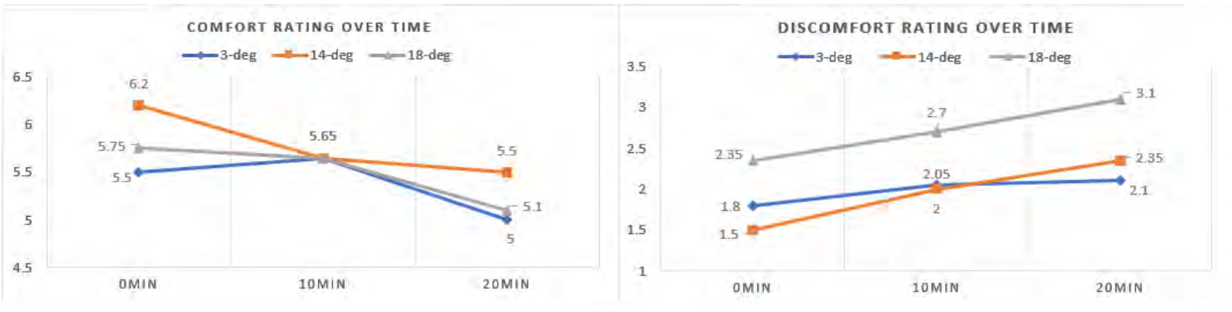

Figure 4: overall comfort/discomfort ratings over time under 3 settings

Table 3 Overall discomfort ratings under 3 settings for each subject

NO.	3-deg	14-deg	18-deg
1	3.5	5.5	4
2	3	0	1.5
3	22	18	24
4	3	4	7
5	8	7	9
6	6	5	15
7	3	8	6
8	6	4	3
9	4	3	8
10	1	4	4

Table 3 shows the mean overall discomfort scores for each condition regarding each subject. The Wilcoxon signed rank test shows that the perceived discomfort between 3- and 18-degrees AOA and between 14- and 18- degrees are significantly different ($p<.05$). However, regarding the 3-degree and 14-degree setups, there is no significant difference ($p=0.42$)

LPD questionnaire

Regarding discomfort on different body parts, results from LPD questionnaires (Figure 5) showed that the back of the neck and the lower waist scored highest on discomfort for all the 3 settings. It can also be noticed that with a larger AOA, more body parts of the participants get higher levels of discomfort.

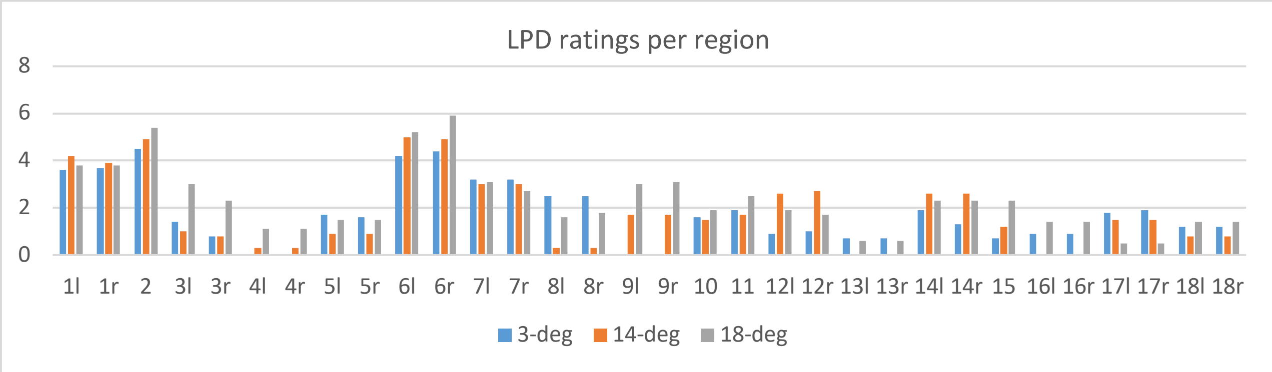

Figure 5: Average discomfort ratings in LPD questionnaires for 3 settings

HRV

The values of HRV features for each setting were computed with a 1-minute interval and averaged over 20-minutes to identify the correlations between the HRV features and comfort/discomfort ratings in 3 settings (Table 5). 3-degree setting had the lowest mean values compared with the other two regarding SDNN, pNN50, rMSSD and Mean NN. Mean HR was the highest under 3-degree condition. Yet for most features the relationships were not significantly different.

Table 5 HRV Features per setting

	3-deg	14-deg	18-deg
SDNN	55.3	60.4	58.3
pNN50	28.6	32.8	34.6
rMSSD	55.3	61.1	61.1
Mean NN	801.4	843.4	837.6
Mean HR	75.9	72.8	72.3

Table 6 Pearson' correlation of values of HRV features and subjective comfort/discomfort ratings at corresponding settings (**, p<.05; **, p< .01*)

Parameters	**discomfort**	**comfort**
SDNN	0.0756	0.2721
pNN50	0.1806	0.274
rMSSD	0.0733	0.329
Mean NN	0.5778**	-0.5079**
Mean HR	-0.5263**	0.4409*

Table 7 Comfort ranking of 3 settings

	3-degree	**14-degree**	**18-degree**
Mean ranking	2.3	1.4	2.2

Pearson's correlation coefficients were calculated between the mean of HRV features of 10 subjects and the corresponding comfort/discomfort rating (Table 6). The results indicate that Mean NN and Mean HR were significantly correlated to both the comfort and discomfort ratings.

Mean HR was also found to have a larger correlation to discomfort (r=.5263, p<.01) than comfort (r=.4409, p<.05). It was different to the results of the study of Beggiato et al. 2018. Mean NN was found to be significantly correlated to both comfort (r=-.5079, p<.01) and discomfort (r=.5778, p<.01). This is in accordance with previous studies, where it was found that the mean NN was correlated to physiological stress and physical pain (Terkelsen et al., 2005). This indicates that both stress and pain are the constructs of comfort and discomfort.

The comfort rankings given by participants after all three settings showed that they experienced the 14-degrees setting as most comfortable while the 3-degrees is the least comfortable. The rankings were consistent with the results of mean NN. Previous research found that sitting on a backward tilting seat may have benefits on pressure relief and increased blood flow (Sonenblum & Sprigle, 2011), which might be a possible explanation of this phenomena.

Pressure distribution

Table 8 presents the contact areas and mean pressure of these 3 settings, which are visualized in Figure 6. In the figure, the horizonal axis and the vertical axis stands for the index of the cells (48x48) in two directions and the colour represents the amplitude of the pressure. As expected, the mean pressure on the backrest increased as the angle becomes larger, while it decreases on the buttock. However, with respect to total force on the buttock, it increased slightly from 14-degree setting to 18-degree. It might mean that the supporting force from the floor on participants' feet changed, which may imply that participants changed their sitting posture. The contact areas on both the backrest and the buttock increased as the inclination angle gets larger. It can be inferred that people tend to sit more to the back of the seat in an inclined configuration, which results in larger contact areas.

Table 8: Contact area (cm^2), mean pressure (N/cm^2) and total force (N)

	Top			**Bottom**		
AOA	Contact area	Mean Pressure	Total	Contact area	Mean Pressure	Total
3-deg	887.1	0.118	104.7	1484	0.318	471.9
14-deg	1100	0.128	140.8	1555	0.275	427.6
18-deg	1161	0.138	160.2	1642	0.261	428.6

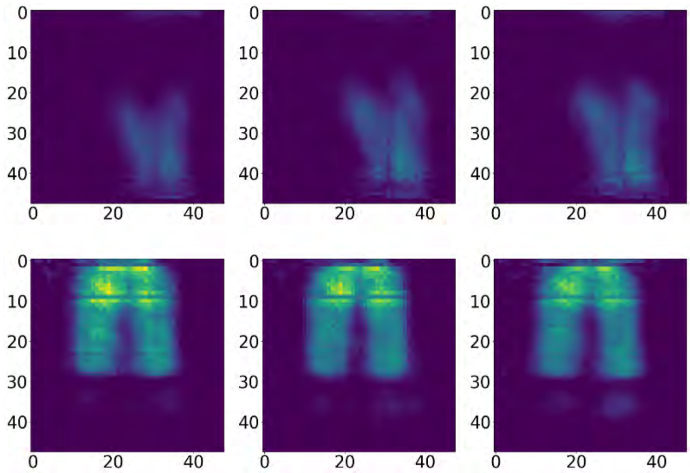

Figure 6: pressure map (left to right: 3-deg, 14-deg, 18-deg)

Limitations

This study was the first phase of the exploration where only a limited number of participants were recruited. The short stature of the population might explain that there were only a few participants that reported discomfort about the leg rooms. Besides, in the experiment, participants were allowed to talk as in the real flight, and the talking time and duration were not precisely controlled and recorded. This may have affected the perceived comfort/discomfort of participants.

Conclusion

In this research, 10 participants experienced 3 setups of the angle of attack (AOA) for 20 minutes. Subjective and objective measures indicated that the AOA is not linearly related to perceived comfort and discomfort of passengers. A certain degree of inclination might improve the feeling of comfort. Besides, it was found that 14-degree AOA is experienced as more comfortable than 18 degrees, which might be useful for airlines in setting up the take-off and climbing procedure.

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COMFORT CONGRESS 2021
Motion 2

Simulating 3D human postural stabilization in vibration and dynamic driving

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ABSTRACT

In future automated vehicles we will often engage in non-driving tasks and will not watch the road. This will affect postural stabilization and may elicit discomfort or even motion sickness in dynamic driving. Future vehicles shall accommodate this by properly designed seats and interiors whereas comfortable vehicle motion shall be achieved with smooth driving styles and well designed (active) suspensions. To support research and development in dynamic comfort, this paper presents validation of a multi-segment full body human model including visuo-vestibular and muscle spindle feedback for postural stabilization. Vibration transmission is evaluated using new tests with compliant automotive seats, applying 3D platform motion and evaluating 3D translation and rotation of pelvis, trunk and head. Dynamic driving is evaluated using a recently published "sickening drive" including a 0.2 Hz 4 m/s^2 slalom.
The model matches corridors of 3D human motion and reproduces vertical and fore-aft oscillations. Visuo-vestibular and muscle spindle feedback are shown to be essential in particular for head-neck stabilization. Active leg muscle control at the hips and knees is shown to be essential to stabilize the trunk in the high amplitude slalom condition but not in low amplitude horizontal vibrations. However, active leg muscle control can strongly affect 4-6 Hz vertical vibration transmission. Compared to the vibration tests, the dynamic driving tests show enlarged postural control gains to minimise head roll and pitch, and to align head yaw with the driving direction.
Human modelling can create the required insights to achieve breakthrough comfort enhancements while enabling efficient development for a wide range of driving conditions, body sizes and other factors. Hence, modelling human postural control can accelerate innovation of seats and vehicle motion control strategies for (automated) vehicles.

KEYWORDS

Comfort, Vibration, Biomechanics, Stabilization

Introduction

Automated cars provide opportunities for performing non-driving tasks such as reading books and looking at screens during the ride. Users will often take their eyes off the road hampering verticality perception and anticipation of vehicle motion. This will affect postural stabilization and may elicit discomfort and even cause more severe and/or frequent motion sickness [24]. The postural response of the human body to vehicle motion is of great value for studying human motion comfort [1, 2]. Deeper knowledge of postural stabilization and its relationship with motion comfort is particularly relevant for automated cars. Future (automated) vehicles shall accommodate these new requirements into the design of seats and interiors. Biomechanical modelling of the human body is essential to reveal underlying mechanisms such as postural stabilization and models predicting human movements and comfort can support vehicle design.

Biomechanical models with different approaches have been developed and validated to study seat interaction. Multibody and/or finite element models have been used to study impact conditions in full 3D. Lumped approaches (incorporating mass, spring and damper elements generally in single axis motion) have been used to compute the forces on a seat, usually during vertical and less often during fore-aft motions [3-5]. Three-dimensional multibody models represent the human body with multiple segments [6-8] whereas finite element models capture soft tissue and seat deformation in more detail [9, 10]. Due to computational efficiency, multibody models are more common to investigate factors such as human weight, road class, and vehicle speed on human postural response in different directional motions [8]. Previous comfort oriented full body models focused mostly on the vertical [15] and fore-aft directions [16], but simulation of lateral movements is also essential. A recent multibody model captured combined lateral, vertical and roll vibrations, in terms of apparent mass but was not validated in terms of predicted head and trunk motion [11]. Inverse dynamic musculoskeletal models have been used to analyse factors such as joint forces and muscular activity [12-14]. However, inverse models have limitations to be used for designing seat and vehicle control strategies as they are not able to predict body motions and body response forces.

Besides the body response to seat vibration, on which many previous studies focused, head control strategies are essential for motion comfort. The perception of head motion by vestibular organs and vision plays a significant role in (dis)comfort and motion sickness [17]. The head control objectives are suggested to be partly conflicting as head motion can be controlled relative to trunk or space [1] dependent on motion conditions and task. Previously, an advanced neck model that included vestibulocollic reflex (VCR), the cervicocollic reflex (CCR), and neck muscle co-contraction was validated [18]. Visuo-vestibular and muscle spindle feedback mechanisms were shown to be essential in particular for head-neck stabilization.

In order to predict head motions in presence of seat vibrations and dynamic motions, 3D full body models that include these mechanisms are required. In the current study, a full body model has been validated during fore-aft, lateral, and vertical perturbations and slalom dynamic motion, and used to study effects of active leg stabilization.

Methods

Model

Figure 1 : Human model in vibration test on experimental seat with configurable backrest with foam block modelled using finite elements.

The human active model (version 3.1), as distributed with MADYMO 7.8, was adopted using Matlab and Simulink for running simulations and post processing. The model was developed and validated primarily to simulate high severity crashes [19], and extended with postural stabilization for low severity conditions [20, 21]. The model includes active controllers to stabilize body segments, with feedback parameters specified for each body segment. These parameters manipulate the feedback gains of postural controllers. The head orientation can be controlled relative to a global coordinate reference system resulting in so called “head-in-space” control or alternatively relative to a local segment such as the trunk resulting in “head-on-trunk” control. In this paper a head-on-trunk control strategy was used to control the head. Recorded motion was applied to the seat and floor which interact with the body through contact with feet, seat, and seat back. The model interacted with seat cushion and floor using multibody contact surfaces and gravity was simulated. Details were provided in our previous study [22]. In the current study, finite elements were used to model the compliant seat back (Figure 1).

Scenarios

The model has been validated in two scenarios,

1) Vibration: Motion platform tests with wideband noise signals, separately testing 3 seat motion directions, on compliant seats [23].
2) Slalom: Dynamic vehicle tests with slalom manoeuvres [24].

The motion platform tests allowed validation in the frequency domain across a range of 0.15-12 Hz. The vehicle tests allowed validation with a dominant lateral frequency of 0.2 Hz. In both experiments 3D full body motion (translational and rotational) was recorded with an XSENS motion suit. From both experiments we selected eyes open conditions.

The slalom experiment was primarily designed to induce motion sickness. Subjects were driven with slaloms of 3.5 m amplitude at a frequency of 0.2 Hz leading to peak lateral accelerations of 4 m/s^2 [24, 25] while seated in the middle of the rear bench of a Toyota Prius. Motion was simulated by importing accelerations of the vehicle in lateral (Y) and fore-aft (X) as well as the Yaw angle of the vehicle in space.

The vibration experiment was designed to investigate the effect of sitting posture and backrest height [23]. In this paper we simulated the preferred posture with middle back rest height condition with 0.3 m/s^2 rms acceleration. The frequency domain transmission from platform to body segment (head, trunk, and pelvis) acceleration was determined using a Hanning window with 15 segments (i.e., a window size of 24 seconds) with 50 percent overlap [23].

Results

Slalom Validation

Using the recommended neck postural activation gain of 1.0, model outcomes were fairly similar to experimental translational and rotational responses for head, trunk, and pelvis (Figure 2). Head roll fitted the measured data perfectly, while trunk and pelvis roll were overestimated by the model. Head yaw seemed to follow the measured yaw with a short delay. The model was also simulated without leg control activation, reflecting absence of reflexive stabilization at the hips and knees. The model without leg activation showed extensive roll particularly for head and trunk and eventually fell over.

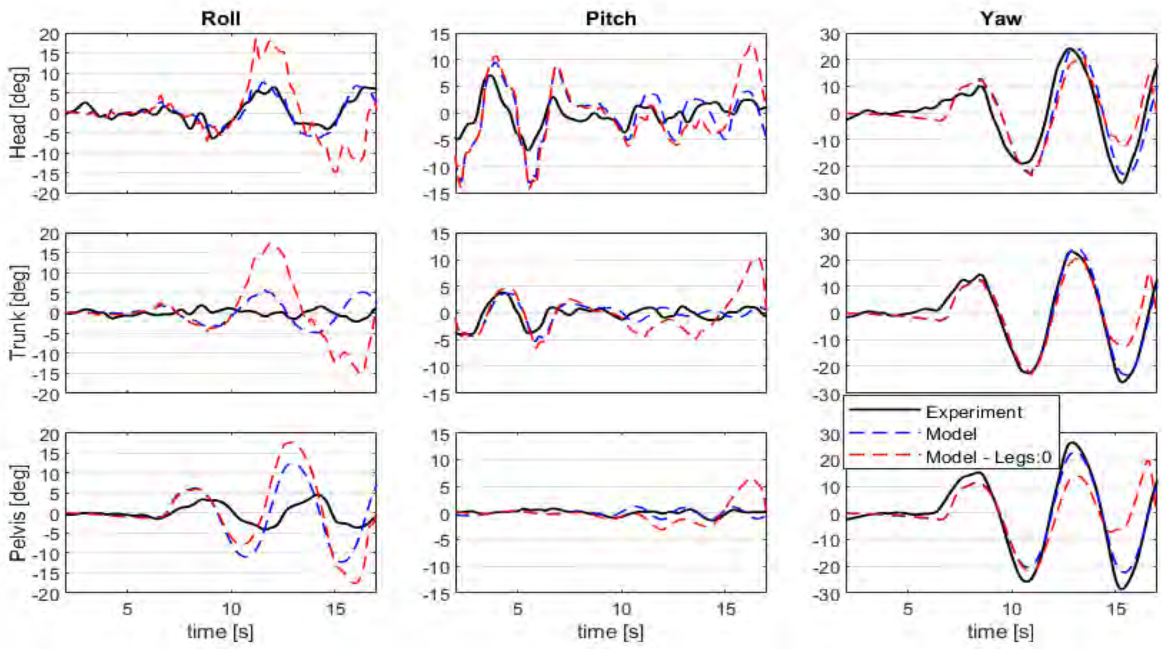

Figure 2 : Slalom. Model's prediction of head orientations (Blue Line for Model with legs activation set at 1, Red line leg activation set at zero) against the measured kinematics (Black line).

Vibration Validation

Frequency domain responses of body segments (head, trunk, and pelvis) were compared with the model for both translational and rotational body motion. A reduced neck activation gain of 0.2 was required to match the corridors of experimentally measured kinematics (Figure 3). Trunk responses to lateral perturbations from 2-4 Hz were underpredicted by the model. Rotational prediction of the model for head and pelvis closely matched the measured kinematics but trunk rotation was underestimated. Modelling without active leg controller strongly changed the vertical oscillations in all body segments, and slightly enlarged pelvis and trunk rotations during fore-aft and lateral perturbations.

Discussion

To our knowledge, this paper presents the first full body model validation for 3D head, trunk, and pelvis motion combining dynamic driving and vibrations in fore-aft, lateral, and vertical directions. Results showed that the slalom simulation (4 m/s^2 cornering) matched the measured data fairly well. The model also correctly predicted frequency domain responses with 0.3 m/s^2 perturbations.

Slalom simulations showed a good prediction of body segment rotations (Figure 2). Please note that body accelerations were also well predicted as presented in our previous work [22] for the first 45 seconds of the experiment, which includes one round of slalom, turn and part of the next round in the opposite direction. Trunk and pelvis yaw are well predicted, but the model's predicted head yaw is delayed compared to the measured head yaw. We attribute this delay to the fact that the subjects looked into the corner during the slalom.

In addition to the dynamic driving condition (slalom), the model responses to perturbations were tested in the frequency domain. Gain responses of body segments (head, trunk, and pelvis) well matched corridors of 3D measured motion. However, trunk rotational responses were underestimated by the model. Hence the spine of the model seems overly stiff. However we also found trunk rotations to be sensitive towards variations in the seat back model compliance and friction.

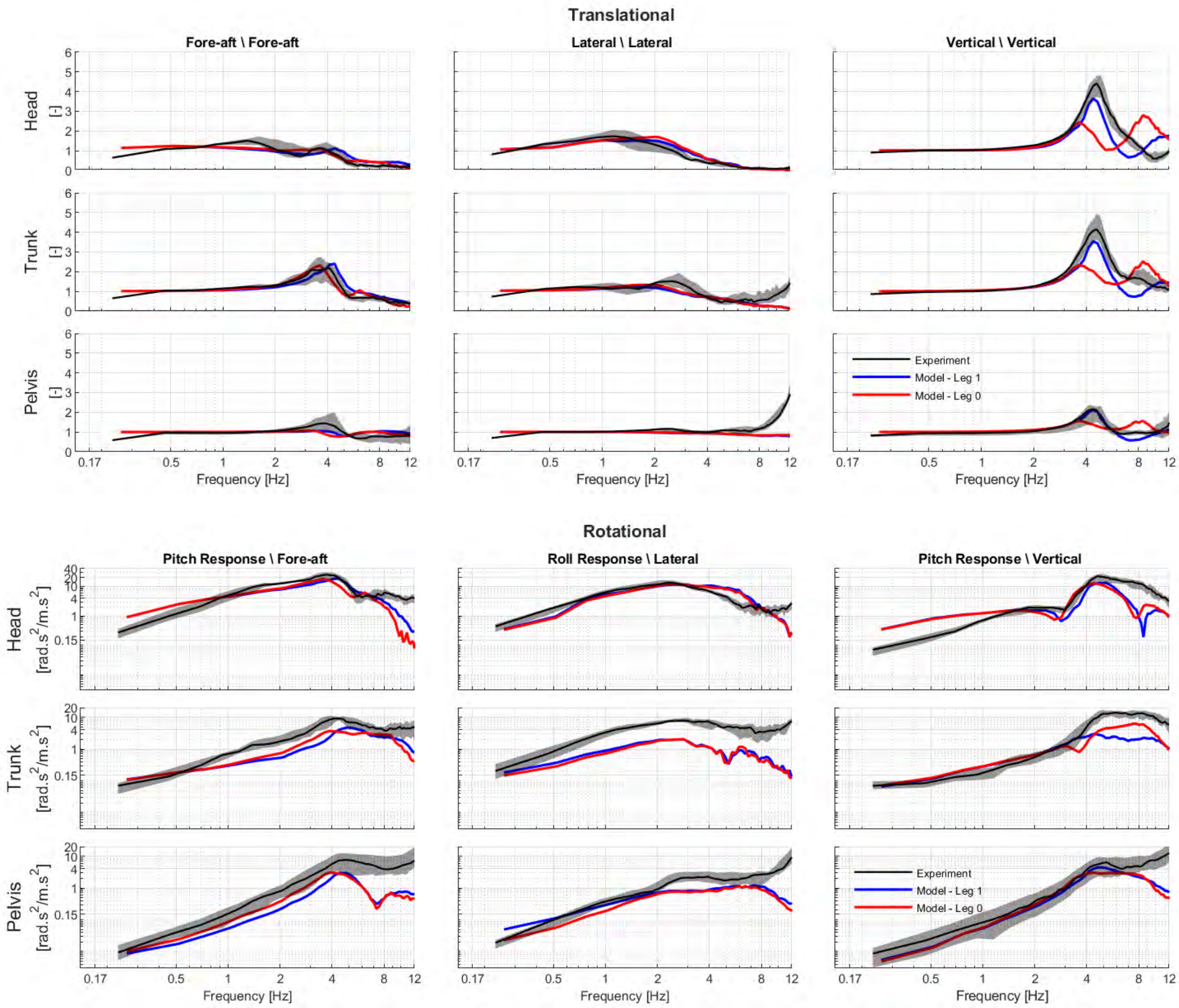

Figure 3 : Vibration. Model translational response (upper panel) and rotational response (lower panel) to platform perturbations in fore-aft (left), lateral (mid) and vertical (right) direction. Black lines represent the median of subject responses and dark shadows indicate 25th and 75th percentiles.

Modelling the slalom without active leg control resulted in excessive trunk and head roll (Figure 2) and the model eventually fell from the seat after two cycles of slalom. These results show the relevance of active leg control in lateral body stabilization in dynamic driving. However with low amplitude vibrations, active leg control hardly affected responses to fore-aft and lateral motion. This indicates the trunk to be mainly stabilized by the seat and the seat back in low amplitude loading. However vertical vibrations revealed a profound effect of leg control on 4-6 Hz oscillations. This may well relate to seat to upper leg interaction where leg control will stiffen the hips and thereby enlarge the contribution of seat to upper leg contact to vertical vibration transmission. We will further explore trunk stabilization including the role of the seat, seat back and active leg control in future studies.

The required neck activation control gain for a good fit with experimental data was much higher in the slalom (1.0) than the vibration scenario (0.2). It seems that postural stabilization is more active in intense dynamic manoeuvres. With advanced postural control models [18] we will further quantify the contribution of visual, vestibular and muscle spindle feedback in postural stabilization including adaptation to motion conditions.

There is room for improving the responses of head and trunk in the full body model. As a next step we aim to improve the model fit measuring and implementing seat characteristics. Further experiments with advanced seats, while varying posture and perturbation type will refine seat modelling techniques and improve our understanding of postural stabilization of seated vehicle users.

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Novel Car Seat Posture Assessment through Comfort and User Experience

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ABSTRACT

The increasing automation in many industries, including the vehicular market, involves a profound transformation. Since in automated driving systems, driving is no longer the primary task, the driver no longer needs to be the epicenter of the interior design. This research-based design approach explores occupants' physical experience with prototypes, and this becomes an essential part of the design and validation of the future vehicle interior. The current study is the first to examine comfort of different seat angles in order to fulfil the need of sleeping in a vehicle, based on the effect of comfort perception in close-to-real conditions testing. Therefore, user experience and comfort are the main drivers to assess the most suitable seating position, including the seat pan and backrest angles, for sleeping in a vehicle environment. Our findings suggest that users prefer the reclining and the lying seats in, respectively, short/medium and long-term use cases.

KEYWORDS

comfort, user experience, car seat, testing, seat angles

Introduction

In recent years, the trend towards higher automation has increased in many industries, including the vehicular market, where the release of automated driving systems is expected in the imminent future (ERTRAC Working Group, 2019). This new type of transport will involve a deep transformation of mobility to achieve its main general goal, which is to improve quality of life. Within this aim, two specific potential benefits of automated driving are increased transport comfort, safety and more efficient use of time during travelling (Meyer, Blervaque & Haikkola, 2019).

Since in automated driving systems, driving is no longer the main task, the driver no longer needs to be the epicentre of the interior design. Therefore, the purpose of the car interior should be radically changed so that the space can be used to allow alternative activities other than driving. Hence, the shift towards higher automation levels implies a focused search for new use cases that allow optimizing the interior design of automated cars. This search for new vehicle concepts is evident at leading automobile manufacturers, where an intensive and adventurous exploration is taking place in the creation of designs and models in order to define the upcoming future of the car interiors. At the same time, various studies are being carried out with the purpose of finding the most desired or expected uses for the interior of vehicles. As a result of several surveys, when car occupants were asked about more desired activities within automated vehicles, they showed an increased interest in sleeping or resting in this new setting (Cyganski, Fraedrich & Lenz, 2015). However, in order to sleep inside a vehicle, the interior as we know it today would have to be significantly modified.

The current knowledge about car interior, safety, comfort, usability, etc. has been generated for several decades through the optimization and gradually settlement of this technology in society to establish the current high standards, by learning from user daily use. In the case of the forecasted automated driving revolution, it is now necessary to predict, study and analyse a completely new future scenario in order to be able to develop new viable systems. To date, we have seen both visual and physical replicas of how different conceptual interior environments might look like, including interiors with sleeping as their primary use case. Furthermore, the effort to find technical solutions for the interior arrangement is evident in recent scientific articles and patent publications on the topic. However, most of the knowledge creation on this scope is relying on the setup of theoretical scenarios, where the actual occupant physical experience is none, or very limited. This makes the future scenario difficult to imagine accurately, as most of the information currently is based on simulations, predictions, and assumptions with little or no actual human experience of the proposed systems.

In particular, research on seats for sleeping in cars is quite limited, primarily due to the high level of novelty of the topic. In order to address the issue of sleeping in a new autonomous vehicle environment, multidimensional research becomes necessary to be able to look at the topic from different perspectives, and to find comparable examples in different fields. Thus, when dealing with seats, a predominant topic in the literature has been comfort and discomfort, and, especially, the ergonomics of the seats that are used in different contexts, such as cars, trains, planes, offices, etc. Surveys have been a common method to determine comfort factors affecting user's sleep experience. For example, the work (Rosekind, et al, 2000) studied the factors affecting sleeping comfort on existing aircraft bunks beds versus the experience of sleeping comfort at home, based on the perceptions and opinions of the participants. The main limitation of that study is that it only included crewmembers from three airlines sleeping in bunks of three different aircrafts, limiting the geometries, situations and conditions to those defined by the existing facilities.

The idea of sleeping while travelling has been explored primarily for long-haul transportation industries, such as airplanes. The work (Roach et al, 2018) explored the influence of different seat angles on sleep quality at naptime. The results were consistent with previous studies and concluded that the quantity and quality of sleep increase as the back angle of the seat increases, as they depend mainly on head stability and autonomic activity. However, the study has several limitations, such as dissimilarity to real conditions and characteristics of airplane seats.

Another approach to defining the characteristics of the best ideal seat for sleeping in a vehicle is to focus on biomechanical quality. The study (Stanglmeier et al, 2020) evaluated the biomechanically quality using the interface pressure score, according to the effect of the different seat pan angles and three different backrest angles. These evaluations were complemented by the subjective evaluation carried that the participants made when they were asked how adequate the position is for sleeping. Some seat angles were defined as the most suitable because they provide the most favourable pressure properties, but this does not correlate with the highest rating in suitability for sleeping. Some limitations of that study include the short duration of the test session, a static scenario, and only male participants. Analysing a scenario closer to reality, i.e., more dynamic and with a wider range of participants and a longer test time, would be beneficial to obtain a more reliable result. Moreover, subjective ratings need to be further explored, as purely pressure data can overlook the actual user needs.

The main aim of the present study is to develop a replicable framework where user experience, comfort and safety are the main drivers for the design and validation of future vehicle systems, and where the occupants' physical experience with prototypes becomes an essential part of the development process. This paper specifically focuses on explorations of the seat towards the definition of the most suitable position of the seat, including the seat pan and backrest angles, for sleeping in a vehicle environment.

Method

In the study carried out for this paper, subjective comfort and user experience were analysed to discuss possible answers to the following questions:

- How is the perceived comfort of the seat position affected by driving dynamics of real-world conditions?
- Do seat angles affect perceived comfort in real-world conditions?
- Do discomfort of different human body areas and restraint systems affect general comfort ratings?
- How does time affect comfort and discomfort ratings?
- How do first impressions of different seatback angles reflect on their suitability for sleeping?

To answer these questions, an experimental evaluation was carried out consisting of a trial drive in a vehicle equipped with a prototype seat configured based on a close-to-real scenario. In particular, the used vehicle was a Volkswagen T6.1 Bus equipped with a mounted prototype seat at the back part of the vehicle. The vehicle environment was representing the environment of a driverless vehicle, and the space for the participant was a free, clean area, with darkened windows, in order for the user to concentrate on the seat, comfort and experience. The seat used for all the conditions and all the participants was designed to be suitable for three positions as well as for the transition between them in a suitable manner. The seat had a minimal geometry, similar to car seat designs, and did not include any armrest.

A study of several parameters on perceived comfort was carried out and the influence of different seat angles in the same condition was evaluated. To determine which driving scenario would be more suitable for investigating the questions discussed here, a number of possible cases involving different tracks, times, speeds and manoeuvres were screened, and higher speeds and accelerations were excluded to avoid unclear and unsafe conditions. The selected scenario involved a 15 minute-drive per position at a constant speed of 30 km/h through a dynamic track that included a series of different curves. Moreover, the accelerations were controlled ($ay \leq 0{,}2g$) during the drive. Furthermore, in order to maintain maximal safety levels, the seat included a 7-point seat belt, result of the combination of a typical 3-point seat belt and a 4-point seatbelt in the opposite direction with an extra buckle point between the users' upper legs. The trial drives were conducted in the dynamic track of Ehra-Lessien Proving Ground in Germany for two days.

The definition of the conditions involved the selections of the suitable seat pan, seat back and leg support angles. The choice of angles was done with the selection of use cases in mind to cover a broad range. The three seat positions were: upright, reclined and lying (see Figure 1). The back angles of the seat to the vertical were: 20° in the upright condition, which is comparable to the one in typical car; 40° in the reclined condition, which is the back angle of some car seats under development for future cars (Nica, 2020); and 87° in the lying position, very close to the flat angle of a bed. Respectively, the seat pan and leg support angles were selected in order to support the body in a natural way for each of the use cases. The seat pan was positioned at 10°, 20° and 0° (with respect to the horizontal) and the leg support was set at 10°, 65° and 90° (with respect to the vertical). The seat was adjusted always from the upright position to the designed position (e.g., reclined) before each trial drive in a smooth pre-programmed transition with the user already correctly sitting. Each round was 1.25 km approximately and involved a series of different curves. The goal of the trial drive was to represent a drive with an autonomous car, which would have a smooth drive

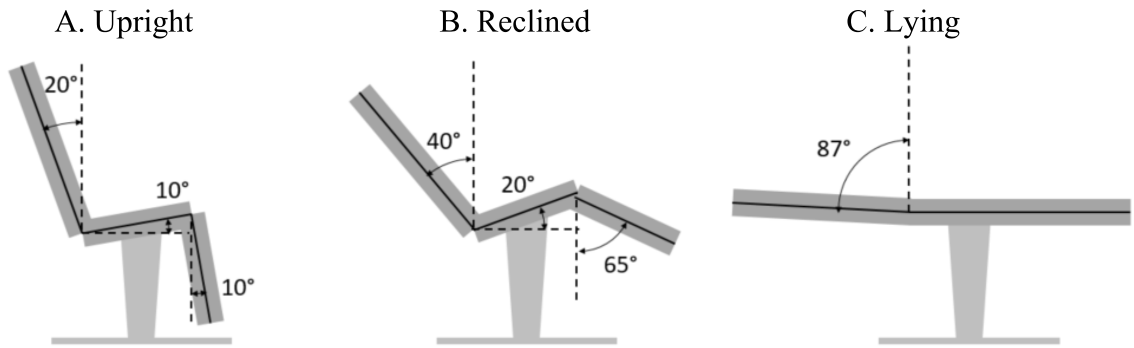

Figure 1: Configuration of seats for the upright, reclined, and lying conditions.

Ten healthy adults (8 men and 2 women) volunteered for a subjective experimental testing of a reclining seat. The participants had some previous knowledge on the topic, but no previous experience in using the seat under the defined conditions. The participants had a mean age (±SD) of 42.9 ± 12.0 years, a mean height of 182.8 ± 9.6 cm, a mean weight of 80.9 ± 13.1 kg, and a body mass index mean of 24.1 ± 2.7 kg/m2.

The participants were welcomed and the instructions were explained. In particular, before the experiment, the participants were informed in detail about the content and procedure of the study and given their informed consent. Besides, all participants confirmed that they did not have any musculoskeletal injury or disease that affected sleep. Afterwards, they had the chance to drive in the car and answer a comfort questionnaire. Throughout the experimental testing, the subjects were object of a survey with 15 questions of varied format, including multiple-choice, short written responses, and fill-in-the-blank answers. The survey was divided into four sections: "Questions Before Trial Drive" (basic demographic - 5 questions), "Comfort during the trial drive" (questions while the participant is using the seat for each condition - 4 questions), "Pause Questions- After each Seat Position" (questions after the trial drive for each condition - 4 questions) and "Comfort after the complete trial drive" (question after the complete trial drive - 1 question). In the section "Comfort during the trial drive" for each condition, the participant answer questions starting at minute 0 and again at minute 10 of the drive. The study had repeated measures, counter-balanced and randomized design with the three conditions.

Measurements of comfort and discomfort were obtained using a modified scale of the Borg (1990) CR-10 scale and the Corlett and Bishop (1976) discomfort scale, which assesses the degree of discomfort/comfort with respect to the seat. Participants rated one item on a seven-point Likert scale as to how comfortable they felt (-3 = strong discomfort, +3 = strong comfort) and four items on a four-point numerical rating scale as to how uncomfortable they felt (-3 = strong discomfort, 0 = neutral/no discomfort). Participants were asked to rate these items three times, at 0 minutes of the test drive, at 10 minutes of the test drive, and just after the test drive. These ratings help identify areas of discomfort and track the perception of comfort in a brief experience. The hypothesis of the study was that increasing the back angle would to contribute to occupant comfort and be perceived as a more adequate for sleep in a driving scenario.

Initial findings

The 1.2.5042 version of RStudio (RStudio Team, 2020) was used for all statistical analyses. The data was tested for normality using the Kolmogorov-Smirnov test, and tested for association between paired samples using one of Pearson's product moment correlation coefficient, Kendall's tau or Spearman's rho, in order to describe the effect of different back and seat angles on the result variables. No significant conclusion was found in an initial analysis, probably because this first test was of a short duration and included a low number of participants. However, an analysis through observation yielded more successful results drawn from the study. Table 1 details a summary of mean values, standard deviations, and test statistics for the analysed data. A difference can be perceived in the ratings of the different positions throughout the three different recording times (0 min, 10 min, 15 min). In the case of the upright position, the comfort ratings worsen with the time. Meanwhile, the reclined maintained the ratings mostly stable for the duration of the study. Finally, the lying position rating improved over time, from minute 0 at 1.2 to the end of the drive at minute 15 at 1.9. This phenomenon can be explained by many comfort perception models, such as the model proposed in (Naddeo, Cappetti & D'Oria, 2015), where comfort is the result of several factors, such as environment, psycho social, and cognitive factors, rather than strictly physical qualities. In several similar models, one of the inherited parts of comfort perception is the expectation or previous experience. Thus, it could be assumed that the participants had experience with normal car seats and their angle, and that they had no experience with lying position in similar circumstances (i.e., inside a car in a dynamic scenario).

Table 1: Measures for the comfort and discomfort perceptions for the upright, reclined and lying condition

Variables	Time	Body part	**Upright (20°)** M (±SD)	**Reclined (40°)** M (±SD)	**Lying (87°)** M (±SD)
Overall comfort	0´		2.0 (±0.9)	1.6 (±1.1)	1.2 (±1.4)
(-3 = strong discomfort, +3 =	10´		1.6 (±1.0)	1.8 (±0.7)	2.0 (±0.4)
strong comfort)	15´		1.2 (±1.5)	1.7 (±0.8)	1.9 (±1.4)
Discomfort	0´	Head/Neck	0.0 (±0.0)	-0.4 (±0.9)	-0.6 (±0.7)
(-3 = strong discomfort, 0 =		Back	-0.4 (±0.5)	-1.1 (±1.0)	-0.7 (±0.6)
no discomfort)		Buttocks	-0.1 (±0.3)	-0.4 (±0.7)	-0.2 (±0.4)
		Legs/Feet	-0.7 (±0.8)	-0.9 (±0.8)	-0.4 (±0.5)
	10´	Head/Neck	-0.2 (±0.4)	-0.4 (±0.7)	-0.7 (±1.0)
		Back	-0.6 (±0.7)	-0.8 (±0.7)	-0.8 (±0.9)
		Buttocks	-0.1 (±0.5)	-0.4 (±0.7)	-0.3 (±0.6)
		Legs/Feet	-0.8 (±0.7)	-1.0 (±0.8)	-0.2 (±0.4)
	15´	Head/Neck	-0.2 (±0.4)	-0.4 (±0.5)	-0.8 (±0.7)
		Back	-0.4 (±0.5)	-0.7 (±0.6)	-0.7 (±0.8)
		Buttocks	-0.4 (±0.7)	-0.4 (±0.7)	-0.3 (±0.6)
		Legs/Feet	-0.8 (±0.7)	-0.9 (±0.7)	-0.3 (±0.6)
Any discomfort by the seatbelt?			No (80%), Yes(20%)	No (100%), Yes(0%)	No (50%), Yes(50%)

With regard to discomfort in different body parts, there was only a clear effect on overall comfort ratings in the case of the legs/feet and back areas. The discomfort ratings in the head and the buttocks areas showed no correlation with the overall comfort ratings, which could be seen as a somewhat surprising result. Besides, the presence of seatbelt discomfort shows no direct relationship with overall comfort ratings. Thus, the restraint system impact on user experience and comfort should be further explored in future research.

When the participants were asked about preferred position for sleeping the results varied according to the use case. The lying position was the favoured position by most of the subjects (90%) for sleeping in long-term travelling. In contrast, the reclined position was selected by 60% in both the short and medium term travelling.

The current study is the first to examine comfort of different seat angles in order to fulfil the need of sleeping in a vehicle, based on the effect of comfort perception in a close-to-real conditions.

Preliminary findings suggest that both the seat base and the back angles affect the comfort perception and that users are drawn to choosing a flatter position than the current one in series production cars, for the sleeping use case.

Conclusions

The present study proposes a combination of tests in real conditions with methodical subjective ratings to provide the most favourable conditions to understand how user opinions can change in the short term. The results suggest that users prefer the reclining and the lying seat in different use cases (long versus short and medium term). This work provides the basis for further investigations on long-term comfort, safety and vehicle movement effects on comfort related to sleep. On the other hand, to overcome the inherent limitation that the data collected is subjective, in future works the pressure record or other objective measurements will be included to complement subjective data. Besides, a longer-term study in which different types of car occupants can have the chance to sleep in close-to-real conditions would be ideal for a profound and reliable conclusion.

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Reduction of Carsickness using a Headrest with Support to Suppress Head Motion

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ABSTRACT

There are growing concerns about increasing carsickness in a self-driving car as drivers perform various non-driving tasks during autonomous driving. It would appear that reducing motion of the head where the vestibular and the visual systems locate effectively reduces carsickness. Hence, we developed a novel headrest with occipital bone support (OBS) that could suppress passengers' head motion and examined its effectiveness on carsickness. In the experiment, participants sat in a minivan's second-row seat behind a driver's seat and watched a video on a tablet terminal during a 30-minute vehicle journey on urban roads and reported the carsickness ratings at 1-min intervals. One of four seating conditions (a combination of two seating postures, 'upright' and 'relaxed', and two types of headrests, 'normal' and 'OBS') was examined in each journey. Head and thorax motion was also acquired using wireless motion sensors. Motion Sickness Dose Value (MSDV) was calculated for each axis. The results showed that the developed OBS headrest significantly reduced MSDVs at the head, and the mean accumulated illness ratings for 30 minutes were also significantly reduced by more than 40%.

KEYWORDS

Carsickness, Head motion, Headrest

Introduction

It is known that vehicle drivers rarely get carsickness, but passengers often experience it. It has been reported that vehicle passengers suffer less carsickness when they can see the external forward view and more sickness when the external view is blocked or under reading/video viewing conditions (Griffin and Newman (2004), Kato and Kitazaki (2006, 2008)). Therefore, there are growing concerns about increasing carsickness in a self-driving car as drivers perform various non-driving tasks during autonomous driving (e.g. Diels and Bos (2016)).

Kato and Kitazaki (2006) evaluated the effects of different head and body restraints on head motion and carsickness of the passengers who sat in the second-row seat behind a driver seat and could see the external view. They reported that the increased restraints reduced passengers' low-frequency head motion and carsickness. They also found that the reduction of relative visual motion between passenger's eyes and an in-vehicle display using electric pitch compensation and optical collimation could reduce carsickness. Wada and Yoshida (2016) examined the effects of head tilting in a passenger car where passengers could see the external view through the front window. They found that head-tilt against centrifugal direction decreased passengers' carsickness compared with tilting in the opposite direction.

Hence, we hypothesized that reducing the motion of the head where the vestibular and the visual systems locate could reduce the occurrence of excessive low-frequency acceleration at the head and mitigate carsickness in an internal-view condition.

This paper describes the effects of a newly developed headrest with occipital bone support designed to suppress passengers' head motion on carsickness in a video viewing condition in a moving vehicle.

Methods

Vehicles and Journey

The study was undertaken using a minivan (NISSAN ELGRAND, 2.5L engine type) which had an automatic transmission. The second-row seats of the vehicle were equipped with articulated backrests, which passengers could adjust the reclining angle of the upper and lower backrest individually. A 10.1-inch tablet terminal was attached to the driver's headrest for the participant's visual tasks during the experiment. The distance between the tablet and the participant's eyes was approximately 800 mm, and the height of the tablet screen and the participant's eyes was the same. The vehicle was driven for 30 minutes on urban roads in Yokohama city, where there were many intersections without traffic signals. The driving course was fixed, and the drivers were instructed to drive safely and keep a consistent driving manner in each journey. As described later, the drivers could monitor the real-time vehicle floor MSDVs in fore-aft and lateral direction and adjust the acceleration, braking and cornering.

Motion Measurement

Acceleration (fore-aft, lateral and vertical)) and angular velocity (roll, pitch and yaw) was measured continuously during every journey on the vehicle floor, participant's head and thorax using wireless hybrid sensor WAA-010 (Wireless Technology Co. Ltd., Tokyo, Japan). The angular velocity data was differentiated with respect to time and transformed into the angular acceleration. The linear and angular acceleration was frequency-weighted using W_f frequency weighting and the motion sickness dose valus (MSDVs) defined in ISO2631-1 (1997) were calculated for every journey.

$$MSDV = \left[\int a_w^2\,(t)dt\right]^{1/2}$$

where $a_w(t)$ is the frequency-weighted acceleration.

Though the MSDV and W_f were developed to predict motion sickness caused by vertical motion, we extended them to other directions.

Participants

Eight healthy volunteers participated in the study. All participants were male, aged 19 to 56 yr, and had previously experienced carsickness. They were selected from the employee population of NHK Spring company. They gave their informed consent to participate in the experiment, which was approved by the Ethics Committee of the Seating Division, NHK Spring Co., Ltd.

Illness Rating Scale

Every minute during the journey, participants were asked to rate their illness using a scale from 0 to 6 (0: no symptoms; 1: any symptoms, however slight; 2: mild symptoms, e.g., stomach awareness but not nausea; 3: mild nausea; 4: mild to moderate nausea; 5: moderate nausea but can continue; 6: moderate nausea and want to stop). The journey was terminated if an illness rating of 6 was reached or the full 30-min journey had been completed.

Experimental procedures

Participants were seated in a second-row seat of the test vehicle behind a driver seat and wore a safety belt. They were asked to keep their heads in touch with a headrest during the journey and watch a video on a screen. One of four seating conditions, a combination of the following two seating postures and two types of headrests, was examined in each journey.

1) Sitting postures (Figure 1)
   a) Upright: Normal sitting posture without armrest and leg rest; Backrest angles were 23 degrees (lower) and 19 degrees (upper) from a vertical direction at the backrest surface.
   b) Relaxed: Relaxed posture with armrest and leg rest; Backrest angles were 33 degrees (lower) and 18 degrees (upper) from a vertical direction at the backrest surface.
2) Headrest (Figure 2)
   a) Normal: Normal headrest.
   b) OBS: Headrest with occipital bone support.

(a) Upright (b) Relaxed

Figure 1: Experimental seat with a normal headrest and seating geometry

Figure 2: Headrest with an occipital bone support

The V-shaped occipital bone support was made from polyurethane foam firmer than foam for a standard headrest. It could support occipital bone's right and left side regardless of passengers' body type and shape of the cranial bone. For safety reasons, the height of the occipital bone support was carefully designed not to overstress the occupant's neck when excessive lateral force acted.

The order of the seating conditions was counterbalanced. Each participant experienced one condition a day and at the same hour each day to prevent the influence of the circadian rhythm.

After the participants experienced all of the four conditions, they were asked to rate how easy it was to watch a video in OBS condition compared to in normal headrest condition using seven-point rating (3: very easy, 2:easy, 1: slightly easy, 0: the same, -1: slightly hard, -2 hard, -3: very hard).

Data analysis

Non-parametric statistical methods were used throughout for data analysis. As all eight participants experienced all four conditions in this study, a matched-pair analysis was applied to compare four conditions. Multiple Comparison Procedure was applied for significant tests. Firstly, p-values for all pairs were calculated using the Wilcoxon signed-rank test (two-tailed). Then the values were adjusted using the Benjamini-Hochberg Procedure to control False Discovery Rate (FDR) (Benjamini and Hochberg (1995)). We employed $q^* = \alpha = 0.05$ for the adjustment.

Statistical data analysis was performed using JMP version 16.0.0 (SAS Institute Inc., Cary, U.S.)

Results

Figure 3 shows the mean illness ratings of eight participants for every minute of the 30-min journey, and Figure 4 shows the accumulated illness ratings for 30 minutes. The results of the Multiple Comparison test is shown in Table 1 (a). Significant differences were found between the three conditions ($p<0.05$). The accumulated illness ratings decreased by 42.2% in the Upright-Normal condition, 50.7% in the Relaxed-OBS condition against the Upright-Normal condition.

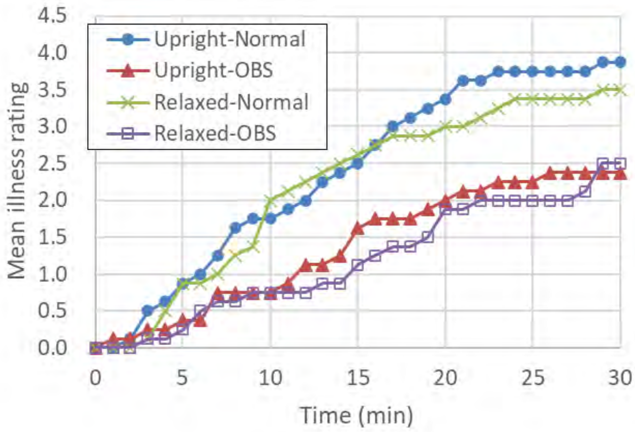


Figure 3: Mean illness ratings during the 30-min journey

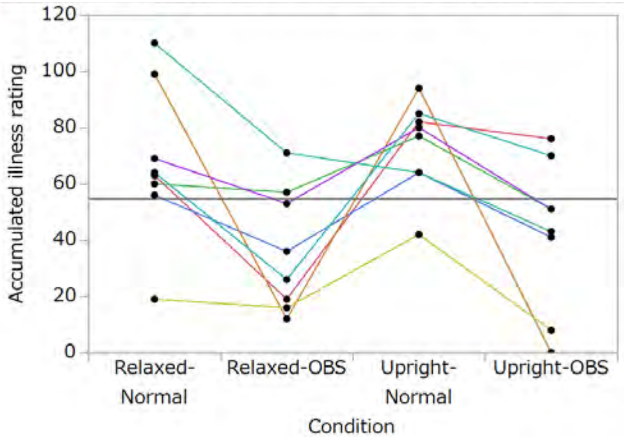
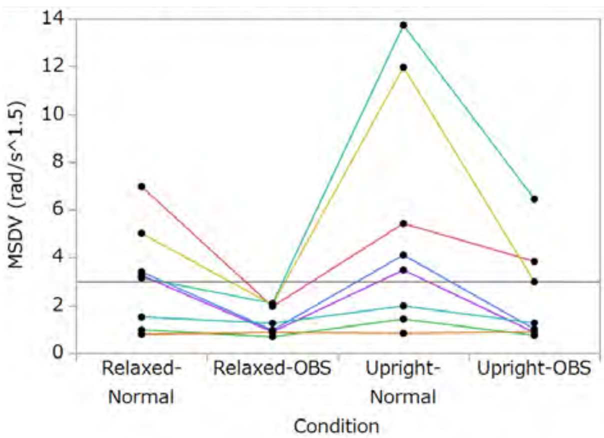
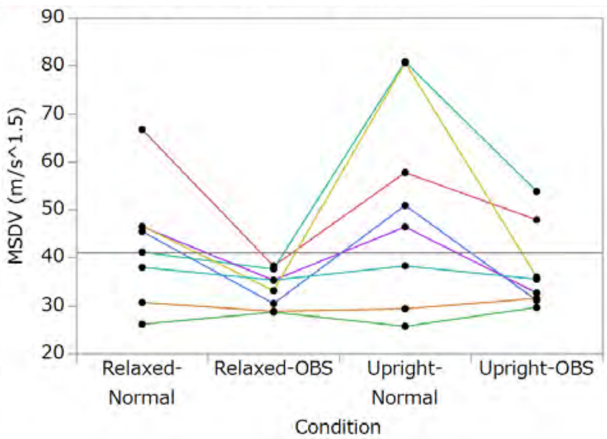


Figure 4: Accumulated illness ratings during the 30-min journey. Lines connect data of the same participant with the same colour.

Figure 5 shows MDSVs in four conditions in head roll and head lateral directions. The results of the Multiple Comparison test showed that there were significant differences between the four conditions in the head roll direction ($p<0.05$; Table 1(b)). The decrease rate of mean MSDVs was 57.9% in the Upright-OBS condition and 75.0% in the Relaxed-OBS against the Upright-Normal condition. In the head lateral direction, only significant trends were found between the four conditions ($p=0.0821$, 0.0702; Table 1(c)). The mean MSDVs reduced by 27.3% in the Upright-OBS conditions and 34.7% in Relaxed-OBS against the Upright-Normal condition. No significant differences were found in the other directions ($p>0.05$). The results of the Wilcoxon signed-rank test on video viewing ease showed that there was a significant difference between OBS and normal headrest conditions ($p<0.05$), and it was found that the OBS was suitable to watch a video in a moving vehicle.



(a) Roll direction



(b) Lateral direction

Figure 5: Comparisons of MSDVs in roll and lateral directions in four conditions. Lines connect data of the same participant with the same colour.

Table 1: Results of Multiple Comparison test between the four conditions.

(a) Accumulated illness ratings

Rank	Pair	p-value	Adjusted p-value
6	Upright-OBS vs Relaxed-OBS	0.9453	0.9453
5	Upright-NML vs Relaxed-NML	0.2500	0.3000
4	Upright-OBS vs Relaxed-NML	0.0781	0.1172
3	Upright-NML vs Relaxed-OBS	0.0156	0.0312*
2	Relaxed-NML vs Relaxed-OBS	0.0078	*
2	Upright-NML vs Upright-OBS	0.0078	*

(b) MSDVs in roll direction

Rank	Pair	p-value	Adjusted p-value
6	Relaxed-NML vs Upright-OBS	0.2500	0.2500
5	Relaxed-NML vs Upright-NML	0.1094	0.1313
4	Relaxed-OBS vs Upright-OBS	0.0234	0.0351*
3	Relaxed-OBS vs Upright-NML	0.0156	*
3	Upright-OBS vs Upright-NML	0.0156	*
3	Relaxed-OBS vs Relaxed-NML	0.0156	*

(c) MSDVs in lateral direction

Rank	Pair	p-value	Adjusted p-value
6	Relaxed-NML vs Upright-NML	0.6406	0.6406
5	Relaxed-NML vs Upright-OBS	0.2500	0.3000
4	Relaxed-OBS vs Upright-OBS	0.0547	0.08205 †
4	Upright-OBS vs Upright-NML	0.0547	0.08205 †
2	Relaxed-OBS vs Upright-NML	0.0234	0.0702 †
2	Relaxed-OBS vs Relaxed-NML	0.0234	0.0702 †

(*: $p<0.05$, †: $p<0.10$)

Discussion

As Figure 4 indicates, all participants assigned a headrest with OBS with lower illness scores than a normal headrest in the sitting posture. However, the MSDVs in roll and lateral directions didn't show such unanimous results though significant differences and trends were found. On the other hand, the differences in the illness ratings between with and without OBS were consistent with those of the predicted motion sickness incidences in different head movement conditions calculated using a six-degree-of-freedom head motion model (Wada et al., (2018)). These suggest that carsickness in video viewing condition is not induced solely by the roll or lateral head motion but by complex six-degree-of-freedom head motion and relative motion between passenger's eyes and a display and other factors such as somatosensor.

Regarding the video viewing ease in a moving vehicle, the participants commented that they considered the OBS better than the normal headrest because the former suppressed head yaw motion relative to a headrest and made it easier to glance toward a display. However, differences in MSDVs in yaw direction between the OBS and normal headrest conditions were not statistically significant. It appears that rapid head yaw movement during cornering was not included in calculated MSDVs as the upper cut-off frequency used to calculate MSDV was set at 0.68Hz and resulted in such inconsistency.

Conclusions

The effects of a developed headrest with occipital bone support (OBS) on carsickness were examined in a field study. The results showed that the OBS effectively reduced occupants' low-frequency head motion and mitigated carsickness significantly compared to a normal headrest. It was also found that the use of OBS improves the video viewing ease on an in-vehicle display. The results suggest that the simply structured OBS headrest can be low-cost and effective measures to reduce carsickness in passenger vehicles, including a self-driving car in which an increase in carsickness is concerned.

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Dynamic Comfort Testing of Automotive Seats in a Laboratory Setting

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ABSTRACT

The goal of this study was to use three identical looking automotive seats with different foam formulations (different stiffness, similar hysteresis) to determine whether there were differences in WBV exposures and self-reported comfort ratings across the three seats (Seat A, B, and C). Ten participants (5 male; 5 female) were recruited for this repeated-measures laboratory study. The seats were mounted on a 6 degree-of-freedom (DOF) vibrating platform on which the participants were exposed to sinusoidal vertical (Z-axis) and field-measured, tri-axial car floor vibration profiles. The participants ranked their seat preference before and after using all three seats. Self-reported seat comfort was evaluated using 7-point Likert scales at the end of each seat test. Results indicated that the least stiff seat C had the lowest resonance frequency and the lowest WBV magnitudes across all road types. Seat C was also the most preferred among the participants. This study indicates that it may be possible to improve both vibrational performance and comfort by altering foam mechanical properties through different formulations.

KEYWORDS

Vibration, Automobiles, Foam Properties, Transmissibility

Introduction

Automotive seats are one of the most important interior components when it comes to vehicle-occupant interactions as well as occupant ride and drive comfort. The seats provide support to the occupants while mitigating vibration from the vehicle floor (Ebe & Griffin, 2000, 2001). Unlike the commercial and industrial vehicles which seats have mechanical or pneumatic suspension components to mitigate vibration, passenger cars rely on the seat cushion foam for damping and vibration isolation. Previous studies have shown that foam mechanical properties such as firmness and vibration transmissibility had major influences on occupants' comfort and discomfort (Joshi, Bajaj, & Davies, 2010; Mansfield, Sammonds, & Nguyen, 2015; Mehta & Tewari, 2002; Patten, Sha, & Mo, 1998; Zhang, Qiu, & Griffin, 2015; Zagorski & Pereny, 2019). However, in these previous studies, the standardized vibration transmissibility test uses a sine sweep input, rather than the actual road profile, and such test only outputs the seat properties, instead of occupant perceptions (SAE J2896, 2012). Moreover, many of these existing studies have focused on evaluating seating comfort in the short-term and static setting ("Showroom Comfort" in the absence of vibration or motion). Hence, there is an understudied gap between the mechanical characteristics of the seats and perceived seating comfort from the occupant in a dynamic condition.
Historically, however, recent studies have indicated that Whole Body Vibration (WBV) substantially impacted occupants' comfort perception, fatigue, and vigilance, especially for long term (> 45 mins) riding and driving scenarios (Ebe & Griffin, 2000, 2001; Johnson & Neve, 2001; Park & Subramaniyam, 2013). Despite these potential adverse effects of WBV on seating comfort,

there is limited research evaluating the seating comfort in the presence of vibration exposures and investigating potential intervention to improve the comfort in automobiles.

To fill this current research gap, this study aimed to evaluate the effects of different seat properties (stiffness) on WBV and seating comfort in a dynamic environment. While the on-road test is ideal for dynamic comfort evaluation, the occupant's perception and comfort can be also greatly affected by the vibration transmitted to the occupants' hands and feet (Griffin, 2007), rather than the seat cushion only. Therefore, in order to understand how the seat cushion foam influences vehicle occupant's exposure to WBV and related comfort, it is critical to conduct a controlled study in a laboratory setting, which exclude additional environmental factors. Thus, the goals of this study were to: 1) quantify the influences of WBV exposures to the perceive dynamic comfort; 2) determine how different objectively measured foam properties affected occupants' exposure to WBV and perceived seating comfort.

Method

***Test Samples (Seats)*:** A full-size pick-up truck seat was selected for this study. The seats were built with base level attributes (i.e., only with simple adjustment functions, no heating or cooling was included) to eliminate potential bias on comfort perception. Three different cushion foams were poured for this study, among which seat B was the current production foam whereas seat A and C were produced with different chemical formulations. The seat foam mechanical properties, with the foam in a new and unused state, are shown in Table 1.

Table 1: Mechanical properties of the cushion foam pads

Seat ID	25% Indentation Load (N)	50% Indentation Load (N)	Hysteresis Loss (%)	Thickness (mm)
A	357.4	698.4	20.3	83.7
B	194.2	386.6	26.5	81.9
C	170.3	333.8	19.7	81.9

Based on these mechanical properties, seat A was the firmest, followed by seat B, and seat C was the softest (Figure 1). Otherwise, all the seat were identical in dimensions, structures, and surface materials to avoid any confounding effects.

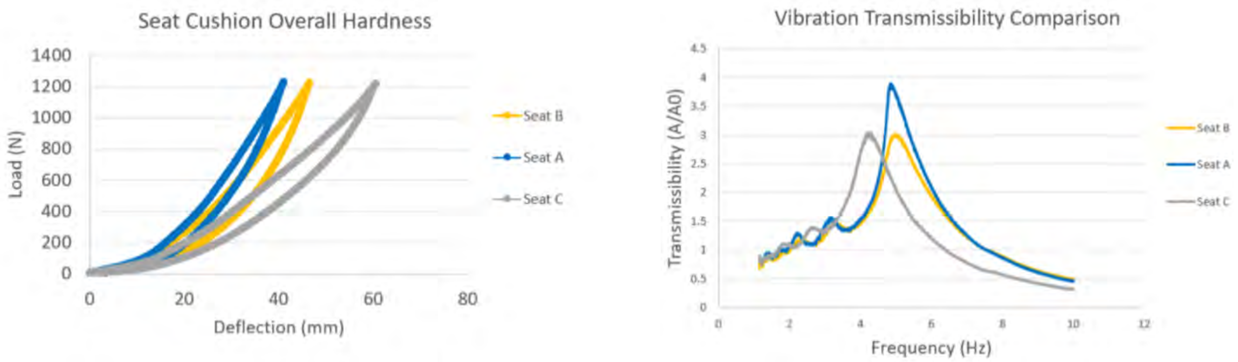

Figure 1: Baseline mechanical characteristics of three seats tested. Overall Hardness (left) and Vibration Transmissibility (right). Overall Hardness and Vibration Transmissibility measured per SAE J2896.

Test Participants

Ten participants (5 males, 5 females) were recruited via email and flyers throughout a university community (Demographics show in Table 2). All the participants had a minimum of 3 years driving experience, no existing musculoskeletal pain, and no history of musculoskeletal disorders in the neck, shoulder, back regions. Written consent was obtained from the participants prior to the study, and the test protocols were approved by the university's Institutional Review Board.

Table 2: Test Participants' Demography

	Age (years)	Height (cm)	Weight (kg)	BMI (kg/cm^2)	Driving Experience (years)
Mean ± SD	27.3 ± 6.7	169.6 ± 11.2	67.5 ± 9.8	23.7 ± 3.0	10.0 ± 6.9
Range	19 - 40	154 - 185	50 - 80	19.6 - 29.6	3.5 - 24

Test Protocols

This study used a double-blinded repeated-measure approach with a randomized order of three testing seats to minimize potential systemic bias (i.e., the first seat could receive higher score because participant has not yet fatigued from sitting). The seat cushion angle was adjusted to ensure participants' thighs were parallel to the floor while the seatback recline was set 110 degrees per ergonomic guidelines (Figure 2). Each participant sat on all three seats in a random order while being exposed to two different types of 15-minute-long vibration that were played on to 6-DOF electric-motor-based motion platform:

1) Field-measure vibration collected from the floors of a mid-size sedan (2015 Hyundai Sonata) and a full-size SUV (2019 GMC Yukon XL) while travelling over a city street, a smooth freeway, a freeway with expansion joints, a cobblestone road, speedbumps, and speed humps;
2) Vertical (Z-axis) sine sweep vibration with the peak amplitude of ±1.5 m/s^2 and frequency range of 1-30Hz.

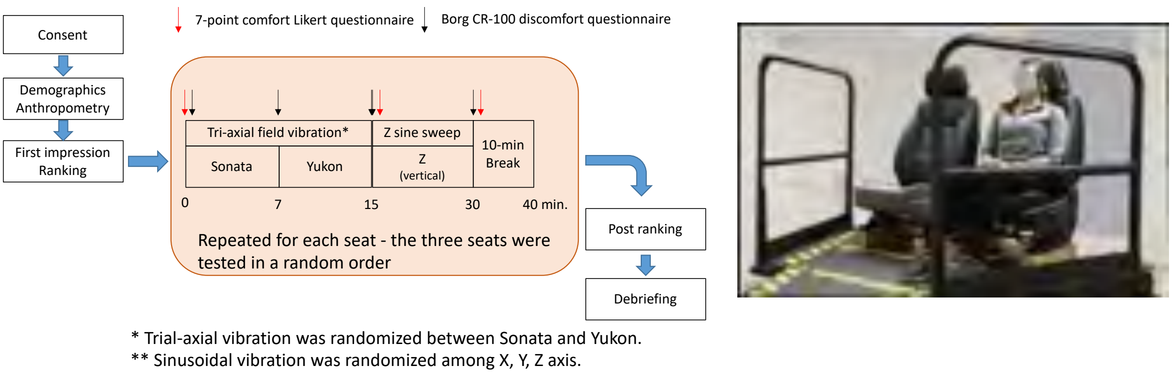

Figure 2: Test protocol (left) and test setup (right)

Outcome measures

WBV: The weighted vibration values were calculated with the methods outlined in the ISO 2631-1 standard. Power spectral density analyses were used to evaluate the vibration energy transmission and vibration attenuation properties of the three seats.

Perceived comfort: Two different questionaries were administered before, during, and after seat trial: 1) participants' preferential ranking of the three seats for comfort was collected before and after the entire protocol; and 2) A perceived seat comfort was measured using a 18-item Likert questionnaire after each seat.

Test Data Analysis

The independent variable was 'seat'; the dependent variables were WBV [A(8)] and perceived seat comfort ranking and ratings. A mixed model in JMP (Pro 13; SAS Institute Inc., Cary, SC, USA) was used to test our hypothesis that A(8) exposure and perceived comfort will be affected by the different seat stiffness. 'Seat' was included as a fixed effect and 'participant' was included as a random effect. When statistically significance was noted at the alpha level of 0.05, the differences were followed up with post-hoc multiple comparisons. In addition, the ranking data were analyzed by a chi-square test to determine the differences in rankings before and after WBV exposure.

Results

Whole Body Vibration

As seat-measured WBV were not significantly different between the sedan and SUV for the field-measured vibration profiles, the results were combined. A(8) measures were significantly different across the three seats (p<0.0001) and across the different road types (p=0.002). As shown in Figure 3, seat C had the lowest A(8) for all six different road types and performed better on the impulsive exposure conditions such as the speed bumps and expansion joints.

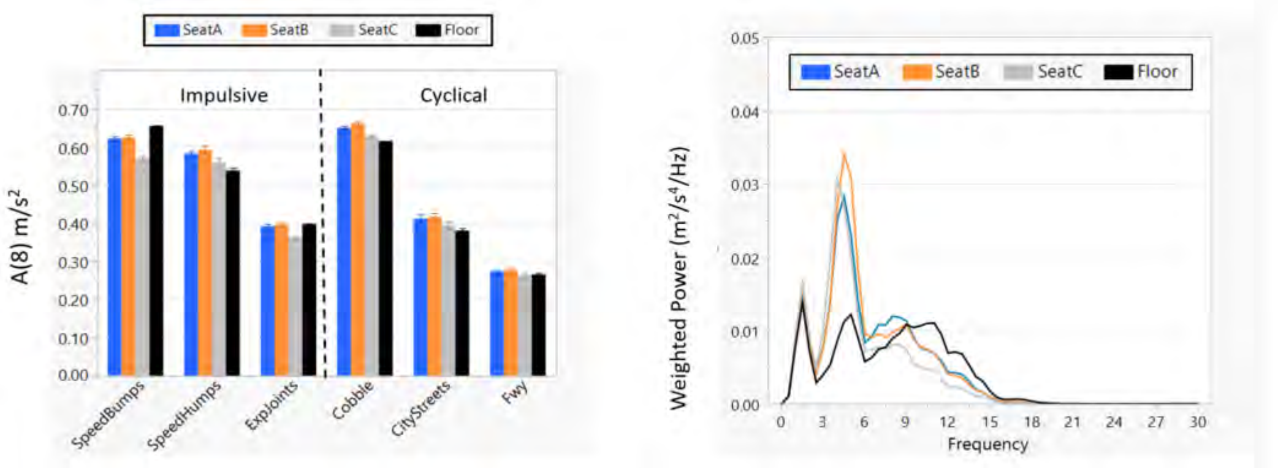

Figure 3: Comparisons of average weighed vibration [A(8)] among the three seats by different road types (left) and the average Power Spectral Density from the city street road profile (right) [n = 10].

Additionally, the Power Spectral Density analyses on the city street profile showed that seat C attenuated vibration energy above 6 Hz more so than the other seats while all three seats amplified vibration energy between 3 and 6Hz. Figure 4 showed how the tested seats performed under Z-axis sinusoidal vibration. The results showed that seat C, which was the softest from the pre-study mechanical characterization test, had the lowest resonance frequency (3.2 Hz) and greater WBV attenuation at frequencies above 6.5 Hz.

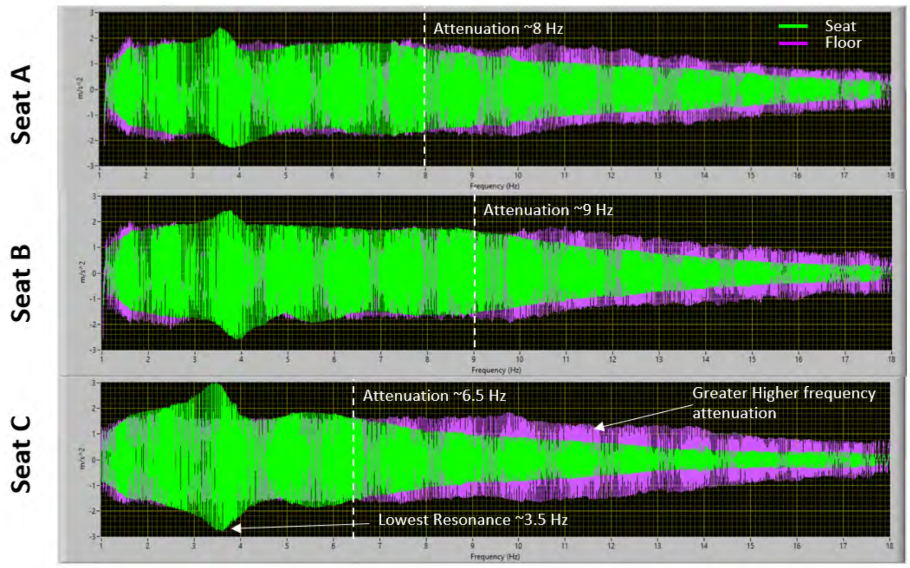

Figure 4: Comparisons of Z-axis sinusoidal whole body vibration [A(8)] comparison in a frequency domain (0-18 Hz) with the 0.5 Hz resolution.

Subjective Comfort Evaluations
With respect to seat comfort rankings (Table 3), significant differences existed initially with seat C being the ranked as the most preferred seat, followed by seat B and seat A (p=0.0015). After the dynamic seat testing, seat C still had the lowest rank; however, the differences in seat rankings across the three seats were not significant. The perceived comfort measures showed that seat C was consistently highly rated as compared to the other seats. The overall rating on seat C was significantly higher compared to other seats in comfort (p=0.02), feeling (p=0.01), and willingness to buy (p=0.03). Moreover, seat C was perceived as more comfortable in cushion firmness (p=0.02), seat pan bolstering (p=0.01), and seat pan width (p=0.01) as compare to the other seats.

Table 3: Pre- and post-testing seat comfort rankings. Lower ranks indicate greater preferences.

	Pre-Ranking (count)			**Average**	**Post-Ranking (count)**			**Average**
Seat	**1st**	**2nd**	**3rd**	**Ranking**	**1st**	**2nd**	**3rd**	**Ranking**
A	2	2	6	2.4	2	5	4	2.1
B	2	4	4	2.2	4	2	4	2.0
C	6	4	0	1.4	4	3	3	1.9

Conclusion and Discussion

The study aimed to evaluate the effects of potentially new polyurethane foam formulations (seat A and seat C) on WBV and comfort when compared to the current production (seat B). Both the pre-study foam mechanical characterization test per SAE J2986 and the Z-axis sinusoidal WBV exposure during the study indicate that seat C had the lowest resonance frequency. Seat C being the softest among all three seats also exceled in almost all the subjective and objective evaluations carried out in this study.

Seat Rankings and WBV: Seat C was most preferred both pre- and post- WBV exposures. Although the preferential rankings were no longer significant post- exposure, the vibration attenuation results indicated that the softness of seat C might be the differentiating factors for the initial ranking. The Z-axis sinusoidal vibration exposure further proved that seat C (softest) also had the lowest resonance frequency and started attenuating the WBV at the lowest frequency. However, the firmness differences among all three seats and the differences in vibration amplification at resonance indicate that the static foam firmness alone might not be the sole dictator for dynamic performance. From basic mechanical vibration theories, one can hypothesis that foam firmness and hysteresis might interact, and both parameters could influence dynamic seating comfort altogether.

Subjective Comfort Rating: Seat C usually had the highest comfort ratings with many of the differences reaching statistical significance. Given that three seats were identical (within manufacturing allowance) expect for the foam pads, it can be concluded that by changing the foam formulation, it is possible to alter how foam mitigates the vibration exposure to the occupant and how occupant could perceive dynamic comfort.

Limitation and Future Work: The study duration was shorter than the dynamic exposure actually occurred in on-road driving scenarios. Moreover, the occupants were sitting in the seats without surrounding vehicle attributes; therefore, the seat-occupant interactions could be simplified when compared to the in vehicle dynamic testing.

Although Seat C was most preferred in the study, indicating that foam firmness could have direct impact in long term dynamic comfort, further investigations are still needed to identify the role of foam hysteresis loss, density, thickness, and chemical formulations in energy dissipation and occupant perceptions.

Acknowledgements

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COMFORT CONGRESS 2021
Comfort Assessment

Exploring factors influencing visual comfort in an aircraft cabin

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ABSTRACT

Visual stimulus might influence comfort of passengers in air travel. For a better understanding of the visual comfort, it is crucial to identify the constructs of the visual stimulus in the cabin and the contributions of different elements. A two-step approach was adopted in this study where in the first step, several creative sessions were executed for exploring the effect of different elements in the cabin regarding their impact on visual comfort. To inspire the participants, all creative sessions were held in a Boeing 737 cabin where participants were free to explore and had an immersive experience. All identified elements in the creative session were collected and grouped to different categories, that is use as input for the second step, which is an online survey investigating a possible hierarchy of the impact of those categories of elements on visual comfort. Eight were summarized and the three most influential categories were lighting, colour and the space arrangement. These were significantly different from other categories, namely the seat shape, the pattern, the windows, accessories and existence of advertisements. Regarding the gender and the age of the participants, we did not find significant differences regarding the preferences.

KEYWORDS

Aircraft interior, visual comfort, user involvement

Introduction

Offering a high level of comfort and reducing the level of discomfort of passengers will increase the competitive advantage of the airlines (Ahmadpour et al., 2016) as there is a strong correlation between comfort experience and willingness to fly with the same airline (Bouwens et al., 2018). Comfort "*is seen as a pleasant state or relaxed feeling of a human being in reaction to its environment*" (Vink & Hallbeck, 2012), and it consists of many constructs including the product, the environment, the physiological, physical and mental state of the subject influenced by his/her interactions with the environment. Visual comfort is "*a subjective condition of visual well-being induced by the visual environment*" (ECS., 2002), and it is an important construct of the overall comfort. For instance, lighting, as a visual stimulus, is considered as one of the most influential factors of comfort (Krist, 1993),(Bubb et al., 2015).

Passing through the pupil, sensed by photoreceptors in the retina, transmitted by the optic nerve, the visual signal passes to the nervous system (Land, 2020). Signals received by the eyes are processed by different areas of the brain. For instance, the parahippocampal place area (PPA) is highly activated when the task is related to the physical environment, such as buildings and place scenes (Epstein & Kanwisher, 1998). The PPA is also considered highly related to identifying social context tasks (Hurley, 2008). However, the PPA did not play a major role in sensing human faces, which are carried out by the fusiform face area (FFA)(Kanwisher et al., 1997).

Visual perception might be a conscious and/or subconscious process (Orlandi, 2014). The high level brain activities involved in the vision process of the complex tasks indicate that the visual perception has strong physiological effects (Balcetis & Lassiter, 2010), subsequently it influences the perceived comfort and discomfort of users in different contexts. For instance, in previous studies, it was suggested to have daylight through windows to reduce stress (Boyce et al., 2003). Lighting designers also used dynamic stage lighting to affects the perception for a better experience (Yu, 2015). For instance, Konis (Konis, 2014) found that despite the frequent subjective responses of visual discomfort from windows, occupants in the perimeter zones generally left a portion of the vision window unshaded to maintain visual connection to the outdoors.

Poor illumination conditions or over exposure to strong lights may cause discomfort in the eyes, influencing eye (Than, 2010) health in the long term (Wang et al., 2020). As a result, studies regarding lighting conditions in the working environment concern mainly screen involvement, are conducted by many researchers in the past decades (Saito et al., 1993)·(Carlucci et al., 2015). For instance, they concluded that glare should be eliminated because it is one of the main causes of errors, fatigue, and accidents in the working environment (Velds, 2002) (Kim & Kim, 2010)(Wolska & Sawicki, 2014). Besides, patterns in the light might influence the visual comfort as well, though the shape of window and sunlight patterns might have limited to no impact on visual comfort and interest in offices when workers are preoccupied performing typical office work. Only the fractal and striped patterns negatively influenced view quality compared to the homogenus condition (Abboushi et al., 2020).

Different spectra of the light also have different effects on the perception. Psychologists discussed the impact of different colours on human cognition and behaviour in different social contexts (Elliot & Maier, 2014). To describe feelings triggered by different colour combinations, colour harmony was defined as '*colours seen together to produce a pleasing affective response*', for instance, positive emotions can be evoked by looking at a painting (Sartori, 2014). Intensity and colour spectrum often have a combined effect on the comfort of the user, e.g. in the use of a computer screen, a warm (3000K) and high intensity (1500 lux) desktop light might reduce the visual and cognitive fatigue of the user and improve the comfort of the user (Han et al., 2021).

In summary, the visual environment can influence human's perception in different ways. While travelling, passengers often do not have a clear cognitive task and they have more spare time to explore the environment, therefore, the visual experience is an important construct of their overall comfort. However, most studies regarding visual comfort are focusing on lighting in buildings and the visual effects on the screen. Factors besides lighting in a physical environment, especially in a specific context, aircraft cabin, are not fully explored (Carlucci et al., 2015).

This paper aims to explore the factors that influencing visual comfort in an aircraft cabin and the hierarchy of the factors for giving an overview of the impact of different factors, especially the factors besides lighting condition, regarding visual comfort.

Methods

To explore the constructs of visual comfort in the aircraft cabin, a two-step approach was adopted. In the first step, we held several creative sessions to explore the types of factors that may influence the visual comfort in the cabin. Based on this exploration, we grouped the identified factors and conducted an online survey, where more participants were invited.

Step 1: Creative sessions

As the first step, three creative sessions were hosted in a Boeing 737 cabin equipped with different types of seats. 12 participants who had the experience of travelling by airplanes in the past three years were invited. Their age varied from 23 to 39. Each session had four subjects and a researcher hosted and moderated the session. All the sessions follow the following procedure:

- The researcher welcomes the participants, explains the purpose and the protocols of the session;
- Participants sign the consent forms;
- Participants are encouraged to try different seats in the cabin freely to look at the cabin from different perspectives;
- Participants sit together to talk about their feelings on visual experience in the cabin;
- Participants check the pictures of different aircraft cabins prepared by the researcher before the session and discuss the visual comfort of different aircraft cabins;
- Participants cluster the pictures base on their experience regarding visual comfort.
- Participants discuss and summarize critical elements of visual comfort.
- Participants try to categorize the elements based on the discussions.

A complete session was often finished within 1.5 hours. Figure 1 shows the materials prepared for the session and in the creative session, participants were summarizing visual comfort factors base on their experience. After finishing all sessions, the categories and elements summarized by the three groups were merged. Some elements were only mentioned by some groups, the times of being emphasized were recorded as well.

Figure 1: (a) A sample of the materials that used for the creative session, (b) Participants are summarizing the factors of visual comfort

Step 2-online survey

After three creative sessions, the researcher summarized all the elements mentioned by the participants, and they are used as the input of the online survey. In the survey, pictures used in sessions were grouped based on different factors as collage(s) (Fig.2) and presented to subjects regarding each categories. After viewing this collage, participants were asked about the importance of the factors regarding visual comfort. The importance of each category for visual comfort experience was evaluated by a 7-point Likert scale (1 stands for not important all and 7 stands for very high importance). 30 responses from people aged 23-38 (22 females and 8 males) were collected. None of the participants has colour deficiency but the vision of five participants was not corrected(have myopia but not wear glasses).

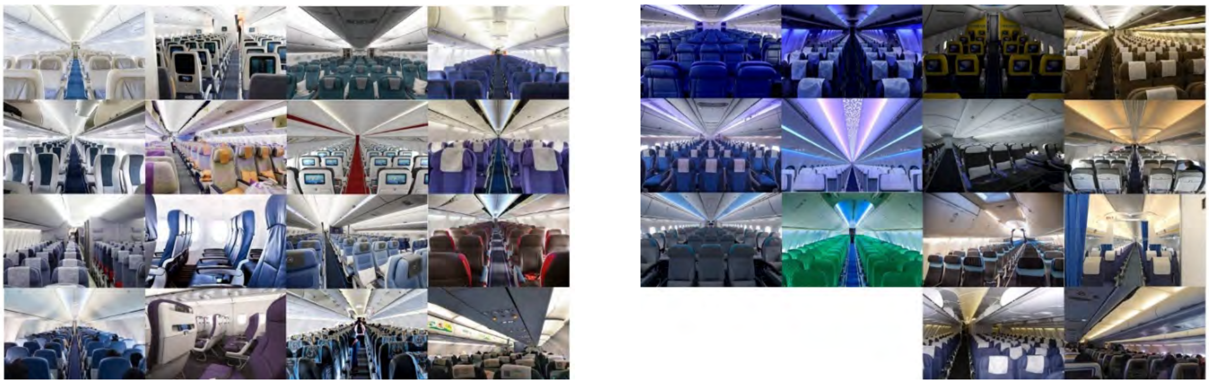

Figure 2: Examples of the collages used in online survey

The mean and standard deviation of the rank was calculated for each factor. All the elements within the same category were averaged to get the scores for different categories. A Shapiro Wilk test was conducted to check the normality of each category. Besides the category 'Existence of advertisements', the preference of the participants are normally distributed. T-tests were conducted between every two categories except category 'Existence of advertisements'. Wilcoxon rank tests were conducted between 'Existence of advertisements' and other categories. Two categories are considered significantly different when $p<0.05$. Spearman correlation coefficient was calculated between age and 'Existence of advertisements'. Pearson correlation coefficient were calculated between age and other categories. Kendall correlation coefficient were calculated between gender and all the categories.

Results

The results of the creative sessions are presented in Table 1. Among all factors, the three most influential elements are lighting brightness (6.07 of 7), lighting colour(6.03 of 7) and colour harmony, including contrast and combination (5.93 of 7).

Table 1: Elements and categories summarize from co-creation sessions and mean score of each element from online survey (higher score is of more importance for visual comfort)

Merged results of three co-creation sessions			**Results of the online survey**	
Categories	**Elements**	**Number of groups mentioned**	**Mean scores (in a scale between 1 to 7)**	**SD**
Colour	Colour harmony(contrast &combination)	3	5.97	1.08
	Hue	3	5.50	1.09
	Lightness	3	5.53	1.38
	Saturation	3	5.27	1.44
	Seat colour	3	5.80	1.35
	Carpet colour	2	4.80	1.42
	Ceiling colour	1	5.53	1.33
Pattern	Seat cloth pattern	3	4.97	1.60
	Lighting pattern	1	5.37	1.45
	Carpet pattern	1	4.17	1.79

	Integration of the pattern	1	4.77	1.82
Lighting	Brightness	3	6.07	0.96
	Colour	3	6.03	1.02
	Temperature	3	5.73	1.18
	Diffuseness	2	5.43	1.48
	Amount of natural light (from window)	1	5.43	1.56
Seat shape	Thickness of backrest	3	4.70	1.66
	Size	2	5.70	1.46
	Fluffiness	2	4.70	1.53
	Round edges	3	4.63	1.83
	Headrest	3	4.27	1.79
	Seat materials	3	5.37	1.40
Windows	Size	2	5.30	1.34
	Position	1	5.40	1.33
	Amount	2	5.17	1.46
Space arrangement	Aisle width	2	4.67	1.66
	Openness of sight	3	4.90	1.60
	Seat allocation	1	4.60	1.43
	Integration of luggage rack	1	4.53	1.82
	Alignment	2	4.80	1.72
Accessories (Pillows, screens)	-	1	4.27	1.84
Existence of advertisements	-	1	3.93	2.05

When looking into categories, 'Lighting' is considered the most important (5.74/7), and 'Existence of advertisements' is considered the least influential factor(3.93/7). Significant differences are found between 'Lighting' and 'Space arrangement'(p=0.017), 'Seat shape'(p=0.006), 'Pattern'(p=0.004), 'Windows'(p=0.002), 'Accessories'(p<0.001) and 'Existence of advertisements'(p<0.001). The category 'Colour' is significantly larger than 'Seat shape'(p=0.049), 'Pattern'(p=0.031), 'Windows'(p=0.014), 'Accessories'(p=0.002)and 'Existence of advertisements'(p<0.001). The category 'Space arrangement' is significantly larger than 'Accessories'(p=0.045) and 'Existence of advertisements'(p=0.005) but smaller than 'Lighting'(p=0.017). We did not find strong correlations between age, gender and the preference towards different categories (Table 2).

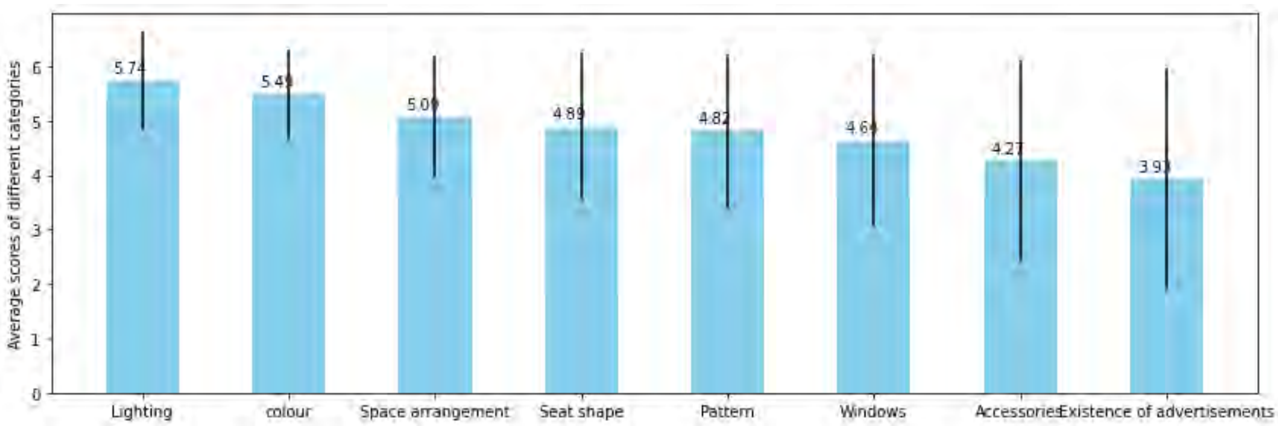

Figure 2: The preference of participants regarding different categories from online survey(n=30)

Table 2: Correlations between gender, age and the eight categories

	Lighting	colour	Space arrangement	Seat shape	Pattern	Windows	Accessories	Existence of advertisements
Age	0.235	0.398	0.324	0.369	0.329	0.275	0.199	-0.202
Gender	0.212	-0.045	-0.015	0.165	0.187	-0.297	-0.023	-0.159

Discussion

Lighting is the most influential category for visual comfort in this study. Light is already listed as one of the six most essential factors that determine perceived comfort and discomfort in past studies of Bubb et al. (2015), Krist et al. (1993) and Bouwens et al. (2018). Colour is the second most important factor for visual comfort, and "harmonic colour combinations" are an essential factor of this category. This can be related to the psychological effects of colours and different combinations (Elliot & Maier, 2014). Space arrangement is also essential for visual comfort in an aircraft cabin. This is not often mentioned for visual comfort in other contexts (Carlucci et al., 2015),(Frontczak & Wargocki, 2011). The reason could be that the space in aircraft space is a cramped (Bagshaw & Illig, 2018), and in a view, the focal distance of different elements might be quite different, which led to fatigue in a long exposure (Shibata et al., 2011).

According to a previous study, preference towards visual environment differs among different age groups (Veitch & Newsham, 2000). However, in this study, no strong correlations were found, which is perhaps due to the limited age ranges of the participants or the limited number of participants. Besides, the imbalanced gender in the survey might also "cover" different preferences of other gender(s).

In this study, creative sessions involving users are used as a method to define the factors influencing visual comfort. As one of the most effective tools in the early stage of the design, it allows users to point out what they need and helps researchers understand the situation in a more effective and efficient way (Sanders & Stappers, 2012). However, due to the limited sample size, the results can be greatly influenced by personal experience of the participants (Rahman, 2016). Thus, a quantitative approach, the survey, intended to provide more data, was conducted in the second step to validate the results of creative sessions (Kelle, 2006). The number and the diversity of the participants influence the quality of the result. In the future, we will continue collecting data for a better classification and more precise hierarchy.

Conclusion

The specific context of an aircraft cabin is a unique environment for the exploration of visual comfort. In this study, a two-step approach is used to study different factors of that may influence visual comfort in an aircraft cabin. The identified factors were summarized to eight categories through creative sessions. A proposal of the hierarchy of factors influencing visual comfort is given where the lighting, the colour(s) and the space arrangement are the most influential factors. It is suggested to improve visual comfort in an aircraft cabin, designers might address the lighting, the colour and the space arrangement first, followed by the seat shape, the pattern, the windows and accessories and advertisements.

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Which design features differentiate expectations in automotive seating comfort? A mixed methods approach

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ABSTRACT

The study built on previous work and earlier findings where it asks the question which seating design elements in particular are effective in differentiating expected automotive seating comfort. Two hypothesis were tested with a mixed methods approach 1) that automotive seats with triangular integrated headrests and angular shape characteristics lead to a holistic evaluation strategy for consumers, and 2) for seats that displayed padded areas which were deemed more comfortable would afford more localised attention hotspots. Twenty seven participants were asked to evaluate 15 automotive seat designs. Participants were asked to evaluate in terms of comfort. The seats were evaluated using a combination of methods and measures: gaze behaviour, subjective emotional responses and mark-up by participants on images followed by card sorting. The cumulative heat map plots across the different designs showed that a considerable amount of visual attention was focused on the *shoulder support* and *the lumbar upper back support areas.* Significant main effects as a function of design on expected automotive seat comfort and emotional response were found.

KEYWORDS

Comfort perception, design attributes, visual evaluation, automotive seating

Introduction

Automotive seat comfort is a key attribute in consumer satisfaction surveys, hence plays a significant role in repurchases and on vehicle loyalty (J.D. Power 2017). The concept of comfort is regarded as a highly subjective and multi-faceted experience, affected by numerous factors and emotions (Helander 2003, Vink, Hallbeck 2012, Vink, Overbeeke et al. 2005). Underlining that in current literature comfort and discomfort are treated as two different constructs, Vink and Hallbeck (2012) provided the definition of comfort as "…pleasant state or relaxed feeling of a human being in reaction to its environment". Helander (2003) demonstrated that sitting comfort not only pertains to physical but also visual characteristics in office chairs. Similarly, de Rouvray et al. (2008) also found that the visual sense is the predominant sense in a user's evaluation in office chairs. Thus, the appearance of a product not only influences the aesthetic value of a product, but also the perceived functional and ergonomic values (Bloch 1995).

Our previous research has shown that the mere appearance of physically identical automotive seats significantly affects perceived comfort (Erol et al. 2014). In this context, Erol et al. (2020) investigated the effects of appearance on comfort impression with 38 automotive seat designs from a premium automotive manufacturer. The study focused on the major descriptors established in the seating comfort literature (Pinkelman 2014) ; *Sporty, Comfortable, Luxurious* and established a taxonomy of design attributes that potentially affects comfort perception. The findings indicated that for the descriptors of Comfortable and Sporty with various seat designs lead to a repeated categorization effect where the headrest and integration with the shoulder support was the most significant attribute. It was observed that the family of seats with identical physical dimensions but with differing features (e.g prominence, details) led to very different evaluations. The findings led to the hypothesis that seats with triangular integrated headrests and prominent shoulder support with angular shape characteristics lead to an overall holistic perception of category e.g. sporty, standard etc. In comparison the seats that possessed padded cushions and patterns would afford more localised attention and therefore hotspots for comfort assessment.

As stated by Bloch (1995), designers decide and make choices on characteristics e.g. shape, scale, proportion, materials etc. and create a coherent whole that form products. The amount of change in size and the properties of a feature inferred by the consumer is an important parameter leading to an overall customer preference for any product (Du and MacDonald 2014). Orquin and Loose (2013) specifically have indicated that eye movements during decision making are both controlled by top down and bottom up processes. They have also indicated that fixated information influences decision making more than non-fixated information, where decision makers' trade-off between fixations and working memory. In this perspective one has to bear in mind that, gaze allocation does not have a direct causal effect on preference formation, however it might be informative with regards to assessment strategies for consumer preferences (Orquin and Mueller Loose 2013). Köhler, Falk and Schmitt (2014a) findings suggested that eye tracking as a methodology reveals the "perception clusters" where the consumer when viewing products which mainly depended on the complexity of the studied product. It could be argued that a similar approach could yield areas with distinct elements or containing higher information are effective in comfort evaluation (Köhler, Falk and Schmitt 2014a; Köhler, Falk and Schmitt 2014b).

Aim of the study

The main aim of this study was to understand which seating design elements (e.g. head rest, backrest) were important in determining perceived seating comfort assessed on the basis of images. It was hypothesised that structuring or virtually disassembling the seat into its subcomponents had a potential to reveal which segments of an automotive seat bear the highest importance when the consumers' is evaluating comfort based on visual information. In an attempt to answer this question, the study was conducted using a mixed methods approach.

Methods

An unobtrusive eye tracker capable of recording the position of the eyes at a sampling rate of 300 Hz was used in order to assess the participants' gaze behaviour for the implicit measures (Tobii TX300, Tobii, Sweden). A total of 27 participants (13 male, 14 female; convenience sample) took part in the study and were asked to evaluate a high resolution monochrome image set of automotive seats from a premium automotive manufacturer.

Experiment Protocol

Participants were asked to sit at a distance of 65 cm from the monitor and to move as little as possible with the aid of a chin rest. The images were presented on a 23" Tobii TX300, 1920 x 1080 pixel monitor in a controlled usability lab environment. The seat image size on screen was approximately 22 x 14.5 cm. Fifteen seat images were displayed for 10 seconds each and the participants were asked to" look for comfort" for each of the stimuli. The image display sequence was randomized for every recording. After the initial eye tracking capture session, each seat image were re-displayed on the screen individually for the explicit measures; ratings with emotional response scales and scale items. For each stimuli, participants were asked to use Self-Assessment

Manikin (SAM) scale (Bradley and Lang 1994) to rate their emotional response to the different designs using the valence and arousal dimensions on a 9-point scale. They were also asked to rate perceived "comfortable" item for each stimulus using a Likert scale ranging from; 1: Not at all to 7: Extremely. After each rating carried out, they were asked to utilise an iPad to mark-up & annotate on the seat image. The participants were asked to indicate the features that they thought to be the most effective in the assessment whilst looking for comfort. During the mark-up, they were motivated to draw on features or areas in any way they like (free interaction) to highlight the features. Finally, participants were asked to rank order the seats from most to least comfortable or according to their "comfort preference". Each of the 15 seat images was printed on 12 x10 cm cardboard card and participants were given as much time as they needed to rank order the seats. The whole procedure of data collection and sorting exercises took approximately 1hr to complete.

Results

Out of the 27 participants, 3 female participants were omitted form the eye tracking analysis, where there was a cut off of minimum 75% capture rate for the gaze data. The recordings of 24 (13 male, 11 female) participants were analysed. Three participant recordings were not captured effectively for the duration of exposure of the 15 seat images, where weighted gaze samples of percentages were lesser than the advised recording capture for both eyes.

Determination of areas of interest (AOI)

Gaze behaviour and fixation count/duration in predefined square Areas of interest (AOI), i.e. headrest, shoulder support, back/lumbar, seat pan were analysed. Automotive seats tend to be divided into several regions based on both occupants' support and stylistic requirements. The rationale in the selection of the AOI regions took in to consideration the body-parts supported by each partition of the seats (see figure 1) and the relative body discomfort mapping scales used for physiological assessment based on the literature studies (Mergl et al. 2006).

Figure 1: Pre-determined Areas of Interest (AOI) for statistical analyses between the seat designs.

Heat map analysis

The cumulative heat map of each plate for all 24 subjects on the 15 seat images are presented in the Appendix. These cumulative heat map plots on the 15 stimuli seat images shows that when viewing seat designs, a significant amount of attention was focused on the 1) shoulder support partition, 2) back-lumbar support partition (see figure 2; red indication of higher counts) of the seat design attributes. The heat map plots in this study also suggest that when the participants were asked to "look for comfort", the comparison and attention on the 15 stimulus presented in three quarter (¾) views was mostly focused on the central axis of the seats that can be observed from the cumulative heat map plots (see Appendix).

Figure 2: *A4 RS4 Sport* seat design (left) and cumulative heat map plot (right).

AOI analysis of eye tracking metrics

In order to assess if the eye tracking capture data was fit for statistical analysis, the metrics for the whole seat image area which consisted of all the gaze data for each seat was subjected to scrutiny with SPSS. There were no statistically significant differences for the gaze metrics of fixation counts (FC) and fixation durations (FD) amongst the 15 seat stimuli over the 9.6 seconds of exposure. This meant that the eye tracking capture was homogenous for all seats and the data was sound for further statistical testing of AOIs.

Chi square goodness of fit tests revealed significant main effects of seat design for fixation counts (FC) for the *headrest* AOI ($\chi2$ (14) = 57.23, p< .0001), *shoulder-upper back* AOI ($\chi2$ (14) = 33.8, p< .005) and *seat pan* AOI ($\chi2$ (14) = 31.12, p< .005). Hence the *seat back- lumbar support* AOIs had the highest FC counts across all the seat designs. The Chi square goodness of fit test did not yield any significant main effects for the fixation durations (FD).There was no significant effect for the number of fixation counts (FC) for the *lumbar support-side bolsters* AOI hence did not differ across the different seat designs. However it has to be reported that the highest mean FC were in this AOI across the seat designs. A mixed linear model analysis of the FC were carried out as this approach does permit the ANOVA analysis with the missing values for AOI data.

The number of fixation counts (FC) for the *headrest* AOI differed across the different seat designs and the effects were found to be statistically significant ($F_{(1,14)}$ =2.93, p <.001). Post-hoc multiple comparison analyses showed that for the main effects the fixation count for showed that the mean difference for the *A7 Standard* was significantly higher than *A5 Comfort, A5 RS5 Comfort, A5 standard, A6 comfort, A6 sport, A8 standard,* and *TT standard* seat designs (p < .0033 , Bonferroni correction applied).

The number of fixation counts (FC) for the *shoulder-upper back AOI* differed across the different seat designs and this effect was found to be statistically significant ($F_{(1,14)}$ = 2.69,p <.005). Post-hoc analyses (Bonferroni) showed that the fixation count mean difference was significantly higher for the *TTRS sport* seat than *A5 comfort, A5 RS5 Comfort, A8 sport, A8 standard and A8 comfort* seat designs (p< .01).

The number of fixation counts (FC) for the *seat pan AOI* differed across the different seat designs and this effect was found to be statistically significant ($F_{(1,14)}$= 2.9, p <.001). The post-hoc multiple comparison tests held for the 15 seats pairwise analyses showed that *A4RS4* sport seat received significantly *lower* fixations in comparison to *RS6 seat design, A5 standard* seat (p<0.003) and *A6 comfort* seat pan designs.

Affective response: Self-assessment Manikin & Comfort rating

The results of the 27 participants were analysed for affective SAM responses (see table 1). The non-parametric Friedman 2-way ANOVA tests revealed significant differences across the different seat designs along the valence dimension (χ^2 (14) =50.1, p<0.01). Post-hoc pairwise analysis indicated *A6 sport* seat design was rated significantly lower than two other seats in the set. Hence the *RS6 Sport* seat with the integrated headrest, prominent shoulder support and quilt design was significantly rated higher than *A8 sport, A6sport, TTRS sport, A5 standard, A8standard, A8 Comfort* in participants' responses.

Table 1: The most and the least mean values for the valence and arousal dimensions and corresponding seat designs

Affective Response	**Highest**	**Lowest**
Valence (1:Least – 9:Most)	RS6 Sport seat (Mean=6.40,SD=1.59)	A6 Sport seat (Mean=4.33,SD=1.9).
Arousal (1:Least – 9:Most)	RS6 Sport seat (Mean=5.70,SD=2.12)	A6 Sport seat (Mean=3.78,SD=1.84)

The arousal dimension was also significant (χ^2 (14) =66.6, p<.01), with post-hoc analysis again indicating the particular seat design rated as significantly higher than the others in the set. In this case, the *A5/RS5Sport* seat and *RS6 Sport* (p<.01) with *integrated head rest -shoulder support* area appeared to be the main driver for this effect when considering *RS6 Sport* having also the highest valence rating. For the "comfortable" scale item, non-parametric test (χ^2 (14) =36.3, p<.01) was significant ,where the post-hoc pairwise analysis indicated the *RS6 Sport* seat was again found significantly more comfortable than the *A6 sport* seat design (p<.05) (see table 2)

Table 2: The most and the least mean values for the valence and arousal dimensions and corresponding seat designs

Item Response	**Highest**	**Lowest**
Comfortable (1: Not at all – 7: Extremely)	RS6 Sport seat (Mean=5.26,SD=1.29)	A6 Sport seat (Mean= 3.89,SD=1.34).

User Participatory Mark-up/annotation Approach

The mark-ups were subjected to frequency count analysis; i.e. how many times they had been marked was reported on the basis of the pre-defined AOIs of the eye tracking for comparison. The initial frequency counts interpreted from the mark-up results for the *shoulder-upper back support* area subjected to chi square tests (χ^2(14) = 22.7, p = .08) in combination with eye tracking results appeared to act as the main differentiator between the seat designs.

Certain participants also provided comments, where *A4RS4 Sport* and *TTRS Sport* seat which have similar integrated headrest and shoulder support area received comments on how "alien" and "futuristic" it looked. However there were divided opinions expressed as to indicate the "cut-outs" in the back were not received well. *RS6 Sport seat* and *RS7 Sport* received comments on how the headrest looked sculpted and the quilt insert design as being a major attribute when they were evaluating the seats. *A6 sport* and the *A7 Standard* seat received comments on how plain-dull the seats looked on the back support. Hence *A7 Standard* was also commented on how "blocky" headrest appeared and out of sync with the design.

Rank order statistics

The rank order data of the seats have also been subjected to non-parametric Friedman tests. The comfort preference ranking amongst the seat designs varied significantly (χ^2 (14)=51.33, p<.001). For the total sample of participants, *A5 RS5 Comfort* (Mean = 10.33, SD= 2.97) and the *A5 RS5 Sport* seat (Mean = 10.19, SD= 3.89) were ranked the highest. The *A7 standard* (Mean = 5.81, SD=4.1) seat was the lowest out of the 15 designs. Hence post hoc pairwise comparisons revealed that both *A5 RS5 Comfort* and *A5 RS5 Sport* seats were significantly ranked higher than *A7 standard* (p<.05) , *A6 Sport* (p<.05) and *A8 comfort* seats (p<.05) with bonferroni correction applied.

Discussion

The main aim of this study was to understand which seating design elements (e.g. head rest, backrest) were important in the assessment of the perceived seating comfort on the basis of seat images. The utilisation of the eye tracking was sought as an asset to analyse and determine the importance of the seat features. The cumulative heat map plots revealed that when viewing seat designs, a significant amount of attention was focused on the *shoulder support – upper back* area. Orquin and Loose (2013), argued that attention is directed towards information with a greater utility or importance to their decision termed as the "utility effect". It can be argued that in this study *headrest-shoulder upper back support* areas possess these effects in the visual comfort assessment (Orquin & Loose 2013, 190-206). The heat map plots in this study also suggested that the comparison and comfort evaluation within the sequentially presented fifteen stimuli was mostly focused on the central axis of the seats, hence this was not something expected and is a novel finding in automotive seat research. As displayed by the cumulative visual scan paths it can be argued that, the generic scan paths and the peripheral vision around this axis offered an efficient means of search for comfort cues.

In order to test for hypotheses posited in the beginning of the study, AOI analysis was carried out across the different seat designs with fixation Counts (FC) and fixation duration (FD) metrics. The fixations counts yielded significant differences. *A7 Standard* had significantly higher fixations on the headrest AOI than *7* other seat designs. This could be interpreted in conjunction with the comments and mark-ups as particularly indicative of the shape of the headrest and the backrest design were incongruent and led to questioning of the comfort at that particular area. Some subjective comments in the mark-up/annotation task revealed that explicitly the *A6 sport seat* headrest were found "blocky".

As argued by Du and Macdonald (2016) the number of fixations (FC) necessary to complete a task is related to the information density of the area. Hence the analyses revealed an overall significant main effect of seat design (features) for the *head rest*, *shoulder support* and *seat pan* AOIs. Behe et al. (2015) argued that understanding which elements first capture and then hold visual attention aids in assessing the role of product display elements in consumer choice. Based on the findings in this study, it can be argued that the cut outs and extensive shoulder supports are particularly counter intuitive for the comfort perception for a number of participants who have commented as "not liking", "constricting", "alien" and too "futuristic" looks. Extreme sporty seat designs having features such as the cut out holes in the back of the seat may have influenced the results on fixations and attitudes where most advanced yet acceptable (MAYA) effect can be deemed affective in this sense (Hekkert, Snelders and Van Wieringen 2003). The acceptability showed variation as per participants' comments differing in a bipolar fashion; like or not like. This is in contrast to Lee et al. (2018) findings in sitting pressure mapping experiments, as they found no significant relationship to emotional responses in shoulder –upper back support area and "hugging" feeling.

Furthermore in terms of *valence* and *arousal* responses, particularly one seat design *RS6 Sport* seat was significantly rated higher than the *A6 sport seat* design. The same significant outcome for the basic overall comfort evaluation for the same pair of seats indicated that a pleasing and exciting design created a positive emotional attitude, which arguably affects the comfort evaluation in the same positive way. This outcome was congruent with the hypothesised conceptual model in earlier studies (Erol et al. 2016). In terms of design features, the *RS6 Sport* seat had particularly softer design features, quilt inlays in the *seat back- lumbar support* and *seat pan* area in comparison to the *A6 sport seat* design which only has flat flute designs and a blocky head restraint design. Specifically as per the subjective comments the participants to perceive the *A6 sport seat* more flat, firm and "not much of a great design". It is important to note that these two seats belong to the same car segment and shows the significance of the design differentiation.

At the end of the protocol, when participants were asked to do a preference ranking, the results yielded a significant difference where *A5 RS5 Comfort* and *A5 RS5 Sport* seat were ranked higher than *A7 standard, A6 Sport* and *A8 comfort* seats which displayed less prominent bolsters and separate headrests. As per ranking results, it can be argued that the backrest shape with prominent shoulder support- integrated headrest guided a *categorisation effect*; primarily in terms of a "design" element hierarchy. It can be further argued that significant evidence accumulation and comparison took place in headrest-shoulder upper back support area when making a trade-off decision.

It is important to point out, given the exploratory nature of the present study, that there were a number of limitations in the interpretation of the eye tracking data. For future studies, it can be argued that rather than a priori AOI determination (pre-set areas kept constant throughout fifteen seat designs), as proposed by Köhler et al (2014b) AOIs can be assigned relevant to the "perception clusters" post data collection. This might enable better comparison of the highest heat map count areas for further analysis of corresponding design features. The findings from this study indicates that consumers looking at a seat did not look at every single part of the product rather to a specific group of areas. Hence the "clusters of perception" corresponded to certain design features when "looking for comfort" which may also have led to "anticipation of discomfort" e.g. *A6 Sport seat* headrest design.

Conclusion

The present study has found significant main effects as a function of design on expected automotive seat comfort and emotional response. Eye tracking may pose a potential to identify the components utilised in comparing the designs, however the mixed method approach is vital in determining the importance of the attributes with regards to comfort. In this context, the quantitative data and qualitative responses together enabled the identification of the design features that differentiated the seats in terms of comfort evaluation. The eye tracking results and the mark-up task led to the conclusion that the *shoulder support area* and *the lumbar upper back support areas* receive the most attention. Furthermore, individual ratings identified two clear results for the "best" and the "worst" design within the seat sample used, which indicates *RS6 sport* seat design with its prominent shoulder supports and quilt inserts lead to higher expectations of comfort when individually assessed. In contrast ranking results yielded a categorisation behaviour, where the perceived sportiness of a seat lead to a trade off in comfort preference, indicating that the global versus local attention to design cues are in effect. For future studies in order to determine how much importance is associated with the particular design features identified in this study, the controlled manipulation of the features as individual parameters is necessary.

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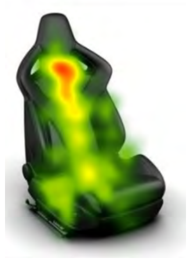
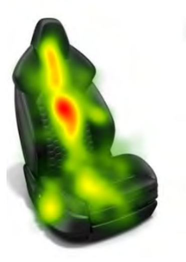
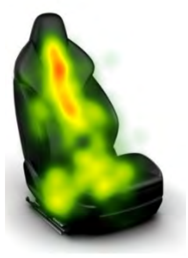
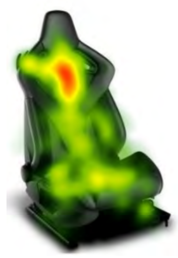
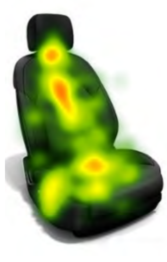
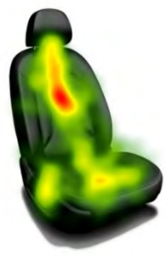
Appendix. Fifteen stimuli utilised in the study

		
A4 RS4 Sport	**RS7 Sport**	**RS6 Sport**
		
A5 RS5 Sport	**TTRS Sport**	**TT Standard**
		
A8 Standard	**A8 Comfort**	**A8 Sport**
		
A6 Comfort	**A5 Standard**	**A5 comfort**
		
A5 RS5 Comfort	**A6 Sport**	**A7 Standard**

Cumulative heat map plots for each of the stimulus (N=24)

		
A4 RS4 Sport	**RS7 Sport**	**RS6 Sport**
		
A5 RS5 Sport	**TTRS Sport**	**TT Standard**
		
A8 Standard	**A8 Comfort**	**A8 Sport**
		
A6 Comfort	**A5 Standard**	**A5 comfort**
		
A5 RS5 Comfort	**A6 Sport**	**A7 Standard**

Smart-learning: home-workplace effect on (dis)comfort and lessons effectiveness during Covid-19 lockdown

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ABSTRACT

The COVID – 19 pandemics paralyzed the traditional "in presence" classes and obliged professors and students to organize their homes to make them suitable to provide and attend the online courses. The institutions quickly shifted to eLearning and provided online courses through several technological platforms and virtual classes. Students organized their home-workstation to recreate a comfortable learning environment. This closure led to solving several problems, such as adapting complex/traditional lessons in eLearning format even though problems with Wi-Fi connections. A published survey among Italian academic staff and students allowed to identify and highlight the factors that affect ergonomics of a workstation (learning and teaching place), postural and environmental comfort and teaching/learning effectiveness. Based on these factors, students' most popular workstation layouts were identified through a previous experiment with 32 students. In this paper, those layouts were deeply investigated, analysing in-depth effects on perceived (dis)comfort and learning effectiveness by considering anthropometric variability and body postures. Results showed that the best layout in terms of postural comfort, visual comfort and learning effectiveness is the one with laptop and notebook placed frontally.

KEYWORDS

eLearning effectiveness, perceived (dis)comfort, electronic devices layout

Introduction

The health emergency COVID-19 (World Health Organization, 2020) forced students and professors to change, suddenly and radically, their learning and teaching way: the traditional "in presence" lessons were converted into online lessons (Girik Allo, 2020; Mulla et al., 2020). The current scenario had no previous similar situations, and it was something new at the very early stages of the pandemic. The new eLearning approach implied several changes that positively or negatively impacted the teaching/learning effectiveness and wellbeing of all the people involved (Girik Allo, 2020; Malkawi et al., 2021; Mulla et al., 2020; Reyes-Chua et al., 2020; Roman & Plopeanu, 2021). Naddeo A. et al. (Naddeo et al., 2021) investigated factors that affected teaching/learning effectiveness and general human comfort and wellbeing after the sudden transition from classrooms to eLearning platforms due to COVID-19 in Italy. The necessity to interact with colleagues, adapt our apartments for eLearning courses, and use several devices are examples of the various aspects that emerged from this work (Naddeo et al., 2021). As a main result, essential influencing factors, in terms of learning/teaching effectiveness and perceived postural comfort/discomfort, that need to be deeply investigated have been highlighted in a table (Naddeo et al., 2021). Some of them, like cognitive factors during the eLearning process, devices', postures', distraction's, and visual comfort-related factors, have been investigated through Califano's work (Califano et al., 2021), giving guidelines to recreate the best workstation in terms of high perceived comfort and learning effectiveness. In this paper, three different workstation layouts were analysed. The aim was to investigate if and how a different layout influenced the (dis)comfort perception and the eLearning effectiveness.

Methods & Materials

Questionnaires

Questionnaires were developed with the Google Forms platform and spread during the online lessons. First clustering questions regarded gender, age, weight, height, left/right-handed. Also, information about the type of desk and table and the screen size of the utilized devices were acquired. Then, Body Part Discomfort questionnaire with 5-point scales (Grinten, 1992), global discomfort, global comfort, visual comfort (on 10-point scales) were asked to monitor students' wellbeing. Moreover, since there was a break, students were asked to rate the global perceived comfort on a 10-point scale and select the actions taken during the break to analyse the break's influence on wellbeing. Finally, the last question (multiple choice) regarded the disturbing factors that emerged during the online lesson. As far as learning effectiveness, students were asked to perform an end of lesson test about the topic covered during the attended lesson.

Participants

Thirty-Two Master Degree students (5 Females and 27 males) took part in the experiment. 28 of them were right-handed, 2 left-handed and 2 both-handed. Experiments were designed according to Ethical Guidelines of University of Salerno and all participants signed the Experiment's Informed Consent. Participants' anthropometric data are gathered in Table 1.

Table 1: Anthropometric data (n=32)

	Age (years)	Height (cm)	Weight (kg)
Mean	24.91	175.19	74.42
Std. Deviation	1.78	9.30	15.32
Range	22-30	155-193	47.50-115

Layouts

For the experiments, students adopted a workstation with a desk, an office chair and a laptop whose screen size varied between 14" and 17".

During the experiments three workstation layouts were analysed (Figure 1):

- Layout 1 (test 1 & test 4): Laptop and notebook (or draft book) frontally and the smartphone beside (right or left indifferently)
- Layout 2 (test 2 & test 5): Notebook (or draft book) frontally, the smartphone beside (right or left indifferently) and laptop on the opposite side to the hand each student was writing with, so laptop on the right for left-handed and laptop on the left for right-handed
- Layout 3 (test 3 & test 6): Notebook (or draft book) frontally, the smartphone beside (right or left indifferently) and laptop on the same side to the hand each student was writing with, so laptop on the right for right-handed and laptop on the left for left-handed

Figure 1: Layouts used during experiments (with examples for right-handed)

Protocol

Each layout was analysed twice, a two-hour lesson (with one break) and a three-hour lesson (two breaks). Thus, experiments were conducted in 6 online lessons. The experiment protocol for a two-hour lesson was the following:

1. Before beginning the lesson, students filled the first part of the questionnaire (5 min) about personal data, the type of chair and desk, and the laptop screen size.
2. Forty minutes of online lesson.
3. Immediately after 40 minutes of the lesson, students were asked to evaluate Body Part Discomfort questionnaire on 5-point scale, the perceived global discomfort, global comfort and visual one on 10-point scales.
4. Break of 10 minutes.
5. Immediately after the break, students were asked to report their actions during the break (coffee break, talk to someone, make a call, etc.) and their overall perceived comfort.
6. Same of points 2 and 3.
7. At the end of lesson, students had to report information about disturbing factors during the 2-hours lesson (5 min).
8. Finally, the professor gave a test (20 min) to evaluate the learning effectiveness of the topic covered during the lesson.

The experiment protocol for the 3-hour lesson was the same but with 2 breaks, so points 2-5 were repeated twice.

Results

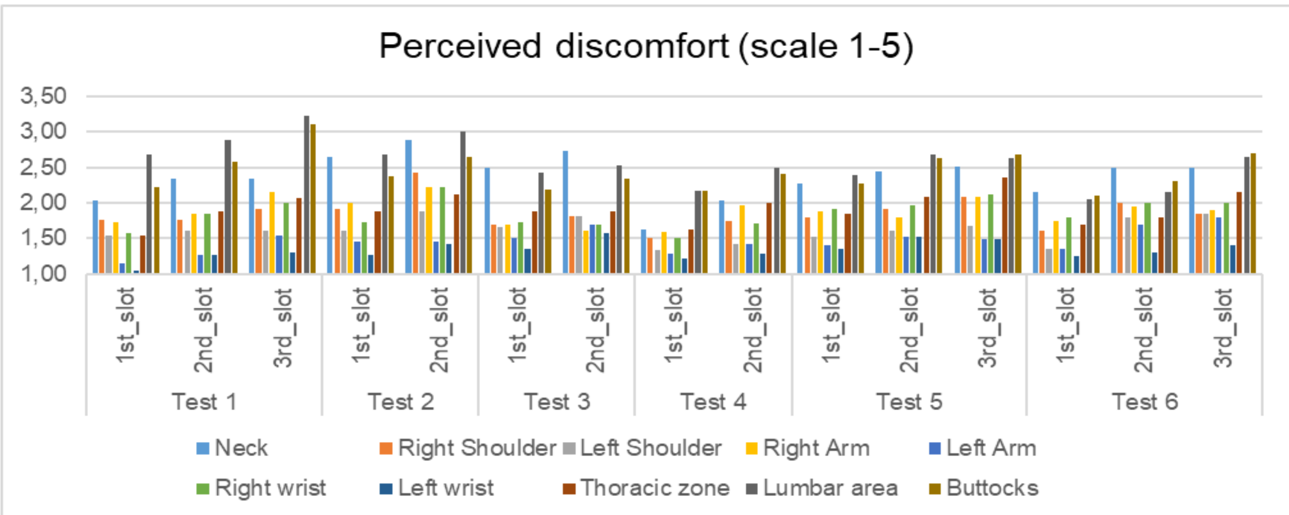

Figure 2: Results from Body part discomfort for 6 lessons

Figure 2 shows results from the Body Part Discomfort rated after each 40-minute lessons. For each lesson, the perceived discomfort arose, and the most affected body part were the neck, lumbar area and buttocks. Adopting the eLearning approach implies staying sitting for several hours, which influences discomfort in the back (particularly in the lumbar area) and the buttocks. Moreover, following the lessons on the laptop and at the same time taking notes means that students have to move their heads very often (their gaze switches continuously from the desktop to the notebook and vice versa). Data analyses show that the break, for almost all body parts, did not improve the perception of discomfort

Figure 3 shows Global Perceived Discomfort, Global Perceived Comfort and Visual Comfort rated after each 40-min lessons and break. For all the setup, the trend is similar. The pause had a positive impact on Global Perceived Comfort (Figure 3). The Global Perceived Discomfort increases overtime for all the setups, and this trend is aligned with the students' Body Part Discomfort. For the visual comfort, the trend varies for each setup slightly, and the values are higher for Layout 1 (Table 3). The most actions taken during breaks were walking (26%), using social media (20%), physiological/personal needs (28%), chatting (16%). Moreover, there were disturbing factors most of the time, either related to device/connection problems (about 30%) and presence of people in the house or calls/texts during lessons (50%).

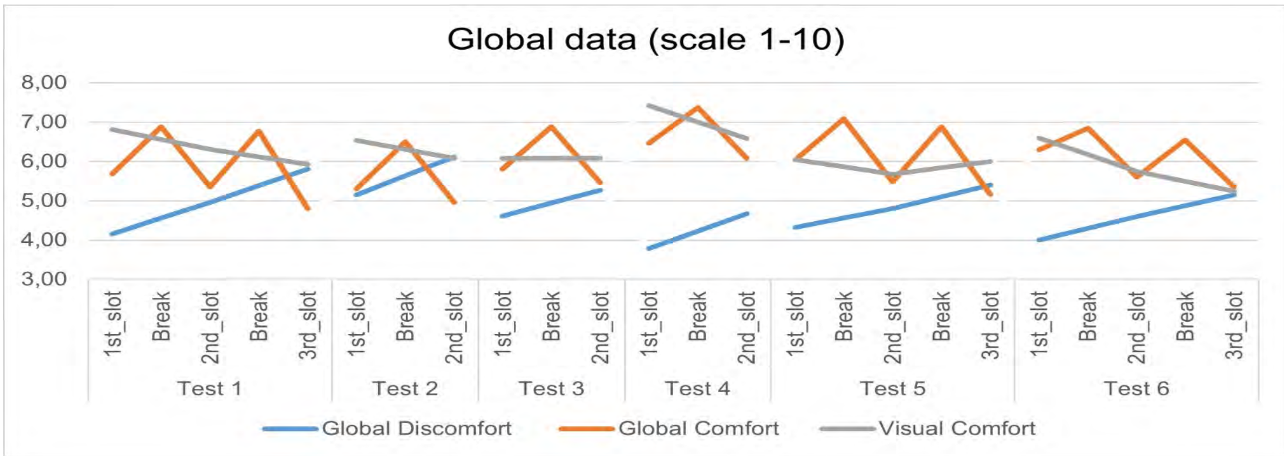

Figure 3: Results from questionnaires for global perceived discomfort, global perceived comfort and visual comfort for each test

Table 2:Mean values of Visual Comfort

	Layout 1		**Layout 2**		**Layout 3**	
	Test 1 (3h)	**Test 4 (2h)**	**Test 2 (2h)**	**Test 5 (3h)**	**Test 3 (2h)**	**Test 6 (3h)**
Visual Comfort (Mean)	6,34	7,00	6,31	5,88	6,08	5,86

As far as the learning effectiveness, evaluated with a test, thus students' marks, it has been statistically analysed with global perceived comfort, global perceived discomfort, visual comfort and disturbing factors. Results showed there are correlations only with visual comfort (Table 4). In particular, as visual comfort increases, learning effectiveness increases.

Table 3: Significant Spearman correlations between students marks and visual comfort

	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**
Vis_1	0,229	0,323	-0,172	,494*	0,013	0,368
Vis_2	,407*	,433*	-0,118	,476*	0,036	0,422
Vis_3	0,278	-	-	-	0,079	0,271

* The correlation is significant at level 0.05 (2-queues)

So, considering the data collected and the results obtained, at this point, the question is: which is the layout that guarantees the best performance in terms of comfort? Are these results confirmed by the students who took the test? In Figure 4 results overview is shown. Layout 1 scored higher levels of global perceived comfort and visual comfort and lower global perceived discomfort. The students confirmed this result. At the end of the tests, indeed, students were asked to choose the preferred layout out of the three. From the test emerged that 61% of the sample preferred Layout 1, 35% Layout 2 and 4% Layout 3. One of the reasons is that placing the laptop in front, the neck, which is the more stressed body part (Smulders et al., 2019), was less subjected to lateral flexion and rotation. Moreover, Figure 4 shows that Layout 3 is better than Layout 2 in terms of comfort and discomfort. Despite this, only 4% of students preferred Layout 3 because the laptop position limited the available space to write. All these motivations emerged from feedback discussions with the students.

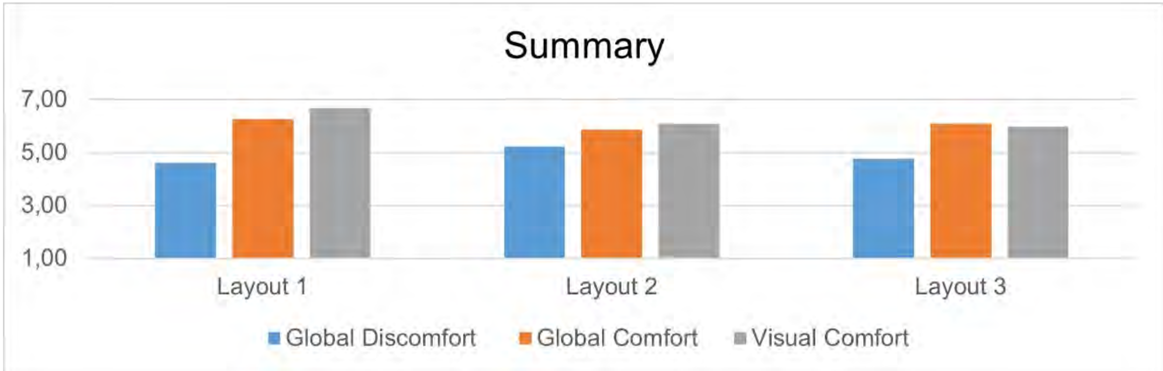

Figure 4: Analysis of the 3 layouts in terms of perceived Global (Dis)comfort and Visual Comfort. The data relating to the 2 online lessons (2 and 3 hours) have been merged in their specific layout.

Conclusions

In this study, three different layouts, during eLearning lessons, have been analysed on a class of 32 Italian Master Degree students. Students have been following eLearning for over a year and are aware of the problem faced. Each layout was characterized by a laptop, a draft book, and a possible smartphone, placed differently. The aim was to evaluate if and how a different workstation layout influenced the (dis)comfort perception and the eLearning effectiveness. Results showed that the best layout in terms of (Dis)comfort perception and Visual comfort was Layout 1, which was with laptop and notebook (or draft book) placed frontally and the smartphone beside (right or left indifferently). Indeed, Layout 1 implied fewer neck movements such as lateral flexion and rotation, and it was the preferred layout for students. About the body part discomfort, no essential differences among the setups emerged. Furthermore, for all setups, the most discomfort affected body parts were the neck, lumbar area and buttocks; perceived discomfort increased over time (also showed in (Cecco et al., 2019; Vink et al., 2017)), and the break was beneficial for student's perceived comfort. About the learning effectiveness, there was not an essential difference among the tests. At the same time, the statistical analyses showed a significant positive correlation with visual comfort. It is interesting to underline that, even if data analyses indicated the layout 3 (laptop at the same side of the arm with which students write) was better than layout 2 (laptop on the opposite side of the arm with which students write), layout 3 was preferred only by 4% of students. Students motivated by this choice affirmed that this layout limited the space available. The results could be useful to recreate and organize an ideal workstation for eLearning to reduce discomfort and to increase learning effectiveness. However, some limitations need to be acknowledged. The sample is homogeneous and the setup with more screens was not investigated. Thus, further research with different samples and layouts is recommended.

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Commercial Vehicles

MODSEAT – Innovative Railway Seat Design

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ABSTRACT

The Modseat project objective was to design an innovative, modular, customisable train seat using new materials and processes. This paper highlights the importance of design methodologies in developing a new seat, from concept design to building physical models to test and validate solutions. We will describe the design process and testing methodologies, presenting the results of the different design iterations. We expect to provide an overview of industry development methodologies and design as a key discipline in articulating different specialists, fostering discussion between stakeholders and creating the best possible passenger experience. The Modseat project was an EU funded project and brought together companies and R&D groups in the Portuguese railway sector to showcase the know-how and technological competence.

KEYWORDS

Railway Seat, Design methodologies, Prototyping, Testing

Introduction

In this paper we will explore the results from the Modseat Project, a regional and inter-city railway seat developed using new materials and processes. The project objective was to meet the future demands of public transportation, through the design and development of a seat to target cost-reduction in retrofitting and disassembly, use innovative materials and manufacturing processes, and provide high standards of designed comfort for the passengers. The design team tackled the challenges of designing a railway seat using a methodology which brought together different specialists and focused on early prototyping to test and validate solutions. The prototypes allowed for several iterations regarding the design, manufacturing processes and comfort testing. We will describe the design process and testing methodologies, presenting the results of the different design iterations. We will also present the final prototype, meant to integrate different percentile populations and provide the functional features for different activities. The experience across different industries has led the design team to develop a collaborative approach to the development of seats, bringing together different companies and using cross-pollination strategies, migrating and integrating technologies and manufacturing processes from other industries.

Methodology

The project methodology included the following steps: Design Concept, Design Development, 1st Prototype, Testing, Design Development revision, 2nd Prototype. The project had a duration of 3 years, with the main steps of the design methodology being developed over a period of 2,5 years. The project included a design consultancy, a manufacturer of metal parts, a materials and process university department, a technical textiles company and a tooling company. The seat was designed and developed according to a railway specification, for an inter-city seat. The methodology followed in the project is described in the following steps:

Design Concept

The initial design target was to increase modularity in the production process, considering a) the assembling of new seats, b) the adaptability of the seat to different market specifications and needs, c) the upgrade of existing units and d) the end-of-life disassembling process. The visual integration of the different parts was developed to reflect a lightweight look and feel, to provide comfort in seating, to enable the use of technologies for the passenger and to test and validate new materials and technologies to produce the seat. Regarding seat comfort, “several studies indicate that increasing leg room, knee space, and personal space have a positive effect on the comfort experience. So, leg room and personal space have a have priority in the design and also expectations and preflight experiences.” (Vink, Brauer, 201:25) [1]. The design team used its experience in designing aircraft seats and tried to apply the lessons learned in developing the railway seat, by increasing personal space and leg room, and adding modular accessories like folding armrests and footrests, an “aircraft seat type” reclining backrest and a side-winged headrest for a more comfortable resting position. The seat was also designed with accessories to support the technologies of the passengers such as a folding table (which stays horizontal even when the seatback reclines - Modseat reclining system patent pending) power sockets and USB mobile charging module, as well as a near-field communication (NFC) systems to allow access to infotainment such as movies, music, games, etc. Regarding materials and production technologies, the design team looked for modular and weight reduction strategies, using aluminium alloys and high tensile steels in its structural parts. Processes such as non-welding assembly technologies and cold-forming processes were used to reduce energy consumption in production. The backrest table features a “patent pending” self-levelling fold-down system that allows the table to be kept horizontal at all seat reclining angles. The seat reclines over a backrest bottom pivot, instead of having a “wheelcart” for the seat pan, as railway seats typically have.

Figure 1: Modseat Design Concept

Results of the 3D Virtual Model Verification

Following the Concept Design, the design development phase featured different ergonomic, functional, formal and comfort testing. These tests allowed to make iterations / corrections to the 3D surface models, and after first prototype testing changes were made to accommodate different results from the tested population characteristics and to allow for the passengers to do different activities while seating (such as eating, sleeping or interacting with digital supports). The first design development virtual model followed the railway standard UIC567, which provides standard dimensions to consider in a railway seat, trying to achieve a good comfort compromise. The design team used these basic guidelines and developed a 3D surface model such as depicted in Figure 1. This first iteration allowed the different project stakeholders, namely the different companies and university experts, to discuss the proposals and identify some problems in the future production of the seat. This was the case of the armrest, which, as initially designed, was very difficult to manufacture accounting for the compliance of regulations (more specifically the arm rest load requirements of UIC567), so a second solution was developed with a more robust solution and a simpler folding mechanism, thus improving passenger comfort (by providing and wider armrest) and production. One of the main features of the seat was to have an adjustable backrest. According to UIC 567, in order to increase comfort, the inclination of the backrest should be adjustable in 20º. From the first 3D model, digital “dummies” were used to check for the main dimensions (Figure 2). From the initial verification, the main concerns were regarding the seat pan height, which was too high for both Male and Female Percentile 5, which meant the legs of these users would be without support (Figure 2). Regarding seat width, it was also noted that the backrest width could be slightly larger to accommodate percentile 95 male. The main anthropometric values were retrieved from the Anthropometric Study of the Portuguese Population (Arezes, Barroso, Cordeiro, Costa and Miguel (2006)) (see Table 1). Other features, such as the height of the table and armrests were also revised from the first 3D model and changed before the build of the first prototype.

Figure 2: Virtual model ergonomic verification with seat structure 15º

Population	MP5	FP5	MP50	FP50	MP95	FP95
Shoulder width (bideltoid)	425	394	475	445	525	496
Previous functional range	627	620	730	675	833	730
Seated height	859	807	920	865	981	923
Eye height (ratio seat)	754	703	810	760	866	817
Lumbar Height (seat ratio)	183	187	215	220	247	253
Maximum thigh thickness	146	140	175	165	204	190
Hips width	340	355	380	400	420	445
Knee height	475	435	525	480	575	525
Popliteal height	358	327	400	365	442	403
Poly thigh length	432	421	485	470	538	520
Maximum thigh length	536	518	590	570	644	622
Chest thickness	227	226	265	275	303	324
Abdominal thickness	213	201	265	260	317	319
Seat shoulder distance	575	539	630	595	685	650
Seat elbow distance	206	204	255	250	304	296

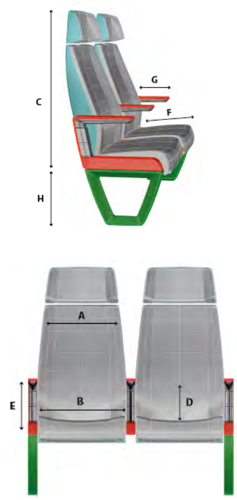

Table 1: Antropomethric measures of Portugues Male and Female Population (Arezes, Barroso, Cordeiro, Costa and Miguel (2006)) Figure 3: Virtual model verification measurements

The first verification was carried out based on the 3D modeling existing to date, and included the following aspects: A - Shoulder seat width should vary between 394 and 525 mm - 394mm, will accommodate people from the lowest percentiles. The P50 is 445 (F) and 475 (M). The suggestion is to increase this dimension, in order to increase comfort and promote an adequate posture. B - Hips seat width should vary between 355 and 420 mm - 408 mm, will accommodate above-average percentiles. If there is a possibility, it can be increased to 420 mm. C - Backrest height should vary between 807 and 981 mm. The measure chosen for the backrest height, 851mm will accommodate people from the 40 percentiles (F) and below P5 (M). D - Height of lumbar support should vary between 187 and 247 mm - 164mm. The measure chosen for the height of the lumbar support, 164, is below the P1 (F and M), 174 and 169. The suggestion is to increase this dimension to accommodate at least the P50 (F and M) 220 and 215. E - Elbow seat distance should vary between 204 and 304 mm - 244 mm. F - Maximum thigh length should vary between 518 and 644 mm - 414mm. Attention to the pressure points of the posterior thigh to accommodate the profiles 10 of the female population and 90 of male population. Attention to the pressure points of the posterior thigh. G - Elbow wrist distance should vary between 292 and 380 mm The measure chosen for the length of the armrest accommodates people from the majority percentiles P1 (F) 280 and P1 (M) 308. If there is interest, it can be increased up to 280 so as not to compromise the handle mobility. H - Popliteal ground distance should vary between 327 and 441 mm to accommodate the profiles 10 of the female population and 90 of male population The measurement chosen for the seat height, 388 mm (including foam) is above the P50 (F) and below P50 (M). The seat coverings, would consist of textile covers, foams and fire barriers, and it was considered that the covers could be made of textile or leather and polyurethane or silicone foams. For typical railway seat cushions, the recommended densities 80 - 90 - 105 (Kg / m3), respectively for headrest, backrest and seat. High density injected polyurethane foams have a low performance compressibility rate. The foam tends to shrink and become loose and the comfort of the seat lowers as more passengers sit on it. The production of silicone foam is a more sensitive and complex process; however, silicone foam does not require fire retardant treatment and does not lose its resilience. As a result, the life of a silicone foam pad is longer and therefore there are also less repair and refurbishment costs.

Results of the 1st (physical) Prototype testing

For physical model verification, a first full-scale prototype was built to enable ergonomic verification, with direct observation of the interaction of users with the seat. Through observation it is possible to understand how prototypes would be used (albeit in a laboratory environment) manipulated, perceived and experienced to create a positive user experience. This model was based on changes made to the first 3D surface modelling. The model was adapted to a simplified prototype, maintaining the essential features for ergonomic verification with regard to the dimensions of the seat pan, seat backrest, pitch between seats, ranges and even functions such as the use of the table and the backrest recline. This model was machined in rigid polyurethane foam and did not have a padded seat pan or backrest. So, a padded foam for the backrest and seat was added to help approximate the density of the seat pan and backrest of the future production version. A physical simplified prototype of the backrest of a second seat was also produced to check available space for the passenger (according to pitch) as well as table height. The prototype backrest had the ability to change degree in order to test backrest inclination comfort. The following images (Figure 4) show the prototype construction and the testing with users.

Figure 4: 1st (physical) Prototype testing

The testing session was carried out by project partners responsible for ergonomic verification, together with an ergonomic researcher who directly observed the interaction with the seat, recording and monitoring the tests with the volunteers. The tests had the participation of 9 subjects, external to the Modseat project, 2 female and 7 male. The height of the subjects varied between 1.54 m and 1.86 m, with an average of 1.70 cm in height. The tests on the prototype built, had the following alignment: Explanation to each volunteer what is intended and signing the authorization; Experimenting the seat in fixed and reclining mode about 5 to 10 min; Completing the questionnaire and suggestions about 5min. Through direct observation of the sample interaction with the seat, some conclusions were drawn about its design, considering the parameters of ergonomic analysis, namely, space for each individual, the space between the seats - pitch, the relationship between the backrest and the seat. Seat with the anthropometry of the different profiles chosen for the sample in fixed and reclining mode and access to the table. From direct observation with the seat in the normal position, it is important to retain the following results: (-) The use of the table was considered difficult for notebooks; (-) Some subjects suggested the need for a lining and padding on the armrest; (this aspect was included in the final version of the seat; (-) Suggestion to improve lumbar support and headrest (cervical area); (-) Suggestion to increase the length of the armrest; (+) There is enough space between the seats to accommodate the lower limbs; (+) Seat height was considered comfortable. From direct observation with the bench in the reclined position, it is important to retain: (-) The use of the table is even more difficult for laptops than in the previous position, it does not allow enough angle for viewing the screen; (-) The lumbar support moves when the backrest is reclined and seems to accommodate only the base; users tend to feel less lumbar support with the seat in this position; (-) The previous situation was also found for cervical support, which was lacking; (-) It was noted that there was a lack of lateral support to support the head to a more comfortable resting position, or even to be able to sleep. Based on the information collected in the virtual and 1st prototype physical tests, it was noted that a lot of changes had to be implemented in the prototype. The main recommendations were collected by the design team and the ergonomic specialist and changes were made to the 3D model in order to accommodate the testing results.

Results of the 2nd (physical) Prototype

After completion of the first prototype and its testing with a group of users, several improvements were made to the design. These led to a second design development iteration and to the development and construction of a second prototype. This prototype would take into account the testing feedback, but also improvements in the production of parts, assembly strategy and parts finishing. Practically all elements of the seat were the object of detailed analysis and redesign. Considering the feedback from the testing, the foam geometry of the seat pan and backrest were redesigned. Also the seat pan height, backrest width and armrest size and height were changed. The backrest table was repositioned, and its dimensions were changed to accommodate the possibility to use a laptop computer. Also, a system was developed to ensure the table would remain horizontal, even with the reclined backrest. Other changes were developed such as the increase of the head lateral supports dimension to improve comfort while resting / sleeping. More lumbar support was provided with more foam padding. The general ergonomics were revised to accommodate both the 5 and 95 percentiles, hence trying to accommodate the whole population. In order to build a final prototype, foam production was done through machining foam with the right density and preparing the model for future production using injection moulded polyurethane foam. The fabric lining covers were produced and the NFC systems were integrated.

Figure 5: 2nd (physical) Prototype

Discussion

The project methodology included the following steps: Design Concept, Design Development, 1st Prototype, Testing, Design Development revision, 2nd Prototype. Actions should follow:

1. Visualize the first Design Concept, fostering discussion between project partners and different stakeholders and allowing to make a first assessment of the proposed solution.
2. Execute the Design Development and first 3D verification (low fidelity prototype) using virtual "dummies" allowed the teams to check the geometric configuration to accommodate different percentiles (namely 5, 50 and 95). This process provided a tool to foster further discussions between partners and was able to provide some information on basic dimensions which were wrong, such as the seat height (which for the percentile 5 was clearly too high). These visual processes of verification can be very powerful as a collaborative tool.
3. Address a medium fidelity prototype - 1st Prototype - at an early stage: only after the first verification process and iteration to the concept design, it was possible to build a first prototype. This prototype was a "medium" fidelity prototype, which used the geometric 3D CAD model information of the seat and backrest, but which did not account for the specific parts of the seat. Nevertheless, it provided an important tool to validate comfort and to make a first physical ergonomic assessment. By also adding the backrest of the front seat, both seat pitch and table height were able to be assessed. It is considered that a way of rapidly prototyping physical models which can be adjusted (such as the backrest inclination in this first prototype) is a very useful tool in the project development to quickly make changes and get user feedback.
4. Use the Design development revision as a fundamental part in refining the 3D model after the first testing. Mainly due to the changing of dimensions and overall proportions, a lot of work went into making all the necessary changes.
5. Achieve a much more refined 2nd prototype that looked closer to the final product with less iterations and investment. It was also built according to the production materials and technologies (e.g., foam, seat covers, metal structure) which would allow for further testing and refinement. Due to the time constraints of the project, no further testing was devised in the second prototype.

Overall, the design methodologies allowed to visualize solutions, were able to create collaborative ways of working and fostering discussions between stakeholders. The methodologies were also able to produce low, medium and high-fidelity prototypes which can enable user testing and validation, balancing the engineering and development effort at each stage. Although the methodology developed interesting results and was able to manage the expectations and include the contributions of different partners, the following recommendations can be addressed, based on the lesson learned from the project:

1. The virtual verification should be done by using the latest 3D virtual "dummies" available, which can work as a "digital twin" of the physical prototypes and help in the concept and development stages. The project used 3D models which are already dates and not the most advanced tools.
2. Low/Medium fidelity prototypes can be used to check for general dimensions, but do not account for the whole look, feel and comfort of a seat. As such, they can be used by researchers and ergonomic specialists to help get dimensions and proportions right. Nevertheless, a high-fidelity prototype must be used and a lot of user testing is needed to validate the design.
3. A laboratory test does not compare to an actual test in a similar setting (train carriage) and timeframe (e.g., 2 hours sitting doing different kinds of activities). Only by testing t in a more real environment and for the duration of a typical train trip, would it be possible to validate the seat comfort. Some authors argue that a possibility is that "discomfort comes into play as a

negative experiencing of a space or whilst using a product" which means user will experience the seat differently, if they are seating in a Lab or cramped in a train carriage full of passengers.

4. Only by using specific measurement tools, such as pressure mats, it is possible to obtain enough unbiased data, capable to being compared to the users feedback and turned into design information to refine the prototypes. Users opinions greatly vary so scientific measurement tools are needed as well as information collection through surveys and questionnaires.
5. The second prototype, already a high-fidelity, was not able to be tested and validated with users.

Conclusions

It is considered that the design methodologies used during the development of the Modseat project prove the role of the design discipline in articulating different stakeholders to develop new products. It also underlines the importance of digital and physical models, and the importance of early prototyping. In fact, we can argue that the more prototypes the better, with increasingly different levels of fidelity to "fail fast" and learn quickly. From study models with low/medium definition for formal and functional validation to medium/high-definition models to refine and validate dimensional and technical specifications, to high-fidelity prototypes to verify ergonomic standards and user evaluation. During the project we were also able to access different opinions about comfort, based on personal qualitative and biased perception. The need to use scientific tools to measure, such as pressure mapping, should be combined with user survey creating a more complete framework to access comfort by combining quantitative and qualitative analysis. Another limitation identified in the methodology was the lab conditions versus real setting for testing and the timeframe considered. For the testing and validation to be closer to a production version of the seat, the tests should be conducted during a typical travel time for intercity trains (e.g., 1-3 hours). This time frame for testing would allow users to experience different activities (such as reading, playing games, resting, etc.). Overall, the methodologies used allowed for a rapid development of a high-fidelity prototype, but due to the complexity of the product, it is suggested that more detailed testing and validation protocols - closer to reality of end use - and experimentation with more rigorous measurement equipment should be considered in the future.

Acknowledgments

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Sleep quality and (dis)comfort in a minimal space envelope

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ABSTRACT

Sleep facilities in vehicles often have a limited space due to economic and/or operational reasons. Currently no guidelines exist on minimal sleep space envelopes for qualitative, effective and comfortable sleep. This study aims to preliminary investigate the influence of a 2D minimal space envelope on sleep quality, sleep effectiveness and (dis)comfort, in order to work towards such guidelines. Forty-one participants slept in three different conditions: night 1) in their normal bed space, night 2) in a limited space (170 x 70 cm), and night 3) in a minimal space designed by the participant. Night 2 was rated significantly least comfortable and most discomfortable, where night 1 in the own bed was rated as most comfortable and least discomfortable. Sleep quality and sleep effectiveness were rated worst in the limited space (night 2), which had a 30% space reduction relative to an average one person bed. However no significant difference in sleep quality and sleep effectiveness between the own bed (night 1) and the minimal space designed by the participant (night 3) were found, although space on average was reduced by 25%. This indicates that tweaking the dimensions of the reduced sleep space envelope can increase sleep quality, sleep effectiveness and comfort. Further research on minimal space envelope design (non-rectangular and 3D) and its influence on sleep quality and efficiency, and (dis)comfort is needed, in which sleep behaviour, sleeping postures and movement, and anthropometrics should also be taken into account.

KEYWORDS

Posture, Bed, Bunk, Aircraft, Vehicle

Introduction

Sleep facilities in aircrafts, trains, busses, ships, submarines, (autonomous) cars, and other vehicles often have a limited space due to economic and/or operational reasons (Smulders, 2018; Stanglmeier et al., 2020). Providing an effective and comfortable sleep is important for passenger satisfaction (Kluge, Ringbeck, & Spinler, 2020) – also to justify surplus prices (Hugon-Duprat & O'Connell, 2015; Kuo & Jou, 2017) – and crew effectiveness and operational safety – e.g. in operational safety critical environments such as aircraft cabin crews (Avers, King, Nesthus, Thomas, & Banks, 2009; Drury, Ferguson, & Thomas, 2012; Hartzler, 2014), medical staff (Dorrian et al., 2008; Gold et al., 1992; Weinger & Ancoli-Israel, 2002), offshore and maritime workers (Hope, Øverland, Brun, & Matthiesen, 2010; Hystad, Nielsen, & Eid, 2017; Sneddon, Mearns, & Flin, 2013) and military personnel (Good, Brager, Capaldi, & Mysliwiec, 2020; Grandou, Wallace, Fullagar, Duffield, & Burley, 2019; Parker & Parker, 2017). There are minimal standards for sleep facilities in safety critical environments such as aircraft (Simons & Spencer, 2007), but no guidelines exist on minimal sleep space envelopes. Such guidelines could help designers and engineers to design qualitative, effective, comfortable and compact sleep facilities.

This study aims to preliminarily investigate the influence of a 2D minimal space envelope on sleep quality, sleep efficiency and (dis)comfort, in order to work towards such guidelines.

Method

Forty-one participants (see Table 1) were asked to score the experienced sleep quality (by means of the Pittsburgh Sleep Quality Index (PSQI) (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989)), sleep effectiveness (by means of the Karolinska Sleepiness Scale (KSS) (Åkerstedt & Gillberg, 1990; Kaida et al., 2006), the Samn-Perelli 7-point Fatigue Scale (SPFS) (Samn & Perelli, 1982) and a Rested Scale) and (dis)comfort after a night sleep in three conditions: night 1) in their normal bed space (the bed they sleep in in their house, which was usually between 190-200 cm long and between 90-140 cm wide), night 2) in a limited space (170 x 70 cm), and night 3) in a minimal space designed by the participant (a bed space which is limited, but still rather comfortable, based on own insight and their experiences from nights 1 and 2).

Table 1: Participant demographics (n=41)

		Mean	**SD**
Male (n=12)	Age [Years]	22.8	1.7
	Stature [m]	1.85	0.07
	Weight [Kg]	75.0	7.6
Female (n=29)	Age [Years]	22.9	1.6
	Stature [m]	1.72	0.07
	Weight [Kg]	62.1	8.5

The Wilcoxon test ($p<.05$) for paired examples was used to test for significance in PSQI, KSS, SPFS and (dis)comfort. The measurements of the designed minimal 2D space envelopes are combined into one average square minimal space envelope.

Results

The average comfort and discomfort scores differed significantly ($p < .01$) (see Figure 1). In their normal bed space (night 1) the comfort score was 3.96 (scale 1-5; 5=maximum comfort; SD= 0.73), in a limited space (night 2) 2.59 (SD=0.91) and in their own minimal designed sleep space (night 3) 3.0 (SD=0.90), and in their normal bed space (night 1) the dis-comfort was 1.53 (scale 1-5; 5=maximum discomfort; SD= 0.60), in the limited space (night 2) 2.98 (SD=0.86) and in their own minimal designed sleep space (night 3) 2.4 (SD=0.90).

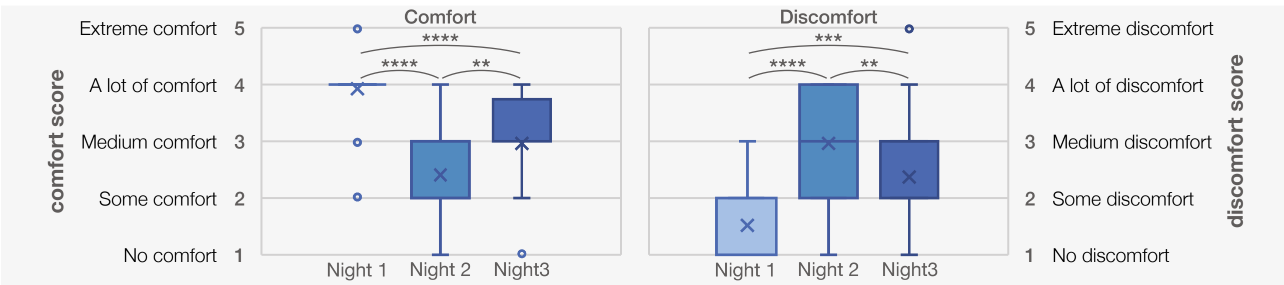

Figure 1: Distribution of comfort and discomfort scores per night (n=41). Higher comfort and lower discomfort scores are considdered better. Significant difference is stated as follows: ** = $p \leq 0.01$, *** = $p \leq 0.001$, **** = $p \leq 0.0001$.

The minimal sleep space designed by the participant varied a lot: the minimal width was 46 cm and the maximum was 140 cm, and the length varied from 100 to 200 cm. The mean designed sleep space was 166 x 78 cm; a reduction of 25% compared to an average one person bed (see Figure 2).

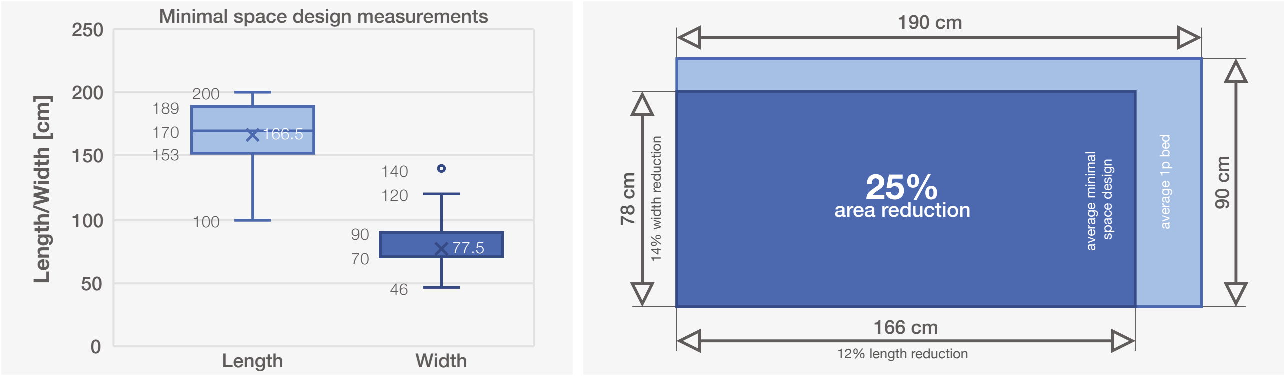

Figure 2: Distribution of minimal space design measurements by the participants for night 3 and a visualisation of the 2D space area reduction from average one person bed (190 x 90 cm) to average minimal bed design by participants (166 x 78 cm) (n=41).

When looking at the impact on sleep quality, night 2 in the limited bed was scored worse on the PSQI score (see Figure 3), the Karolinska Sleepiness Scale (see Figure 4), the Samn-Perelli Fatigue Scale (see Figure 5), and the Rested Scale (see Figure 6) by participants than sleeping in their own bed (night 1) or their own designed sleep space (night 3). No significant difference was found in sleep quality (PSQI) between night 1 and 3. No significant difference in alertness-sleepiness (KSS) was found between pre- and post-night for night 2, where nights 1 and 3 resulted post-night in significant more alertness to pre-night. Fatigue (SPFS) significantly differed for all nights between pre- and post-nights. Participants felt significant more rested post-nights 1 and 3 compared to night 2, where no significant difference was found between nights 1 and 3.

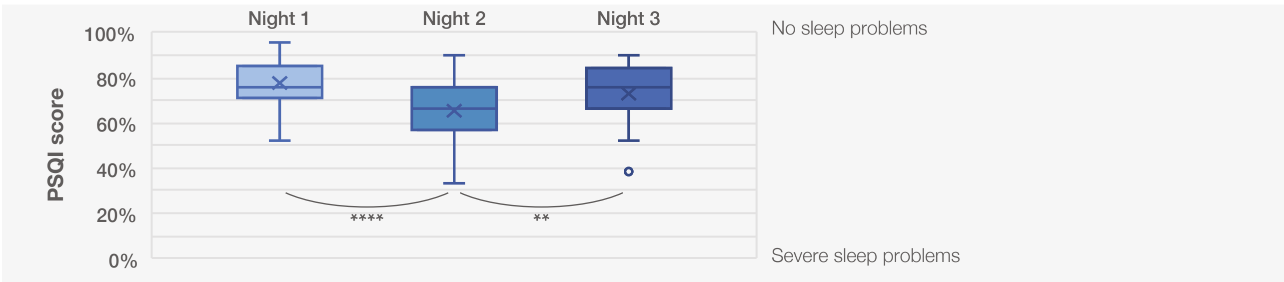

Figure 3: Distribution of PSQI scores per night (n=41). Higher PSQI scores are considdered better. Significant difference is stated as follows: * = p ≤ 0.05, ** = p ≤ 0.01, **** = p ≤ 0.0001.

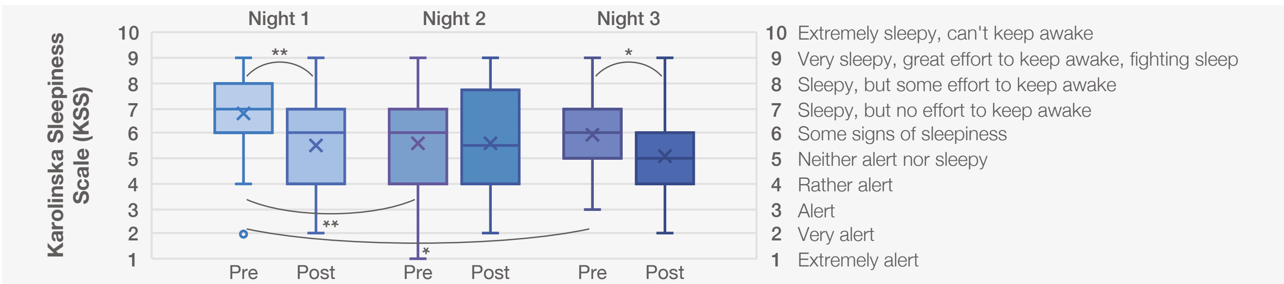

Figure 4: Distribution of KSS alertness/sleepiness scores per pre- and post-night (n=41). Lower post- than pre-night KSS scores are considdered better. Significant difference is stated as follows: * = p ≤ 0.05, ** = p ≤ 0.01.

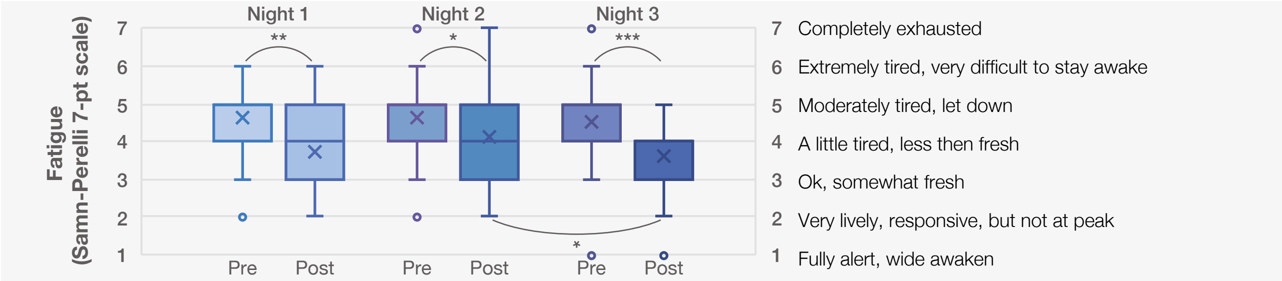

Figure 5: Distribution of SPFS scores per pre- and post- night (n=41). Lower post- than pre-night fatigue scores are considdered better. Significant difference is stated as follows: * = $p \leq 0.05$, ** = $p \leq 0.01$, *** = $p \leq 0.001$.

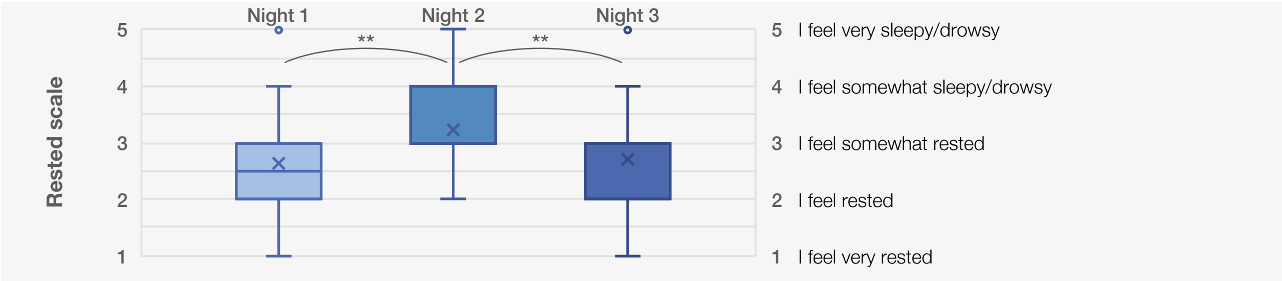

Figure 6: Distribution of rested after night scores per night (n=41). Lower rested scores are considdered better. Significant difference is stated as follows: ** = $p \leq 0.01$.

Discussion

This study shows that reducing the sleep space envelope influences (dis)comfort, sleep quality and sleep effectiveness. Participants were able to sleep in all three conditions, but sleep quality (PSQI), sleep effectiveness (KSS, SPFS and Rested scales) and comfort were rated lowest, and discomfort rated highest in the limited space of 170 x 70 cm (night 2). The lack of significant difference in alertness-sleepiness (KSS) between pre- and post-night 2, and the significant higher post-night fatigue (SPFS) and significant lower 'rested' score for night 2 compared to night 3 indicate a limited recovery and thus limited effectiveness of the night 2 sleep. The minimal space designed by the participants (night 3) also showed significant lower comfort and significant increased discomfort than the own bed (night 1) (although to a significant lesser extent than night 2), but the sleeping quality (PSQI) and sleep effectiveness (KSS, SPFS and Rested scale) scores were not significantly different between night 1 and 3, despite the space envelope reduction. What stands out is the minor difference in space envelope reduction between night 2 and 3 (30% versus 25% reduction compared to an average one person bed of 190 x 90 cm), while night 3 scored significant better on (dis)comfort, sleep quality (PSQI) and sleep effectiveness (SPFS and Rested scales) than night 2. This makes the space reduction in the average minimal space designed by the participants of 166 x 78 cm for night 3 possibly more acceptable for the benefit of space reduction while limiting the negative impact on comfort, sleep quality and sleep efficiency. These results also show that tweaking the dimensions can significantly improve the comfort, sleep quality and sleep effectiveness with still a quite similar reduction in space envelope.

This study was conducted with a limited population size (n=41) and limited variation in age (range of 20-28y). As older age groups have different sleep behaviour than younger age groups (De Koninck, Lorrain, & Gagnon, 1992; Luca et al., 2015), generalising the data of this study should be done with care. In future research, older populations should also be included. This study was also limited as only 2D rectangular spaces were used, whereas non-rectangular and 3D shaped spaces could have resulted in more space reduction (e.g. combining multiple beds next to each other with non-rectangular spaces and/or stacking on top of each other could create possibilities to have more passengers sleep comfortably in a minimal space envelope) with the same comfort and sleep quality. Different minimal sleep space designs, movement patterns during sleep and anthropometrics, and their relation to sleep quality and (dis)comfort need to be investigated further.

There could be an order influence, as the conditions were sequential, but this was on purpose: by experiencing the reduced space (night 2) compared to their normal bed (night 1), participants were made aware of the consequences of space reduction in both length and width, allowing them to make a motivated redesign based on their own experience for night 3. However, as night 2 generally resulted in a reduced recovery, it could have influenced the PSQI, KSS, Samn-Perelli 7-pt fatigue scale and rested scores of night 2 and sequential night 3. This study is also only based on subjective data, as sleep quality was self-reported. Further research might include objective polysomnography (PSG) to measure sleep quality and sleep efficiency.

Conclusion

Sleeping in a limited space is possible (as shown in this experiment), however the quality of sleep and comfort are significantly lower and discomfort significantly higher in the limited space. Tweaking the 2D dimensions of the reduced space can limit the negative impact on sleep quality and (dis)comfort.

Further research on minimal space envelope design (non-rectangular and 3D) and its influence on sleep quality and efficiency (preferably with PSG), and comfort are needed, where also sleep behaviour (Smulders & Vink, 2020), sleeping postures and movement, and anthropometrics should be taken into account.

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Evaluation of Interventions Designed to Improve Truck Driver Comfort, Sleep, and Health

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ABSTRACT

The work schedules and sleep environments of long-haul team truck drivers increase the risk of having inadequate sleep which may adversely affect driver health and contribute to vehicle-related crashes. The purpose of this study was to determine whether an intervention that involves replacing a regular, industry-standard innerspring mattress with an interlocking foam therapeutic mattress would improve truck drivers' sleep and reduce adverse health consequences associated with poor sleep. Using a repeated measures design, for one-month periods, 8 truck driving teams (n=16 subjects) evaluated their existing, industry-standard, regular innerspring mattress, a new regular innerspring mattress and a new interlocking foam therapeutic mattress. Sleep quality was measured using short daily sleep questionnaires, 7-point Likert scales were used to rate mattress comfort and satisfaction, a Nordic questionnaire to assess body pain and whole-body vibration measurements were collected from each truck team while sleeping in each type of mattress. Effect sizes, using Cohen's-d were used to measure changes in the study outcomes. Relative to their existing, pre-study, innerspring mattresses, truck drivers' self-reported sleep and fatigue improved with the new regular mattress (small to medium effect sizes) and improved even further with the interlocking foam therapeutic mattress (small, medium and large effect sizes). All truck driving teams reported substantially higher comfort ratings with the new interlocking foam therapeutic mattress. There we no differences in the vibration transmitted through the mattress occupants when sleeping but there were some differences in the vibration frequency transmitted through the mattresses. An unexpected outcome was that the truck tires had the greatest influence on the vibrations in the truck cab. These results indicated that both the new regular mattress and the new interlocking foam therapeutic mattress improved team truck drivers' sleep, health, and well-being. The outcome improvements were slightly greater with the interlocking foam therapeutic mattress and all truck driving teams had a substantially greater preference for this mattress. An unexpected factor creating the largest difference in vibration transmission through the mattresses was the type of tires on the trucks.

KEYWORDS

Therapeutic Mattress, Sleep Hygiene, Whole Body Vibration

Acknowledgments

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Haptic Feedback in Automotive and Commercial Vehicle Applications

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ABSTRACT

In times of digitalization as a megatrend, haptic feedback by touch or contact interfaces can be a means to relieve the driver/passenger on other channels of perception while communicating relevant information. In this context, the perceived comfort of haptic systems is particularly important to ensure the best possible user product interaction. Two ergonomic cross-sectional studies from the automotive and forklift sectors are presented in this contribution. The first study involved the randomized assessment of three different haptic center console devices for automotive applications in a laboratory environment. 21 subjects tested the different devices, which had three activation thresholds of 0.3N/1.0N/2.0N. The second study analyzed haptic feedback in terms of an indication and attention signal in different seats for forklifts. The tested expert group encompassed 8 subjects in the static laboratory study and 4 subjects in the field tests. The results of the first study showed for all three devices that female subjects perceived the defined activation thresholds as higher than the males did. Overall, activation thresholds no higher than 1N were preferred by the sample group. The results of the second study showed ratings for the distinctiveness of the two tested signals ranging from 6 – Sufficient to 10 – Perfect by the tested forklift truck drivers. The results of the first study suggest gender as an influencing factor on the perception of a haptic feedback at the fingertip, which is relevant for the compilation of sample groups in the product validation process. The second study verified the acceptance of a newly implemented haptic technology with an expert sample group.

KEYWORDS

Haptic feedback, perceived quality, automobile, forklift, interfaces

Introduction

In times of digitalization as a megatrend, there appear to be no limits to the visualization of data. Head Up displays in automobiles and displays attached to the cabin and / or multifunctional armrest of commercial vehicles are just a few examples for the increasing availability of information in the operator environment. It is often stated that people take in 80% of the information to be processed via the visual channel. Taking into account the new digital possibilities, it is more important than ever not to overload the operator. The development of smart GUIs, filtering and selecting identified information, enhances the ability to process visual data. Still, in cases where visual control is needed, there is a risk of missing important safety relevant input in driving situations, so this time should be minimized (Burnett & Porter, 2001). The change of sensory channel for communication can be a means to relieve the operator and increase the perceived comfort and safety.

Besides the visual sense, humans have four other senses which provide the brain with information: Hearing, Touch, Taste, and Smell. While the highest priority in the sense ranking, regardless of culture, is sight, the importance of the other four senses seems to vary (San Roque et al., 2015).

Different approaches to address one sense or more of them simultaneously (synesthesia) are being researched. In the context of a hand operated device in an automobile environment, haptics seem to be a promising option (Pitts et al., 2012). In order to help drivers to focus their visual attention on the driving situation instead of other areas like the center console, multifunctional prototype devices with haptic feedback were developed. The scope of the first study was to assess system characteristics of three different center console devices for automotive applications regarding their influence on perceived comfort. In addition to the application for automobiles, the commercial vehicles sector in particular offers enormous potential for this technology, since areas of operation often exhibit high noise levels such as in the material handling sector (Dass, Uyttendaele & Terken, 2013). Highly demanding environments like warehouses or factories are common areas of application for forklift trucks. Here, the operator has to focus on the tasks at hand like the transport or stacking of goods while at the same time continuously monitoring his/her environment for safety reasons (e.g. pedestrians). The purpose of the second study was to rate the implementation of haptic feedback in an operator seat as also the signal specifications for two different signals.

Methods

Automotive Study

This cross-sectional study was conducted in a controlled laboratory environment. Three different console devices, in which haptic feedback was implemented in individual technical solutions, were tested in randomized order by a sample group consisting of 21 adult subjects (age: MW = 40, range: 25-62), 6 female and 15 male. Each of the devices had three different activation thresholds. To activate the device, the test subjects had to apply a force with their fingertips higher than the activation thresholds of ≈0.3N / ≈1.0N / ≈2.0N. For device 3, there were two variants 3a/b, which differed from each other regarding the direction of motor rotation. Additionally, device 3a/b had three motor speed settings of 6960rpm / 7830rpm / 8700rpm. For the test set-up, the device´s absolute position was defined while the relative position of the armrest in X-direction towards the device was freely selectable by the test subject. A partly standardized interview was conducted capturing subjective ratings regarding various aspects of the haptic devices. Using a seven-point Likert-type scale, the activation threshold level, signal volume, signal quality and perceived signal intensity were assessed. In addition, a ten-point ordinal scale was used to assess the overall system perception. To exclude a possible influence of system acoustics on haptic perception for reasons of variable reduction, defined sections of the test were performed with earplugs and earmuffs.

Commercial Vehicle Study

The second cross-sectional study was divided into two parts. The first was carried out under controlled laboratory conditions. Three different GRAMMER seats for forklifts with implemented haptic systems were tested in a randomized order by a sample group of 8 subjects, 1 female and 7 male. Prerequisite for study participation was a forklift license and daily use of the vehicle at the working site. The position of the haptic device was configured to the different seat cushions addressing their varying contours and foam thicknesses. Two different signals had been established, an indication signal and an attention signal. The system was implemented in the three different seats for rating perception comparability and effectiveness for different seat sizes and versions. Partly standardized interviews were conducted capturing subjective ratings regarding various aspects of the two haptic signals. Using a seven-point Likert-type scale, the position of the two actuators, signal intensity perception, distinctiveness of the two offered signals and the duration of the signals were assessed. Additionally, a ten-point ordinal scale was used for rating the overall perception of the signals. A six-point ordinal scale was employed to evaluate the potential discomfort perception (showroom t = 0min./short-term t = 20min.) caused by the actuators themselves in combination with pressure distribution measurements. The pressure distribution measurements were conducted for each seat and for 4 subjects. The used hardware was an XSENSOR LX100:48.48.02 system (XSENSOR Technology Corporation, Calgary, Canada) with an X3PRO_V7 software (XSENSOR Technology Corporation, Calgary, Canada) for data post processing. To exclude a potential influence of system acoustics on the haptic perception, defined sections of the testing were carried out with ear plugs and earmuffs.

For the second part of the study, one seat of the above-mentioned (MSG65/521) was installed in an industrial counterbalance forklift for testing in a steel processing factory (Figure 1). 4 subjects, 1 female and 3 male, tested the indication signal of the system for at least 30 min. during a regular dayshift. To capture the subjective perceptions for the occurring use cases, forward/rearward driving and pallet stacking (pick-up/drop-off), a partly standardized interview was conducted afterwards. The actuator position, signal intensity and duration were rated using a seven-point Likert-type scale.

Figure 1: Industrial counterbalance forklift and exemplary seating system

Selected Results and Work in Context

Automotive Study

The results of the first study showed a high spread in the perception of the activation thresholds, ranging partially from 1 – Much too low to 7 – Much too high for system 1. The medians of the male subjects were 3 – Slightly too low (0.3N) / 4 – Exactly right (1.0N) / 7 – Much too high (2.0N) for the three activation thresholds and thereby lower in comparison to the female medians of 4 – Exactly right (0.3N) / 6 – Too high (1.0N) / 7 – Much too high (2.0N). In general, female subjects perceived the activation thresholds for all three tested devices as higher than the males did. Independent of the device´s feedback and geometry the male´s preferred threshold was 1.0 N in comparison to the females of 0.3N. Overall, activation thresholds no higher than 1.0N were favored by the sample group.
All ratings in the form of a box-/scatterplot divided according to the system and the gender on a seven-point Likert-type scale is displayed in figure 2. Here, the acceptance range of the sample group is illustrated by the dashed blue lines.

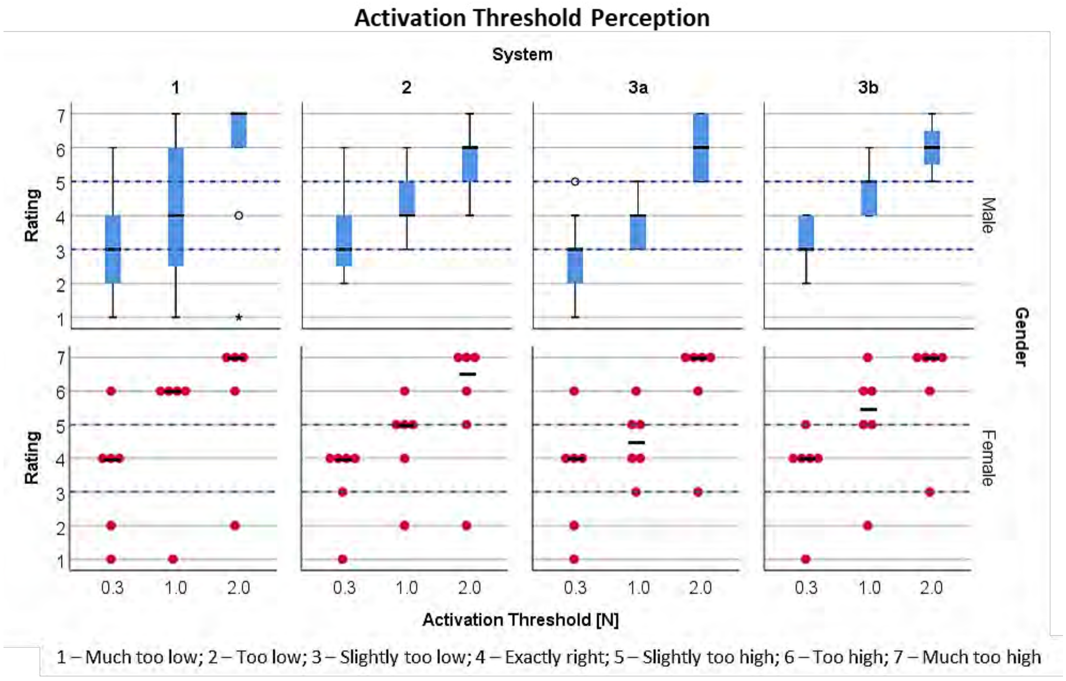

Figure 2: Box-/scatterplot of the activation threshold perception divided by gender

The results of the feedback strength as one factor of the perceived signal comfort showed similar results for both systems 3a / 3b. The offered intensity “low” with 6960rpm was rated by the sample group with medians of 3 – Slightly too weak (3a) and 2 – Too weak (3b). The medians of the “medium” intensity representing 7830rpm were identical, 3 – Slightly too weak and were thus within the acceptance range of the user group. The ratings of the “high” intensity with 8700rpm were partly outside of this range with 5 – Slightly too high (3a) and 6 – Too high (3b). Overall, the preferred intensity of the user group was “medium” (7830rpm). The ratings in form of a box-/scatterplot divided according to system and signal intensity with the associated acceptance range (dashed blue lines) on a seven-point Likert-type scale is displayed in figure 3.

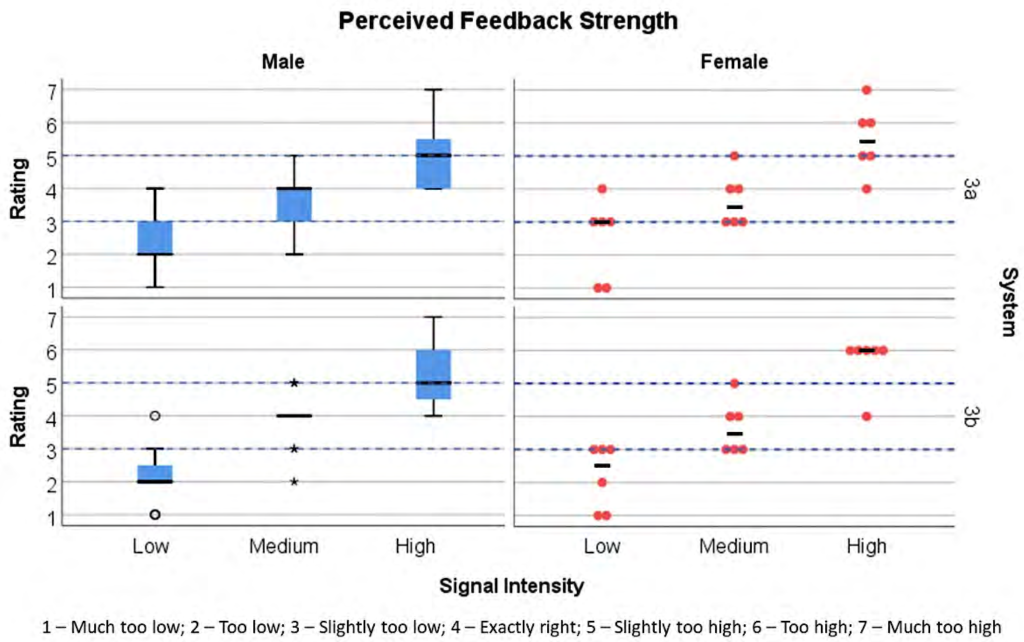

Figure 3: Box/scatterplot of the perceived feedback strength for the three tested signal intensities divided by gender

When the user group is divided by gender, the preferred intensity for both systems 3a / 3b is still “medium”. A slight trend could be observed for the intensities "low" and "high", such as female subjects perceived them as higher compared to male subjects. Confoundingly, this was reversed for the “medium” intensity, however, the difference was very small. Still, the data did not show a conclusive tendency for one gender being more or less sensitive to haptic signals at the fingertip. One possible reason is the small quantity of female participants in this study. In total, signal intensities around 7830rpm (“medium”) for the rated systems 3a / 3b were preferred by the sample group. The direction of motor rotation did not significantly influence the results within the users´ acceptance range. In this study, vibration as a haptic signal as implemented in System 3a / 3b was preferred by both genders over other types of signals (e.g., clicking).
Overall, the tested sample group showed an activation threshold of ≤1.0N for fingertip touch haptic devices in vehicle contexts. The “medium” intensity representing 7830rpm had highest acceptance among the user group with no influence of direction of motor rotation having been apparent. Even though the sample size was a limiting factor for statistical analysis of gender differences, the results strongly suggest taking gender into account when evaluating haptic devices to ensure an optimized comfort during use for the targeted user population.

Commercial Vehicle Study

In the first part of the forklift-truck user study, the pressure distribution and associated comfort and discomfort on three seats was assessed. An important finding was that the implementation of the actuators in the seat cushion did not result in any increase in discomfort or change in local peak pressures / pressure distributions on the cushion (Figure 4). Two positions that are typical for daily work were assumed by the forklift drivers. It was found that the established position of the actuators in X and Y axes as vibration origin were appropriate for both working postures.

Results of the subjective ratings on signal parameters showed that the two signal types (indication / attention) could be well differentiated in the three different seats in realistic sitting positions. The distinctiveness of the two tested signals was given ratings ranging from 6 – Sufficient to 10 – Perfect with one outlier at 5 – Marginal. The attention signal was classified as just right, and as a good alternative to an audio signal which might be overheard. Overall, the configured signals were found to be appropriate for the respective purpose, however, user feedback pointed to improvement potential: In the given configuration, the intensity of the indication signal was rated as slightly too strong. Based on their feedback, signal configuration changes were recommended to product engineering.

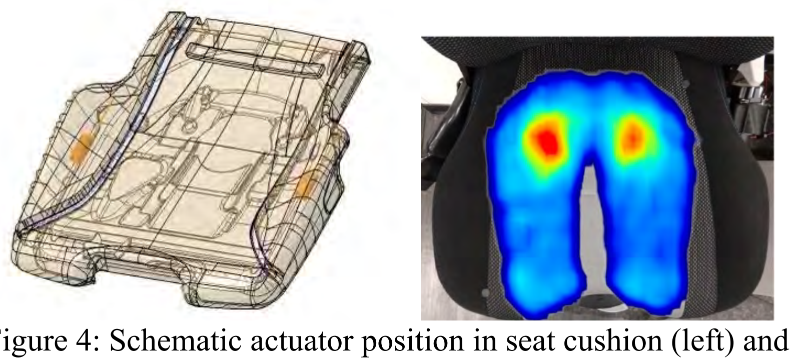

Figure 4: Schematic actuator position in seat cushion (left) and unaffected pressure distribution (right)

In the second part of the study, one of the seats had been installed on a counterbalance truck and was tested under appropriate factory working conditions. Actuator position, signal duration and intensity were observed by the users while operating the forklift and rated positively also under dynamic conditions. Signal distinctiveness and effectiveness was thus confirmed by active forklift users in the prototype seat evaluations. The established configurations were considered as valuable by the expert group and ensure that the haptic signal is perceived by drivers when the vehicle is in operation and operators are in positions activating the operator presence switch.

Conclusions

The user input gained in these comfort projects serve as a basis for defining future products and equipment options, with the aim of optimizing user wellbeing and man-machine performance. Concerning haptic feedback in vehicle contexts, different applications were tested in this research for fingertip and whole-body feedback, and their perception and rating by users was analyzed for verification or further product improvements. It is foreseen that reliably perceived haptic feedback in automotive interior components can support drivers by passing on information in other than the visual channel and thus help keeping eyes on the road (Kuehner, 2014). For fingertip actuation, the activation force between 0.3N and 1N was confirmed as the top comfort threshold for a mixed-gender group. For whole-body feedback by haptic signals in the seat, the configured signal characteristics and actuator positions were verified for the application in counterbalance forklift trucks. Two major advantages that were stated by the professional user group were (1) Haptic channel information does not require directed attention from the drivers, only physical contact, so drivers do not have to be concerned about missing a signal, and (2) the information is "private", i.e. it can only be perceived by the driver and does not additionally pollute the environment. These statements fit with data from earlier studies, such as those by Chang and colleagues (Chang, Hwang & Ji, 2011). In this way, concepts become future-proof by incorporating users, understanding usage, detailing use-cases and forecasting future purposes of interior components and systems. Megatrends and environmental factors are taken into account, such as the continuous increase in signals and need for information processing. Information densities in modern automobiles and material handling vehicles require leveraging all possible sensory channels for information processing.

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COMFORT CONGRESS 2021
Clothing

Effects of safety gloves used by gardeners on perceived discomfort and performance

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ABSTRACT

A shovel is a common tool in agricultural activities. It is very popular among Iranian gardeners and they used it for a variety of purposes. To avoid such damages, some gardeners wear safety gloves. Some other gardeners do not use safety gloves because they maintain that the gloves negatively affect their performance. Accordingly, the aim of the present study was to investigate and compare several safety gloves used by gardeners in terms of comfort and performance. Ten gardeners with at least two years of experience were invited to participate in this study. The participants were asked to plow the ground with two commonly-used gloves and also bare hands for 30 minutes. After completing the task, they were given a hand and fingers map to express their discomfort level in each region. The performance of the participants was determined by measuring the surface area plowed by them. Area P was the one with the highest level of perceived discomfort, followed by TP, MM, and IM. In all areas, the lowest level of discomfort was perceived when the participants used the cotton glove. The average area plowed by participants with bare hands, cotton gloves, and Latex gloves were 1266cm^2 (±112.7), 1230cm^2 (±80.4), and 1186cm^2 (±138.6), respectively. Therefore, wearing any type of safety gloves can negatively affect the performance of gardeners. Safety gloves used by gardeners were different in terms of the perceived discomfort and performance.

KEYWORDS

Glove, Comfort, Shovel

Introduction

According to the International Labor Organization (ILO), almost half of the world's workforce are employed in the agriculture sector. Agricultural activities have been known to be dangerous such that the risk of occupational injuries has been reported to be high in this sector (ILO, 2003). There have been introduced many reasons why the rate of occupational injuries and fatalities are high among agricultural workers. Forceful movements, awkward working posture, harsh environment, use of improper agricultural tools and equipment, misuse of agricultural tools and equipment, and lack of willingness in using protective equipment are some important causes in this respect (Fathallah, 2010; Frank et al., 2004; Kirkhorn et al., 2010).

Agriculture plays an important role in Iran's economy. A considerable proportion of Iranian workforce, particularly in rural areas, are farmers, tillers, and planters. Unfortunately, in most cases, agricultural activities are still carried out in its own traditional ways using a variety of basic tools, resulting in a high prevalence of occupational injuries (Amad, 2012; Dianat et al., 2020). Shovel, sickle, and farming claw are some hand tools extensively used in agricultural activities (Chang et al., 1999). The use of these tools increase the risk of occupational injuries among agricultural workers because most of them have been designed and manufactured with the least attention to the human factor issues (Abdalla et al., 2017).

Shovel is an important agricultural basic tool used for various purposes such as preparing the ground, removing weeds, and harvesting (Bhardwaj et al., 2004). The handle of shovels is commonly rough and very damaging to the hands and hand skin. Therefore, agricultural workers use protective gloves to avoid hand injuries. Although protecting hands and fingers against a wide range of mechanical (cuttings, punctures, abrasions, and so on), chemical (hazardous materials), and physical hazards (extreme temperatures), protective gloves are known to downgrade hand performance and discomfort (Dianat et al., 2012a; Sorock et al., 2004).

There are several types of protective gloves used by agricultural workers. However, no study has investigated these gloves in terms of their effects on hand performance and perceived comfort. Therefore, the present study was conducted to assess the effects of these gloves on hand performance and perceived comfort.

Material and methods

Participants

Ten gardeners with at least two years of experience were participated in this study. All participants were right-handed and without any pain and discomfort in their musculoskeletal systems. The participation in this study was totally voluntary and they were free to leave the study at any stage. All participants read and signed an informed consent form before the study.

Protective gloves

Two types of protective gloves commonly used by gardeners were investigated. Presented in Table 1 are the characteristics of these gloves. The first type of gloves, Glove A, is made of cotton with a coating of latex and the second type of gloves, Glove B, is made of cotton. Both types of gloves have general applications in agriculture, construction, and warehouse activities.

Table 1, the characteristics of gloves investigated in this study

Gloves	Application	Main Materials	Thickness at Palm (mm)
Glove A	Public works (Construction, warehouse work, Agriculture, mechanic work, moving, landscaping)	Latex-coated glove	1.3
Glove B	Public works (Agriculture, Construction, Manual Handling)	cotton	1.1

Figure 1: gloves invetigated in this study

Study protocol

Participants were asked to plow the ground for 30 minutes. Each participant performed this activity three times: (1) with the bare hands, (2) with Glove A, (3) with Glove B. The order of experiments were random to minimize the learning effect. A 30-min rest time was given to the participants between two successive experiments.

Discomfort/Comfort assessment

After completing each experiment, a hand and fingers map (Figure 2) was given to the participants to express the level of pain and discomfort that they perceived during shoveling in each area. A 6-point Likert scale, ranging from 0=no pain and discomfort to 6=very high pain and discomfort, was used to express the level of perceived pain and discomfort. For assessing the overall perceived comfort experienced with each type of gloves, a nine-point comfort scale ranging from 1=extremely discomfort to 9=extremely comfort was a=applied at the end of each experiment.

Figure 2: The hand and fingers map used in this study

Performance assessment

The surface area shoveled by each participant was regarded as an indicator of performance. It should be noted that the ground shoveled by the participants was the same in terms of physical characteristics.

Statistical analyses

Descriptive statistics was used to describe the data. Repeated measures ANOVA test was applied to investigate the differences among three experiments in terms of shoveling performance.

Results

The level perceived discomfort in various areas of the hand and fingers are presented in Figure 3. It can be seen from this figure that area P was the one with the highest level of perceived discomfort, followed by TP, MM, and IM. Areas SD, SM, RD, ID, and TD were the ones with the lowest level of perceived discomfort. In all areas, the lowest level of discomfort was perceived when the participants used the cotton glove (Glove B). Interestingly, the level of perceived discomfort with the latex coated glove (Glove A) was higher than that of bare hands. This may be because the fact that the latex coating reduce the friction between the hand and handle of shovel, requiring the gardeners to exert extra force to grasp and control the shovel.

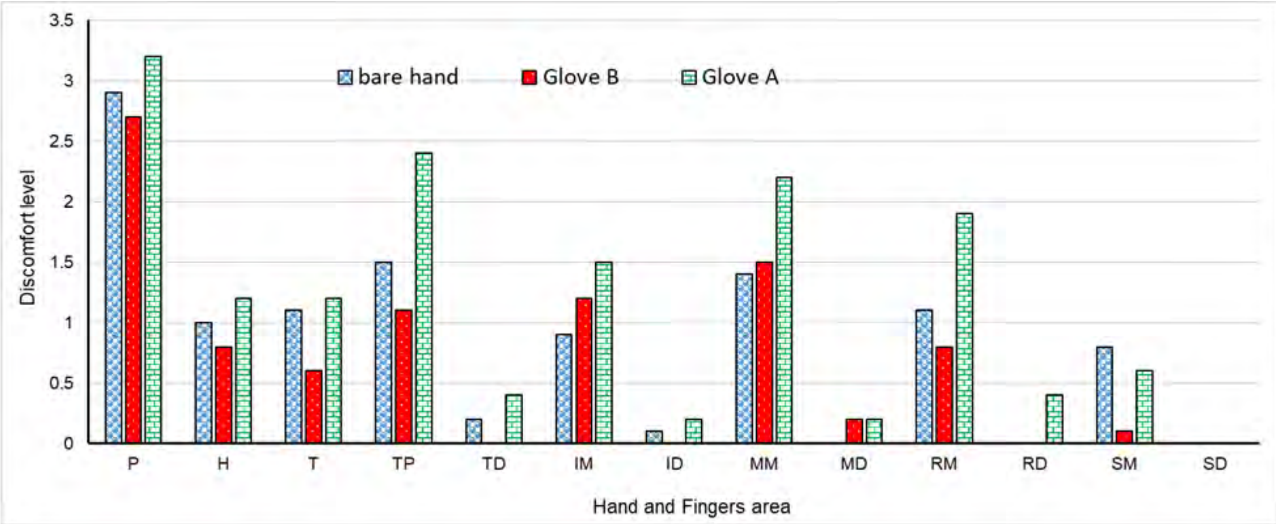

Figure 3: the level of discomfort perceived in various regions of the hands and fingers

The performance of participants while wearing various types of gloves is demonstrated in Figure 4. The average area plowed by participants with bare hands, the cotton glove (Glove B), and latex-coated glove (Glove A) were 1266cm^2 (±112.7), 1230cm^2 (±80.4), and 1186cm^2 (±138.6), respectively. Therefore, wearing any type of safety gloves can negatively affect the performance of gardeners. The results of repeated measures ANOVA analysis revealed that there was a significant difference among the bare hand, Glove A, and Glove B in terms of shoveling performance. The Bonferroni Post Hoc test revealed that there was no significant difference between the bare hand and Glove B (p=0.191), similarly the difference between the bare hand and Glove A was also no significant (p=0.071). Likewise, no significant difference was observed between Glove A and Glove B in this respect (p=0.920). Therefore, it can be inferred that wearing protective gloves could reduce shoveling performance but this reduction is not significant.

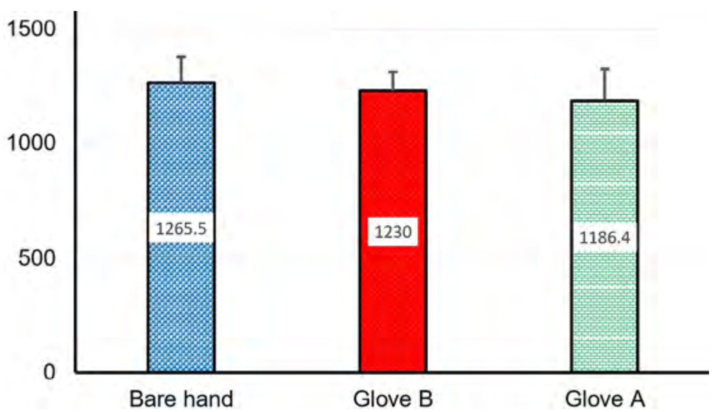

Figure 4: the shoveled area (cm^2) by participants while wearing various types of protective gloves

Discussion

In this study, the effects of two types of gloves used in agriculture activities on comfort and performance were investigated. The results revealed that wearing both cotton gloves (Glove B) or latex-coated gloves (Glove A) could reduce the level of perceived discomfort in various areas of hands and fingers. Reducing the contact stress imposed by the shovel handle on the hand and fingers skin may be the most important reason why wearing any type of gloves could reduce the level of perceived discomfort. The reduction in the level of perceived discomfort was higher for the cotton gloves. This part of study was in line with the study carried out by Dianat et al. (2012b) in which it was demonstrated that wearing cotton gloves causes less discomfort than wearing nitrile and nylon gloves in a screw driving task. A reason for this observation can be the flow of air which is much easier in cotton gloves than gloves with a polymeric coating. The air flowing on the skin removes sweat and prevent sweat accumulation.

Moreover, areas M and TP were the regions with the highest level of perceived discomfort, this finding is also in line with (Dianat et al., 2010). These areas seem to be more subjected to contact stress than other areas. Therefore, it can be inferred that these areas need more attention in designing and manufacturing protective gloves. For example, they can be made with double or a thicker layer.

In this study, we found no significant difference among the performances of partcipants while wearing various types of gloves. A study carried out to assess the effect wearing gloves on muscles activity demonstrated no significant difference between the bare hands and hands with cotton gloves (Dianat et al., 2012b). Accordingly, wearing cotton gloves or cotton gloves with a latex coating has no effect on muscle activity and thereby fatigue, so it would be unlikely for performance to be altered.

Conclusion

Safety gloves used by gardeners were different in terms of the perceived discomfort and performance. The cotton gloves could reduce the perceived discomfort, while the Latex-coated glove did not have such an effect. According to the hand and fingers map, the perceived discomfort is not at the same level in all areas. In the other words, a few parts of the hand and fingers are under pressure when a shovel is used. Accordingly, these areas can be made using thicker materials while other parts can be made of thinner materials.

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Footwear innovations for people with the diabetic foot with ergonomic design

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ABSTRACT

Background: The foot is one of the organs of the body that have a major role in health, especially in diabetics. During the day, a lot of pressure is transmitted through the legs to the knee, pelvis, and spine, and any motivation in the shoe may put pressure on the gait parameters. Shoes should be such that diabetics can feel comfortable enough and also not suffer from neuropathy or ulcers caused by wearing them after work.

Method: In this study, 5 types of shoes available in the market that are offered as medical shoes were selected and compared with quality ergonomic indicators. In the second stage, the effect of these shoes for wearing for a long time was evaluated, and also the ratio of increase and comfort of the person in the sole of the feet and knees was examined.

Results: Only one of the shoes had relatively good conditions for people with diabetes, which by adding new items such as choosing the right fabric for ventilation of the foot area, considering the appropriate anthropometric measurements in the toe area for more comfort, and having a suitable insole to prevent the occurrence of musculoskeletal disorders in the lumbar region could be sufficient.

Conclusion: In general, a design framework with specific tools is provided to have the right shoes for the proper use of diabetics in the long run. Further research should focus on outsole design tools and other shoe components.

KEYWORDS

Footwear, Diabetic, Comfort

Introduction

Historically, the foot is known as the second human heart; in addition to transmitting pressure-induced reactions to the ground, it plays a key role in creating a balanced and uniform pressure on the joints and upper treatment parts, creating the correct position. The foot environment changes throughout life, and factors such as age, pregnancy, obesity, and daily stress cause the foot to become flat. [1-4].

Almost all causes of foot pain can be classified into 3 groups: Improper shoes, certain diseases, and heavy and inappropriate exercise. Above all, various diseases such as diabetes can cause pain and sores in the legs over time. In general, 15% of diabetics experience diabetic foot ulcers. Diabetic foot ulcers are one of the leading causes of death and disease [5, 6].

Diabetic foot syndrome is one of the main and late complications of this disease and the main cause of disability and hospitalization of patients with diabetes and accounts for 58% -50% of nontraumatic lower extremity amputations [7, 8]. Therefore, having the right shoes for these people, which can prevent possible injury to the foot area even for a long time, can be very important.

In addition to providing proper foot coverage, a good shoe adapts to the ground without putting pressure on the foot. Careful selection of shoes and observance of standard principles in its production is one of the most essential needs to maintain people's health. Prescribing and modifying shoes is a very useful tool in protecting the joint, preventing skin problems, and increasing optimal performance in patients with problems such as arthritis, diabetes, and peripheral vascular disease. Medical shoes reduce the treatment of building problems and functional problems related to foot problems to some extent. People with healthy feet do not need medical shoes. The shoes have different designs and heights and depending on the type of correction required, they may be made of different materials. Ordering medical shoes for each person is like special medicine. Medical shoe standards are determined by the type of deformity and disease of the individual and the purpose of treatment. This study aimed to evaluate and design ergonomic shoes suitable for diabetics.

Methods

In the present experimental study, 40 employees, all of whom had diabetes, participated, 30 of whom were female and 10 male. 20 of them had type 1 diabetes and another 20 had type 2 diabetes. Information about the samples was collected by the form and the minimum age was 44/05 years, height 168/12 cm, weight 70/43 kg, and BMI 25/02. After examining their condition, it was found that 37.5% of them had knee pain, 27.5% had pain in the sole and 35% of them did not report any specific disease.

Equipment used

In this study, 4 types of shoes available in the market with the names of SLS, Melli, Adak, Shahir, and Iran teb have been used. From each type of shoe, 10 pairs were prepared and given to the samples. The form is used to compare these shoes with the standard. The samples are selected under the supervision of the researcher and according to the size of their feet, they select the shoe and then put the sample on it and compare the researcher according to the condition of the individual foot, the compatibility of the studied parts of the shoe with the foot and scores as 1 (low), 2 (medium) and 3 (high) are specified.

Ergonomic standards and indicators used in the study

To compare the shoes, the quality indicators in Table (1) were used.

Table (1): Ergonomic indicators of shoes

Shoe upper	The sole of the shoe should be made of leather to neutralize the sweat produced by the foot, and it should also be flexible and Maintain the shape of the shoe and its durability is high
Toe box	It should be wide, long, and round and the fingertips should be 0.5 inches away from the toe box

Vamp	Must be sufficient height and width; the widest part of the Vamp, the Ball, must conform to the Metatarsal heads or the bones that make up the foot (Metatarsal); So that the toes and shoes can be broken at the MP joint during the Laster stance phase. Enough should be considered in Vamp shoes; because when bearing the weight, the foot circumference in the Ball increases by 0.5 inches
Quarter	This area should be large enough to cover the midfoot and back of the foot; Quarter in the heel area should be firm and cover the heel so that the foot does not protrude from the shoe when walking.
Insole	It is usually made of leather, which in addition to durability, can expand and be flexible during long-term use.
Heel	Heel height should not be more than 3.5 cm for men and 4.5 cm for women

Method of determining the performance score

The knee position assessment form was used to determine performance scores. This form had 10 questions, at the end of which the IRDC score was calculated and the performance score was set as a percentage. A 10-point scale (VAS) was used to score the sole and was expressed as a percentage at the end. How to use these forms was that the forms were completed once before use and once after the use of shoes by the samples and the difference between the two scores was compared. The samples used the shoes for two months and an average of 4 hours a day.

Statistical Methods

Estimation of the standard deviation of change in performance score before and after use and minimum difference in performance score before and after shoe use were determined. Finally, the results were analyzed using SPSS software and Paired-t and Kruskal–Wallis ANOVA tests.

Findings

The results of comparing shoes with ergonomic indicators showed that none of the shoes in the studied sections fully comply with these indicators and only one of them can be closer to the standard type by making changes. The comparison results are summarized in Tables (2-3). The experiment also showed that Adak and the famous shoes in the toe box are more compatible than the other three shoes. In the Vamp section, the SLS and Melli shoes were less compatible with ergonomic performance than other shoes. So that only 10% of the samples received the highest score of full compliance in this section. In this part, Adak shoes with 40% excellent game points are reported to be better than Iran Tab. The Kruskal-Wallis test showed that in the Quarter, the Adak and Iran Teb shoes are not significantly different, but are more compatible than the SLS shoes. In terms of insoles, most shoes had a mediocre score. The results are given in Table (2).

Table (2): The degree of compliance of the examined shoes with ergonomic indicators

Compliance with ergonomic indicators (percentage)																		
Heel			Insole			Quarter			Vamp			Toe box			Shoe upper			Shoe type
High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	
30	70	0	20	60	20	20	40	40	10	70	20	20	70	10	20	0	10	SLS
30	70	0	30	70	0	50	50	0	40	60	0	30	70	0	50	50	0	Adak
10	90	0	20	80	0	40	60	0	30	70	0	20	80	0	40	0	60	Iran Teb
10	90	0	30	70	0	0	10	0	30	70	0	20	80	0	40	60	0	Shahir
30	70	0	30	70	0	20	40	40	10	70	20	20	70	10	20	70	10	Melli

In the second stage, the effect of these shoes on reducing pain samples was investigated. For example, the ANOVA test showed that the mean age, height, weight, and BMI were not significantly different between the four groups and the samples were usually the same in terms of variables. Paired t-test showed that in all shoes, the average foot performance has significantly improved so that using SLS shoes, outsole performance score from 53 to 64%, Adak shoes from 53 to 65%, Iran Tab shoes From 55 to 66 percent, and using Shahir and Melli shoes, the score increased from 56 to 63 percent.

Table (3): Foot and knee function score before and after using shoes

Shoe type	Knee performance score (percentage)		Foot performance score (percentage)	
	Before use	After use	Before use	After use
SLS	40/48	42/73	53	64
Adak	46/14	48/67	53	65
Iran teb	49/63	51/08	55	66
Shahir	59/63	59/63	56	63
Melli	59/75	59/75	56	63

Discussion and Conclusion

The human foot has a complex structure made up of bones, joints, nerves, and muscles, about a quarter of the body's bones. The small size of this complex organ compared to the size of the whole body and that it plays an essential and supporting role in the whole body. Therefore, choosing the right shoes is very important; According to research, by adding appropriate items and indicators such as choosing more suitable fabric for ventilation, more attention to more accurate anthropometric measurements in the toe area for more comfort, and having a suitable insole to prevent musculoskeletal disorders in the sole and Kneeling to one of the shoes is very important for people with certain diseases such as diabetes. Therefore, it is recommended that more research be done on the design tool of the outsole and other components of this shoe to find a suitable shoe to prevent wounds during long-term use. It should be noted that all these items should be done and selected under the supervision of a specialist and ergonomists do.

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Reducing garment mass for end-user comfort: a literature review

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ABSTRACT

There has been some anecdotal evidence to suggest a ~30% reduction in garment mass would be meaningful for end-user comfort. However, evidence of a systematic relationship between mass of a garment and end-user comfort is not available. The aim of this literature review was to explore the relationship between heaviness, comfort perception and garment mass to provide a framework for meaningful development targets. In the field of psychophysics, several models have been proposed to quantify relationships between weight and the perceived response by an individual; Weber's Law, Fechner's Law and Stevens Power Law. These laws identify weight discrimination thresholds and provide an indication of perceived intensity for weight evaluated in the hand, relative to a comparison. This has important application to in-store or sale environments, where consumers evaluate products using their hands. For hand evaluations, meaningful development targets for reductions in garment mass should therefore be made with consideration of these models and in particular Weber's Law. For the evaluation of garment mass during wear, the relationship between heaviness, comfort and mass has only been investigated in two studies, specifically for shoes. Although heaviness, comfort and shoe mass were reported to be unrelated, observations were based upon the mass of five shoes only, limited in range. Currently, there is not sufficient evidence to provide meaningful development targets for garment mass reductions required for end-user comfort during wear. Thus, the relationship between heaviness, comfort and mass requires further evaluation, particularly for apparel.

KEYWORDS

Garment, Mass, Comfort

Introduction

Minimising additional weight of clothing garments in order to maintain human performance is a well-recognised ergonomic principle, particularly for the development of protective and military clothing and to a lesser extent, clothing for sport and recreational activity. Definition of the maximum acceptable weight of clothing products has been attempted in several studies. For example, the maximum weight of an industrial helmet is claimed to be under 300 g (Abeysekera 1992) and a shoe mass less than 440 g per pair has been reported to have no detrimental effect on running economy relative to barefoot (Fuller et al. 2015). However, the perceivable threshold for differences in weight and the hedonic sensory experiences elicited in response to the weight of clothing products has received lesser attention.

There has been some anecdotal evidence within the clothing industry to suggest a ~30% reduction in garment mass would be meaningful for comfort. However, evidence to support a systematic relationship between reduction in garment mass and end user comfort is not available. In the field of psychophysics, several models have been proposed to quantify relationships between weight and the perceived response by an individual; Weber's Law, Fechner's Law and Stevens Power Law.

These models have identified weight discrimination thresholds, indicating the smallest change in weight that a person could sense when the weight of an object remains constant in one hand and is increased or decreased in the other hand and provide an indication of perceived intensity for weight. In the context of clothing, this may be representative of an in-store or sales environment, whereby consumers evaluate products using their hands. However, during wear and in the absence of centrally generated input to the muscle with active lifting, the perception of weight, although still possible, may be considerably different. Thus, cutaneous inputs such as pressure (the amount of force applied per unit area of skin) with fabric-to-skin interactions, may be important stimulus parameters for feelings of lightness/heaviness, tightness/looseness, and for emotional responses of pleasantness or comfort.

The aim of this literature review was to explore the relationship between heaviness, comfort perception and garment mass to provide a framework for meaningful development targets.

Findings

In the field of psychophysics, several laws have been proposed to quantify relationships between mass and the perceived response by an individual; Weber's Law, Fechner's Law and Steven's Power Law (Harper and Stevens 1948; Weber 1996).

Weber's law expresses a general relationship between a quantity or intensity of something and how much more needs to be added/removed for us to be able to tell that something has been added/removed (Weber 1996). For instance, it explains why are we able to tell if three nuts have been taken from a bowl that is nearly empty compared to if the bowl is full. In his study of discrimination thresholds for weight conducted in 1834, Weber blindfolded participants and gave them two weights of equal magnitudes (standard weight) to hold in each hand. He then began to gradually add weight (test weight) to one hand. The participants were asked to compare the weights in both hands and determine which was larger. In doing so, Weber describes a just-noticeable difference (JND); 'the minimum difference in weight that a person can detect 50% of the time' (Weber 1996). Although the JND changes depending on how much mass there is before an increment is added, the ratio of JND to background intensity is constant within a certain range.

Building on the work of Weber, Fechner investigated the relationship between the intensity of a stimulus and the perceived (estimated) magnitude (Weber 1996). To derive this relationship, Fechner made two assumptions: (1) the JND is a constant fraction of the stimulus (i.e. Weber's law holds) and (2) the JND is the basic unit of perceived magnitude, so that one JND is perceptually equal to another JND. Mathematically this produced a logarithmic relation between stimulus intensity and sensation, indicating whether a doubling of a stimulus results in a doubling in perception of the stimulus.

In the early 1950's however, Weber-Fechner's log law was modified to a power function by Stevens (Harper and Stevens 1948; Weber 1996). Stevens challenged the assumptions made by Fechner, conducting experiments with human participants to investigate how perception increases with an increase in stimulus intensity. Stevens found that for most senses, the relationship between the intensity of a stimulus and the estimated response magnitude is best described by a power law, which directly converts judgements of a sensation into measurements of sensory magnitude. Using this approach, Stevens identified three types of stimulus response curves. The first is a response compression curve, indicating that as the intensity of a stimulus increases, the perceived response also increases but not as rapidly as the intensity; the exponent is < 1.0. The second is a response expansion curve, indicating that as the intensity of a stimulus increases, the perceived response is more than doubled; the exponent is > 1.0. Finally, a linear stimulus response curve indicates that as the intensity of a stimulus increases, the perceived response increases relative to the intensity; the power of the exponent is 1.0 or close to 1.0. For the perception of weight, Harper and Stevens

(1948) report a power function with an exponent of 1.45. Therefore as the intensity of weight increased, the perceived response more than doubled (Harper and Stevens 1948).

Overall, Weber-Fechner Law and Stevens Power Law provide valuable insight into the perception of weight when evaluated in the hand, relative to a comparison. This has important application to in-store or sale environments, whereby consumers evaluate products using their hands. Meaningful development targets for reductions in garment mass for hand evaluations should therefore be made with consideration of these models. In particular, reductions in garment mass should be made in line with Weber's Law with targets representing the minimum reduction in mass required for an individual to notice 50% of the time. It is currently unknown whether Weber's Law holds true when wearing a garment.

To our knowledge, only two studies have investigated the relationship between heaviness, comfort and mass during wear, specifically for running shoes (Slade et al. 2014; Saxton et al. 2020). Saxton et al. (2020) reported poor correlations between perceived mass and actual mass (1 min evaluation: $r = 0.28$ and 5 min evaluation: $r = 0.33$) and between comfort and actual mass (r values not reported). Moreover, a relationship between comfort and perceived mass was not observed (1 min evaluation: $r = 0.07$ and 5 min evaluation: $r = -0.07$). Together, these findings suggest shoe comfort and mass to be unrelated. However, it is important to note that observations were based upon the mass of five shoes, limited in range (Saxton et al. 2020). This consequently resulted in all shoes being rated between four and six on the visual analogue scale for heaviness (0 not heavy at all to 10 most heavy imaginable) and comfort (0 not comfortable at all to 10 most comfortable). The ratings provided therefore suggest that all shoes were identified as neither heavy nor light and comfortable. A greater range in actual mass may be required to pertain the true relationship between perceptions of mass, perceptions of comfort and actual mass. Moreover, it is unclear how these findings might apply to mass perception and discrimination of apparel.

Finally, although there has been some anecdotal evidence within the clothing industry to suggest a ~30% reduction in garment mass would be meaningful for end-user comfort, the outcome of this literature review provides no external evidence to support such a metric. The relationship between heaviness, comfort and mass therefore requires further evaluation.

Conclusions

Where comparisons between garments are being made with hand evaluations (in-store point of purchase, or point of first contact), reductions in the mass of garments should be made in line with Weber's Law. These targets represent the minimum reduction in mass required for an individual to notice 50% of the time. Although it is currently unknown whether Weber's Law holds true when wearing a garment, according to Stevens Power Law, as the intensity of weight increases, the perceived response is more than doubled (Harper and Stevens 1948). Thus, reductions to garment mass could translate to meaningful and perceivable benefits during wear. Unfortunately, the results from this literature review indicate no evidence of a systematic relationship between comfort and mass during wear. The reduction in garment mass required for meaningful end-user comfort is therefore unknown and requires further investigation. This is fundamental to the development of garment mass reduction targets relevant to end-user comfort.

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Discomfort from wearing face coverings in public transport

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ABSTRACT

Within 12 months, the usage of Face Masks (FM) has shifted from being specifically used by some specialists, to being the norm for most of the world's population. The design of FM has changed as they have become more common. Compliance with wearing any PPE (personal protective equipment) is closely associated with comfort, whether it be FM, hearing protection, body armour, etc. It is now normal for passengers to travel for long periods of time wearing FM, but these are anecdotally considered uncomfortable but there is little independent research helping to understand what makes for a comfortable, or uncomfortable, mask. This is of particular concern in the airline industry.

This paper reports a study that assesses the comfort of Face Mask/Face coverings (FM/FC) through eliciting the opinions of FM users, with a closer look at design features. An online questionnaire survey of the public (n=202) was conducted covering topics such as experience with FM, FM irritation, comfort perception of a range of FMs. Priming questions on perception of comfort in travel environments were included to provide context.. The highest factor of irritation in surgical FM was associated with the ear loops, where for a short period (44%) and long period (50%) achieved the highest percentage of votes in both conditions. For FM, the fabric FM performed best across the board with a key result of showing a statistical significance ($p<0.05$) against the surgical FM. Dissatisfaction of the ear loops on FM was clearly shown in data, as well as in the general comments section at the end of the survey. The data has clearly shown that an interest in further development of the ear loops will see a significant improvement in the comfort of FM.

KEYWORDS

Face mask, face covering, COVID-19

Introduction

In the six months from the beginning of 2020 the use of Face Masks (FM) shifted from being limited to specific workers for PPE, to becoming a requirement in order to function in society across much of the world. At the time of writing the COVID-19 pandemic continues to dominate global travel and social interactions. It is anticipated that FM use will perpetuate for some time in order to minimise viral spread.

In order to obtain protection from any PPE it is necessary that it is worn by users. For those items that need to be worn for extended periods of time, comfort is a critical factor in selection for individuals in order to maximise compliance (e.g. hearing protectors; Gerges, 2021). The immediate demand for FM during the COVID-19 pandemic meant that there was little opportunity for manufacturers to optimise design before taking to market and therefore a wide range of products and designs are commercially available. The effectiveness of many designs at minimising virus spread, and their comfort, is largely unevaluated for products targeted at the general consumer (e.g. Lee et al. 2020).

A questionnaire study was designed to investigate the properties of FM that users associated with feelings of comfort and discomfort. The study was designed in September 2020 in order to review and survey commonly used FM types available in the UK.

Methods

A questionnaire was developed using Google forms and comprised several sections. The first sections of the questionnaire elicited information on experience of FM and experience of travel whilst using FM. The second section introduced the concept of vehicle comfort by asking questions related to general seating comfort; this section was designed to prime respondents to comfort concepts later in the questionnaire. The third section elicited information on which elements of FM caused discomfort for short and long periods of wear, and rankings of FM comfort. Finally, participants were asked to select a type of FM for use on a regional flight, and given opportunity to give general comment. The study design was approved by Nottingham Trent University Ethical Advisory Committee.

202 participants completed the survey. They had a mean age of 42.3y (s.d. 17.4y). 53% were male, 47% female. 92% resided in the UK, with others residing in USA, Germany, Australia, India, Indonesia, Ireland, Iran, Netherlands, Malaysia, Spain.

For the purposes of this paper, the term Face Masks (FM) is used generically to mean all types of face covering. The effectiveness or certification of the FM was not considered, although its importance is acknowledged.

Results

Data for *Frequency of use, Location of use, Who does it protect?, Experience of use,* and *Duration of use* are shown in Table 1.

64% reported wearing masks 'Everyday' or 'Most Days' with 2% stating 'Never'. Almost all respondents reported wearing FM for shopping and about half wore them at work. Most (78%) thought that the FM protected both them and others; 6% did not consider them effective. Of those who had experienced FM in public transport, 80% had experienced them on trains (both underground and overground), and 63% taxi. Approximately 1/3 or respondents had experienced using FM whilst flying. The longest time worn in public transport was reported as over 2 hours for 36% and less than 30 minutes for 27%.

Participants were asked two similar questions:

- In your opinion, identify the area of a face mask which causes you the most discomfort when wearing for a SHORT period of time (E.g. Single supermarket shop)
- In your opinion, identify the area of a face mask which causes you the most discomfort when wearing for a LONG period of time (E.g. Long train journey, Full day of work)

Table 1. Percentage of participants with responses to questions relating to Frequency of use, Location of use, Who does it protect?, Experience of use, and Duration of use on public transport. (Rounding errors have not been adjusted).

Frequency of use	Location of use	Who does it protect?	Experience of use	Duration of use on public transport
Everyday 39%	Shopping 96%	Protects both me and others 78%	Train 80%	<30 mins 27%
Most days 25%	At work 46%	Only protects me 1%	Aircraft 32%	30-60 mins 20%
A few times a week 27%	Commuting 44%	Only protects others 15%	Bus 40%	1hr-2hrs 18%
About once a week 5%	Travelling for leisure 34%	Is not effective 6%	Tram 13%	2hrs+ 36%
Less than once a week 5%	Travelling for business 24%		Taxi 63%	
Never 2%			Boat 9%	

The region of the FM identified by participants as the main source of discomfort was similar for both short and long wear times (Figure 1). The ear loops were considered the most uncomfortable part, reaching 50% of complaints for long duration wear. The upper stitching across the nose was the second most commonly rated area of discomfort.

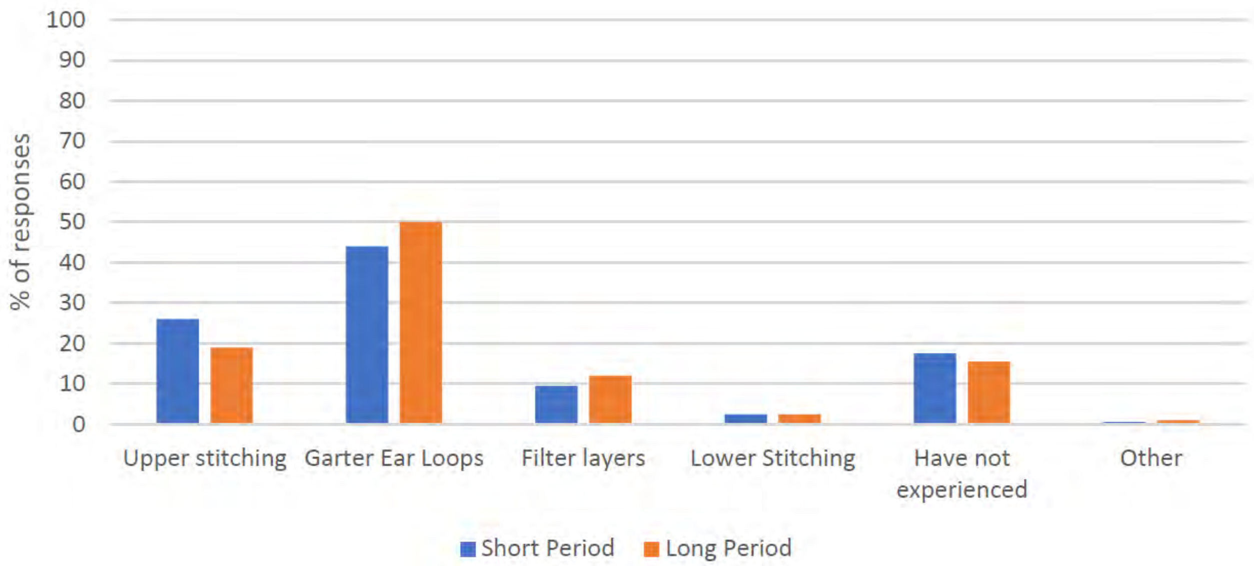

Figure 1. Distribution of responses showing area of FM considered to cause the most discomfort for short and long-term wear.

Participants were asked:

- If you were travelling on a regional flights (e.g. 1-2 hours within Europe) which type of mask would you choose to wear (assume all are allowed, legally)?

Of the 7 choices offered, the most popular (26%) was a surgical mask followed by two fabric FM with ear loops (19% and 17%) and a CE marked dust mask (Figure 2). Despite garter ear loops being previously identified as the most uncomfortable part of FM, two of the three least popular FM included fastenings that did not use ear loops.

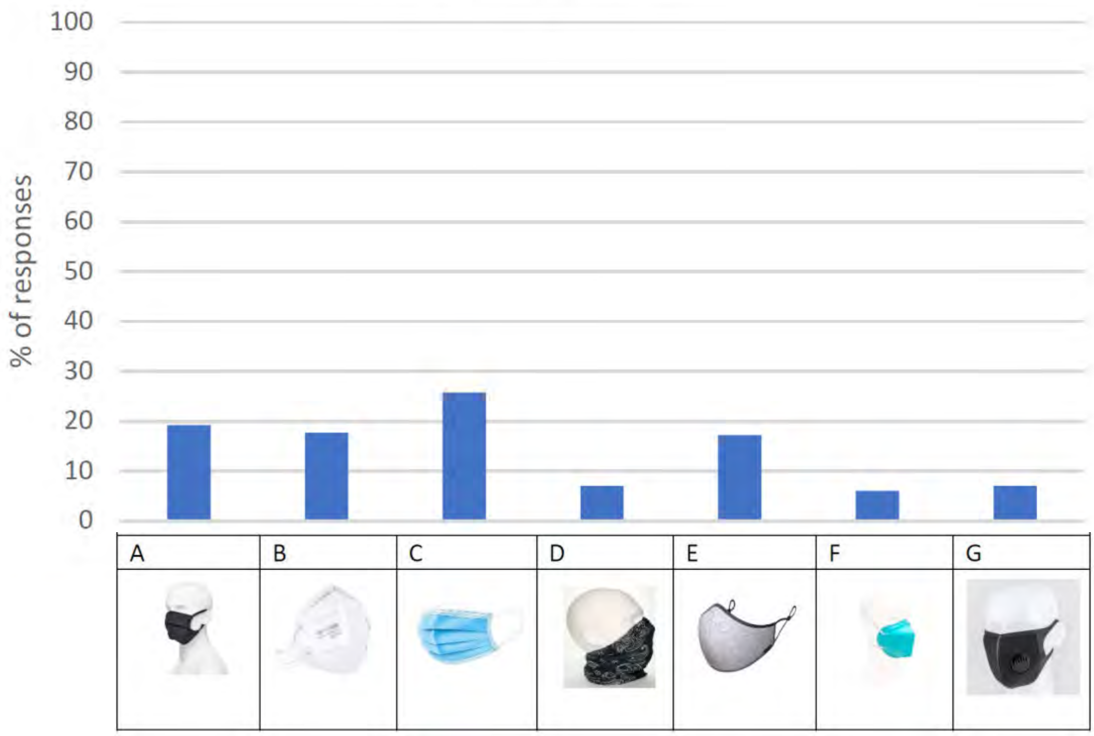

Figure 2. Distribution of responses showing preferred type of FM for use on a regional flight or similar.

Participants were asked to score FM A, C, D, F and G based on their perceived comfort (NB this was only based on the presented image and previous experience – physical examples were not presented). FM A, fabric with garter straps, was considered the most comfortable ($p<0.02$, t-test). FM G, including an air valve system, was considered the least comfortable, although the differences were not significant between G and C, D and F. Considering the selection of FM (Figure 2), this indicates that the choice of the preferred type of FM is not made on comfort alone.

Conclusions

The majority of participants completing this survey had worn FM in a variety of settings. Most had travelled on public transport whilst wearing a FM and over 1/3 had travelled for more than 2 hours wearing a mask. The ear loops and nose bridge are considered the most uncomfortable regions of FM.

It is concluded that the design of FM needs to be improved in order to maximise comfort for the wearer. Improved comfort is likely to improve compliance with wear. Although comfort is considered important, it is noted that the preferred type of FM was not the most comfortable, but one that is widely associated with being effective (i.e. surgical mask).

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Clothing comfort – Consumer expectation and perception of sports garments

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ABSTRACT

Consumers are the driving force behind innovations in sportswear. Their demand for supportive and performance enhancing sportswear is increasing. The requirement for comfort in sports garments is fundamental, but its multifactorial nature makes it difficult to easily define. Whilst literature commonly gives a division of comfort in terms of psychological, physical (sensorial/tactile) and physiological comfort there is hardly a definition of clothing comfort from a consumer's perspective. Within the sports garment's development the choice of fabric is an integral part and has effects on the overall appearance and performance. Sports garments are manufactured from a combination of natural and synthetic fibres in knitted or woven materials. Product information labels and webpages state fibre contents and are used to identify the composition of the garment; however, consumers need knowledge of which properties are associated with the product attributes. This study explored factors contributing to the clothing comfort concept from a consumer perspective. Priorities of attributes contributing to the concept varied according to the person's sex. Females put more emphasis on garment fit, whereas males prioritised physiological comfort descriptors. A conceptualised feel in regard to commonly known textile materials taking sex into consideration was identified. A preference for cotton fibres in females and for polyester fibres in males was found. For the apparel industry, information on product attributes from a consumer perspective is key for an effective product development.

KEYWORDS

Clothing comfort, Sports garments, Purchase behaviour, Fibre preferences and perception, Haptic, E-commerce

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Introduction

Sports garments play an important role in the well-being of both recreational and professional athletes. They protect the wearer from changing environmental conditions and provide a comfortable feel. Particularly in sports garments, comfort influences the overall performance and utility of the garment. The division of comfort in psychological/ergonomic, physical (sensorial/tactile) and physiological comfort defines its multifactorial nature (Kamalha *et al.*, 2013). The psychological/ergonomic comfort covers aspects of style, aesthetics, design, colour, fit, and freedom of movement, etc. The physical comfort creates sensations such as tactile (smoothness, roughness, softness, etc.), thermal (warmth, coolness, breathability), moisture (wetness, stickiness) and pressure sensations (light, heavy) (Bartels, 2005). The physiological comfort finally refers to the body thermoregulation. A perception of comfort is created when sensory information is received, processed and finally compared to past sensory experiences. The latter represents people's expectations and perceptions which influence the formulation of differently weighted clothing attributes (Rahman, 2011; Freire Castelo and de Oliveira Cabral, 2018). The perception of quality in clothing is commonly defined by two general types: extrinsic and intrinsic cues. Intrinsic cues cannot be modified without changing the overall product and are inherent to the physical composition. Comfort is part of the intrinsic cues, and with-it fibre content, fabric structure, garment construction, and quality. Intrinsic cues are considered to have greater importance than extrinsic ones, which are related to the product, however are not physically part of it (price, brand label, store, etc.) (Freire Castelo and de Oliveira Cabral, 2018). This study will investigate comfort characteristics and the perception of different fibre types as part of the intrinsic cues of sports garments. The knowledge of materials and preferences that user have will aid the definition of garment properties and contribute to garment development, for providing (post purchase) satisfaction. The purpose of this study is to identify the main attributes contributing to comfort. Furthermore, the prioritisation of garment type in relation to comfort, and consumer attitudes towards specific textile materials are investigated. Sex related differences are taken into account.

A brief outline of the work carried out

An online survey was performed included 292 respondents, classified by sex, age, and amount and type of physical activity. The respondents were asked a total of 18 questions through the Bristol Online Survey tool to explore consumers' expectation and perception of clothing comfort in sports garments. Furthermore, preconceived opinion regarding the feel of different textile materials such as cotton, polyester, cotton/polyester blend and wool was investigated. All procedures have been approved by the Loughborough University Ethics Approvals Sub-Committee.

Data was analysed by running frequency distributions, multiple response frequency analyses as well as crosstabulations using SPSS version 26. A (Pearson) Chi-square (χ^2) test of independence was performed to find significant differences between sex (male/female). A probability level of $p < 0.05$ was defined for the threshold for significance. Open answer questions were analysed using a qualitative data analysis program (NVivo version 12) to identify themes and word trends.

Findings

Identification of the main attributes contributing to comfort.

Comfort is an important attribute in the purchase of sports garments. To be able to identify the main attributes contributing to the clothing comfort concept the question *"what is comfort in sports garments for you"* was asked and a list of suggestions provided. The ticked answers were evaluated. The three most important descriptors are *freedom of movement* (73.3%), *fit on the body* (60.3%) and *a nice feel when wearing the garment* (58.6%). Respondents were also asked to describe comfort in sports garments in their own words. Figure 1 (left) is a visual representation of the descriptions of comfort. *Fit* and *Feel* are the most prominent words, which respectively obtained a high ranking in the fixed answer question (*fit on the body, nice feel when wearing the garment*). Smaller displayed words were mostly combined with more prominent words such as *loose/baggy* with *fit* or *smooth/soft* with *feel*. *Tight* was mainly used in the context that the garments should not be (too) tight.

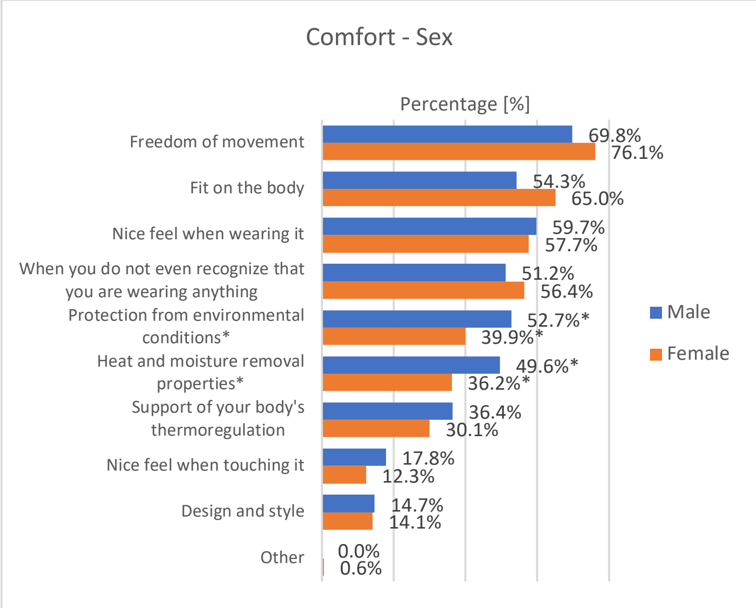


Figure 1: *Left:* Word cloud representing the description of comfort by the participants ("*How would you describe comfort in sports garments for you?*"). *Right:* Comparison of comfort descriptors broken down by sex ("*What is comfort in sports garments for you?*"). * indicates a significant difference between the two groups.

Priorities of attributes contributing to comfort differed according to the person's sex (female/male). Figure 1 (right) shows the frequency distribution amongst males and females. Significantly more males prioritised physiological comfort descriptors such as *protection from environmental conditions* and *heat and moisture removal properties*. They place emphasis on having functional clothing with good breathability. There is a trend of females prioritising *freedom of movement* and *fit on the body*. Males and females differ on how they think, feel, and act concerning their bodies. Especially females place more cognitive and behavioural emphasis on managing their appearance (Cash and Brown, 1989), which could be an explanation why females placed greater emphasis on good fit.

For which garment type is wear comfort most important?

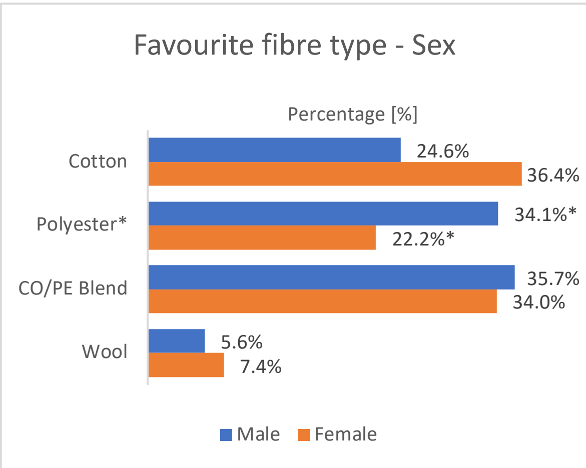
Respondents were asked to select up to two garment types for which wear comfort is most important (sports bra, t-shirt, pants, leggings, socks, jacket). A significant difference was found in all categories. Females chose sports bras (83.4%), leggings (56.4%) and pants (28.2%) and males t-shirts (79.1%), pants (69.8%) and socks (27.9%). That female respondents chose sports bras as the garment type for which wear comfort is most important is not surprising. The variety of individual breast shapes as well as breast asymmetries make it difficult to find well-fitted sports bras. For male participants t-shirts are considered most important. This garment type is, similar to sports bras, in direct contact with the skin, which is especially relevant when talking about moisture management properties of textiles. The next-to-skin garment takes up sweat and spreads it to a larger area on the fabric where heat loss due to evaporation takes place (Wang et al., 2013). Socks also gained higher percentage amongst male respondents. They are regarded as an important component within the foot-shoe system and have a positive impact on the reduction of tactile and mechanical inputs generated between the foot and the shoe (West et al., 2021).

Is there a preconceived opinion regarding the feel of different textile materials?

Throughout the survey participants relied on stored personal information about previous experiences with fabric materials. Therefore, participants could possibly have had difficulties distinguishing some attributes, since they were not able to touch or lift the textile materials. Still, the results for the conceptualised feel of the textile materials are as could be expected: Cotton (CO) is considered to be a natural (65.4%), soft (53.8%) and smooth (50%) material with a warm feeling (46.2%). Polyester (PE) was evaluated to be synthetic (75%), light-weight (62.7%) and has a cold feeling (41.1%). The cotton/polyester blend (CO/PE) was judged smooth (56.2%), light-weight (42.8%), soft (39.4%) and synthetic (32.9%). Respondents seemed to struggle with rating the blend reflected in lower response rates. The main characteristics for wool were warm-feeling (73.6%), scratchy (54.5%), natural (51.7%), heavy-weight (46.6%) and rough (34.2%).

Considering female and male responses separately, there was a statistically significant difference in males seeing cotton as a heavy (34.1%; females: 20.9%) and warm (55% and females: 39.3%) material, which are both negative associations in regard to sports clothing. The preconceived feel of polyester between sex was significantly different in the attributes of cold-feeling (males: 48.8%; females: 35.0%) and stiff (males: 0.8%; females: 4.9%). Furthermore, significantly more males perceived the blend (CO/PE) as silky (17.8%; females: 9.8%).

The results regarding the selection of fibre types confirm that there is a trend that females have a stronger preference for cotton, which is confirmed by the significant difference in the selection of the fibre type for the summer running t-shirt (26.4%; males: 11.6%). This is in accordance with a study of Byrne et al. (1993) who also found a preference for natural fibres in female consumers. A preference for polyester in males is visible in both frequency distributions (Figure 2).



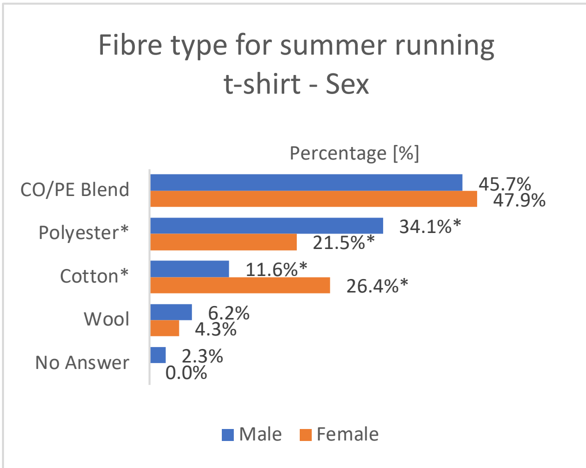


Figure 2: *Left: "Please sort the fibre types from most favourite (1) to least favourite (4) one in your sports garments". Right: "Imagine you could design your own individual running-shirt from scratch. Pick the fibre type for the production of your running t-shirt for summer"*. * indicates a significant difference between the two groups.

These results lead to a conclusion that males prefer t-shirts made out of polyester due to a cold touch and its light-weight whereas females prioritise a warm, soft-felt and natural material such as cotton. Hyun et al. (1991) noted that the overall garment comfort is influenced by fibre type.

Impact

For the apparel industry information on product attributes from a consumer perspective is crucial. Comfort is not only affects well-being, but also the performance and efficiency of athletes, which ultimately influences their success (Bartels, 2011). Comfort is of multifactorial nature and consumers do not seek a single attribute, but multiple factors within the product to satisfy their preference. *Freedom of movement, fit* and *feel* have been identified as the main parameters contributing to the clothing comfort concept. A major barrier for the sports garment industry in the e-commerce domain, is how to present the ‘feel’ of a garment in a descriptive or visual form. Webpages only state fibre contents; however, the consumer must be knowledgeable about how the materials feels on the skin. In order to develop and optimise e-commerce further, sports companies should focus on not only stating information on the material composition but communicating on how the material feels on the skin, since this is a missing crucial parameter when shopping virtually. The survey identified common associations for textile materials (cotton, polyester, cotton/polyester blend, wool), identified the cotton/polyester blend as the most favourite fibre composition for a running t-shirt in a warm environment and showed a sex related nuance on cotton and polyester in their pure form. Furthermore, females put more emphasis on garment fit, and males prioritised physiological comfort descriptors for a good thermoregulatory support. Sex nuances regarding clothing comfort concept should be considered for an effective product development and marketing strategies. The challenge is to find a way of bridging the gap between description and appearance and the haptic sensations experienced by the wearer.

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COMFORT CONGRESS 2021
Methods, Models and Standards

On the objective assessment of comfort

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Abstract

In this paper, a literature study is presented on the types of objective measures that can contribute to the prediction of (dis)comfort, the feasibility of measuring those factors, and the potential of building a model based on them. Results indicate that in addition to subjective measurements, objective measures might help us to understand the process towards comfort or discomfort better, and some of them might be used as predictors in modelling comfort/discomfort.

Keywords

Comfort, discomfort, measure

Introduction

Improving comfort and reducing discomfort are the wishes of designer of a product, service or environment. While the product/service/environment itself cannot be comfortable, the user speaks during and after the use of it (Mansfield et al. 2020). Such comfort experience can be summarized as “a pleasant state or relaxed feeling of a human being in reaction to its environment” and the discomfort experience is “an unpleasant state of the human body in reaction to its physical environment” (Vink and Hallbeck 2012). In comparison with comfort, the feeling of discomfort is more associated to the physical interactions between the user and the product/environment.

In the measurement of the levels of (dis)comfort of a user, subjective measures are still the “golden” standard. Researchers developed many useful questionnaires for evaluating the levels of (dis)comfort in different design phases for different applications (Anjani et al. 2021). However, the process of using subjective measures is often time consuming and the results are prone to inter- and intra-observer variabilities (Ramkumar et al. 2017), and sometimes it is even difficult for the users to complete a comfort questionnaire while using a product. Besides, though it is possible to study (dis)comfort in the use of products/services based on the outcomes of questionnaires, it might be a challenge to detect them in real-time, and apply possible interventions if needed. In addition, in explaining the questionnaire outcomes, measurements of a certain physical phenomenon might be helpful. For this, objective measures of (dis)comfort are useful additions.

While the word (dis)comfort offers a nice cosmetic coating of the phenomenon, it has a lot constructs (Mansfield et al. 2020). Those constructs are associated with the users’ backgrounds, the expectation(s), the (social) environment(s), the product(s) he/she is using, the interactions between the user and the product/environment, and the duration of the use (Naddeo 2017). All of these form a multi-factorial model (Mansfield et al. 2020). Though complicated, factors that can be objectively measured, or inferred from other related measurable parameters, might be useful in quantifying (part of) this phenomenon in a specific context.

In the European project COMFDEMO, researchers are working on modelling the (dis)comfort experience of passengers sitting in the aircraft cabin. The purpose of this paper is to make an investigation of the types of objective measures that can contribute to the prediction of (dis)comfort, the feasibility of measuring those factors, and the potential of building a model based on them.

Materials & Methods

We searched in the databases Web of Science, Scopus and PubMed with the search term "Comfort AND Discomfort AND Measurement". The numbers of found records were 589, 869 and 1089, respectively. After removing duplications, 1767 records were identified. By screening all abstracts with the criterion of "using objective measures to evaluate (dis)comfort", we identified 284 relevant papers. This number was further refined to 190 after reading the full papers. These studies can be categorized according to different criteria: the product/ environment to be evaluated, the types of user activities, the measures, etc. Characteristics of these studies will be described in the results.

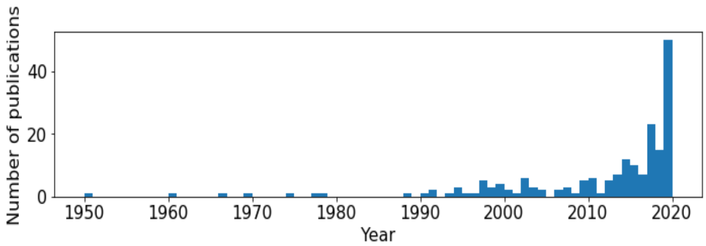

Figure 1: The number of comfort studies using objective measures

Results & Discussions

The selected 190 studies indicated that from 1950s, researcher started to pay attention to the objective measures of the perceived (dis)comfort of users in the use of different products/services/ environments. Recently, this research topic attracted more attention as Fig.1.

Product (environment) being investigated

(Dis)Comfort is evaluated in different environments with different populations. While the building environment (33 of 190) and seats in transportation (67 of 190) were the focus of researchers, clinical environment also attracted much attention. Besides, screens (incl. Head Mount Display), hand tools (incl. handles, glove, smart phone), respirator facepieces (incl. masks), shoes (incl. insole), protective clothes were also investigated. An important finding is that recently, researchers also paid much attention on the perceived comfort in using personalized products, especially personalized medical products (Jeong-Hoon Yang, Shinsuke Kato, and Ho-Tae Seok 2009)(Paternò et al. 2020), due to its uniqueness nature.

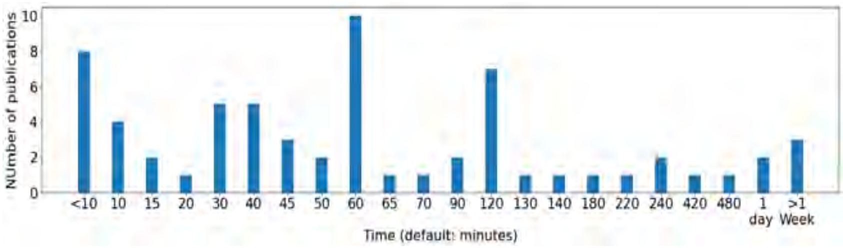

Figure 2: Time duration of the measurement

Time durations of the studies

The feeling of (dis)comfort can be influenced by time where the level of discomfort often increases over time in the use of the product (Sammonds, Fray, and Mansfield 2017). Figure 6 lists the numbers of studies versus the time duration of these studies. It shows that less than 10 minutes, 30~40 minutes, 60 minutes and 120 minutes are often selected by researchers, mainly due to that: 1) studies suggested that the effect of (dis)comfort regarding the use of product/ environment is significant after 40 minutes exposure (Mansfield, Sammonds, and Nguyen 2015); 2) the time duration in the usage scenario, e.g. in the use of a bike (Gomes and Savionek 2014), a trip is often within 120 minutes and in the study of comfort of standing on a floor (Zander, King, and Ezenwa 2004), researchers set the exposure time same as the length of a working day (8h); 3) practical constrains in the study, e.g. in the evaluation of keyboards, one study set the duration as 5 -10 minutes (Smutz, Serina, and Rempel 1994) and another set the duration as 120 minutes (Liao and Drury 2000).

Measures

In Figure 3, we list the objective measures that are used in the selected studies regarding different applications. In the following, we summarize the findings according to temperature & air quality, vibroacoustic environment, physiological and physical measures of the subject.

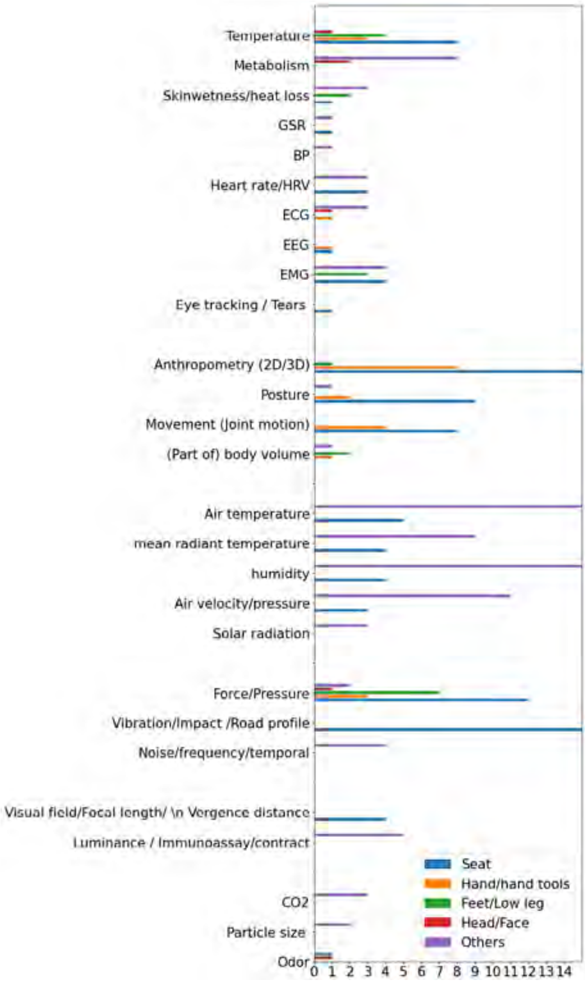

Figure 3: Measures used in the selected studies

Temperature & Air quality

In the study of thermal environment, four physical variables, the air temperature, the mean radiant temperature, the air velocity and the relative humidity, are often mentioned according to the ISO7726 (Gameiro da Silva 2002). For the air temperature, females became aware of thermal discomfort before males under low air temperature conditions (Hashiguchi, Feng, and Tochihara 2010). Regarding the humidity, it was indicated that the most comfort relative humidity range is 30%-50%. However, in the use of products and in some environments, the levels of humidity may differ around human bodies. For instance, Dell and Romitelli (Della and Romitelli 1993) found that the feeling of humid warmth in the body area in contact with seat becomes the most important. Air velocity may influence the perceived comfort, especially regarding the thermal comfort experience by influencing the convective heat transfer coefficients. Sakoi (Sakoi et al. 2007) indicated that the peak of the overall comfort sensation appeared around a mean sensible heat loss of 40 W/m^2. However, even if the mean skin temperature and the mean sensible heat loss were kept constant at 34 °C and 40 W/m^2, respectively, the overall comfort sensation tended to decrease with an increase in the magnitude of environmental thermal non-uniformity.

Besides these four major factors, the concentration of CO_2 and the odour might also influence the feeling of comfort. The range of CO_2 concentration may differ from 577 to 1787 ppm in a classroom, and high concentrations of CO_2 (e.g. due to poor air ventilation) may lead to significant difference between the performance of students (Vilcekova et al. 2017). The odour might also influence the perceived (dis)comfort of users over time, however, the scent preferences differ a lot among a population (Yao, Song, and Vink 2021).

Black-globe thermometers were often used in the measurement of mean radiant temperature. The air temperature, the humidity, the CO_2 concentration, the air speed of the environment are often measured by air quality monitoring systems (Huang and Kang 2020). (Zhang and Srinivasan 2020) gave an overview of these devices regarding the ability, the accuracy and the cost. In measuring the humidity around human body, smaller humidity sensors were selected by researchers (Paternò et al. 2020). Earlier works of using odour sensors to evaluate comfort was reported by (Hamanaka et al. 1997). Recently, different types of odour sensors, e.g. e-nose, are developed as summarized by (Hu et al. 2019)

Vibroacoustic

Vibration: Vehicle occupants can feel a wide range of frequencies, from less than 1 Hz to more than 300 Hz (Griffin 2007). For the whole-body vibration, a seat (and the backrest) usually attenuate high frequencies, and a bandwidth from 0.5 to 80 Hz is considered sufficient in ergonomics evaluation (ISO 2018). Although the seated human is especially sensitive to vertical vibration in the 4.5-5.5 Hz range, vibration and shock should be attenuated as much as possible, as in practice the lower and higher frequencies might influence the feeling of comfort as well (Wilder et al. 1994). The judgments of discomfort caused by stimuli having a common waveform were significantly increased by an increase of 6-12% in the magnitudes of the stimuli (Matsumoto and Griffin 2002). For hands and feet, there may be a direct contact with the product without attenuation by compliant materials. The frequency of hand-transmitted vibration can be up to 1000 Hz, although experimental data are difficult to acquire at such high frequencies (Griffin 2007).

To measure the vibration up to 80 Hz, according to the Nyquist law, the sampling frequency should be at least 160 Hz, preferably even higher for preserving more information in the original signal. Piezoelectric accelerometers are the most popular choice in industrial applications (Wijaya, Jönsson, and Johansson 2003). However, the sizes of these types of sensors are large and the cost is often high. In the past decade, capacitive MEMS accelerometers are widely used in measuring vibrations due to its small size, efficient power usage and low cost. However, the quality of acquired data is also low compared to data acquired from piezoelectric sensors, especially regarding high frequency and amplitude. More efforts are often needed in the post-processing (Han et al. 2020).

Noise: Occupational Safety and Health Administration (OSHA) requires employers to implement a hearing conservation program when noise exposure is at or above 85dB averaged over 8 working hours, or an 8-hour time-weighted average (Occupational Safety and Health 2021). However, it does not mean that the experienced noise lower than 85dB is comfortable. Different groups of people may have significantly different opinions on the acoustic comfort regarding the same noise (Al-Arja 2020), due to different intentions and exposure durations. Noise and vibration often occur simultaneously and the 'masking effect' regarding comfort is inevitable (Huang and Griffin 2012), i.e. high amplitude of vibrations may "cover" the changes of lower noise levels and vice versa. In the context of the airplane, noise at 70–88 dBA level cannot be "covered" by the vibration (Huang and Griffin 2014). For the noise at the same loudness, the subjective feeling might differ according to its spectra in the frequency domain as well (Vernet and Vallet 1977). For instance, (Li and Huang 2018) built a series of models regarding acoustic comfort of passengers on different road based on the loudness, the sharpness, the roughness, and the articulation of the sound.

The loudness of sound (in db/dBA) can be measured by decibel meters where a free-field microphone is often equipped. Considering the wide range of the loudness of noise levels in the daily life (e.g. 50 dbA/office, 75 dbA/outside), a class II device with ±2db accuracy might be enough in the study of acoustic comfort. The characteristic of sound can be acquired by analysing the sound records using software tools, e.g. by ArtemiS SUITE (Li and Huang 2018). However, ethical issues should be addressed as the voices of subjects and researchers are often recorded as well.

Physiological Measures of the user(s)

Though the psychological feeling of (dis)comfort does not necessarily be reflected on physiological measures, there are many relationships between them. Physiological measures convey precise information about an individual's bodily functions, and many of them, e.g. EEG, ECG (incl. HRV), EMG, were found to be related to the feeling of (dis)comfort in different contexts. As the measurement device itself might influence the feeling of comfort, e.g. it is difficult for the user to neglect the feeling of the EEG cap while evaluating the level of comfort in the use of a product, in this short review, we focus on several non-intrusive physiological measures only.

Skin temperature: In the studies focusing on thermal comfort, the skin temperature at different locations was always recorded. In more detailed studies, researchers also measured the rectal, muscle, finger and trunk temperate. Thermometers and thermistors were often used to measure the temperature of the skin and for measuring the temperature of the skin which is exposed to air, using infrared thermometers/cameras is getting more popular due to its non-invasive nature (Cosma and Simha 2019).

HRV: Hear rate variability (HRV) is often used in studies where the emotional stimulation is relatively strong (Choi et al. 2017). As human emotion and the feeling of comfort have strong relationships (Naddeo and Cappetti 2021), HRV was used in several studies related to comfort (Liu, Lian, and Liu 2008). More than 30 HRV features can be extracted from the acquired RR intervals of the subjects, and they can be classfied to time-domain, frequency-domain and non-linear features (Shaffer and Ginsberg 2017). Among them, time domain features SDNN, pNN50, RMSSD and frequency domain features LF/HF (Lorenzino et al. 2020) were often used in comfort evaluation. HRV features can be extracted from ECG signals in a clinical setup, however, the ECG measurement itself might be intrusive for the users. Recently, many wearables, e.g. Scosche Rhythm24, were introduced and they are able to log real-time RR intervals. Such a function might facilitate researchers in different comfort studies.

Galvanic Skin Response (GSR) is an “electrodermal” signature of the sympathetic nervous innervation of the skin, and it reacts sensitively to emotional provocation, salient thoughts, and attentional demand (Nagai, Jones, and Sen 2019). Similar to the use of HRV, GSR can be used to detect the emotional aspect of comfort. GSR devices with finger electrodes are widely used. Recently, low-cost wearable GSR sensors were also introduced by researchers in the evaluation of human emotion (Kyriakou et al. 2019).

EMG: EMGs of certain muscles are correlated with the comfort feeling while seated. The slumped sitting posture is most likely associated to relaxing as it puts a minimum of stress on the back and neck muscles (Zhao and Tang 1994). Accordingly, Franz et al. developed a massage system to reduce the muscle activity in the shoulder and upper back for increasing comfort (Franz et al. 2011). On the other side, prolonged muscle activities may lead to discomfort, e.g. standing for 2h shows muscle fatigue (Hansen, Winkel, and Jørgensen 1998), which can be identified by a fall in the centre frequency (Chiu and Wang 2007). SENIAM recommends that the bandwidth of wearable sEMG (surface EMG) systems should cover a frequency range from 20 Hz to 400/500 Hz (Hermie J Hermens 1999). In the analysis of the data, the RMS of the acquired sEMG signals is one of the most reliable features in the time domain analysis. In the frequency domain, researchers often took the slope of MPF versus time as an indicator for local muscle fatigue (Balasubramanian, Jagannath, and Adalarasu 2014). For acquiring sEMG signals, as the amplitude of signals are in the range of 1 to 10 mv, the SNR of signals acquired by dry electrodes is generally lower than using wet electrodes. However, using dry electrodes is more convenient for a non-professional setup (Prakash, Sharma, and Sharma 2021).

Eye tracking: In the study of screen related activities, eye tracking is an important tool in the evaluation of visual comfort (Han et al. 2021). Eye blinks, fixations and saccades are often used in comfort studies. Besides, gaze point, the pupil size, focus point and crossed disparity are also mentioned in the evaluation of visual comfort (Abromavičius and Serackis 2018). Tobii eye trackers (Tobii 2019) might be the most popular choice for acquiring eye moments information. Recently, new development in image processing made tracking the movement of eyes via Webcams also possible (GazeRecorder 2021), which greatly increases the potential usage of eye tracking in the research on visual comfort.

Physical Measures of the user(s)

Regarding the physical aspects of the user, age, gender, anthropometric measurements (incl. 1D, 2D and 3D), posture, body/joint motion (incl. fidgeting), volume of (part of) the body and (reaction) force/pressure applied on the (part of) body are often used in comfort studies.

Anthropometry: Bouwens et al. (Bouwens et al. 2018) indicated that anthropometry is the most crucial factor influencing the perceived comfort of passengers in an aircraft seat. The selected anthropometric measures differ among studies regarding the products and environments to be evaluated. In the context of sitting comfort, age, gender, weight, BMI, hip-width, leg length and sitting height were often measured. Regarding measurement methods, besides self-reporting and 1D measures, 2D imaging and 3D scanning techniques are often used by researchers to accelerate the process and improve the accuracy, though the post-processing might be demanding regarding both time and the manpower (Tony and Alphin 2019) (Yang et al. 2021).

Posture changes/motion: In the use of different products, a user might change her/his postures not necessarily related to the use of product. In the context of sitting, (Sammonds et al. 2017) classified those movements as movements of the limbs, the torso and the whole body. They also found that the number of independent movements is correlated with the level of perceived discomfort. Many methods were used to detect movements of the body. The easiest might be conducting a blob analysis on the adjacent frames of video recordings. A more precise measurement can be achieved by coded fiducial markers (Fiorillo et al. 2019) or motion tracking system (Asundi et al. 2010). Pressure sensors/mat can also be used to detect motions of a subject (Aziz et al. 2020). Using wearable sensors are also popular choices (Han et al. 2021)(Bootsman et al. 2019). As movements of the body are often associated with motions of joints, acquiring EMG signals of relevant muscles can be used as an indirect method to detect movements of the body (Liu, Niu, and Zhou 2020).

Pressure/Force: A long-time exposure to large forces/pressures often results in discomfort. Researchers measured the force/pressure in comfort studies regarding the spinal load (De Looze, Kuijt-Evers, and Van Dieën 2003), the (lower) leg (Zander et al. 2004)(Sessoms et al. 2020), the hand (Kamel, Hakeem, and Tantawy 2020), etc. Forces on different parts of the body can be measured by different devices, e.g. force on the hand can be measured by a dynamometer (Kamel et al. 2020). In most cases, pressure in comfort studies was measured by sensors such as the force sensitive resistor (Ma et al. 2017). For a relatively large area, pressure mats in different forms (e.g. (XSensor 2021), (Tekscan 2020)) were often used.

Implication

Ergonomics evolves with evolvement of the digital era. In the 2020 hype cycle, Gartner enlisted the digital twin of the person as one of the most promising emerging technologies (Panetta 2020). In 2021, they further strengthened the concept with three strategic directions: internet of behaviours, total experience strategy and privacy-enhancing computing (Panetta 2021). While these trends highlight the needs of a quantitative (dis)comfort model in different contexts as part of the digital shadow/twin of the person (He, Song, and Wang 2021), the only one who decides on comfort is the end-user. However, predictions can support the design of environments/ products/service as by measuring, we do understand the process towards comfort or discomfort much better (Anjani 2021).

This short review is more a starting point of comfort modelling rather than a conclusion. Based on this review, it seems that building a quantitative model regarding (dis)comfort might be a challenge, as the background and expectation of users differ. However, using a hybrid method which incorporates questionnaires for identifying the background and expectation of the subject(s), and a quantitative model on the change of (dis)comfort might be possible, providing more data is available and the use of advanced modelling tools. This is especially true for modelling discomfort, as it is more linked to the physical factors of the user (Vink and Hallbeck 2012).

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Trust, Comfort, and Communication: Human Machine Interface Testing with Virtual Reality Robot

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ABSTRACT

Would you feel safe and comfortable working side by side on a task with a robot? Researchers conducted Human Machine Interface (HMI) Testing for a proposed new robot as an additional team member for a warehouse facility. The overall purpose of this project was to explore how to build human/robot trust, robot communication, human expectations from robot behaviour, and how to measure the positive or negative effects relating to trust as we test HMI variables.

Because of the size and weight of the robot, Virtual Reality (VR) was used to simulate the warehouse environment to test the VR robot. The researchers created four VR sessions to test the new robot and obtained the reactions and responses of 10 participants. Most participants did not have a significant change in their trust in robots' baseline responses. Participants showed overall trust in robots and their comfort and trust in working with the new proposed robot and the new robot's capabilities. Participant comments about suggested further robot improvements were gathered and accompanied the results.

The researchers discovered that the HMI testing for the robot was more about defining the borders of comfort rather than trust. Additionally, researchers discovered to first deal with the psychology of trust and comfort, then concentrate on robot indicators. Additional HMI Testing using VR is planned for the proposed changes for the new robot and future new robots and contemporary design and development features.

KEYWORDS

Robot team members, workplace robots, virtual reality robot

Introduction

Imagine going to work, and one of your team members is a giant robot. Would you feel comfortable moving through your workday with your team robot and other large robots passing around you or in front or behind you? Would you trust and understand the robot's behaviour and intentions during an encounter, interaction, or work task?

A fundamental role in a human's trust formation is the predictability of a system that plays a fundamental role in a human's trust formation (Lee and Moray, 1994). However, with advanced technologies, it has become increasingly more difficult for humans f to know every working and technical detail of their teammate robot. According to Ribeiro et al. (2016), humans base their trust on limited perceptions of the machine partner and make decisions accordingly.

Perception is critical for human decision-making. However, a perception bias may occur now and then, which may ultimately compromise the quality of human decision-making (Dietvorst et al., 2015). According to Woods et al. 1994, the human is susceptible to bias. The attribution bias is one of the most well-known forms of perception bias in which people tend to neglect their own faults but attribute them to others, especially machines (Lee and Moray 1992). Humans are much less tolerant of mistakes made by machines than by themselves. Humans are much less tolerant of mistakes made by machines than by themselves (Muir. 1994).

According to Muir (1996, 1994), humans overrode the machine if they had higher confidence in themselves than their trust in the machine. However, this conclusion is subjective and difficult to measure or compare with trust. There is still limited knowledge of the quantitative relationship between perception, trust, and decision (Yu et al., 2019.

Today there are a variety of robots in the workplace. Unhelkar et al. (2014), Gleeson et al. (2013), Knight (2013) researched introducing co-workers into factories and, Graf et al. (2004) provide insight on in-home robot helpers. Fong et al. (2013), Diftler et al. (2011), Bualat et al. (2015) discuss the development of robotic assistants for astronauts onboard the International Space Station (ISS). Transportation (Smith, 2019), and many other industries, often utilize robots to perform tasks because the robot capabilities are better suited for the functional allocated task than their human counterparts. Some job tasks require human and robot interaction.

Method

Researchers conducted Human Machine Interface (HMI) Testing for a proposed new robot (potentially working on tasks and interfacing directly with humans) as an additional team member for a manufacturing facility. The overall purpose of this project was to address the following questions:

- How do we build trust between users and the robot?
- How does the robot communicate its intent to users?
- What do users intuitively expect from the robot in terms of behaviour?
- How can we measure the positive or negative effects relating to trust as we test HMI variables?

Researchers created storyboards and a series of scenarios for software engineers (See Figure 1) to gather participant input on the proposed new robot design features, communication abilities, and perceived comfort and safety through observation, participant interviews, and a series of survey questionnaires. The introduction, four sessions, and follow-up for each participant was one hour.

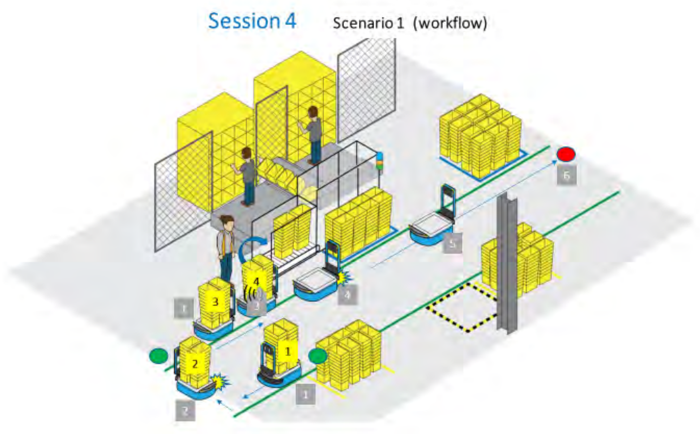

Figure 1: Example of Storyboard for software engineers.

The researchers prepared an extensive survey, based on works by Schaefer (2016) and Charalambous et al. (See Figure 2); Lee and Moray (1992), using the Merritt et al. Scale (2011), a 5-point Likert-type scale that assesses a user's trust in an automated system; Madsen & Gregor (2000), Human-Computer Trust. The Human-Computer Trust (HCT) Questionnaire is a 25-item subjective measure of "cognition-based" and "affective-based" trust. Körber et al. (2015), German TiA Scale 19 items on a Likert-type rating scale with subscales for reliability and competence, familiarity, trust, understanding, and developers' intention.

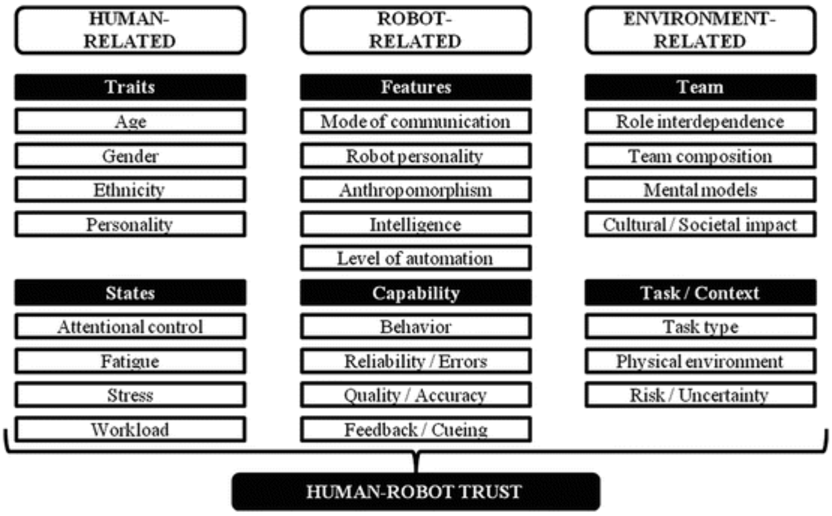

Figure 1: Categories used for a Scale to Evaluate Trust in Industrial Human-robot Collaboration (Schaefer, 2016).

The survey included several workload questions to assess the interaction task in Session 4. Ososky et al. (2014) and Hou et al. (2011) state that it is critical to measure the impact transparency information has on workload. Operator overload is a high-consequence problem that can be reduced with display designs that prioritize features to minimize visual clutter.

This HMI Testing was conducted in a virtual reality (VR) environment with a VR robot. Participants evaluated the VR robot in a VR environment simulated real-world use conditions.

Ten participants (adults) were recruited for the HMI VR Testing that was for two days. The participants worked one of three shifts for a warehouse. There were four sessions containing several scenarios in each session. At the beginning of session one, the researchers established a baseline with participants regarding their trust in robots and their comfort level through a one-on-one survey /interview.

Participants were instructed on how to put on and take off the VR headset. What sensations they might experience during their sessions in the virtual reality environment and what to do if the VR headset experienced technical difficulties, and what to do if they experienced uncomfortable sensations during the VR experience and wished to stop and remove the headset before the scenarios were finished for a session.

The researchers conducted four VR sessions to assess the proposed new VR robot's communication indicators, intent, likeability, and perceived safety. The researchers recorded objective and subjective data regarding participants' physical, psychological, and emotional reactions to the proposed new VR robot throughout the four sessions.

After the interactive VR sessions, researchers asked the initial trust and comfort baseline questions again. Participants were asked about the tasks completed with the new VR robot, their trust and comfort of robots in the workplace, and as a team member.

Results

The HMI Testing obtained the reactions and responses of 10 participants. 8/10 did not have a significant change in their trust in robots baseline responses. 9/10 participants showed overall trust in robots and their comfort and trust in working with the new proposed robot and the new robot's capabilities. Participant comments about suggested further robot improvements were gathered and accompanied the results.

How do we build trust between users and the robot?

The researchers discovered that the HMI testing was more about defining the borders of comfort rather than trust. There were large robots in the workplace already, although they had not worked with a robot or had a robot on their work team.

The workplace culture was tribally crossed with a sports club fan mentality. Participants were loyal to each other and the company; they were incredibly supportive and took care of one another as a team. However, if someone did not pull their weight, the team members told them they were letting down the team. Participants stated that they trusted the company and therefore felt that the company would only introduce a robot they could trust and work with productively and safely and would not put an employee in harm’s way.

How does the robot communicate its intent to users?

During the sessions, the VR robot would sometimes appear behind, in front, or cross in front of the participants. The researchers began with some fundamental indicators on the robot that mirrored the participants' mental model of a car. As the sessions progressed, the indicators became more sophisticated with sound, eyes on the robot, and gesture and movement. The participants reacted positively to robot communication indicators that were most familiar to them and were startled but not fearful by those that were not.

Motion or gesture was the number one indicator that alerted participants that the robot was in the environment. Additionally, participants noticed social cues before the robot approached, not during the interaction. When the robot was at a distance, the participants saw indicators and perceived the robot much sooner than the researchers had anticipated.

What do users intuitively expect from the robot in terms of behaviour?

Participants expected the robot to stop if it came too close and trusted it to move around an object or person safely. They expected an indication of the robot's intent, much like two people walking down the street and nodding at each other or looking in the direction of arrival to a destination. During Session four, participants expected the robot to know what the common task was and to be part of the team. After the robot teamwork interaction, most participants could see the feasibility of the robot being a team member.

How can we measure the positive or negative effects relating to trust as we test HMI variables?

Although researchers had developed a baseline process with an in-depth survey, observations, and interviews, the results from the first test were a shotgun spread (too many variables, very qualitative), and later tests were more specific to variables. As it turned out, the trust baseline survey and interview were more about exploring the effectiveness of trust rather than moving it from one point to the other.

Limitations

Participants evaluated the VR robot in a VR environment that simulated real-world use conditions and environment. All robot interaction was in VR, and no actual robot was used in this HMI Testing. It was not anticipated that the VR environment and VR headset would interfere with the testing objectives. Still, all instances of moderator intervention were noted and analyzed for impact on results.

Conclusion

This study investigated participant trust, comfort, responses, and reactions to VR robot communications and indicators in a VR environment. The HMI Testing obtained the physical reactions and verbal responses of 10 participants. Participant comments about suggested new robot improvements were gathered and accompanied the results.

This was the first time researchers had used VR for testing HMI for robot testing. During the preparation and later the testing, researchers discovered too many variables, and the feedback was primarily qualitative. For future testing, the researchers determined they would first address trust and comfort (psychology) and then concentrate on robot indicators for subsequent tests. Later tests were more specific to variables.

During the observation, researchers noticed the participant body language changes were correlated with the trust follow-up questions, and the responses would border more on comfort than trust. The workplace environment/culture was against institutional trust in a general baseline of trust in industrial settings for robots xxx. The participants trusted the company would not send in a robot as a team member that would hurt them. During the first session, participants tended to assess the robot early, from a distance, long before approaching. Additionally, the body language changed when the robot got closer or adjusted course; most participants wanted to trust the robot.

According to Yu et al. (2019), trust in a robot teammate is based on how the machine is designed, perceived, interacted with, and detected via the user decisions and perceptions.

The results generated from this HMI Test informed designers and engineers what worked and what did not work for the proposed new robot. Additional HMI Testing using VR is planned for the proposed changes for the new robot and future new robots and contemporary design and development features.

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Evaluation of Loadings in Head-Cervical-Thoracic Region for a Parameterized Aircraft Seat Backrest with Different Headrest Designs

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ABSTRACT

The contact loading and pressure distribution on the back are important measures to assess the comfort of a seat's backrest. On the other hand, the backrest design also influences the pressure on the back. Limited studies show how the variation on the backrest affects the loadings to the back surface, especially for the upper trunk region of the human body. In this study, a parameterized backrest model with the back support and headrest combined is created to describe design variations with different headrests. This study uses a 3D multibody model to evaluate the loadings and predict the pressure to analyze the headrest design's influences on the loading and pressure within the head-cervical-thoracic region. As a result, the headrest variation based on the parameterized model impacts the supportive load on the head. Within the thoracic region, the upper part is more sensitive to the change of design and sitting condition than the lower part. Different designs also affect the location of higher-pressure areas. The pros and cons of the analyzed designs are discussed. This study provides an example of assessing the design using the proposed load and pressure prediction method for the backrest.

KEYWORDS

Seat comfort, headrest, backrest, biomechanical model, pressure distribution, loadings

Introduction

The comfort of aircraft seats plays a critical role in the onboard experience, and improved seating comfort is a critical component that many seat manufacturers consider. One important measure for the quantification of static seating comfort/discomfort is the interaction loadings on the backrest, which is usually presented as the pressure distribution. Different methods were proposed to evaluate the pressure on the seat cushion, such as experiment-based prototype measurements, utilization of finite element model(Du et al., 2013; Paul et al., 2012), and multibody biomechanics (Cappetti & DI Manso, 2020; Liu et al., 2021). To find the pressure distribution, the backrest cushion, aside from the human model, is also an essential factor, which motivates various designs or innovations regarding cushion material and surface geometry(Franz et al., 2012; Smulders et al., 2019). However, the research that studies how different backrest designs affect the pressure distribution mainly focuses on the lower back region(Lim et al., 2000; Makhsous et al., 2009). The studies focusing on the interaction between the upper trunk and the backrest design are insufficient. This paper uses a spatial multibody model to simulate the interested head-cervical-thoracic region of the body and calculate the interaction loadings with different types of the backrest. This paper defines the backrest as a simplified parameterized model, which allows simple design variation by changing parameter values. As this is an initial study, the analyzed design variations only include the changed dimension of the headrest, which behaves as part of the seat backrest in the created backrest model.

Parameterized Design

There usually is more room and flexibility for each seat for business aircraft, the design or condition of which in this paper is simplified as a parameterized model as shown in figure 1. The five main labeled parameters describe the dimensions of the components and the surface feature of the backrest cushion. The surface geometry is presented by a surface polynomial equation referring to the cushion's body frame of x-y-z, whose origin is located at the cushion surface's mid-bottom line. The degrees of the equation may vary according to the complexity of the surface geometry. In this paper, a flat cushion surface is assumed. Therefore, the surface equation is simply $x = 0$. Due to the multiple parameters introduced, numerous designs may be generated. As an initial study, this paper only analyses two cases by varying the parameter related to the headrest, as shown in Figures 1(a) and (b). The design parameters and their values are listed in Table 1. The values are estimated respecting the SAE anthropometry data (Harrison & M, 2002) and aircraft seat design standards.

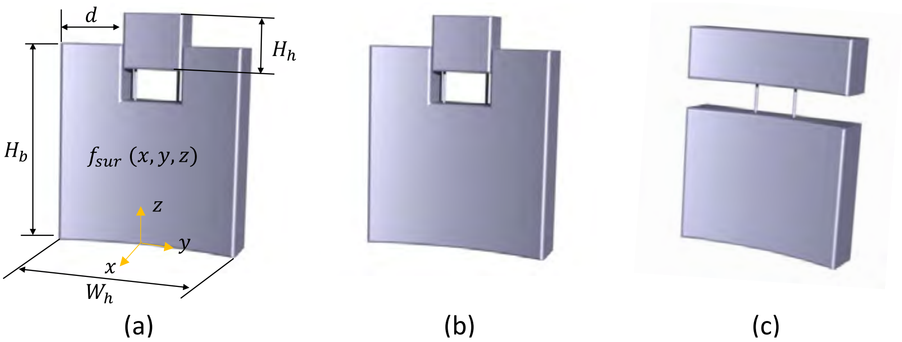


Figure 1: (a) Parameterized backrest with parameters labelled (b) Type A with deployed headrest (c) Type B with deployed headrest

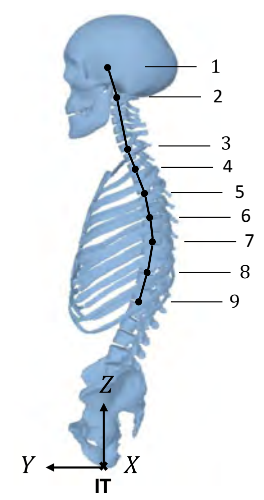
Table 1: Backrest parameters and their values

Design parameters	Acronyms	Type A	Type B
Headrest offset	d	0.15 m	0 m
Headrest height	H_h	0.18 m	
Backrest height	H_b	0.652 m	
Surface shape	f_{sur}	$x = 0$	
Backrest width	W_h	0.5 m	

Modeling of Sitting

The shape of the spine dominates the posture of the upper body. The region from the head to the level of T12 is modeled with eight segments connected by spherical joints. The joint locations take the reference of the head's center of gravity and locations of intervertebral discs. Three static relaxed postures under the backrest recline angle(θ_{br}) of 30deg, 40deg, and 50deg from the vertical direction were considered for the analysis. The body inclination in the sagittal plane is determined by the trunk vector that points from Ischial Tuberosity (IT) to the joint of the C7-T1 disc. The included angle between the vector and the vertical line on the sagittal plane is named trunk inclination angle (θ_T), which is approximated to the backrest recline angle. Constrained by θ_T, the new location of the spine can be obtained by varying the joint angles within the thoracolumbar region. The change of rotation angle from a slouched initial posture (Kitazaki & Griffin, 1997) is based on interpolation referring to the range of motion data (White & Panjabi, 1990) of each intervertebral disc. The slouched posture was selected as it is considered the most relaxed initial condition. Table 2 collects the joints' coordinates that define the spine shape under different postures referring to the global frame of X-Y-Z at IT.

Table 2: Joint locations of head-cervical-thoracic segment model at different recline angles



Joint	Location	$\theta_T = \theta_{br} = 30°$	$\theta_T = \theta_{br} = 40°$	$\theta_T = \theta_{br} = 50°$
1	Head (CG)	(0, -0.362, 0.687)	(0, -0.483, 0.617)	(0, -0.589, 0.527)
2	C1-C2 disc	(0, -0.382, 0.630)	(0, -0.491, 0.557)	(0, -0.583, 0.466)
3	C7-T1 disc	(0, -0.345, 0.518)	(0, -0.431, 0.456)	(0, -0.503, 0.380)
4	T2-T3 disc	(0, -0.332, 0.478)	(0, -0.409, 0.420)	(0, -0.474, 0.350)
5	T4-T5 disc	(0, -0.319, 0.438)	(0, -0.388, 0.383)	(0, -0.446, 0.318)
6	T6-T7 disc	(0, -0.305, 0.395)	(0, -0.365, 0.344)	(0, -0.416, 0.284)
7	T8-T9 disc	(0, -0.286, 0.349)	(0, -0.338, 0.303)	(0, -0.381, 0.249)
8	T10-T11 disc	(0, -0.260, 0.302)	(0, -0.303, 0.261)	(0, -0.339, 0.215)
9	T12-L1 disc	(0, -0.224, 0.248)	(0, -0.258, 0.215)	(0, -0.286, 0.178)

The condition of the analysis is static. The loadings on each body segment can then be calculated by using the recursive method going inferiorly. The region between C1 and T2 is bridged. It has no contact with the cushion under all analyzed conditions due to the lordotic curving of the cervical spine and the flatness of the analyzed backrest. Six contact points were considered for each of the other inferior segments supported by the backrest. The contact points are at the half segment length (l_i) and in width, they are evenly located along the width of the contact region at the same level (w_i). The contact region is based on the measurement of a pressure mat on a relatively flat backrest cushion. The contact points also have an approximately equal offset (d_i) from the spinal vertebra, whose value can be related to the vertebral level and trunk length (Drerup & Hierholzer, 1994). Therefore, the contact point locations for both sides can be expressed in the local frame as $\left(\pm\frac{ew_i}{14}, -d_i, \frac{l_i}{2}\right)$, where $e = 1,3,5$. The force direction is along the cushion surface's normal at the contact point location. Since the analyzed backrest is flat, the direction is defined by $(0, \cos\theta_{br}, \sin\theta_{br})$ referring to the global frame. The described condition is illustrated in figure 2. Then, the static loadings on segment i can be found by solving equations (1) and (2) based on force and moment equilibrium.

$$\boldsymbol{M}_{i+1} + \boldsymbol{l}_i \times \boldsymbol{F}_{i+1} + \frac{\boldsymbol{l}_i}{2} \times \boldsymbol{G}_i + \sum_{j=1}^{n}(\boldsymbol{c}_{ij} \times \boldsymbol{N}_{ij}) = k\boldsymbol{M}_i \quad (1)$$

$$\boldsymbol{F}_{i+1} + \boldsymbol{G}_i + \sum_{j=1}^{n} \boldsymbol{N}_{ij} = \boldsymbol{F}_i \quad (2)$$

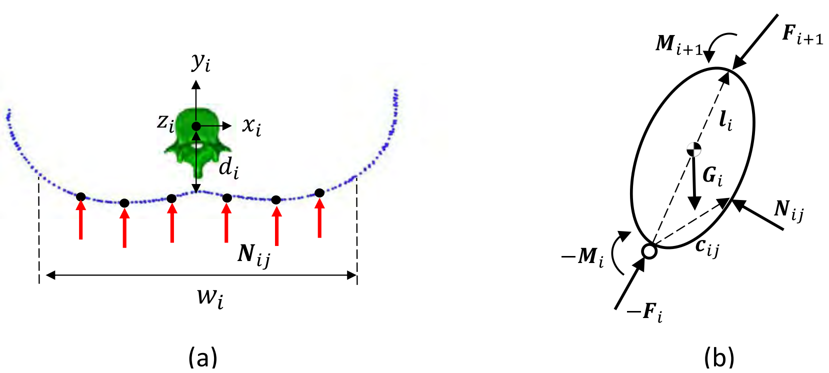


Figure 2: (a) the loading condition of a fully contact trunk segment on the transverse plane (b) loads on i^{th} body segment

In equations (1) and (2), the bolded letters represent spatial vectors. $\boldsymbol{G}$ is the gravitational force; $\boldsymbol{F}$ is the load on the joint; $\boldsymbol{N}$ is the force from the backrest acting on the body of the segment; $\boldsymbol{M}$ is the joint moment from the muscle; $\boldsymbol{l}$ is the segment length vector, and $\boldsymbol{c}$ represents the vector pointing from the bottom joint to the contact point location. n is the number of the contact point on segment i. $k = 1$ when segment i is not supported, and the term $\sum_{j=1}^{n}(\boldsymbol{c}_{ij} \times \boldsymbol{N}_{ij})$ becomes zero as there is no external force. When there is an external force(s) that balances the segment, the required internal moment at the bottom joint ($\boldsymbol{M_i}$) becomes zero and therefore $k = 0$. The applied gravitational force of each segment is obtained based on the percentile weight data(Pearsall et al., 1996), which is collected in table 3. The weight and height of the analyzed body are 165cm and 72kg, respectively, based on the measurement of a subject. The considered weight ratios of segment T1-T2, T3-T4 are less than the data from literature because the arm is supported while seated. So, only half of the superior limb's weight is assumed to load on the trunk. The external forces at the assigned contact points on one side of the back are considered to have the same magnitude. In this way, the loadings of each segment can be solved determinately using equilibrium equations. With the obtained external forces and their locations on the backrest cushion and the back surface point cloud of the subject, the pressure distribution can then be simulated based on the method by Liu et al. (Liu et al., 2021).

Table 3: Percentile weights of the analyzed body segments

Segment	Considered segment weight/Total body mass
Head-C1	0.058
C2-C7	0.022
T1-T2	0.022
T3-T4	0.066
T5-T6	0.046
T7-T8	0.029
T9-T10	0.036
T11-T12	0.046

Results and Discussion

The backrest cushion's bottom line aligns to the spinal S1 level, and then the lower edge of the headrest aligns to the T3-T4 segment. Therefore, the headrest design variation only affects whether there is contact at the specific location above joint 5 (table 2). The gap under the headrest for type A is only at the center area; thus, the forces at the four contact points close to the midline are neglected, and only the two at the side exert forces (figure 2a) on the T3-T4 segment. For type B, since the headrest is across the width of the backrest, no force is exerted on the same segment. With the conditions determined, the contact loads can then be calculated. Figure 3 shows that Type A provides more support in the thoracic region but requires less support to the head compared to the case for type B. That is because the deployed headrest in type B leaves a wide gap, so the body segment weight within the gapped region generates additional moments onto the joint below. Therefore, the load on the head required to balance the moment is greater for the case of type B. Besides, type A is found to have a larger load in the Upper Thoracic (UT) region (T3-T8) because type A is not entirely gapped in the upper area. Thus, there is more contact area providing support within the region. This is also clearly revealed by the simulation of the pressure distribution (figure 4); additional contact areas in the upper region can be observed in the simulation for type A. The load and contact pressure increase in general when the backrest reclines deeper as more weight is projected onto the backrest surface. However, the loadings on the Lower Thoracic (LT) region (T9-T12) are retaining against the variation of the analyzed design and backrest recline angle. One possible reason behind this is that the applied biomechanical model assumes rigid bodies, which deviation from the actual human body made of layers of soft biological tissues. However, it can still be concluded that the recline angle does not affect the LT loading as much as that of the UT.

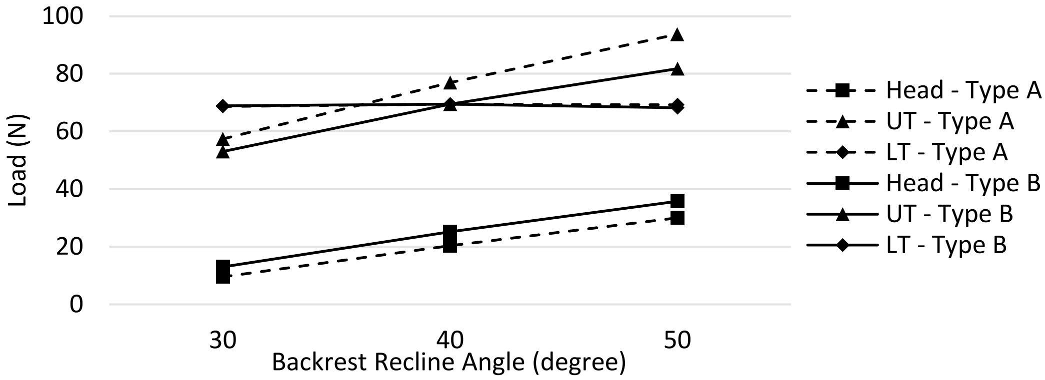


Figure 3: Loads at different regions vs. backrest recline angle for both type A and type B design

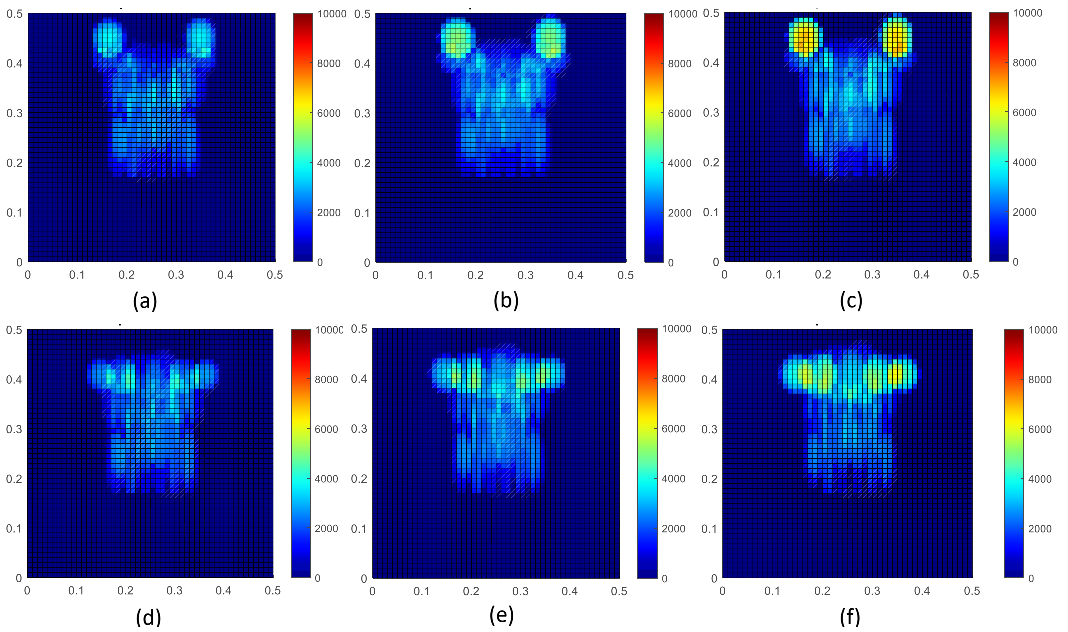


Figure 4: Simulation of the pressure distribution (Pa) in the thoracic region with type A at the recline angle of (a) 30 degree, (b) 40 degree, (c) 50 degree, and with type B (d) 30 degree, (e) 40 degree, (f) 50 degree

From figure 4, Type A is observed having the stresses peaking at the sides of the notch, and stresses are more evenly distributed in the region below. For type B, there is no notch, and the stresses concentrate around the upper edge of the backrest with a slightly lower magnitude compared to the peak pressure of type A. Although type A provides more contact area, the high-stress region is more centered separately on two sides of the upper body, which may round the shoulder and form a restrained posture. For type B, the high-pressure region covers almost the full section at the UT level. Therefore, the body may experience smoother support compared to type A. Besides, type A decreases the load on the head, which can help relieve the internal forces provided by the neck muscles. From a practical perspective, type B's headrest covers the whole width of the seat. Although it is required to provide more load to the head, it can support the head at more postures, especially when the passenger tends to lean laterally.

Conclusion

A parameterized model for an aircraft seat has been developed. Two types of designs with different headrest widths are analyzed regarding how the backrest sustains the head-cervical-thoracic region's bodyweight at different recline angles. This region of the body is presented by eight rigid segments. The assumed sitting postures are obtained, and the contact loadings are calculated based on the developed 3D multibody model. It is observed that type A backrest provides additional support on the upper thoracic region but reduces the loads required for the head support. However, the pressure distribution on type A is more partitioned, concentrated on two sides at the top area, which may round the upper trunk and cause discomfort. Type B has a smaller gradient of pressure change and can provide a wider range of support on the head.

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Integration of ergonomic and comfort aspects in new standards – a challenge for standardisation

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THE WORK IN CONTEXT

Ergonomics and comfort aspects are important for the industry to develop and optimize products e.g. car seats, sleeping bags, protective clothing. A lot of effort is necessary of scientific world and industry to develop methods for the determination of the ergonomic and comfort aspects of products. Companies e.g. in the automotive industry use often their own standards to define the quality and the requirement for their products. In the field of textiles there are often standards, which were developed in national and international standardisation organisation with stakeholders from the material industry, manufacturer, brands and end user. The aim of the standardisation is to improve the quality of the product and give the possibility to compare different products from different manufacturers. E.g., the standard for sleeping bag was developed as national standard with focus on the cold protection of sleeping bags and the practical methods to determine the comfort. Over the years, the standard was developed further to an ISO standard. Now, this sleeping bag standard is used all over the world to guarantee the quality and comfort parameters. Comfort and ergonomics aspects of protective clothing are coming more and more in the focus of the protective clothing producers. A lot of effort is necessary to develop standards in this field from manufactures, scientist and end users. In this talk, different examples fare presented for developing new standards concerning comfort and ergonomics aspects.

KEYWORDS

International standardisation (CEN/ISO), product standard, test standard, standards for protective clothing

Introduction

Standardization is important and organized nationally and internationally. The International Organization for Standardization (ISO) is the independent, non-governmental, international organization with membership of 165 national standards bodies and started the work in 1946. Today, 23921 standards cover almost all aspects of technology and manufacturing. The work is done by experts from 165 national standard bodies in 796 technical committees and subcommittees. Examples for national standards body are e.g., DIN is the German Standard Institute for Standardization, BSI is the British Standard Institute for Standardization, AFNOR is the French Standard Institute for Standardization. The work of national standard bodies is explained at DIN. DIN, the German Institute for Standardization, is the independent platform for standardization in Germany and worldwide. More than 36.000 experts from industry, research, consumer protection and the public sector bring their expertise in the developing process of German standards. Standards help to ensure the free movement of goods. Standards support efficiency and quality assurance in industry, technology, science, and the public sector and serve to safeguard people and property and improve quality in all areas of life. The use of DIN standards is voluntary. They only become mandatory if they are referred to in contracts, laws or regulations (e.g., EU PPE regulation).

But as generally accepted rules of technology, standards make it easier to demonstrate that one has followed best practices. DIN represents German interests in international organizations such as CEN, the European standards body, and ISO, the International Standards Organization. Today, roughly 85% of all national standards projects are European or international in origin. International Standards provide a common language for the technical world, supporting global trade.
CEN's national members are the national standard bodies (NSBs) of the 27 European Union Countries, United Kingdom, the Republic of North Macedonia, Serbia, Turkey, and the three countries of the European Free Trade Association Iceland, Norway, and Switzerland.
Standardisation uses the knowledge of the industry and scientific world. However, to develop a standard is often time-consuming. Every five years, a check is carried out to determine whether the standard developed can exist for further five years, must be changed or whether it will be withdrawn. For the revison of standards, the knowledge of new scientific methods and results are necessary and exchanges between industry and scientist are necessary- However, the long period of the standardisation process is not good compatible with the fast scientific world. The next chapters give some examples of standard with comfort and ergonomic aspects and problems to involve and improve comfort and ergonomic aspects.

Standardisation of sleeping bags

Sleeping bags are often used worldwide. The sleeping bags standards ISO 23437-1:2018 and ISO 23537-2:2018 were developed by the technical committee ISO/TC 83 "Sports and other recreational facilities and equipment" in cooperation with the technical committee CEN/TC 136 "Sports, playground and recreational equipment" in the working group 11 "sleeping bags". Part 1 deals the thermal properties of sleeping bags and the part 2 with the material and product properties. Part 1 specifies the requirements and test methods as well as provisions for labelling of adult sized sleeping bags for use in sports and leisure time activities regarding thermal characteristics, dimensions, and mass. ISO 23537 based of the EN 13527:2002 and the DIN 7943-1 and -2:1995. The standards give consumer the possibility to easily compare the quality of sleeping bags. The thermal properties of sleeping bags can be determined with thermal manikins. The test conditions the test equipment, the test procedure is descripted in detail in the standard. Basis of the sleeping bag tests are the correlation of the data of the thermal manikin and the data of subjects' trials. Part 1 of ISO 23537 does not apply to sleeping bags intended for specific purpose such as military use and extreme climate zone expedition. But more and more people wish to make expedition in extreme climate zones (e.g., cruises in Arctic, and Antarctic region, mountaineers in high mountain region (e.g., Himalaya). In this case, the data of subject trials in controlled condition are missing and no prognosis is possible. The ISO 23537 does not apply to sleeping bags for children or babies. However, the industry and the consumer need the possibility to compare sleeping bags for children. The problem is known since years. There are children manikin available in a few research institutes, however not often in test houses. The correlation of the data of the children manikin with subjects' trials with children in realistic scenarios are missing. These investigations are very expensive and so the financial support is necessary for universities and research institutes to generate such data. Effort of scientist and industry is needed to get such data. Sleeping bags without homogeneous fillings designed to provide local extra insulation in certain parts are coming into the market and that pose issues with the calibration and/or test procedure. Ongoing work continues to provide suitable means of establishing temperature ratings. This can be only done with the help of the scientific world and the industry.

Standardisation of personal protective clothing – protective clothing against cold and cool environments

Protective clothing must protect the user before health risks and at the same time, there must provide a high level of comfort and ergonomics to avoid discomfort. Protective clothing is often heavy and hinders free movement by working because of the protection function. New technologies and materials are now available to improve the protective clothing and leads to problems with the existing standards. In Europe, the product standards for personal protective clothing are mandatory and must applied. Protective clothing against cold environments can be proofed according the EN 342 developed in the working group CEN/TC 162 WG 4. With the EN 342, a common basis in Europe is achieved for requirements and test methods for protective clothing ensembles and garments against cold in the interest of manufacturers, test institutes and end-users. The measured properties and their subsequent classification are intended to ensure an adequate protection level under different user conditions. Thermal insulation and the air permeability of the ensemble or garment are the essential properties of this kind of PPE. Thermal insulation is the most important property, and it is measured by using a full-sized thermal manikin with the ensemble or garment and accompanying reference clothing in order to account for the effect of layers, fit, drape, coverage and shape. In some conditions with intermittent exposures (e.g., cold store work) or in conditions close to and above 0 °C the water vapor resistance value of fabrics become increasingly important and fabrics with a low value can contribute to improved heat balance and thermal comfort.

With the EN 14058 Protective clothing— Garments for protection against cool environments, a common basis is achieved for requirements and test methods for protective clothing ensembles and garments against cool environments for manufacturers, test institutes and end-users. Cool environments mean the moderate low temperatures above -5 °C garments against local body cooling. This can be used for outdoor activities e. g. in construction industry but can be used for indoor activities e. g. in food processing industry. The thermal insulation is measured with material test methods e.g., the sweating guarded hotplate and not with a thermal manikin. The material test is not so expensive as the product test with the manikin. But new materials and new constructions are coming in the market. Inhomogeneous distribution of the insulation material in garment can be observed. However, inhomogeneous distribution leads to problems in the testing because an appropriate specimen number should be used for testing. Also pockets and other design properties leads to additional test specimens. Inhomogeneous distribution of the insulation material in garments leads to additional effort for testing and the question is: What will be the best test methods? What is the best way to calculate an average value for the insulation of the whole garment? There are more scientific investigations necessary. There is also the question if the test with the manikin could solve this problem. Test houses can make services testing and sometimes they develop new methods. The development of new methods is time consuming and need a deep scientific understanding of the materials, test methods and the analysis of huge data and here the support of research institutes is needed.

Standardisation of immersion suits

Immersion suits are another example of PPE which should show certain insulation that allow people to survive in water in an accident. One important property for immersion suit is the insulation which is necessary for this kind of PPE. In the Standard ISO 15027-3:2012, which is developed in the ISO 188 SC 1 and CEN/TC 162 WG 6, two methods are described. The first is the measurement of the insulation with thermal manikin the second one is wearer trials.
The overall thermal protection provided by a suit system shall be assessed by measurement of the effective insulation of the whole suit system and associated underclothing placed on a thermal manikin and immersed in calm but circulated water. The tests with human test subjects are time-consuming but often used for products. There are not so many laboratories worldwide which over the manikin test in water. Because of the different size, shape, and construction of the manikins the results of the insulation received from different laboratories differ. For the revision of the standard,

the manikin test should approve and the problems with differences in the results should be solved. This need a lot of effort for the industry and test houses because a lot of investigation are necessary.

Standardisation of ergonomic aspects of personal protective equipment

The implementation of comfort and ergonomics aspects are more and more in the focus. One example is the new standard "Ergonomics of PPE ensembles" (prEN 17558:2021), developed in the working group CEN/TC 122 WG 14. This standard can be used to compare the performance of different ensembles as part of any PPE selection process and can assist employers in evaluating PPE Ensembles in standardised conditions. Ergonomics of PPE can be tested by use of either test persons, use of manikins and/or use of (computer) models as benchmark or comparative testing. Laboratory as well as field test are incorporated. This standard does not replace the product standards for the certification of individual items of PPE. It specifies the testing of individual items of PPE as an ensemble, so that the interactions between the individual items of PPE can be evaluated and any adverse interactions between the individual items of PPE, the user and the environment can be identified. This work in only possible by networking of the industry, the user and scientist. There are a lot of product standards for PPE available e.g., fire fighter clothing, fire fighter shoes, ear protection or eye protection. The interaction of the different items of PPE during the use is not in the scope of product standard. But a fire fighter must wear a lot of items of PPE in the immersion case for best protection and therefore the ergonomic aspects of all items together which the persons are wearing during immersion case are important and should be investigated. In the industry, often filed test are made for testing the products. But the knowledge about the number of test persons which are necessary for testing, the analysis of the results and the knowledge about significant differences between test result is not sufficient and needs the support from the scientific world. This standard is the first approach and was initiated by a fire fighter association. The next years will show how the standard is used in real life and how the standard can be improved in the next years because this first draft cannot answer and solve all questions.

Standardisation of a methods to measure the cooling function of fabrics

Clothing with additional functions is more and more important in the field of sports but also in protective clothing. The cooling textiles should support the efficiency of athletes and workers. The cooling effect should improve the comfort and the wellbeing. During high activity and/or in warm environments the body core temperature can increase and human starts sweating to prevent an overheating of the body. The evaporation of liquid sweat is the most effective process to cool the body. Cooling textile should support the body to keep the body temperature constant. The cooling effect of textile material in not limited to the use of clothing textiles; the cooling effect is also interesting in the field of bedding, seats, and technical textiles.

The cooling of a textile cannot be determined with the conventional test methods of the clothing physiology. To determine the cooling power of fabrics, the new heat release tester WATson was developed in Hohenstein (Classen). With WATson, the cooling power of cooling materials can be determined and compared. However, the measured cooling power is only a physical value. Without the correlation of these values with data of subject trials, the cooling power do not give any information about the perception of the human body and the achieved cooling effect.

A clothing physiological device for testing the cooling function of textiles was developed. The test method was the basis of the new standard, the DIN SPEC 60015 (English). A DIN Specification, or DIN SPEC, is a document that specifies requirements for products, services and/or processes. However, in contrast to standards, DIN SPECs do not require full consensus and the involvement of all stakeholders. A DIN SPEC is the fastest way for turning research into a marketable product. DIN SPECs are effective marketing instruments that are widely accepted by customer and potential partners alike. Any DIN SPEC can be used as a basis for developing a full standard.

Conclusion

Standardisation is one instrument to develop and optimize products, technology and with a high-quality level. Companies need standards to be able to guarantee quality of products under comparable and comprehensive conditions. Comfort properties are coming more and more in the focus of the industry. The industry needs methods to determine the comfort properties. Scientists can support the implementation of comfort and ergonomic aspects with their research results and their knowledge. This support is very important to improve comfort and ergonomics in products. Standardisation needs the results of actual scientific work and the networking of all stakeholders. Standards are revised every five years to be up to date. In the revision state, the implementation of new research results, new test methods or improved technology is possible and necessary for improvement of standards.

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EN 342:2017 - Protective clothing - Ensembles and garments for protection against cold

EN 14058:2017 - Protective clothing - Garments for protection against cool environments

ISO 15027-3:2012 – Immersion suits Part 3: Test methods

ISO 23537-1: 2016 - Requirements for sleeping bags.– Part 1: Thermal and dimensional requirements

ISO 23537-2:2016 – Requirements for sleeping bags – Part 2: Fabric and material properties

pr-EN 17758:2021 - Ergonomics — Ergonomics of PPE ensembles

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Aviation

Air travel during pandemic context: Designing for a better Economy Class flight experience

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ABSTRACT

This work focuses on the aeronautical industry during the pandemic context experienced recently. The Economy Class represents the largest capacity for carrying passengers. Therefore, the challenge of improving physical comfort and safety in this place is the goal of this project.

The world of air travel has been under threat since the beginning of the COVID-19 pandemic and may never be the same again. The idea of spending time inside a closed aircraft with low social distance is not pleasant. Flying in this context is undeniably hard, taking into account all the understandable ambiguity and stress surrounding passenger's health and safety. Hence, the mission to redefine what travel can and should be in this new era is born.

The following investigation gives rise to a proposal that aims to reduce the infection's possibility on board. After approaching the knowledge through state of the art, surveys were structured, supported by direct and indirect posture and behavior observation inside the airplane. Based on the first inquiry results were made some concept proposals. Later, the previous concepts gave rise to study models and then, to prototypes that allowed a real project validation. The objects were first tested by a virtual survey, then in a physical seat in isolation, and finally during an actual flight context. Based on the results of this mixed, interventionist, and non-interventionist methodology of quantitative character, the author designed two iterations and a set of future search recommendations.

The investigation results were considered conclusive. From a theoretical context, it was possible to identify a design work opportunity for this sector, supported by the first inquiry – which argues that there are ergonomic needs and that safety feeling is relatively low. Regarding the practical component, it was possible to verify an increase in comfort level using the proposed product compared to the original airplane seat. For future research, the inflatable materials exploration, systems with memory foam, and reactive using fabrics would contribute to the project enrichment.

KEYWORDS

Air travel 1, Pandemic 2, Product Design 3, Economy Class 4

Introduction

Most airplanes recycle 25 to 30% of the cabin air, the other 70% are evacuated to the sea every two minutes, which means that there is fresh air at the cabin every two to five minutes, depending on the size of the aircraft. Therefore, Freedman states that air circulation in an airplane is better than in an office building and even in homes, as it is changed more times per hour. However, air filtration is just one piece of the puzzle and is not enough to prevent contagion, said Saskia Popescu, infection prevention epidemiologist in Arizona. Distancing and wearing masks are crucial to mitigate the risk, whether during a flight or in any other situation. At the beginning of the year, when it became known for the first time that social distance could decrease the chances of contracting the coronavirus, many airlines began to leave their middle seats open to create more space between passengers. However, in recent months, many companies have reversed their policies and started to accommodate people in all seats, requiring the use of masks, because this would keep passengers safe.

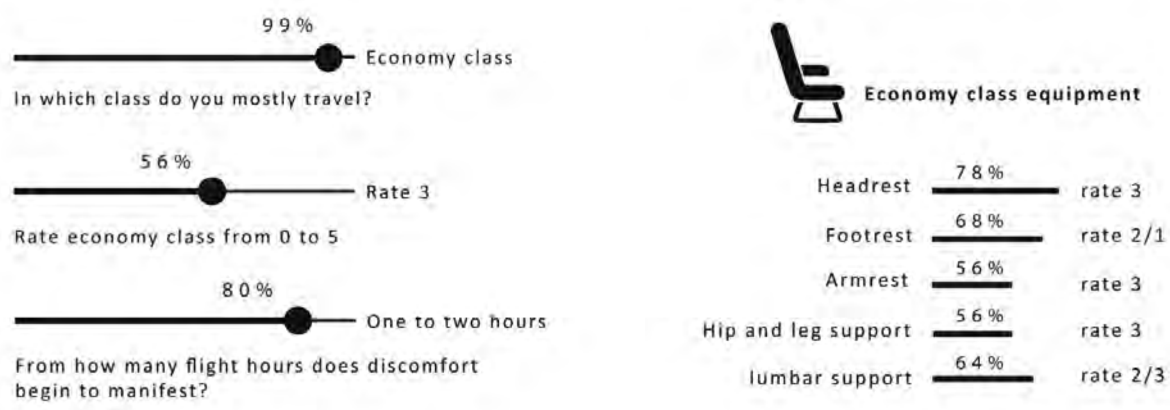
Methodology

Through the State of Art was elaborated a hypothesis, which is structured by a survey directed to those who use this transport. Direct and indirect observation of behaviors and postures, as well as case studies. Based on the results of the survey, some concepts were presented, which resulted in study models and, finally, prototypes that allowed this project validation (composed of three phases). The objects were initially tested through a virtual survey, then in airplane seat, and lastly, in a flight situation. Together with the results of a mixed, interventional, and non-interventional methodology, of a quantitative character, two iterations and a set of recommendations for future research were generated.

Research (surveys)

This approach consists of three phases. The first collects general information, such as gender, age and how often people use this transport. The second it's to classification (from 0 to 5, being 0 the worst and 5 the best) the equipment present in Economy Class (Counting that equipment may be different between airlines, the questions are from a general point of view) as we can see below at figure 1. The third pretends to collect information about the author's proposal that it was designed to improve the Economy Class flight experience.

Figure 1: First survey research results



Relatively to the second concept proposal, 68% respondents answered that could really be an improvement at the flight comfort while using these components. For component b, most respondents found it appealing (15% rated it 5 and 45% rated it 4). As for a potential improvement for the flight experience, the results were positive: 48% rated this component 4, 20% rated 5 and 30% rated 3.

The third concept proposal is composed by two options (I and II), the most voted was option I, although with only 6% difference from option II. Also during the individual classification of each option, option I revealed more promising results. Relatively to the potential protection degree: 54%

respondents rated 4 for option I and 30% assigned the same rating for option II. 73% rated 4 to option I for potential contribution to privacy on board improvement and 62% to option II. Finally, 65% respondent prefered to receive those components already on board, while the remaining 34% prefered to have their personal kit, for hygiene and environmental issues.

Concept proposals

Main characteristics: practicality, protection and privacy
First proposal name: Kit Comfort
Total proposal's number: 3

Table 1: Concept proposals

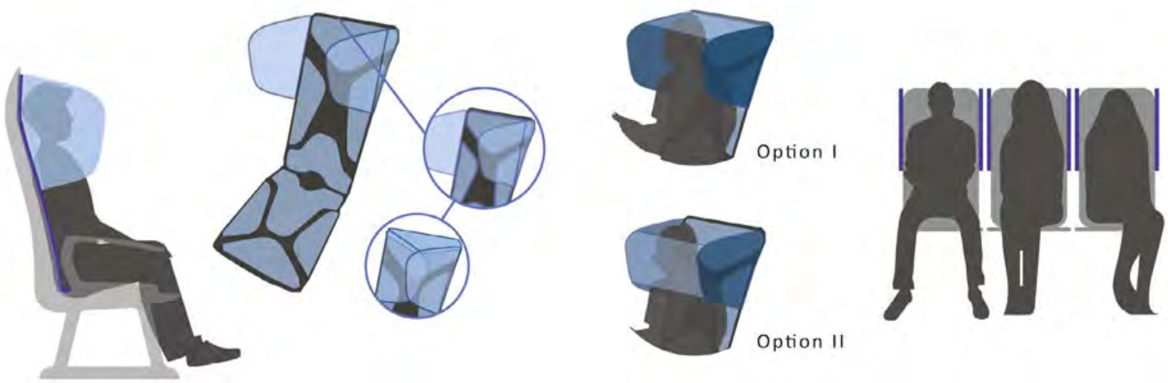
Concept	Components	Advantages	Disadvantages
1.	a) Hood d) Blanket e) Headphones	+ Privacy/protection - Noises	.Too many objects .Strict laws .Difficult storage
2.	a) Hood b) Padded seat cover	+ Privacy/protection - Clarity Better backrest/supports	.Too many objects .Unintuitive storage
3.	c) Padded seat cover with dividers (option I and II)	+ Privacy/protection Better backrest/supports Just one object	.Above dimensions Unintuitive storage

Figure 2: Concept 2 components

a) Padded seat cover
b) Hood

a) b)

Figure 3: Concept 3 component



Both proposals were designed to make passengers feel more comfortable and experience some security face the contagion possibility.

Table 2: Tests

Test	Type	Respondents	Proposal's objects
1.	Virtual survey	101 respondent (61% between 20/30 years old)	b) Padded seat cover a) Hood
2.	Usability test (on airplane seat)	Five respondent: two Men and three women (between 165/180cm)	b) Padded seat cover a) Hood
3.	Usability field's test (two-hour flight)	One women (169cm)	b) Padded seat cover

Figure 4: Usability test on airplane seat (component b)

Summary test's results:

- A padded seat cover revealed an comfort degree increase (about to the seat);
- The material used is visually appealing but, can cause discomfort because it may be warm;
- The support that revealed needing more changes was that of the lumbar;
- Lateral headrest it's missing;
- Integrate a case for some kind of storage;
- The hood should be made of translucent material, or change its shape, to avoid the potential claustrophobia sensation.
- The hood conveys some sense of security (in the face of the contagion situation) and privacy;
- The cover for the seat is slightly larger than desired;
- It would be more practical to have one object, rather than two.
- The incorporation of two dividers may be sufficient (hood instead).
- Volunteers did not reveal any feeling of embarrassment while using the components;
- Need to create a mechanism that would ensure the padded cover to the airplane seat.
- After analysing the previously results the proposal suffered some changes, that generate the second iteration. One of the most requested points was the lateral headrest, which is why we started testing this hypothesis. Using the padded cover upper shape, we tried to incorporate two partitions that could function as a dividing element that serves as protection and privacy, as well as a side headrest. Initially, several models were created to visualize which

size was appropriate.

The lack of material's flexibility used in the second iteration caused wrinkles, which did not allow a uniform and smooth surface, (as it was on the first iteration). Although the visual aspect is not so appealing compared to the previous one, the seat cover seem to have improved, with the thickness foam increase (in the headrest and lumbar). The side dividers addition seems to have increased the privacy feeling, however, it could be slightly projected above the actual position. For those who flight together this complement can help to create a private area, if each passenger folds one of its partitions. They contain high-density foam inside and have enough strength to support the head weight (when leaning). However, it is necessary to do more tests to validate these statements, which have not been possible until now.

Conclusions:

The plane has been overtaken in terms of comfort improvement. This sector has safety standards and measures very demanding, so the challenge of designing something new for this transport also becomes more challenging. We believe that due to these requirements (as is the relationship between weight, quantity - and flight operation profitability), seats have undergone changes in their shape, especially through - thickness reduction, to placing more queues seats and consequently carry more passengers. These modifications have been stalling and, in some cases (long-haul flights), the level of comfort in Economy Class has decreased. One fact that proves this idea is the vast market of accessories bought separately to acquire more comfort while traveling (such as neck pillows, for example). In this sense, and together with the first survey responses, it was concluded that there was an opportunity to act as a designer.

Thanks to the validation phase, it was possible to obtain results that helped in the construction and future evolution of this project. Some results were: The padded cover revealed physical comfort increase, thanks to the strategically filled areas so that the passenger would feel more accommodated/cozy. And as this object covers almost the total airplane seat surface, it also proved to be interesting because it reduces the passenger's direct contact with the seat material. Regarding the material, the volunteers found it visually appealing but noted for the question of could be warm. That raised the possibility of exploring how reactive tissues can be used (ex: Anti-stains, antibacterial, odor encapsulators, thermoregulators, etc).

Shapes should not have sharp edges or rigid structures, as they can make the object dangerous in case of an accident, which ended up the idea of testing these objects with inflatable material in the future. Storage would much easier, weight and the absence of more complex mechanisms, thus making it more intuitive.

In this type of objects using manual models (at full scale) allowed a detailed analysis visualization. It was noted that the seat cover needed something to fix it to the seat, to avoid the slipping tendency. The first iteration's material easy to handle, but the second iteration material revealed characteristics such as stiffness that hindered the layout process, so it would be interesting to analyze other material's behavior.

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AIRBUS´ Approach to Improve Travel Comfort for Wheelchair Users

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ABSTRACT

This paper introduces concepts and solutions which aim at improving the travel comfort for wheelchair users inside the aircraft. Airbus has historically taken a proactive approach on accessibility working on comfort improvements and solutions for passengers beyond regulation. An outline of this user-centred approach is given showing how the needs and expectations of a high diversity of end-users is considered during product research and development. Exemplary solutions are presented that are dedicated to the accessibility of aircraft lavatories for persons with reduced mobility and to the reliable and damage free transport of wheelchairs in an aircraft.

KEYWORDS

Wheel chair, travel comfort, accessibility

Introduction

The World Health Organisation (WHO) estimates that 15% of the global population – around one billion people – is disabled. A recent survey showed that airlines are seeing a steady increase in passenger demand for wheelchair assistance (IATA, 2019a). Expectations towards airlines to provide travel solutions for persons with reduced mobility are increasing due to a growing number of regulatory work, self-commitments of the aviation industry (e.g. IATA, 2019b) and efforts by advocacy organisations.

Looking at the travel comfort of wheelchair users in-flight, two areas of concern are particularly in focus: the access to lavatories on-board and the damage free transport of wheelchairs in an aircraft. On long-range aircraft the available cabin space allows to provide full accessible lavatories with sufficient space to enter the lavatory sitting on an on-board wheelchair, for manoeuvring with the wheelchair inside and for the transfer from the wheelchair to the toilet seat that allows also seated dependent transfer supported by an assist person. On single-aisle aircraft the limited available space is the main challenge for providing accessible lavatories. No comparable regulation is in place yet concerning the full accessibility of lavatories on such smaller aircraft.

Damages to wheelchairs are identified as a problem in air travel which directly impacts the comfort, trust and well-being of their users and generates costs. According to the US Air Travel Consumer Report (US Department of Transportation 2020a), a significant number of 29 wheelchairs and scooters were mishandled in the US per day in the year 2019 (1.54 % of enplaned wheelchairs and scooters).

The Federal Aviation Administration (FAA) is currently conducting a study to determine the feasibility of in-cabin wheelchair restraint systems and if feasible, the ways in which individuals with significant disabilities using wheelchairs can be accommodated with in-cabin wheelchair restraint systems (The National Academies of Sciences, Engineering, and Medicine, 2020)

Airbus approach

The role of an aircraft manufacturer in terms of accessibility is to design and deliver aircraft that can be operated in compliance to present and future regulation (e.g. accessible lavatories, wheelchair stowage, and space for on-board wheelchairs). Table 1 summarizes such requirements that are relevant in the US.

Table 1: US Requirements for Nondiscrimination on the basis of disability in air travel according to DOT 14 CFR Part 382

	Requirements for Accessibility of Aircraft
§ 382.61	aisle seats must be equipped with movable aisle armrests on at least one-half of the aisle seats proportionately in all classes of service in the cabin
§ 382.63	aircraft with more than one aisle in which lavatories are provided shall include at least one accessible lavatory
§ 382.65	one on-board wheelchair to be offered
§ 382.67	priority space in the cabin of sufficient size to stow at least one typical adult-sized folding passenger wheelchair (13” x 36” x 42”)
§ 382.69	audio-visual displays played on aircraft for safety purposes, or informational purposes are high-contrast captioned

Airbus provides standard lavatory solutions specifically for Persons with Reduced Mobility (PRM) on all platforms, even beyond formal regulations and requirements. Here, Airbus ensures that accessible lavatories are compliant to the regulation. According to the US DOT part 382 regulation aircraft with more than one aisle in which lavatories are provided shall include at least one accessible lavatory. Three criteria are fulfilled for accessible lavatories:

(1) The accessible lavatory must permit a qualified individual with a disability to enter, manoeuvre within as necessary to use all lavatory facilities, and leave, by means of the aircraft’s on-board wheelchair.
(2) The accessible lavatory must afford privacy to persons using the on-board wheelchair equivalent to that afforded ambulatory users.
(3) The lavatory shall provide door locks, accessible call buttons, grab bars, faucets and other controls, and dispensers usable by qualified individuals with a disability, including wheelchair users and persons with manual impairments.

Airbus has historically taken a proactive approach on accessibility in order to find and offer solutions beyond regulation, also to account for trends (e.g. aging population). As a prominent example Airbus developed some years ago the Space-Flex Module - a rear door galley/lavatory module featuring a space efficient fully accessible lavatory. It was the first wheelchair capable lavatory on a Single-Aisle aircraft in the market.

Improving the accessibility it is not only about integrating new features for special needs into the aircraft. It has to be ensured that the Cabin & Cargo products and services:

- meet the needs and expectations of a high diversity of end-users in the cabin,
- cover the wide scope in anthropometrics, cultural background and special needs, and
- allow a maximum operational efficiency for the airlines.

There are different and sometimes conflicting needs by different users that all have to be considered for an optimized product everybody is satisfied with. It is a must to understand the needs and expectations of a high diversity of end-users. Accordingly, it is key for new concepts and products that users are involved already in early design phases in order to optimize and validate new concepts by use of mock-ups (e.g. in the Airbus Rapid Architecture Lab) or earlier by means of Virtual Reality.

In the early design phases, Virtual Reality tools and methods are applied. Only if the usability is validated here by use of digital manikins representing the reference persons (children included) a mock-up will be built to further analyse the ergonomics and operational aspects. As soon as a mock-up is available the team tests it with real users including tall and short persons, passengers of size and persons with reduced mobility.

The main advantages of this approach are, that with this analysis, concepts can be analysed, developed and compared very early and that it is possible to analyse the design for the "critical" cases: e.g. small manikins can be used for the reachability of a handle and the tall manikin for clearances and postures where the space is very limited. At the end the best balance between different user groups with different needs and at the same time to design for operational efficiency will be realized. There is not necessarily a conflict between different needs but very often it is the case.

Onboard improvements

In this chapter exemplary solutions are presented that are dedicated to the accessibility of aircraft lavatories for persons with reduced mobility and to the reliable and damage-preventing transport of wheelchairs in an aircraft.

An increase of the space for the footprint of lavatories on single-aisle aircraft is due to the limited space in the aircraft not easily feasible. A lot of constraints are there, e.g. not to protrude in escape paths required for emergency evacuations or to ensure sufficient space for efficient cabin operations.

The US DOT published a Notice of Proposed Rulemaking (NPRM) that provides future guidance (US Department of Transportation 2020b). It is planned to be applicable for new aircraft with more than 125 seats being delivered three years after the legislation has been passed (which has not happened yet) that fly to/from airports in the United States of America. According to the NPRM at least one lavatory per aircraft will be required that fulfils the following requirements for wheelchair users:

- Grab bars inside the lavatory.
- Accessible attendants call buttons and door locks from a seated position inside the lavatory.
- Door sill / threshold with minimum obstruction to an on-board wheelchair.
- No reduction of toe clearance vs. today‘s lavatories
- Visual barrier to afford privacy with an open lavatory door.

The provision of full accessible lavatories on new single-aisle aircraft will be covered in a separate NPRM (part 2) with a time horizon for effectiveness of about 20 years.

With the Space-Flex galley/ lavatory module, Airbus developed the first fully accessible lavatory on a Single Aisle aircraft in the market (Schliwa & Cremers, 2013). The Space-Flex v1 lavatory and the operation is shown in figure 2.

Another concept introduced by Airbus is based on the integration of a foldable transfer-seat within the lavatory, which facilitates independent seated transfer onto the toilet. This seat allows the mobility impaired person to move from the on-board wheelchair to the toilet without entering the lavatory on the wheelchair. This seat was introduced with the Space-Flex v2 lavatory (see figure 3).

The transfer seat is now available also on all regular size lavatories in the new Airspace interior of the A320 Family as an option.

Figure 2: Airbus Space-Flex v1: PRM capability with removable wall

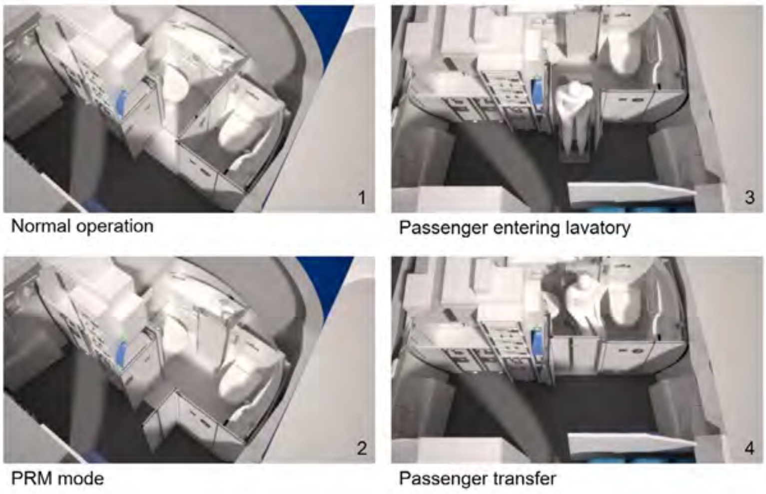
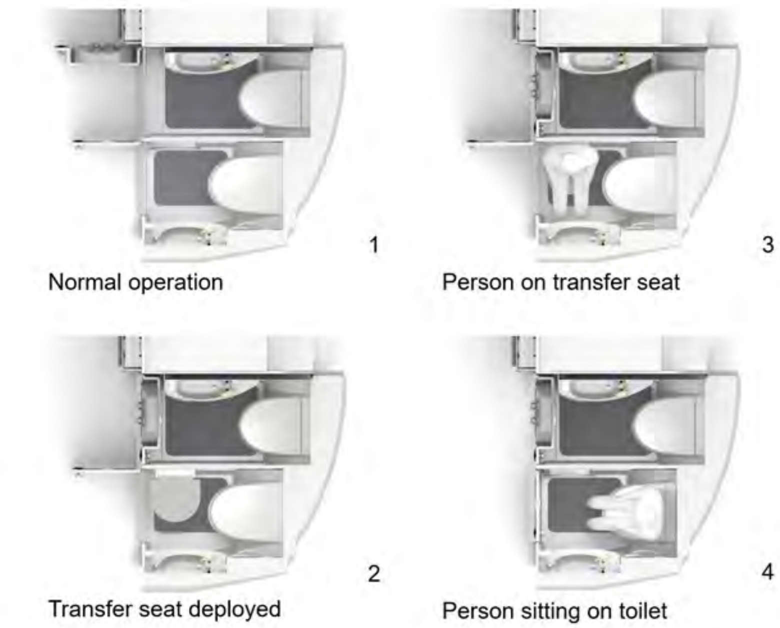


Figure 3: Airbus Space-Flex 2: PRM capability with transfer seat



New approaches

Students at Hamburg University of Applied Sciences developed a concept for a new type of on-board wheelchair that was based on a cantilever structure that allows the person on the wheelchair to remain on the wheelchair that can be positioned over the toilet lid (see figure 4). The passenger can enter the lavatory, use the facilities in privacy, and exit the lavatory without standing up. Accordingly the space needed for the transfer would not be required with such a wheelchair. The idea of the so-called Hamburg wheelchair became with the support from Airbus a reference for the new Advisory Guidelines for Aircraft On-board Wheelchairs which the Department of Transportation (DOT) expects to establish in a forthcoming rulemaking under the Air Carrier Access Act. The US Department of Transportation has defined new requirements to improve the usability to accomplish non-toileting personal hygiene and medically needed tasks in private for wheelchair users.

Figure 4: Hamburg On-board Wheelchair Prototype in A320 lavatory

Currently there are longer-term solutions under discussion that would enable wheelchair users to travel in their own wheelchair on an aircraft. The Federal Aviation Administration is currently conducting a study to determine the feasibility of in-cabin wheelchair restraint systems and if feasible, the ways in which individuals with significant disabilities using wheelchairs can be accommodated with in-cabin wheelchair restraint systems (The National Academies of Sciences, Engineering, and Medicine, 2020)

In 2018 the Canadian Transportation Agency initiated activities on issues related to storing and transporting mobility devices that grow in size and complexity. Wheelchairs are "as diverse as the population and therefore it is difficult to develop standard maximum design envelopes (height, width, length, weight) of mobility aids" (Hunter-Zaworski, 2019).

The integration of the huge variety of individual wheelchairs personal wheelchairs would require a reutilization of cabin areas and new solutions for technical integration and especially certification and qualification and also bears new operational challenges (Giesa & Schliwa, 2020).

Important targets for the integration of personal wheelchairs are:

- Safety for the wheelchair user and other passengers and crew
- Space efficiency (minimum loss of seats and cabin monuments), especially when the area is not in use for wheelchairs
- Minimum additional weight, especially when not in use for wheelchairs
- Low impact on operational efficiency during turnaround and during flight
- No changes of aircraft structure - the integration should work with standard interfaces (seat tracks or upper attachments for monuments)

Figure 5 shows various variables that have an impact on these targets and need to be considered for the definition of a design envelope.

The options for the location of an accommodation of a passenger on a personal wheelchair are physically restricted by the geometries and particularly by the relatively narrow aisles. Accordingly the location in the cabin seems to be preferably feasible close to a passenger door forward or at the rear. There is a wide range of different types of wheelchairs regarding size, weight and fixation interfaces. For an analysis of potential locations a design envelope incl. requirements regarding accommodable wheelchair dimensions, the acceptable loads and structural adaptations and a definition of maximum weight for wheelchairs is required, as they have a major impact on the space needed. The handling of lithium batteries and the related risk of lithium battery fires requires particular attention. The type of restraint systems for the wheelchair and the occupant need to be defined and a standard of the related interfaces is required. In order to minimize any safety risks for the wheelchair user or other passengers or crew a concept for the qualification and certification of the wheelchairs and restraint system need to be defined.

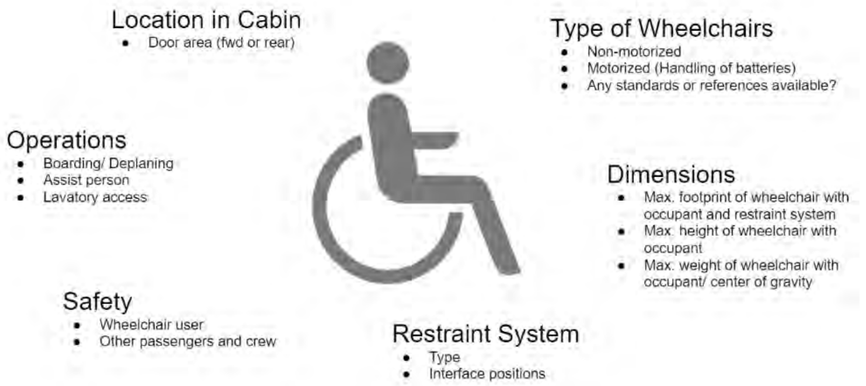


Figure 5: Engineering Design Envelope for Personal Wheelchairs (Giesa & Schliwa, 2020)

Also operational aspects will have an impact on the integration. The boarding and deplaning of a passenger on the wheelchair need to be manageable within the limits of the aircraft turnaround at the airport. Furthermore, interfaces and space allocations could be designed differently if an assist person would obligatorily be available, e.g. for the access to cabin functions as the In-flight Entertainment System, the transfer to a lavatory and for assistance for oxygen mask or life vest use.

The high complexity of the integration into the cabin and the unavailability of an engineering design envelope are reasons to pay attention also to complementary and simpler solutions to improve air travel with wheelchairs in a much shorter time-frame. Most mobility aids are not designed for air travel, and as a result, they cannot be easily modified (Hunter-Zaworski, 2019).

Currently Airbus is working on a new "cargo box" – called Airportainer. This semi-rigid container bag that can be used to protect wheelchairs and other assistive devices during transport in the cargo area.

Figure 6: The Wheelchair Airportainer as innovative approach for reliable and damage preventing transportation of the wheel chairs

Outlook

Going forward, the aviation industry needs to take into consideration that the travelling public includes people who have a wide spectrum of disabilities and challenges, such as hearing or visual impairments, hidden or intellectual disabilities, all of which need to be supported when they fly. With cabin design, the aircraft manufacturer has often to focus on the use of space but digitisation brings new opportunities to improve travel for everyone. Here Airbus will act as an integrator and push new ideas.

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Development of physical discomfort of airline pilots during prolonged sitting

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ABSTRACT

Discomfort was recorded by 26 airline pilots during flight. Thirteen reported their discomfort during a long haul flight and 13 completed the questionnaires during short haul flights. Discomfort values increased with time to high values, but with a modest decrease towards the end of the flight. Most discomfort was reported in the low back area. For the short haul flights upper back values were high and for long haul flights the buttock showed high values.

KEYWORDS

Discomfort, prolonged sitting, airline pilots

Introduction

During prolonged sitting, occupants increase their discomfort irrespective of how good their seat is (Mansfield et al. 2020). Improvements in contouring of the seat, seat pan angle, the backrest angles, lumbar support and neck support and foam can help in maximising the comfort (Vink, 2016). However, discomfort will increase over time anyhow (e.g. Sammonds et al., 2017), even in a business class passenger seat (Smulders et al., 2016). There are indications that high levels of musculoskeletal discomfort among symptom-free workers may develop into musculoskeletal pain in the long term (Hamberg et al., 2008). For instance, if workers had day after day a cumulative LPD (Local Postural Discomfort) rating of over three, they had an increased risk of neck injuries (RR 2.35) after three years, which means 2.35 times more than the 'normal' population. After a few hours of sitting most drivers and passengers, need to take a break and walk in order to provide relief (Mansfield at al. 2020). However, standing up from sitting and walking around is often impossible in occupations like drivers and airline pilots. This prolonged sitting position can be problematic for airline pilots. However, there are not much data available on the increase in discomfort and how discomfort develops in short haul and long haul flights. These data can be useful in the redesign of the flight deck and seat. In this study the amount and location of discomfort is studied.

The data could also be useful for discomfort knowledge as there are not many studies with participants that sit for around seven to eight hours consecutively. Bouwens et al. (2017) studied the comfort among long haul flight passengers, and 149 passengers were interviewed only after their flight. Nine passengers were asked to complete questionnaires during the flight. Interestingly, in this study the discomfort increases, but towards the end of the flight the discomfort decreased. Smulders & Vink (2021) report that more studies show that there is an anticipatory effect towards the end of a long time sitting reducing the discomfort towards the end of the session. Li et al. (2017) followed 18 participants sitting 3 hours and saw a significant increase in discomfort. For the participants sitting in the 28" pitch the discomfort kept increasing, also in the end, but for the 30" and 32", it did not increase anymore after 2 hours. Pitch is the horizontal distance between seats from a point in the seat to the exact same point of the seat behind it.

There are some data available on complaints among airline pilots. For instance, Froom et al (1986) reported that musculoskeletal complaints in the low back are common among the flight deck crew. Lusted et al. (1994) reported that most complaints of pilots are located in the lower back and buttocks. After 5 hours and 20 minutes 168 complaints were reported on the buttocks by 196 pilots and 143 complaints were reported on the lower back. This was followed by the thighs by 81 complaints and the head/neck (60 complaints). Apart from musculoskeletal discomfort also other complaints have been reported by pilots. For instance, Lindgren et al. (2006) reported as the most common symptom fatigue (14%). Pilot seats are designed according to aircraft manufacturer specifications. These specifications have not changed. Pilot seats have to be designed for pilots of stature between 157 and 191 cm. Adjustment features have to assure pilot sitting comfort. Fairly recently studies have been undertaken to explore further improvements in the design of pilot seats.

This study is on discomfort. There are several interpretations of comfort and discomfort. Some state that discomfort and comfort are two opposites on the same line. Ahmadpour (2014) found no differences between the underlying themes of comfort and discomfort. She states that this implies that both could be described using the same set of themes. On the other hand, many authors (e.g. Looze et al. (2003); Helander & Zhang, 1997) state that comfort is more related to psychological and emotional terms, while discomfort is more connected to physical aspects. In this paper, we assume that indeed discomfort is more related to physical factors.

The research question for this paper is: *how is discomfort developing in short haul flights and long haul flights and which areas in the human body are affected?*

Methods

To answer the research question 26 pilots were asked to complete a questionnaire consisting of questions on discomfort. Questionnaires were completed during 13 short haul and 13 long haul flights. The short haul flight data were recorded on an outbound flight followed by an inbound flight in a Boeing 737 with a 35-60 minute turnaround time. The long haul flight data were recorded in a Boeing 777 or 787 only during an outbound flight or an inbound flight. In this study, there were always two pilots in the cockpit (a captain and a first officer). Flights were selected without relief crew. So, there was no rest outside the flight deck seat (in bunk or passenger seat).

Approval from the ethical committee of the university was given. Additionally, the study design was discussed with and approved by participating airlines and pilot unions. Participating pilots were given assurance about confidentiality and that no personal data would be recognizable in the final report. Data of individuals are only stored at the TU-Delft servers and accessible to TU-Delft researchers. Other parties only have access to the data on group level. The questionnaires were completed at times that participating airline pilots themselves regarded as safe.

The questionnaires were completed during the flight to avoid the influence of human memory. All pilots were briefed in the crew centre before the flight and a package of questionnaires on paper was handed out with the instruction when and how to complete the questionnaires. The research protocol was verbally explained. The pilots were asked to complete the questionnaire before the flight in the crew centre, sitting in the seat before take-off (0h), after an hour (1h),then

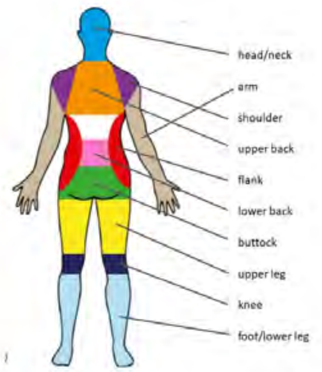

Figure 1: The body map that had to be completed by the pilots approximately every hour.

approximately each hour during the flight and lastly, at the end of the flight while still sitting in the seat. In the first part of the questionnaire general data were gathered like height, weight and gender. In all question-naires local postural discomfort had to be scored on a body map. Discomfort was chosen as it is related to physical complaints (Hamberg et al., 2008). A body map was chosen to see what specific areas are affected. A Local Postural Discom-fort (LPD) body map was used to score discomfort based on the map of Grinten and Smitt (1992). In the pre-test, the pilots mentioned that the flank sides of the trunk need attention too and this was added to the body map. In each body part (see figure 1) the pilots had to score discomfort on a scale 0-10 (0 = no discomfort at all; 10 = extreme discomfort). An overview of all comfort questionnaires by Anjani et al. (2020) suggest that this questionnaire is suitable for this type of research.

The fact that the pilots completed the questionnaire at times that they regarded as safe has the consequence that not all questionnaires will be completed at the same time. In addition, in the Boeing 737 the outbound flight was between 1.5 and 3 hours. Then a break of 35-60 minutes in which they do flight preparation for the inbound flight while sitting in the cockpit, and then an inbound flight of between 1.5 and 3 hours to home base. This means also that there is two times a take-off and landing in the 6-8 hour recording. For these flights the recordings were combined by taking the start recording (outbound 0h), the outbound recording at approximately 1:30 hours, 2:30 hours and at destination (3h). Inbound flight recordings started after take-off approximately at 4:45 h, then 5:45, 7:10 and after the flight approximately 7:40s. In the Boeing 787/777 long haul flights there is only one take-off and landing in the six to ten hours recording. Then the pilots go out of the airplane to a hotel, before taking the inbound flight and this is treated as a separate flight. Because of the differences in time of recording in these flights, the data were edited and placed in categories. The first recording was always the same, but then the data were placed in a category of around 1 hour, 2 hours etcetera. This means that there will be missing data in some categories as pilots were not able to complete at certain times.

For the short haul flight and the long haul flight, the total discomfort (sum of all regions on the map of fig. 1) was calculated for each time category and each pilot. The sum over one region was calculated and averaged over the 13 pilots. Additionally, the total discomfort was calculated for each pilot and the average and standard deviation over the 13 pilots is calculated. In order to determine whether discomfort scores differ significantly between the different time categories a Kruskal–Wallis test using IBM SPSS® 25 was used.

Results and discussion

The long haul flight pilots had more flight hours and less complaints (see table 1), which could be caused by a selection bias (pilots with complaints drop out) or that pilots found a way to deal with it or that the 777/787 has more movement space.

Table 1: Overview of data of the short haul and long haul flights

	Short haul	Long haul
N of flying hours	8700	12100
Age	39 years (23-56)	47 years (39-57)
Stature	1.81 m (1.69-1.98)	1.86 m (1.74-1.97)
Weight	80 kg (70-92)	86 kg (64-95)
% female	25%	8%
Musculoskeletal complaints before flight	72%	50%

The groups differed on several aspects. The long haul group is on average older, has more flying experience, is taller, heavier, has less female pilots and has fewer complaints before the flight.

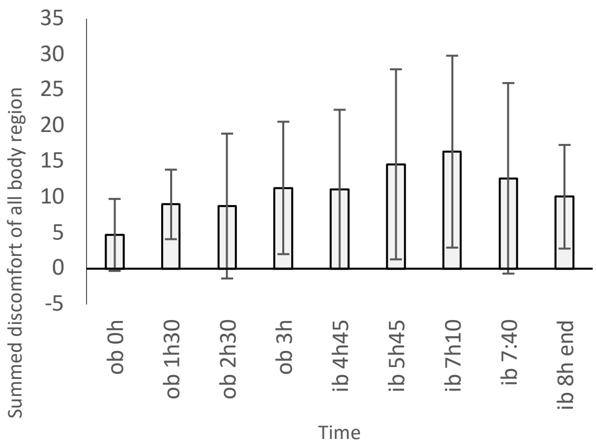

Figure 2: Summed discomfort of all body regions averaged over 13 airline pilots during the flight. The horizontal axe shows time intervals of one hour. Final recording was on average at 8 hours, but varied from 7h40-9h50 dependent on the flight duration. ob=out bound; ib =in bound; h=hours.

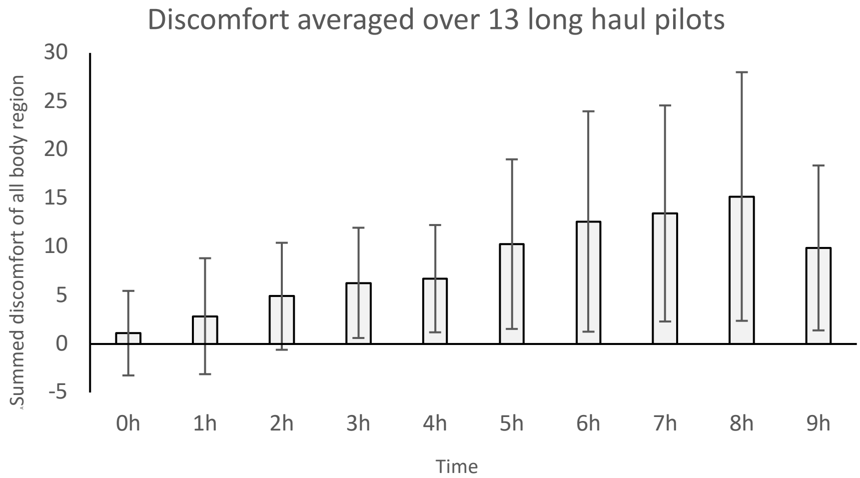

Figure.3: Summed discomfort of all body regions averaged over 13 airline pilots during flight. The horizontal axe shows time intervals of one hour. h=hours.

In figure 2 and 3 the development of discomfort in time for the short haul and long haul flights are shown. The variation between the pilots is high as is shown by the large standard deviation in the figures. In both the short haul and long haul flights, the sum of the discomfort ratings averaged over the pilots reaches a score of 15. There is the risk of developing musculoskeletal injuries when these values continue over three years. Interesting is the fact both groups already had high discomfort scores before the flight, but the percentage of complaints among 737 is much higher (72% vs 50%).

The Kruskal-Wallis test showed for the short haul 737 flight only significant differences between the two highest values (ib 5:45 and IB 7:10) compared with the start discomfort (OB 0h) ($H(7)=17.12$, $p=0.017$). The same is true for the long haul flight; the two highest values (7h and 8h) differ significantly with the lowest (0h) ($H(7)=14.55$, $p=0.042$). The phenomenon that the discomfort drops at the end of the flight for passengers (Smulders & Vink, 2021) is seen in airline pilots as well probably because they know that they will be out of the seat within a short while.

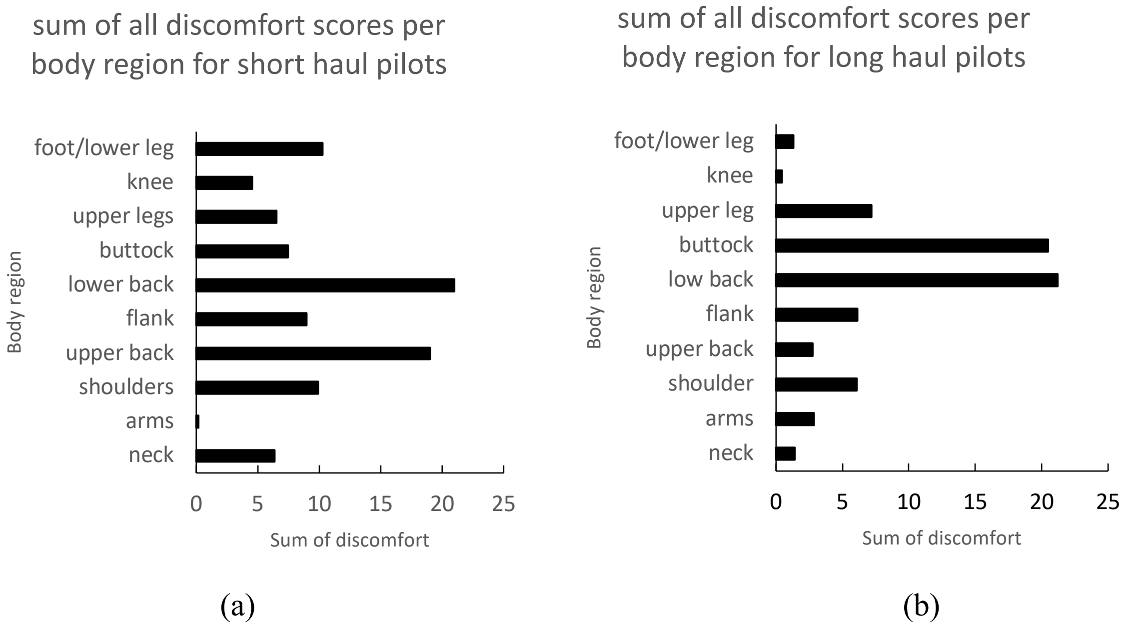

Figure 4: Discomfort for the different body regions for (a) short haul and (b) long haul flights. The horizontal axes is the total discomfort summed over all times.

For both the long haul and short haul flights the lower back region shows highest discomfort, which corresponds to the study of Lusted et al. (1994). If we compare the regions in the body that show discomfort (see figure 4), the short haul flights have more upper back discomfort, while the long haul flights show more complaints in the buttocks. It could be that in the Boeing 737 there is less space leading to a more restricted posture and discomfort in upper back. General comments by the 777/787 pilots were that the seat pan was hard (nine pilots). This hard seat could explain the buttock discomfort. During the long haul flights, the pilots sit very long. There is not a small break at destination, which might lead to higher discomfort in the buttocks. The 737 pilots mentioned (8x) that the lower back was unsupported, and the armrest is difficult to adjust (6x). In redesigning the seat, the seat pan hardness and lumbar support need attention.

Conclusion

The main findings in this study are: (1) Physical discomfort increases during the duty and decreases somewhat close to the end. (2) Physical discomfort in several participating pilots reaches values that may lead to injuries in the end. (3) The body regions that are mainly affected are the lower back in both pilot groups and upper back in the short haul and the buttocks in the long haul pilots.

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Soma design to enhance aircraft passenger comfort

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ABSTRACT

Aircraft passengers can become uncomfortable while seated because of the restricted physical space. This work aims to investigate a new strategy for designing interventions that can be used to encourage aircraft passengers to move more while seated and thus to improve their perceived level of comfort. We discuss the utility of applying the 'soma design' methodology to creating these interventions, which aim to target specific body discomfort areas identified in a previous study. In this paper, we report on a series of design activities to address this challenge.

KEYWORDS

Comfort, interventions, soma design methodology

Introduction

Aircraft passenger physical movements are very limited during the flight, and this can have serious impact on their experience of comfort (Vink & Brauer, 2011). In-seat movements can lead to better comfort experiences and reduced discomfort experiences (Bouwens et al., 2018). In our previous study, we asked participants to sit in a simulated aircraft cabin for three hours and periodically report their comfort score. Their posture and movements were also video recorded. The main body areas associated with discomfort were identified as: the back of the neck, shoulders, buttocks and the lower back. In addition, participants were observed to maintain postures with their neck down and trunk backward for most of the study duration (Sharafkhani et al., 2021). In this paper, we explore the applicability of the 'soma design' methodology to aircraft passenger comfort research. The prior work provides us with a framing of our design space – the combination of the *restrictions of the seat* and the specific *bodily area of interest*. Now we examine what we might do in that design space. We report on a series of activities, which were conducted in order to explore the utility of the soma design methodology to design and evaluate interventions to be used for improving passenger awareness of posture-induced discomfort.

Soma Design

Soma design originates from the philosophy of somaesthetics based on the work of Professor Richard Shusterman (2008). Somaesthetics is the combination of Soma (body, mind, and emotion as one subjectivity) and aesthetics (the deepening of our sensory appreciation skills). Soma design is a holistic design method which encourages users to engage in a smooth and embodied interaction between their own actions and system responses (Höök et al., 2018). In other words, the aim of Somaesthetic Design is to "*design interactions that harmonize - aesthetically and somatically*" (Höök et al., 2018). Höök characterises soma design is a *"qualitative shift from a predominantly symbolic, language-oriented stance to an experiential, felt, aesthetic stance permeating the whole design and use cycle"*(Höök, 2018). This approach allows us to examine and improve on connections between sensation, feeling, emotion, and subjective understanding and values (Khut, 2016). In practical terms, soma design is a methodology that can be used for designing experiences and products in a reflective, first person manner, with established tools for both enhancing participants' understanding of a design space, and articulating their experiences with those designs.

Ideation workshop

We conducted a workshop, implementing soma design techniques to direct participants to focus on upper body posture and ideate a range of potential movements and game interventions that could be used to reduce postural discomfort. Sixteen participants were recruited for three ideation workshops. Sampling was a combination of ten males and six females and with a mix of design and non-design backgrounds. At the beginning of each workshop, the researcher explained the purpose of the workshop and summarised the findings from the previous study (Sharafkhani et al., 2019) including the discomfort areas identified and the main restrictions while sitting in an aircraft seat (e.g. the limited physical space). The researcher also demonstrated this restriction visually making sure that the participants were fully aware of the constraints and discomfort areas. A body scan process (Varela et al., 2000) and the body maps instrument (Loke et al., 2014) were introduced briefly. The participants then read and completed the informed consent forms.

Mindfulness awareness

The first workshop activity helped participants to develop a mindful awareness of their body sensations. The purpose of this activity is to direct the focus of participants into their own bodies as part of the soma technique and thus understand whether people feel more comfortable when they are aware of their bodies and focus on their bodies. Feldenkrais is a typical bodily activity which is used in soma design (Höök et al., 2018). The Feldenkrais method is a body-oriented experience, based on the body-mechanics research of Moshé Feldenkrais (Moshe Feldenkrais, 1982) and shares some characteristics with yoga. This technique helps people to reconnect with their bodies and is often used as a sensitising activity in soma design workshops. The researchers explored, through discussion with the Feldenkrais facilitator, how to move effectively within the constraints of an aircraft seat. The focus was on movements of the neck, shoulders and sitting bones. Similar techniques have been applied in other soma design workshops (Søndergaard et al., 2021).

Idea Development

In the next activity, the researcher rearranged the seats in rows in a similar arrangement to a passenger aircraft layout to represent the physical constraints of the aircraft. The physical restriction of the space for participants aimed to help them embody their design thinking in an equivalent space. Participants were asked to perform typical in-flight posture movements such as neck rolls, shoulder rolls, forward flexes, etc. and to think about their feelings of discomfort in the specific body areas identified in our prior study, including: the back, neck, shoulders, lower back and buttocks. They were asked to think about the possible movements that they could make and the effect of the space on those movements. This included attempting to find the available range of movements, and to consider the effect these movements might have on other connected parts of their bodies. The researcher gave prompts and examples to help the participants to focus on how they could move within the space. For instance; what is the movement space? How far can we move in the aircraft seat? What kinds of movements? How do you like the movements? Do they encourage you to do more? Participants worked in breakout groups to ideate a range of games and playful interventions to encourage physical movements within the confines of the seat. During this section, the researcher observed, recorded and took notes of each group's discussion. Then, to further seed ideas, the participants used challenge and opportunity cards from the Mixed Reality Game ideation cards (Wetzel et al., 2017). These cards are used in design exercises to support ideation, to encourage new possibilities, and to add artificial restrictions which can further drive creativity (Benford et al., 2005). Use of these cards can be seen in Figure 1a. During these ideation sessions, 50 game design ideas were generated - from whack-a-mole, to a racing game, to a dance competition. Figure 1b shows an example of one of the groups' notes.

Figure 1a: Mixed Reality Game cards.

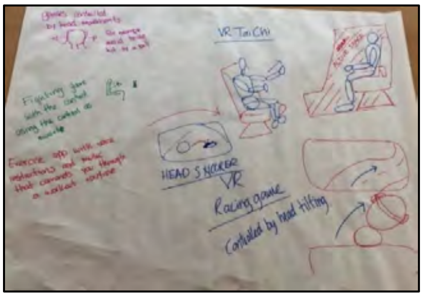


Figure 1b: Group notes from brainstorming game ideas.

Selecting an appropriate game design

Our next step was to select an appropriate example from the game ideas to take forward to prototype. We developed some criteria to help us make this selection then used these as heuristics to narrow the list of options. For example, the game should be practical for the location; the movements of the game should target the known body discomfort areas and should help to distract the passenger from the physical constraint; and it should be deliverable with relatively cheap consumer hardware. *Robot Rescue*, a puzzle computer game loosely based on Avalon Hill's *Robo Rally*[1] and controlled by gesture movements was selected and prototyped. This was then taken forward into a study to evaluate the applicability of this intervention. We created a version of the game that could be used in a virtual environment, with a view to assessing whether the embodied nature of the virtual environment would serve to focus the user on their body and help them ignore their physical environment. This also served the additional purpose of delivering a consistent visual environment as we were unable to test in the "wild' setting of a real aeroplane, or even in laboratory with real plane seats due to COVID-19 national lockdowns – instead participants would be at home.

Robot rescue game

The Robot Rescue game is an exertion game in which a series of arm-movement gestures are used to pre-program the directional movement of a robot character through a 3D virtual environment. This puzzle-based game mechanic appears in a number of existing game designs such as Robo Rally (ibid) and Space Alert[2]. Using a 'pre-programing' approach allows the movements to be slow and explicitly made, rather than performed under time pressure. The participants then viewed the character automatically moving around the environment according to the directional instructions given. This activity was presented to the players in VR. We imagine this game being played on a plane – however, rather than use a model of a plane as the background, we selected a quite serene environment, though the plane seat is still featured to help ground the player in their immediate (imagined in this case) environment. Figure 2 shows the game in play.

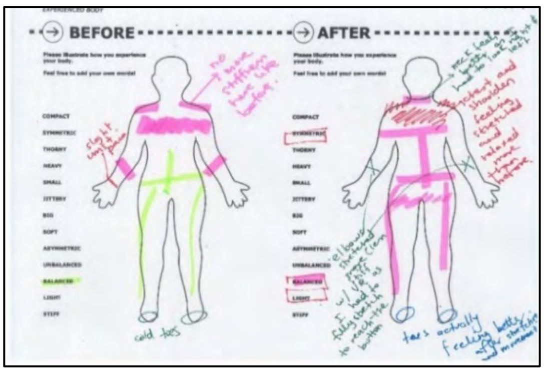
[1] https://avalonhill.wizards.com/games/robo-rally
[2] https://czechgames.com/en/space-alert/

Figure 2: The Robot Rescue game, looking forward, up and down and a participant playing it in VR

Study

Next, we then ran individual studies with six participants playing Robot Rescue, held online over three hours and followed this with a focus group meeting for all six participants. Participants first completed a 'sensitising' Feldenkrais exercise, as with the previous workshop, which was included to help them focus on their bodies. Figure 2 shows a participant playing the game. During the study participants were asked to complete body maps (Loke et al., 2014) and soma trajectories (Tennent et al., 2021) as non-verbal, reflective ways of articulating their felt experience. This formed part of a qualitative, soma-focussed exploration of their experience of the game. Soma design methods were used for our evaluation because of their holistic, non-dualistic focus on sense, sensation and sense-making and the richness of the descriptions provided by the participants using these methods.

The body maps and soma trajectories were used to document the body in a relatively unconstrained way before and after the activity and as articulation tools to support reflection and discussion in these sessions through a range of dimensions including – critically - discomfort. These techniques encourage creativity in articulating 'felt' experiences - albeit informed here by the focus of the study on discomfort, The soma design methodology suggests that language does not tell a true story about design (Höök, 2018). Therefore, participants were allowed to use any kind of words, shapes, figures and paintings. An example of a body map and set of soma trajectories from our study can be viewed in Figure 3a and Figure 3b respectively.



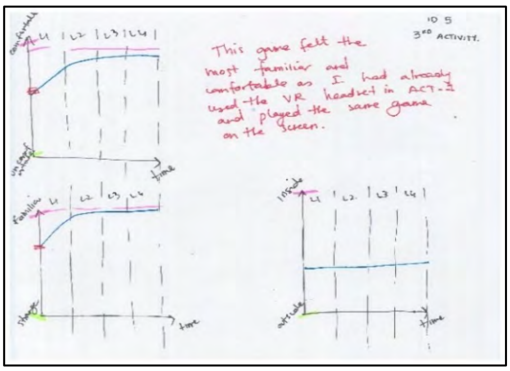


Figure 3a: An example of body map. Figure 3b. An example of a set of soma trajectories.

Focus Group Meeting

As one of the key activities of the soma design methodology is to encourage discussion and articulation of the user experience, especially drawing on the immediate reflections described by the body maps and trajectories, all six participants were invited to a focus group meeting to discuss their experience of the study. Soma design focusses on the plurality of experience – how felt experiences may be very different for individuals - and makes a virtue of this by using it as an explicit focus for discussion. The participants talked about their shared experience and the differences between them and translated their non-verbal articulations into discussions about their feelings. They started to talk about their general opinions about the game and then they explained their body maps and soma trajectories – reflecting on them and adding layers of meaning.

For example, one participant mentioned that she had a bit of stiffness in her neck, but after completing the activity, the stiffness went away and she felt more like light and bouncy, stating: *"I don't know if it's because of the increased range of motion of that activity"*. In general, she mentioned she felt more balanced with heightened awareness of her upper body and sitting bones. Another participant put a happy smiley face in her body map after doing the activity. She mentioned that she enjoyed playing the game and that the game play encouraged her to do more movements: *"You know, once I passed the levels so I felt confident and also energetic and I felt my body and my arms, especially, felt activated"*. For her comfort trajectories, she drew her comfort level increasing over the time. A third participant mentioned that she moved her entire upper body while playing the game and she added that the neck movements felt *"so good."* She also represented her comfort level as increasing. Conversely, however, another participant explained that she started being pretty much comfortable but, when describing her comfort trajectories, she stated: *"it started comfortable, but getting uncomfortable".* She mentioned the forward movements got annoying for her after doing it for more than three or four times.

Reflections on The Method

The fundamentally qualitative nature of the soma design lends itself to small sample sizes with very deep explorations of each individual's experience. It is by nature individual and recognises the plurality of experience. Using the soma design methodology provides the researchers with rich descriptive data providing deep insight into the participants' subjective experiences. In an era where interventions can be personalised though technologies like virtual reality, this pluralistic perspective can serve to deepen our understanding of users' needs and experiences. From a design perspective, using soma design techniques such as the sensitisation and bodily ideation seen in in our workshop led to a wide variety of design concepts. As a method of evaluating a prototype, the tools associated with soma design, such as body maps and soma trajectories, provide a rich set of highly descriptive data that can be used alongside existing evaluation methods to add both qualitative depth and individual experience. We found the bodily articulations to be particularly effective alongside interviews for encouraging participants to detail their experience both spatially (with body maps) and temporally (with soma trajectories).

Conclusion

This paper reflects on the application of soma design to the specific challenge of aircraft passenger discomfort research. Building on the findings of our prior work, which helped us to identify the bodily design space – that is the areas of discomfort associated with being an aircraft passenger, and by extension the associated muscle groups to target, and combining this with the physical design space – the aircraft seat and the limited space around it; we were able to apply a soma design methodology to quickly ideate a wide selection of potential interventions. Taking one of these to prototype stage and evaluating it suggested that our design strategy was a sound one, as our participants reacted mostly positively to the intervention. We therefore suggest that soma design may serve as a powerful tool for designing targeted comfort interventions as part of practical ergonomics research, especially when informed by additional constraints such as target areas of the body, and posture/space limitations, and for gaining very rich qualitative feedback about the efficacy of those designs. We therefore argue that soma design can and should be added to the toolkit of design and evaluation methods found in modern ergonomics research.

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