Proceedings of the 4th International

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Amberg 2023

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Preface

Welcome to the 4th International Comfort Congress!

Building upon the successes of the Salerno Congress in 2017, the Delft Congress in 2019, and the Nottingham Congress in 2021, we are delighted to extend our warmest invitation to the 2023 Congress, hosted in the vibrant city of Amberg, Germany.

In the wake of the COVID-19 pandemic, our world is gradually reopening, ushering in a renewed need for mobility solutions. However, this resurgence coincides with pressing global challenges, most notably the accelerating threat of global warming. Within this complex landscape, a clear mandate emerges: the imperative to prioritize sustainable modes of mobility. This entails advancing technologies such as automated electric vehicles and hydrogen-powered aircraft, and also opening doors to novel possibilities for comfort researchers, including the innovative ideas such as integrating sleep experiences within vehicles, redefining our interactions with cooperative, connected and automated mobility.

Yet, as these groundbreaking advancements unfold, they usher in a fresh array of considerations - specifically, the emergence of new comfort criteria. This proceedings serves as a repository for the latest insights from comfort researchers and designers, representing institutions from across the world, including Europe, North American, and Asia.

The proceedings address topics spanning Future Vehicles, Emotion, Modelling and Simulation, Non-Driving Related Tasks, Sleep and Service, Motion Sickness, Future Interiors, Vibration, Physiology, and Touch. By pooling together collective expertise, these proceedings contribute to a transformative narrative in which evolving concepts seamlessly merge with tangible real-world implementations. Ultimately, this ongoing discourse cultivates an environment where sustainability and comfort harmoniously converge, forging a future that effectively responds to our collective aspirations as well as the dynamic demands of an ever-changing world.

We hope that you enjoy ICC2023 and find inspiration in reading these short papers.

The organizing committee:

Dr. Susanne Frohriep (Chair)
Prof. Dr. Neil Mansfield
Dr. Anna West
Prof. Dr. Peter Vink
Prof. Dr. Alessandro Naddeo
Dr. Wolf Song

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Special needs for special population in autonomous vehicles: A Systematic review

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ABSTRACT

The current decade has witnessed significant improvements in autonomous vehicles that are presenting a great opportunity for people to enjoy their trips and spend the time to do personal activities more. Meanwhile, it can be slightly different for some people with special characteristics, such as elderly or disabled passengers which often expose with challenges in completing daily activities, such as driving. From a viewpoint, autonomous vehicles promise to provide more comfortable transportation facilities regarding their limitations. On the other hand, it could bring some difficulties for their interaction because of their particular requirements and needs. With the combination of two categories of keywords, first related to some concepts about special populations like pregnant, impaired population, senior adults, and aging, and second for autonomous vehicles and other relevant keywords, 262 papers were obtained. After the initial screen, 48 papers were selected for full paper review. The most important concerns for elderly passengers were various difficulties in interacting with technologies. Over time, cognitive and perceptual capabilities of aging people decrease, so they experienced a lot of stress for the takeover. Having a good reaction time to continue driving tasks instead of an autonomous vehicle was mentioned as a difficulty by elderly people. As well, they stated transparent behaviors of the autonomous vehicles as an important expectation, concerning the changes that are happened for their mental processing. Physical disabled individuals have claimed their fear about getting on easily and staying fix inside the autonomous vehicle during the trip. Also, pregnant women's age had a principal role for their acceptance. Increasing age had a positive relationship in pregnant women's acceptance of self-driving cars. It's worth mentioning that shared autonomous vehicles were preferred by majority of mentioned population, as they felt positive attitude and emotions when they were not alone in driverless cars. As a conclusion, it can be guessed that with wide spreading the autonomous vehicles in the near future, these special population will welcome these complex but helpful vehicles, in order to compensate their limitations, while more studies are necessary to investigate different facets of their multiple disabilities.

KEYWORDS

Disabled people; Aging; Autonomous vehicle; Comfort; Design.

Introduction

Driving is a sophisticated daily activity that requires mental acuity and strong physical condition (Knoefel et al., 2019). People gain greatly from this activity, however, there are significant issues about it that must be taken into account (Knoefel et al., 2019). In contrast to several benefits that automation has brought for people, some special groups have serious difficulties with it (Petrović et al., 2022). People with physical and cognitive limitations encounter various problems when moving around (Cordts et al., 2021). One beneficial approach might be the use of autonomous cars and services to overcome their mobility barriers (Dicianno et al., 2021). Around 15% of people worldwide, according to the World Health Organization (2021), suffer from a form of disability (Petrović et al., 2022). Indeed, disabled people can be categorized into 7 groups as following: 1) blind and visually impaired people; 2) deaf and hard of hearing people; 3) those who use wheelchairs, scooters, or canes as a form of transportation; 4) people with autism and the people who care for them; 5) families with young children; 6) seniors (age 60+); 7) pregnant women (Miller et al., 2022). Each mentioned group has special demands and requirements which should be provide to eliminate the restrictions on using cars, thus, autonomous vehicles (AVs) would supply a welcome opportunity for these special groups to experience an independent trip (Klinich et al., 2022). Due to the wide variety of mentioned impairments and limitations, accessible and useable design solutions must be tailored to the needs, circumstances, and preferences of each group to design an efficient and helpful car (Dicianno et al., 2021). The present study goes on to explore a comprehensive map extracted from existing relevant studies about different problems, concerns, and needs of the mentioned special groups, that can impress their transportation, while can even be solved with some minimal interventions and considerations.

Method

The papers we arranged is from Scopus database, which is comprehensive and authoritative as well as well-known in the academic circles worldwide, that contains engineering, computer science, design, and transportation. Two groups of keywords were used including: 1) disabled, special population, pregnant, pregnancy, impaired population, aging, senior adult, elderly, aged population, 2) autonomous vehicle, driverless, connected car, future car, automated car, autonomous car. Afterwards, each keyword in the first part and the second one in pairs was arranged to search and gather relevant literature as more as possible. To be eligible for inclusion in this review, studies had to: (1) be published in a peer-reviewed English journal; (2) have at least one variable related to AVs as the dependent variable; (3) be original full articles, and conference proceedings. The last search was made in February 2023, and we restricted the search to all literature published before that date. Papers identified in the search were screened in two steps: title and abstract screening and full-text screening. In both steps, all manuscripts were assessed by two independently trained reviewers. In addition, the references cited in the included full-text papers were screened due to potential inclusion.

Results

All special groups have not been equally addressed in different studies. Generally, elderly related issues have received more attention, and people with cognitive impairments and pregnant women are in the corner. More than half (67%) of the reviewed manuscripts were belonged to the elderly population. Moreover, the largest number of manuscripts was published in 2021 and the U.S. has been the most productive country in this field. To illustrate concerns and needs of each special group, reviewed studies are split based on the mentioned clusters.

A) Seniors/Elderly People

The incidence of traffic accidents rises in the 50s and 60s, making it more difficult to drive as the person's physical and cognitive abilities deteriorate. Numerous studies have shown that elderly people require more safe mobility (Isbel et al., 2022; Park & Han, 2023). Definitely, upgraded mobility of old people is a significant anticipated advantage of autonomous vehicles (Kovacs et al., 2020). Usually, using an AV has not gained a high rate acceptance among old people (Hassan et al., 2021; Huang et al., 2022). While a few studies have claimed their positive attitudes about it, specifically it can help them to reach more independence to do at least their daily activities such as go to a doctor or shopping (Huff Jr et al., 2019; Isbel et al., 2022). However, the elderly population are the biggest beneficiaries of self-driving cars (Park & Han, 2023). Some of significant concerns of elderly persons that influence their acceptance include safety, comfort, reliability, and their cognitive abilities (Loi, 2019; Oxley et al., 2019; Sun et al., 2020). They reported experiencing fear and stress when using an AV because they could not feel safety, especially when a failure occurred (Rovira et al., 2019). Further, low flexibility of old people in addition to the preference to use their privately-owned traditional vehicle created discomfort for riding an AV (Hassan et al., 2021). One of the repetitive concerns was reliability that showed aging people are not sure about the way of updating AVs' programs, thus they stated a low trust, enjoyment, and attractiveness in self-driving cars (Charness et al., 2018; Lajunen & Sullman, 2021). Regarding various evidence that represent cognitive capabilities decline of old people, a considerable worry can be observed among seniors about their disability to learn working with an AV properly (Rovira et al., 2019). They mentioned that it is impossible to learn how can we work with a high-tech car due to our age and we are afraid to fail in our interactions with various and novel interfaces of an AV (Yang & Coughlin, 2014). Besides this worry, some studies have shown their slow and long reaction time to respond to the AV's alarms and feedbacks, in particular when a takeover is necessary (Gasne et al., 2022; Huang & Pitts, 2022). It's worth noting that old drivers predispose to higher mental workload as well as decreasing their accuracy and performance, and increasing errors during the riding with an autonomous vehicle (Loi, 2019; Turabian et al., 2021). As seniors cannot go out of home and work actively, they need to keep a social relationship at least in some public communities (Rahman et al., 2020). So, they did not intend to use a self-driving car since they lose social relations with drivers (Siegfried et al., 2021). However, some of them claimed their concern to be alone during the trip and face with a health problem, thus, they proposed a suitable system to monitor health situation and assist them in a convenient time (Park et al., 2019; Zandieh & Acheampong, 2021). It's worth pointing out that aging people indicated good acceptance to vocal and multimodal alarms in AVs than visual messages, especially because of their decreased visual acuity as well as the highest required concentration (Eimontaite et al., 2020; Rukonic et al., 2021). Furthermore, seniors with higher level education, like male elderly, claimed more acceptance of AVs (Günthner et al., 2021; Huang et al., 2022). Altogether, several interesting points can be observed in elderly concerns and needs for using an AV, which safety and comfort stand at the center.

B) Physical Disabled (PD) People

As mentioned before, there are different disabled people that suffer from a form of limitation. But in this category, relevant studies to visual, hearing, and walking difficulties are reviewed. Based on Cordts research, physical disabled people took just 29 % of trips by a personal car as a driver (Cordts et al., 2021). Many factors such as hand control, pedal extensions, failure to receive audio and visual signals from other cars can be great barriers for PD, therefore AVs can be a fine solution to improve their mobility (Petrović et al., 2020). Regardless of various benefits of AVs for PD, they cannot accept to use it easily because of some concerns such as safety, poor/lack of control to plan a trip alone, and convenience to get in/out the car (Riggs & Pande, 2022). So, some researchers have stated that public autonomous transportation can enhance their acceptance rate (Miller et al., 2022). However, majority of PD declared a lot of satisfaction about their independency by using an AV (Petrović et al., 2022).

Also in this category, safety and reliability ranked as significant concerns of PD (Miller et al., 2022). Based on their permanent need for others assistance to move, they cannot trust in AVs as a safe car since they are worried to be alone, particularly without a driver in some dangerous conditions, as it was proposed by their caregivers to monitor and communicate with them during the trip (Bennett et al., 2019). Another safety issue was related to the fixation of their seat/wheelchair inside the AV, and a reliable seat belt to keep them properly specially in frontal crashes (Dicianno et al., 2021; Klinich et al., 2022). Some studies indicated that disabled persons who live in urban areas and also non-drivers with PD intend to use AVs more than PD who are able to drive (Petrović et al., 2022). On the other hand, prior knowledge and more exposures with autonomous vehicles have positive effect on their acceptance and willingness to use it because of their increased readiness and curiosity (Bennett et al., 2019). Summing up, safety, trust and reliability, comfort, ease of boarding/alighting, reduced manpower needs, cybersecurity attacks, having an efficient interaction with the AV to inform passengers about its decisions and intentions can be listed as substantial concerns of disabled people (Miller et al., 2022; Petrović et al., 2022). Moreover, designing suitable interfaces based on PD limitations, like clear text messages for people with auditorial difficulties and transparent audio signals for blind persons were mentioned by impaired people (Riggs & Pande, 2022).

C) Pregnant Women

Despite numerous limitations and difficulties that pregnancy creates, only one study was found which assessed factors affecting the acceptance of 7 healthy pregnant women about fully autonomous vehicles (FAVs). The results illustrated that the older the pregnant women, the higher of acceptance rate of FAVs. Contrary to experiencing various and unstable emotional moods during pregnancy, the emotional state did not impress their acceptance of FAV, as the weather conditions did not affect their acceptance (Liu et al., 2021).

Conclusion

In this paper, an overview of special needs and concerns of special people about using an autonomous vehicle was presented. The tremendous benefits that customers can receive from AVs cannot be ignored, although, changing traditional driving patterns has created a low acceptance among people. The three special categories and their concerns that have been addressed in different studies more, are illustrated in the following figure. Acceptance was the only common concern among seniors, PD, and pregnant women. However, safety, comfort, and reliability have stated by special people as significant concerns frequently, but they will increase by improving people's acceptance. One strategy to boost adoption is to introduce autonomous driving in public transportation first, such as buses and the metro, to acquaint consumers with the technology without requiring them to actively choose it. On the other hand, some remarks in designing AVs' interfaces and features that fit with special population limitations can improve their acceptance and provide a pleasant experience for individuals who are always in need of assistance and company. All in all, AVs can offer more comfortable and safe trips for special people in the near future, only with some specific but simple considerations.

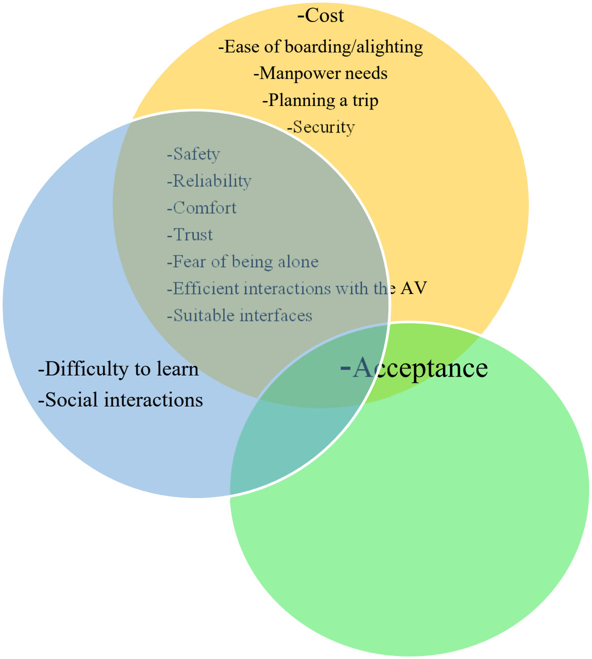

Figure 1. Different concerns of special groups: Seniors (Blue), PD (yellow), and Pregnant women (green).

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Subjective and Objective Comfort Analysis of Three Commercial Vehicle Seats

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ABSTRACT

A study was undertaken to determine whether there were any differences in subjective and objective seat pan comfort measures across three different commercial truck seats. A suite of subjective measures were collected before and after 18 participants, comprising three different BMI categories, sat for 15 minutes in each of the three different seats (Seat A, Seat B, and Seat C). Seat pressure mapping was collected over the 15-minutes and seat pan foam properties were characterized. Initially, after briefly sitting in each, all seats were equally preferred; however, after sitting 15-minute in each seat, Seat C universally had the highest seat pan comfort ratings, the lowest perceived discomfort rating in the tailbones ($p = 0.007$), and was rated as the most preferred seat by 11 out of 18 participants. The seat pressure measurements indicated that Seat C also provided the greatest total area for support ($p < 0.0001$) and the lowest concentration of high-pressure areas ($p = 0.02$). In addition, the foam stiffness measures demonstrated that Seat C also had the softest foam of the three seats. Overall, across the three seats, the suite of subjective and objective tools appeared to have utility for identifying differences in seat pressure parameters, foam stiffness; and in measures of seat comfort, body discomfort, and seat preferences.

KEYWORDS

Seat Pressure Mapping, Foam Properties, Discomfort, Truck Seats

Introduction

The purpose of this study was to determine whether a subjective and objective benchmarking process could be developed for comparing commercial vehicle seat comfort and preference. The ultimate goal was to determine whether there were any associations between subjective body or seat feature comfort measures and objective measures collected to characterize the physical features and characteristics of the seats.

Method

Subjects Eighteen male subjects were recruited to participate in this study, with the goal of having the participants span three weight classes: light (49-72 kg, normal BMI), medium (73-95kg, overweight BMI), and heavy (+210 lbs / +96 kg, obese BMI) drivers. Demographic information collected from subjects are summarized in Table 1. All subjects gave their written and informed consent prior to their participation in the study.

Table 1 – Mean (standard error) subject anthropometrics and demographics (n = 18)

Age (Years)	Weight (lbs)	Height (ft-in)	Weight (kg)	Height (cm)	BMI	Years Driving	Miles Driven/Week
52.5 (3.7)	201.9 (14.7)	5′-9″ (0.8″)	91.8 (6.7)	177.5 (2.1)	28.8 (1.7)	14.6 (3.9)	1119 (146)

Experimental Protocol As shown in the left side of Figure 1, three truck seats were evaluated, two commercial European Truck seats (Seat A and Seat B) and one prototype truck seat (Seat C). The armrests were removed from the seats and the subjects were not familiar nor had any prior experience using any of the three seats.

Figure 1. Left side - the three seats tested in the study. Right side - a subject sitting in the simulated truck cab.

First, with the three seats covered to mask seat identity, the subjects adjusted the seat back angle and the seat pan height, depth, and seat pan angle of each seat to their preferences. In order to minimize the number of adjustments and allow the drivers to focus on seat pan comfort, the seat back lumbar supports were not inflated, and the backrest adjustments (side bolsters and back curvature adjustments) were left in their neutral un-activated positions. Then, the participants ranked the three seats from most- to least-preferred.

Subsequently, in a random order, subjects sat in a simulated truck cab (Figure 1, right side). The location of the simulated truck cab steering wheel and foot pedals were adjusted to each subject's preferences and kept constant across the testing of the three seats. Then, the subjects sat in each seat for a period of 15 minutes; and at the beginning (0 min), middle (7.5 min), and end (15 min) they rated their perceived discomfort in the ankles, knees, back of the thighs, tailbones using a visual analog form of the Borg CR-10 Scale (Borg 1982). At the end of the 15 minutes, subjects rated their comfort with the seat features using 7-point Likert scales with verbal anchors at the low- and high-end of each scale. In addition, During the 15-minute test period, pressure distributions were also continuously collected at 30 Hz from the seat pan of each seat (Model High Resolution BodiTrak; Vista Medical; Winnipeg, Manitoba), and saved on a laptop for subsequent analysis. In addition, at the end of the experiment, after sitting in all three seats, subjects again ranked the three seats from most- to least-preferred. Finally, foam hysteresis and stiffness measurements were collected from each seat using the standardized methods in SAE J2896.

Data Analysis A mixed model with restricted maximum likelihood estimation (REML) Repeated Measures Analysis of Variance (RANOVA) in JMP (Version 14; SAS Institute Inc.; Cary, SC, USA) was used to determine whether there were any differences in perceived body discomfort ratings, seat comfort ratings, and contact pressure measures across the three seats. Any statistical significance was followed-up with a Tukey-Kramer post-hoc test. In addition, the distribution of the pre- and post-use seat comfort rankings were compared using a Chi-Squared analysis. All data are presented as mean and standard error, and significance was noted when p-values were less than 0.05.

The seat pressure map parameters analyzed included the mean seat pressure, total pressure area, and seat pressures that were above 20 kPA, which were used to indicate areas of high contact pressure. For the foam hysteresis and stiffness testing, over 50 mm of foam deflection, the load in Newtons (N) applied to the indenter was measured and recorded. At 20 mm of deflection during the loading phase, the slope of the foam loading curve was calculated and used to characterize the foam stiffness of each seat pan.

Results

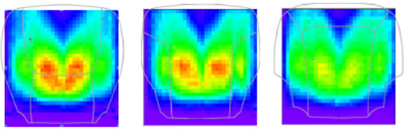
Pre-use, there were no differences in comfort rankings across the three seats, and each seat was equally preferred ($p = 1.00$). Post-use, there were differences in the seat comfort rankings ($p = 0.01$) with Seat C ranked as the most preferred seat by 11 out of 18 participants. Borg body discomfort data was successfully collected from 15 subjects, data from three subjects were excluded as their responses were near the high end of the body discomfort scale and departed from the other subjects. An analysis across body parts and time indicated there were significant differences in self-reported discomfort across body locations ($p < 0.0001$), a significant increase in discomfort with time ($p = 0.02$), and a trend indicating a body location by seat interaction ($p = 0.06$). There was also a significant difference across seats in the discomfort experienced in the tailbones ($p = 0.007$) with Seat C having the lowest discomfort ratings.

The Likert comfort data were successfully collected from 17 subjects and Table 2 shows the seat pan comfort ratings, red indicates lowest/worst comfort scores and green indicates highest/best comfort scores. The differences in the Likert seat pan comfort ratings did not reach significance but there were trends with Seat A consistently being ranked the lowest and Seat C being ranked the highest.

Table 2. Mean Likert seat pan feature comfort ratings on a 0 to 7 point scale, low scores indicate less comfort and higher scores indicate more comfort (n = 17).

Feature	Seat A	Seat B	Seat C	p-value
Width of the Seat Cushion	**5.3**	5.9	**6.1**	0.26
Firmness of the Seat Cushion	**5.3**	5.4	**6.2**	0.10
Thigh Support/Bolstering	**5.0**	5.4	**6.1**	0.15
Pressure on Thighs	**5.5**	5.6	**6.1**	0.34

Seat pressure map data from 17 subjects were included in the final analysis. Data from one subject was excluded due to equipment malfunction. The left portion of Figure 2 shows the mean pressure map data averaged over the 17 subjects at the top of the table and the mean pressure, total pressure area and total pressure area above 20 kPA (red area in pressure maps). There were no significant differences in mean pressure measures across the seats ($p = 0.27$), but there were significant differences in the total surface area ($p < 0.0001$), and high-pressure area above 20 KPA ($p = 0.02$). Seat C had the lowest mean pressure, the highest surface area, and the smallest high-pressure area.



	Seat A	Seat B	Seat C	p-value
Pressure	7.3 kPA	7.5 kPA	6.9 kPA	0.27
Total Surface Area	1266 cm^2 (76.7%)	1236 cm^2 (74.9%)	1318 cm^2 (79.8%)	<0.0001
Seat Area Above 20 kPA	59.6 cm^2 (4.6%)	40.5 cm^2 (3.1%)	12.1 cm^2 (0.9%)	0.02

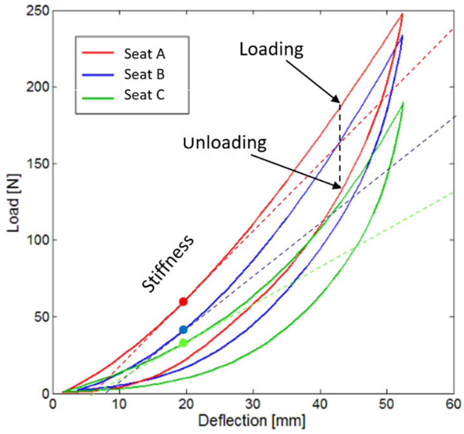


Figure 2. Left, mean seat pressure map result, the red areas in the pressure maps indicate pressures above 20 kPA (n = 17). The green text indicates the lowest pressures and greatest surface areas and the red text indicates highest pressures and lowest surface areas. Right, seat stiffness and hysteresis testing of the foam in the seat pans.

The right portion of Figure 2 shows the load versus displacement curves for each seat when the spherical indenter was depressed 50 mm into the foam (straight lines) and then slowly retracted back to the starting point on 0 mm of deflection (hysteresis – curved lines). The slope of the loading curve at 20 mm of deflection was to calculate foam stiffness. As can be seen in Figure 2, Seat A had the stiffest foam (4.4 N/mm), Seat B had foam of an intermediate stiffness (3.7 N/mm), and Seat C had the foam with the lowest stiffness (2.4 N/mm).

Conclusion

Overall, the suite of subjective and objective tools appeared to be very robust in identifying differences seat pressure parameters, foam stiffness, seat comfort, body discomfort, and seat preferences. Seat C, which had the lowest foam stiffness, universally had the most favorable ratings for seat pan comfort, body discomfort, objective measures of seat pressure, and was the most preferred seat.

Overall, the suite of tools used appeared to be robust and complementary in identifying differences in objective measures of seat pressure and foam stiffness parameters and subjective seat comfort, body discomfort, and seat preference measures. The intended outcome of this work is to standardize this subjective comfort and discomfort benchmarking process and the associated objective seat measurement procedures so that these methods can be repeated by commercial vehicle seat manufacturers in any location/market around the world.

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Developing an effective questionnaire for trust-investigation while using an autonomous vehicle

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ABSTRACT

Vehicles have undergone various technological changes. One of these changes is decreasing humans' responsibilities and tasks related to driving, that has led to the presentation of Autonomous Vehicles (AVs). Indeed, with the advent of AVs, people can do their personal activities as well save their time during the trips, without paying attention to the road like current driving. Although, besides the benefits, people cannot trust AVs completely, thus it has become a global challenge in this high-tech product. A crucial factor known to strongly influence the acceptance and use of automated technology is trust. Up to now, many instruments have presented to evaluate human's trust in autonomous vehicles directly and indirectly. While to the best of our knowledge, there is not a comprehensive instrument to assess people's trust in autonomous vehicles. In the present study, a multi-dimensional instrument was created to evaluate individual's trust during their riding with an autonomous vehicle. To create the questionnaire, the information needed based on the researchers' goals were specified. At the first step, semi-structured oral interviews with different but related experts were performed to determine probable significant concerns of people's trust in AVs. Based on the concerns, a list of keywords was selected to check the literature. In the third step, a brainstorming was done to define different approaches about various aspects of trust in AVs. According to the second check in the literature, 5 different dimensions were gained. The "pool of questions" method was utilized to generate the initial questions for all 5 dimensions. The questions were figured out by an expert panel to determine the most relevant and important ones. At the end of this step, just 3 dimensions with total 24 sub-dimensions remained. These questions were evaluated using a variety of reliability and validity techniques, including thinking aloud, the content validity index (CVI), and the content validity ratio (CVR), therefore just 47 questions with 21 sub-dimensions continued to exist out of 69 initial questions. In the last step, the final questionnaire was filled out by 24 people, after their riding experience with the simulator. Then, the Cronbach Alpha coefficient was computed, and final version's validity and reliability were satisfactory.

KEYWORDS

Trust; Autonomous Vehicles; Questionnaire; Driverless Car; Reliability and Validity.

Introduction

Autonomous vehicles (AVs) are self-driving cars able of navigating roads and planning routes automatically with little to no human intervention (Yuen et al., 2020). Due to the decrement of the control feeling, people's acceptance of AVs will be impressed (Seet et al., 2020). It can be claimed that trust is a critical indicator of people's acceptance of AVs (Haspiel et al., 2018). Simply put, lots of people cannot experience comfort during the riding with an AV because of the lack of trust in handing over the driving tasks (Haspiel et al., 2018). Obviously, people should feel trust in AVs to obtain a positive outcome (Ma et al., 2021). Several researchers have focused on appraisal of individuals' trust in AVs, though there has not been a comprehensive instrument to assess it (Dirsehan & Can, 2020; Nguyen et al., 2022). This paper introduces a multi-dimensional questionnaire which has been developed to evaluate people's trust as regards different facets while using an AV.

Method

To develop the questionnaire, the following steps were carried out: after defining the study goals to 14 related researchers, semi-structured oral interviews were conducted with them to identify the most important probable concerns of people about an AV. They were from different fields such as psychology, ergonomics, and artificial intelligence engineering. Based on the concerns, a list of keywords was prepared to check the literature. Then, a brainstorming among the research team helped the organization of 5 different dimensions related to trust in an AV, including human-related, demographic, social, technical, and environmental factors. In this step, the "pool of questions" method was utilized, and initial questions were created for each dimension. Then, all questions were double checked by the subject matter experts to determine the most relevant and significant ones. At the end of this stage only, personal, social, and technical dimensions with 24 sub-dimensions remained.
Using "thinking aloud" method, all 69 questions were checked and modified by the research team head. Thereupon, the questionnaire was evaluated by 19 people of the expert panel with different nationalities who had various but relevant scientific backgrounds such as human factors and ergonomics, psychology, mechanical, electrical, and artificial intelligence engineering. Then, the Content Validity Index (CVI) and the Content Validity Ratio (CVR) were calculated. According to the scores obtained, only 47 questions in 3 dimensions divided into 21 sub-dimensions remained. Finally, for ensuring reliability, the latest version of the questionnaire was filled out by 24 participants who attended to an experimental study to compute the Cronbach's Alpha coefficient. To compute it, all participants (Mean_{age}=24.87) attended to an experiment which was done using a driving simulator with a 5-step scenario consisting manual and automatic driving. Only the first step was manual driving. These 5 steps were composed of building trust, trust escalation, trust reduction, trust mutation, and rebuilding trust (Shahrdar et al., 2019). Afterwards, participants filled out the questionnaire, and Cronbach's Alpha was computed using SPSS version 26.

Results

Simplicity, transparency, and relevance of all questions were rated by CVI. The lowest CVI was belonged to "mental complexity" subdimension in the personal dimension with 0.63 and the maximum was gained by "personality" in the same category with 0.90. As well, one question about "meaningfulness attitude" in personal dimension obtained the lowest score (0.56) of CVR. The highest CVR (1.00) for showing questions' necessity was owned by 9 questions, including "knowledge" and "situation awareness" in personal dimension, in addition to "internal interfaces", "transparency", "possibility of intervention", and "usability" in technical category. Due to not getting enough score, 22 questions were deleted. Among all 21 subdimensions, knowledge and safety obtained least and highest Cronbach's Alpha respectively (α=0.57 and α=0.88) and the coefficient for all sub-dimensions were 0.93 that shows a very good reliability.

The final version of the questionnaire has 3 general categories, 21 subdimensions, and 47 questions. Three categories are including personal/human-related, social, and technical factors. Personal part has 8 sub-dimensions consisting of knowledge (2 items), personality (4 items), duration of the trip (1 item), companionship (2 items), situation awareness (2 items), expectations (1 item), deskillization (1 item), and meaningfulness attitude (2 items). Social dimension, as the second part has governmental considerations/support (3 items), brand (1 item), and development level of countries (1 item). Lastly, technical dimension with 10 various sub-dimensions has 56.52% of all questions, including personalized design (1 item), car appearance (1 item), safety (7 items), internal interfaces (4 items), transparency (3 items), security (2 items), technical support (2 items), possibility of interventions (2 items), complexity (1 item), and usability (4 items). The questionnaire is attached as an appendix.

To the best of our knowledge, the present instrument is the first questionnaire which can evaluate human's trust in AVs regarding to various facets, however, other questionnaires assess human's trust in technologies, computers, etc., not in AVs exactly. After a deep comparison and survey, some commonalities such as usability (Choi & Ji, 2015; Mason et al., 2020), safety (Choi & Ji, 2015; Jian et al., 2000; Mason et al., 2020; Paddeu et al., 2020), people's knowledge and expectations (Choi & Ji, 2015; Jian et al., 2000), and possibility of intervention during the automatic driving (Mason et al., 2020) were found between the proposed and extant questionnaires. Whereas the provided aspects by the present questionnaire which were ignored in all existing instruments consist of some significant factors that are mentioned in the following.

First, personality traits of passengers/drivers can impress their perception about trust, comfort, and acceptance of this complex vehicle (Zhang et al., 2020). Duration of the trip, and companionship with others can make people calm and induce more trust and comfort, plus development level of countries which can increase your exposure and experience with high-tech products and improve your trust (Kim & Jung, 2019; Tremoulet et al., 2020; Vongvit et al., 2022). Also, deskillization is another sub-dimension that has effect on trust due to not using individual capabilities in autonomous driving (McBride, 2016). Meaningfulness attitude which can fade the driving concept in human's mind, governmental considerations and support that can facilitate people's willing to buy/use an AV, in addition the brand, which is determinative in some people's decisions, and the complexity level of an AV that can affect on people's understanding and trust, are other proposed sub-dimensions (Erskine et al., 2020; Lee et al., 2018). Moreover, passengers/drivers' situation awareness enhances surrounding information and induces more trust, personalized design that helps people to experience a close interaction with an AV and trust it more, the automated car appearance as well as internal interfaces which can assist you to communicate with an AV better and easier, transparency in an AV behaviors which can keep you informed, security issues such as cyber-attacks, and technical support as a customer service to save passengers in all uncomfortable conditions have been all other sub-dimensions that were considered in the questionnaire (Omeiza et al., 2021; Revell et al., 2020; Vongvit et al., 2022). Regarding to the satisfactory validity and reliability of final version of the questionnaire, and the lack of a multi-dimensional questionnaire to investigate individuals' trust in an AV, it seems that this instrument can fill this gap efficiently.

Conclusion

In summary, a multi-dimensional and comprehensive instrument was developed to figure out people's trust in AVs. All 3 dimensions and 21 sub-dimensions can help researchers to evaluate the level of trust in AVs, as well it can represent perceived comfort during the riding with an autonomous vehicle.

Limitations and future research

As the present study is an early attempt at creating a multi-dimensional questionnaire for people's trust in autonomous vehicles, some limitations are to be expected. First, the participant sample had important limitations. In addition to the low number, it was too homogeneous due to their nationality, jobs, and the age range. Second, instead of an autonomous vehicle, a well-equipped semi-immersive virtual reality was utilized for the experiment. It is worth noting that people's feelings and perceptions can be different while they experience a real autonomous car, although the participants received different feedbacks such as vibration in some conditions like the car movement on speed bumps. Nevertheless, it would be beneficial for future research to contribute diverse individuals as a comprehensive sample and use an autonomous vehicle to induce the most real feelings and perceptions.

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Towards an environment friendly comfortable aircraft seat

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ABSTRACT

A new electric aircraft with hydrogen tanks, a fuel cell and propellers is in development at Embraer S.A. aiming at zero emission while flying. For this aircraft, a new seat is in development, which should be comfortable as well. This paper concerns the development of this seat. The original aluminium seat frame is kept the same as it is already lightweight and has to comply with safety restrictions. The top layer of the developed seat is made of cactus leather. This looks and feels like leather but is harvested from cacti, which grow locally, and it can be harvested again after half a year without killing the plant. It might provide the user with an expensive feel. A coating still must be added to reduce flammability. The middle layer is made of flexible TPU, this material is 3D printed via the Fused Deposition Modelling (FDM) technique. It replaces foam, which is much more sustainable as it can be reused. The layer connecting to the frame is made by Maezio, a lightweight composite, which can significantly reduce the carbon footprint by more than 70 percent compared to one made from conventional aluminium-magnesium alloy. For comfort, it was important to have a good replacement of the foam with different densities.

KEYWORDS

Comfort, 3d printed cushion, cactus leather, aircraft seat

Introduction

The airline industry faces many challenges, as the industry should become close to carbon neutral. A hydrogen propulsion could solve this. However, to increase range of an airplane the interior should be lightweight. Additionally, the materials should be environment friendly as well. Within this challenge a new aircraft seat is developed for a new electric aircraft with hydrogen tanks, a fuel cell and propellers by Embraer S.A. aiming at zero emission. Additionally, care is taken to make the seat sustainable, which influences for instance material choice.

The developed seat

In designing the seat, attention was paid to the fact that the seat should be lightweight, comfortable and sustainable. Lightweight influenced the choice for a cushion of the seat, which was made of flexible thermoplastic elastomer TPU-98A via Fused Deposition Modelling (FDM), which is a specific 3D printing technique. Via this technique 'shape memory' can be implemented, the shape returns to its original form after deflection. By using different infill percentages of a gyroid structure (figure 1 and figure 2) in the seating, different parts of the body can be supported. In addition, these different infill percentages mean that there is an overall weight reduction of the cushions. With 15%, the body parts that need more support are supported; this means that just 15% of the material has to be used in this area. The same goes for 10% and 5%. The 3D printed cushion is lighter compared to a conventional cushion of a KLM city hopper recaro SL3170. The weight of this cushion with connections is 1.7 kg. The weight of our cushion is 470 grams.

Fig. 1, The position of the 3d printed cushion in the aircraft seat.

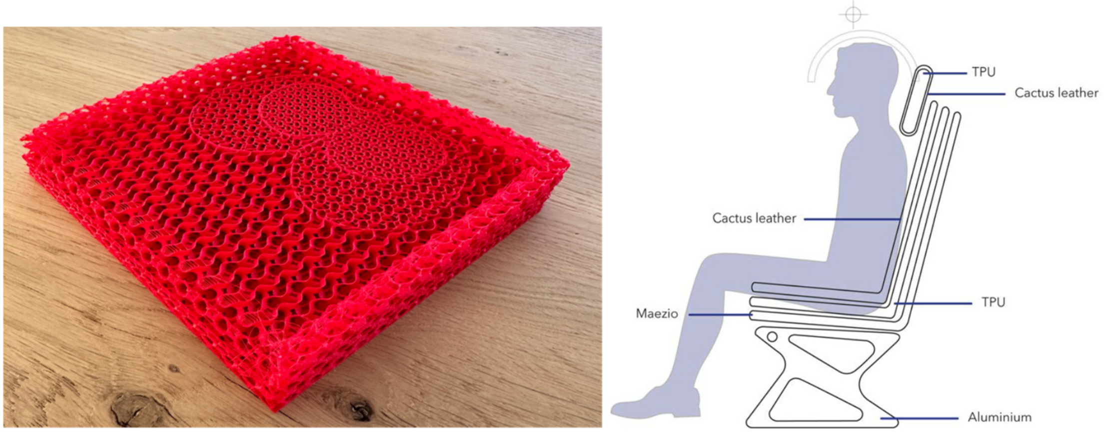

Fig. 2. The 3d printed cushion with different densities to improve the comfort experience (left) and the layers of the seat (right).

These differences in densities increase the chance that the seat is experienced as comfortable as the pressure distribution comes close to the ideal pressure distribution as described by Zenk et al. (2007). To contribute to comfort not only the seat pan hardness is optimized, the curve in the backrest is based on research from Carcone & Keir (2007). Carcone and Keir (2007) describe that the lumbar support should be less than 30 mm and based on the anthropometric data base of Korte (2013) the height of the lumbar support with respect to the seat pan could be defined (the middle of the lumbar support is on average 192 mm above the seat pan). The seat pan angle is based on the principle of 'not gliding out of your seat'. The seat pan angle with no shear force is derived from the study of Goossens and Snijders (1995).

The concept seat is made from three different and partially local grown materials. This was done with sustainability in mind (see fig. 2). Fewer materials make it easier to reuse, recycle and reduce waste. The original Recaro frame is kept the same. This frame is both very strong and lightweight. The top layer of the chair is made of cactus leather. Cactus leather is leather made of cacti. It is durable and is aimed to provide the user with an expensive feel. Every half year the cactus gets a new skin and this can be used for new 'cactus leather'. It is also produced in Brazil, close to the Embraer factory, which reduces transport and thereby carbon emissions. The only thing that should be done to make it applicable in aircrafts is a coating for flammability.

Test

The printing of the 3d seat pan was tested. The first batch consisted of small cubes (3x3x3 cm) made from flexible TPU via Selective Laser Sintering (SLS). The cubes differ from each other by their infill structure and percentage. Some of them are made via a gyroid structure and others via a honeycomb structure. The cubes were tested on flexibility by applying pressure on them. It showed that some cubes were flexible this way, but the majority was too firm. This was discussed with experts and in consultation with an expert, a new print was made. This print consists of a different material: TPU-98A printed via Fused Deposition Modeling (FDM). The cubes only differ from each other by their infill percentage (10, 20, 30 and 50%), while keeping the gyroid infill structure the same. We also tested these cubes by applying pressure to the different surfaces and it was softer, better for the seat pan use and a printed scale model was made with a width of 152 mm, a length of 148 mm and a height of 20 mm.

Conclusion

The project shows that this design of a more sustainable and comfortable aircraft seat has potential. The material choice can make the seat more lightweight and more sustainable. The lightweight aspect of the seat contributes to less fuel consumption and the material choice ensures that at the end of life there is no waste. It is also produced in a sustainable way.

Further research is needed on how passengers experience the real seat in a real flight and how durable the different elements are.

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Emotion assessment in eVTOL cabin design

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ABSTRACT

The increase in urbanization and road congestion has raised the need to address new solutions for transportation of people and goods. In this context Urban Air Mobility (UAM) has come up as a possible near future solution, supported by the advance of sustainable propulsion (Eletric motors), energy storage systems (EV industry batteries), connectivity (5G), automation (AI systems), and lightweight materials (automated composites manufacturing processes). In this paper we describe the testing process of a Mockup cabin for a future UAM vehicle, designed to fly four passengers and one pilot. The Mockup was used as a test prototype to assess passenger emotions in eVTOLs (electric vertical take-off and landing aircraft).

Anticipating that flying in an eVTOLs will be something new and unexpected for users, the design team tried to develop a safe, reassuring and inclusive interior. As an early stage prototype for preliminary testing, the cabin mockup was designed as an experience for the senses: a) visual, achieved by the fluid lines of the cabin enveloping the occupants in a safe frame; rich, varied color palette connecting passengers with nature and providing a calm atmosphere; technological interfaces such as the immersive upper screen integrating relaxing “moods” for different flight phases (from blue sky to sunset or a colorful aurora borealis); b) olfactory, with the use of natural materials and a fragrance based on fresh citric wood fragrances; c) tactile, using natural leather manufactured with sustainable processes (leather tanned with natural oak processes), natural wool textiles and textured and color rich recycled materials. A major challenge was to accommodate four passengers, one pilot, luggage, and provision for people with reduced mobility (PRM) within the constraints of a small lightweight cabin without compromising the overall comfort and future travel experience.

During an “Advisory Board” event to promote the cabin prototype, a study was developed using the “Geneva Emotion Wheel - GEW" (Scherer, 2005) methodology to measure the emotions experienced inside the cabin. The objective was to assess the level of positive or negative emotions when the participants were confronted with the cabin prototype. We will present the methodology and findings of the study, discuss further steps towards improving the design, and provide future research recommendations.

KEYWORDS

Aircraft Cabin Design, Urban Air Mobility, E-Vtol, Geneva Emotion Wheel, Emotion assessment

Introduction

The design team developed and built a physical full-scale mockup of an electrically powered vertical take-off and landing (eVTOL) aircraft cabin. During an "Advisory Board Event" held in Lisbon to address Urban Air Mobility (UAM) challenges, the prototype was tested with users using a GEW methodology. An eVTOL is an electric vertical take-off and landing aircraft, which resembles, in its mission, to a small version of a helicopter, able to carry a pilot, four passengers and luggage. While the interior may be compared to a "flying car", the cabin design of an E-vtol will be guided by aviation regulations just as an helicopter. Weight and safety standards are currently still being developed by the safety agencies as there are still no operating E-Vtols in the market (FAA in the US and EASA in Europe are expecting to see operating versions by 2025). The objetive of the eVTOL will be to create a *"low-altitude transport that can relieve congestion on the ground, with vehicles that operate like a helicopter but are safer, quieter, cleaner and more affordable, due to their multiple electric rotor redundancy, zero-emission-in-use powertrains and associated maintenance"* (Business jet interiors January 2023 issue)

The design team used the "Geneva Emotion Wheel" (GEW) (Scherer, 2005) methodology to measure the emotions experienced inside the prototype, during the "Advisory Board Event". Emotional data was collected by using a retrospective verbal self-report method. *"A central component of emotions, the "feeling component," is inherently subjective and can only be assessed with self- report measures, such as the Geneva Emotion Wheel* (GEW; Scherer, 2005)."(Sacharin, V., Schlegel K., 2012). The Urban Air Mobility (UAM) Advisory Board included participants from fixed-wing and rotorcraft operators and rideshare platforms and was organized to gather feedback and insights for the future of UAM vehicles design and operation.

Scherer et al. developed the Geneva Emotion Wheel (GEW), an *"empirically tested instrument to measure emotional reactions to objects and events."* The objective was to assess the level of positive or negative emotions when the participants were confronted with a new cabin interior. It was an opportunity to access participants' general feelings and emotions towards the eVTOL cabin prototype. GEW uses a visual representation (circular wheel) subdivided into different sectors. Each sector is used as a representation of a (primary) emotion (e.g., joy, fear, anger, disgust, surprise, etc.). The methodology aims to understand and capture the multidimensional and complex nature of emotions using a visual "interface".

Figure 1 eVTOL cabin interior.

Methodology

Stimulus event: The event took place in Lisbon, Portugal, in June 2022, with 21 participants from 10 countries gathered to discuss UAM, including aspects regarding operations, services and cabin design. The participants where mainly male with an average age of 44 years. The UAM Advisory Board included participants from fixed-wing and rotorcraft operators, rideshare platforms, and lessors collaborating in a workshop to gather feedback and insights for the future of UAM design and operation. Targeting the urban and suburban commutes around the world, the group tried to rethink the economics, experience, regulatory and environmental impacts of UAM.

GEW: During one of the several workshop sessions, the Geneva Emotion Wheel (GEW) was used to measure the emotions experienced inside the cabin mock-up. Participants were guided to the mockup by the researchers, asked to enter the cabin, seat and experience the interior. Subjective emotional data was then collected by using a retrospective verbal self-report method. The participants had the opportunity to share their emotions by filling in a paper-and-pencil form where 20 different emotions were arranged in a circular way (according to the GEW). The participants had to identify the emotions that best corresponded to their feelings and check one of the circles in the "spike". The bigger the circle, the stronger the emotional experience. The emotion families were arranged in a wheel shape with the axes being defined by major dimensions of emotional experience: 'High Control' on top, 'Low Control' on bottom, 'Negative Valence' on the left and 'Positive Valence' on the right. Because sometimes emotions can be "blended", if the participants didn´t feel any emotion at all, they had the opportunity to select "None" or if experienced other emotion could check "Other". Figure 1 shows the graphical interface used during the sessions.

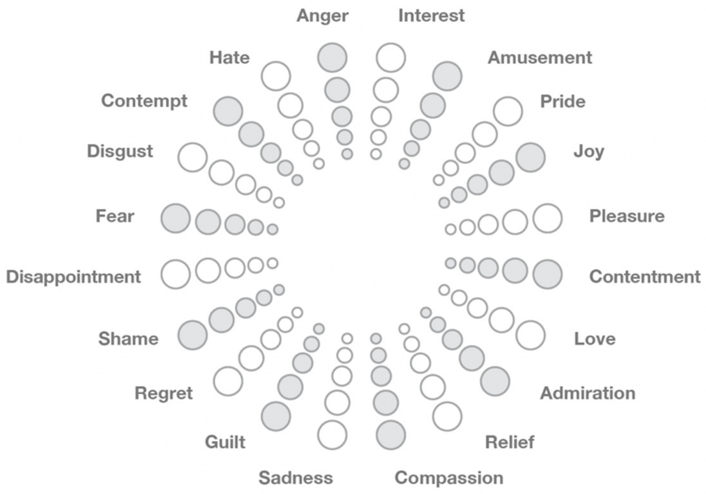

Figure 2 GEW emotions 'spike'.

"The number of emotion families is limited to 4 per quadrant, yielding a total of 16 (which seems reasonable considering that the upper limit of the number of ''basic emotions'' is often considered to be around 14). The choice of the concrete families is also in large part determined by what are generally considered to be either basic or fundamental emotions or those frequently studied in the field." (Scherer, 2005:29)

The Cabin Mockup: The cabin design includes 4 passenger seats, 1 pilot seat, storage space and an IFE system including screens, sound, and fragrances. To create an “enhanced” experience designers tried to engage the passenger at different levels - sensory, social, intellectual, and behavioral. Careful attention was given to the different “touch points” where passengers interact with the interior environment and are stimulated, inspired, and relate with other people. Among the main materials used in the cabin, specific comfortable and sustainable options were considered: Oak-tan Leather, natural leather tanned using vegetable processes, 100% biodegradable; Eco-tile flooring, made with 98% waste from the footwear industry and 100% recyclable; Fire-resistant textiles in virgin wool from sustainable sources. The Mockup design focused on the cabin interior, including seats, and cockpit, considering passenger comfort, color material and finishes, overall look and feel. Considering the seats and overall cabin space, designers tried to address best practices such as the use of different percentile measures for each component (e.g. free space considering 95% percentile male, reach considering 5% female, etc). *“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, 2011). Considering that future eVTOLs will need to be lightweight, cabin dimensions were reduced to the minimum, considering the trade-off between most comfortable vs the smaller cabin possible. The physical mockup tested is the first physical prototype, having been manufactured using different technologies from metallic structures and composites, CNC machining, rapid prototyping (including SLS, SLA, FDM, DLP), foam injection, thermoforming, among others.

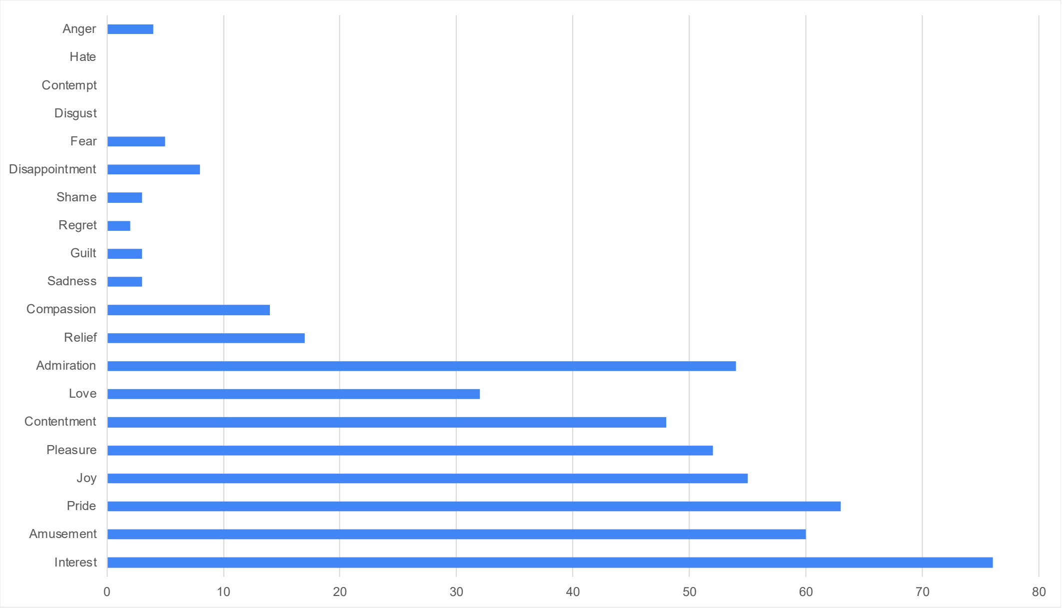

Figure 3 Emotions felt inside the cabin.

Results

It is expected that the results of the GEW methodology can provide cues for the development of future design iterations, as the design teams got first feedback from users on the emotional qualities of the mockup in a controlled “static” (non-flying) environment. *“The Geneva Emotion Wheel may be the first such instrument to design the dimensional layout of the emotion qualities on pure appraisal dimensions (arrangement of emotion terms in two-dimensional space) and the intensity of the*

associated subjective feeling (distance from origin)."(Scherer, 2005:30). The tests with 21 subjects occurred during the "Advisory Board" event sessions and the following results were gathered:
The main emotions felt inside the cabin relate to interest, pride, amusement, joy and admiration, which reveal a positive impact of the mockup *"Positive emotions (such as happiness) as "signs" or "outcomes" of optimal functioning"* (Peters et al., 2020). Positive emotions were generally preferred by participants, as showed in the graphic below, which accounts for the total sum of emotions as voted by participants. The graphic presents the voted emotions scale from "Interest" to "Anger", in the same order as was presented in the "GEW" card.

Regarding the primary emotions which include joy, anger, fear, sadness, surprise, disgust, contempt, and interest, that are considered basic and universal, the feelings interest and joy revealed higher results. Most of the emotions reveal a positive affect when interacting with the new cabin interior, probably because of aesthetic values, as it was difficult to access utilitarian emotions (the e-VTOL was static in a controlled environment and not flying. *"Because of their importance for survival and wellbeing, many utilitarian emotions are high-intensity emergency reactions, involving the synchronization of many organismic subsystems"*(Scherer, 2005:12) *"They are different from aesthetic emotions "are produced by the appreciation of the intrinsic qualities of the beauty of nature, or the qualities of a work of art or an artistic performance."*(Scherer, 2005).
The average results are shown in the figure below:

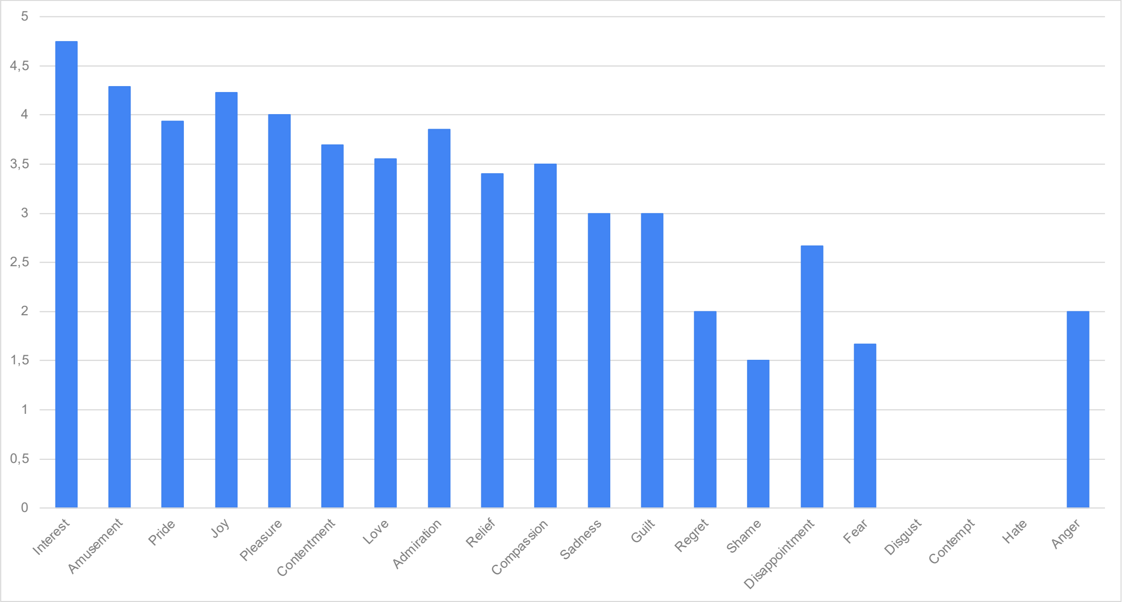

Figure 4 Emotions felt inside the cabin – average results.

We can generally say that the cabin design contributes to positive emotions, with comfortable seats, pleasant lighting, aesthetic design probably contributing the most. *"Comfort is associated with feelings of relaxation and wellbeing and can be influenced by the aesthetic impression"*. (Mastrigt, 2015:17) A calm and relaxing environment was specifically designed by the team developed to reduce fear and anxiety, but these were not able to be tested in a functional (flying) environment. These preliminary results show that the aesthetic and comfort dimensions are probably being correctly addressed by designers, but the functionality of the cabin "in-flight" could not yet be accessed.

Conclusion

The discussion focuses on the methodologies used and the project results, describing lessons learned and recommendations for future design developments of eVTOL aircraft. The results may lead to some changes in the interior design of the cabin towards a better passenger experience.

As the methodology was used to assess participants emotions in the eVTOL cabin prototype during a specific "Advisory Board" event, we believe the context was strongly biased towards a more positive mindset. In case of a "flying" prototype it is possible that results would be very different, with fears and high-intensity emergency reactions probably arising.

We believe the main contribution to this project was to assess emotions inside a first cabin mockup. As such, the preliminary results show the design was well accepted. The biggest challenge throughout the process was to make participants reveal and share their emotions. Overall, the GEW instrument allowed to assess participants emotions during a specific event, but we believe the context affected the results towards a more positive mindset. Although the results are considered promising, the following future recommendations/questions can be addressed:

- How to understand emotions in a functional setting (flying prototype)
- How to translate the results into practical design features to improve passenger experience.

"The definition of emotions, distinguishing them from other affective states or traits, and measuring them in a comprehensive and meaningful way have been a constant challenge for emotion researchers in different disciplines of the social and behavioral sciences over a long period of time."(Scherer, 2005).

Furthermore, the tool provided a framework for understanding and studying emotions and its connection with design and specifically cabin design. "how design can positively influence wellbeing is commonly shared, as is the hypothesis that 'positively designed' products could enhance our wellbeing."(Cain, 2008:2).
By providing a convenient, safe and fast mode of transportation in urban areas, eVTOLs will potenically help reduce traffic congestion and travel time in cities, presenting a viable path to an urban on-demand mobility alternative in the face of rising pressure for environmentally sustainable solutions. But they have to be designed in order to provide a sense of safety and pleasant experience.

The eVTOL prototype will follow a path of gradual evolution, with the refinement of the design and engineering to reduce weight while maintaining high standards of comfort and safety. The design will also be developed with a view to serial/scale production. The Geneva Emotional Wheel is one of several models that help categorize and understand emotions, other methods will be used in future prototypes to test the acceptance of eVTOLs.

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Tactile Comfort Studies on Automotive Seat Trim Materials

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ABSTRACT

The hand feel of an automotive seat trim cover is an important factor in the consumer's perception of seat comfort, which contributes to overall vehicle satisfaction and the decision to purchase a vehicle. A conventional trim cover includes a surface material and a supporting substrate known as a "foundation". Both layers affect tactile perception when it comes to comfort. To better quantify human tactile perception for seating comfort, 10 samples were prepared to subjectively and objectively determine the influence of surface material and foundation to the perceived hand feel of the trim cover. Six different natural and Polyurethane (Faux) leather materials with the same foundation were evaluated in the surface material subjective clinic and five samples made with a single semi-aniline perforated leather as the surface material were evaluated in the foundation subjective clinic. Both subjective clinics were conducted with participants from the trim engineering division, who represented the opinions of industry experts, and participants with no prior trim experience, who represented the voice of general consumers. The samples were then tested with haptic sensors and the measured haptic characteristic properties were correlated with the subjective perceptions. The findings from this study indicated that both surface material and foundation type generated significantly different tactile feelings, which addressed the importance of considering all layers in the seat trim system when designing for comfort. Additionally, there were consistent significant differences in the perceptions between industry experts and general consumers. Such trend showed that pre-existing bias could generate a significant psychological impact on hand feel and tactile comfort perceptions. While the perceptions from the industrial experts might better reflect the product manufacturing process, the objective measurements had higher correlation with the subjective scores from the general consumers. This study laid a foundation to bring future trim material with high comfort performance to the market.

KEYWORDS

Automotive Trim, Leather, Hand Feel, Tactile Comfort

Introduction

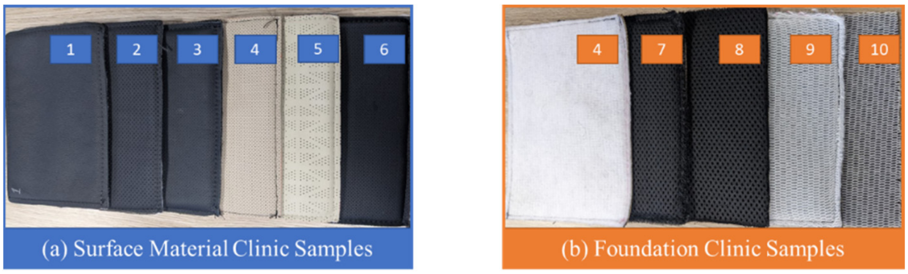
The hand feel of the automotive interior materials played an important role in the consumer's decision to purchase the vehicle, especially in the luxury and premium segments. The tactile sensations of the seat surface (trim cover) contribute to the perception of comfort and overall satisfaction (Kim, 2021; Roh & Oh, 2017). In a complete seat system, the trim cover consists of a surface material and a supporting substrate commonly known as the "foundation". The typical materials in today's market for surface material include leather, textile (fabric), and Polyurethane (Faux) leather. The conventional foundation materials include foam, non-woven, and knitted spacer fabric. The bonding mechanisms between the surface material and the foundation are tack sewing or lamination. Although the surface material is the first layer of touch for comfort, due to its limited thickness, the actual comfort hand feel is influenced by the foundation, and therefore should be evaluated as a whole system.

When measuring and quantifying the tactile perceptions, most of the sensory information is collected by subjective rating (Falk et al., 2013). As comfort is impacted by human experiences and is highly subjective (Barker, 2002), it is important to correlate subjective perceptions with objective measurements (Sztandera et al., 2013).

Therefore, the goal of this study is to understand how the surface material and the foundation affect the hand feel of automotive seat trim covers. The study consisted of a subjective clinic of the surface material, a subjective clinic of the foundation, as well as an objective measurement of the samples with haptic sensors.

Method

Ten samples (L: 215mm x W: 150mm) were used in this study (Figure 1).



(a) Surface Material Clinic Samples

(b) Foundation Clinic Samples

Figure 1 Samples tested (a) Surface Material Clinic Samples; (b) Foundation Clinic Samples. Note: Sample 4 was used for both clinics

For the Surface Material Clinic, all six samples were made with the same non-woven fleece foundation sewn to the back. Sample 1 was Taurus plain leather, Sample 2 was Windsor perforated leather, Sample 3, 4, and 5 were semi-aniline perforated leather, and Sample 6 was Polyurethane (Faux) leather. For the Foundation Clinic, five samples were made with the same semi-aniline perforated leather as the surface material. Sample 4 from the Surface Material Clinic was reused to represent the non-woven fleece sewn foundation. The rest of the samples included: Sample 7 and Sample 9 with 10mm spacer knit fabric foundation sewn to the leather; as well as Sample 8 and Sample 10 with 10mm spacer knit fabric foundation adhered to the leather via lamination.

Customized questionnaires were designed that followed the bipolar rating method, i.e. participants ranked the samples in the spectrum that had opposite descriptors on each end. Participants were instructed to evaluate the samples in three categories: initial impressions, the surface texture, and the material behaviors. Each of the three categories contained various spectrums to reflect the tactile feelings and the rankings were then converted to numerical scores for post analyses (Figure 2 a &b)

Score	0	5
Initial Impression	Cheap	Luxurious
	Artificial	Natural
	Firm	Soft
	Fragile	Durable
Surface Texture	Textured	Smooth
	Coarse	Fine
	Harsh	Buttery
	Grippy	Slippery
	Flimsy	Robust
	Loud	Quiet
Material Behavior	Rigid	Compliant
	Flat	Wrapped
	Springy	Damped

(a) Surface Material Clinic Spectrums and Scores

Score	0	4
Initial Impression	Cheap	Luxurious
	Artificial	Natural
	Firm	Soft
	Fragile	Durable
	Unsupportive	*Supportive*
Surface Texture	Textured	Smooth
	Coarse	Fine
	Harsh	Buttery
	Grippy	Slippery
	Flimsy	Robust
	Loud	Quiet
Material Behavior	Rigid	Compliant
	Flat	Wrapped
	Springy	Damped
	Deformed	*Recovered*

(b) Foundation Clinic Spectrums and Scores

(c) Circular motion for surface texture evaluations

(d) Compression and release for material behavior evaluations

Figure 2 Subjective clinic spectrums and hand motion instructions

During the clinic, participants were instructed to use specific hand motions for the evaluation. For surface texture, participants were instructed to feel the sample with a circular motion (Figure 2c); and for material behaviors, participants were instructed to compress and release the samples (Figure 2d). Such hand motions were defined based on the consumer behavior when touching the seat in the showroom setting.

Objective measurements were conducted on the samples with haptic sensors. The sensors conducted fore-after and lateral motions for quantifying tactile properties such as coarseness and roughness both on the micro- and macro- textures. The sensors also conducted press and release motion for quantifying tactile properties such as compliance, deformation, and damping. All these tactile properties were then correlated to the subjective perceptions.

Statistical analyses were conducted (Minitab 18, Minitab LLC, PA, USA) for both clinic results as well as for the correlation between subjective and objective measurements.

Results

Forty participants were recruited for the study, with 20 of the participants having no prior trim experience, hence, represented the voice of General Consumers (hereinafter refer as “GC”). The other 20 participants were recruited from the trim engineering division to serve as Industry Experts (hereinafter refer as “IE”). It needs to be reported that for the Surface Material Clinic, one IE response was incomplete; for the Foundation Clinic, two IE responses were incomplete. Those responses were excluded from the study resulting in 39 and 38 responses for the Surface Material Clinic and Foundation Clinic respectively.

1. Surface Material Clinic

From the Surface Material Clinic, we have found that the natural Taurus plain leather (Sample 1) received the lowest ratings across all spectrums followed by the natural Windsor perforated leather (Sample 2). One natural semi-aniline sample with the most complex perforation pattern (Sample 5) received highest overall score among industry experts whereas the Polyurethane (Faux) leather (Sample 6) was rated highest by general consumers. Sample 1 and Sample 5 were significantly different between IE and GC groups for averaged overall scores. All samples except for Sample 4 were significantly different between the two groups for luxury and naturalness evaluations.

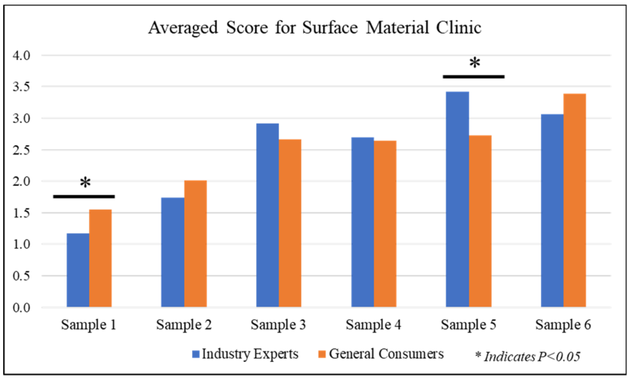


Figure 3 Surface Material Clinic results comparison

2. Foundation Clinic

From the Foundation Clinic, the results indicated the tack sewn samples and adhesive laminated samples generated significantly different hand feel, even when the participants were only instructed to touch the top surface of the sample. More interestingly, industry experts and general consumers had opposite tactile perceptions. i.e. the non-woven fleece tack sewn sample (Sample 4) received the highest overall score by industry experts and lowest overall score by general consumers (Figure 4a). Tack sewn samples (Samples 4,7,9) were ranked higher for luxury, softness, and compliance. Laminated samples (Samples 8,10) were ranked higher for durability, support, robustness, and ability to recover. The industry experts consistently favored three tack sewn samples over the two adhesive laminated samples whereas a similar trend was not observed in the general consumers group (Figure 4b).

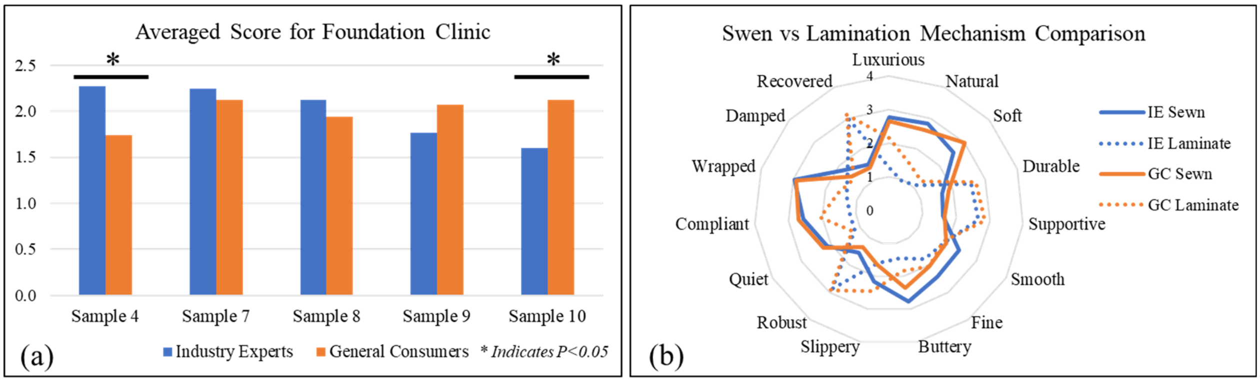


Figure 4 Foundation Clinic results comparison: (a) All spectrums averaged score comparison; (b) Swen vs Lamination comparison across the spectrums

3. Objective Measurements and Correlations

When correlating the objective haptic measurements with the subjective clinic results, it was found that the objective scores for tactile compliance, local deformation, and micro-texture coarseness were most related to the subjective perceptions. The correlation between objective measurements and the subjective scores from the general consumers resulted in higher R^2 value than that between industry experts. This finding indicated the industry experts' pre-existing bias caused by expectation and experience greatly impacted the tactile perceptions.

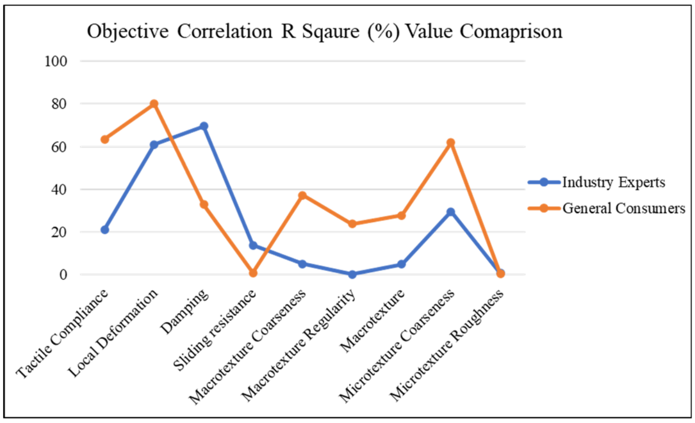


Figure 5 Objective and subjective correlation comparison

Conclusion

This study evaluated the automotive seat trim cover as a system and further investigated the correlations between objective measurements and subjective perceptions. As the descriptors on the higher end of the spectrum normally associated with tactile comfort in the industry, it can be concluded that the surface material, the bonding mechanism, and the foundation all contributed to the comfort perceptions of the automotive seat cover.

The importance of the findings from this study are three-fold. First, the study showed a clear trend of discrepancy for tactile perceptions between populations without prior trim experience and people handling trim material daily. This trend illustrated a significant psychological impact on hand feel and comfort perceptions. Second, the study demonstrated that each layer of a trim system (surface material +trim enhancements+ foundation) impacts the tactile perception. Hence when designing for holistic comfort, all components of a seat system must be considered. Last but not least, the results of general consumers giving the highest overall score to a Polyurethane (Faux) leather over all other natural leather samples provided us a first glimpse into the future of automotive market acceptance in leather alternatives (Kim, 2021).

The limitations in this study include: 1) the samples had various colors and perforation patterns. Although the study was focused on the hand feel, different color and perforation style led to potential visual bias (Roh, 2020) in the first impression of the sample, particularly for luxuriousness rankings. 2) the participants were only differentiated by hands-on experience of the trim cover, other demographic factors such as sex, age, and socioeconomics should also be considered in future works.

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Designing Joyful Journeys for Demand Responsive Transport (DRT)

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ABSTRACT

Demand Responsive Transport (DRT) has the potential to significantly contribute towards our transition to more sustainable mobility futures. Whilst efforts have been made to understand the requirements to provide efficient services, the DRT passenger experience and the role of vehicle and service design is less well understood. Based on the premise that with more appeal comes more usership, we reviewed existing DRT schemes and future autonomous applications to identify and organise design features into a preliminary design framework. This provides designers and transport operators tangible, relatable anchors to direct design activities and inform vehicle fleet choices, respectively, and ensure prospective DRT passengers' needs and motivations are better met. The application of the framework is illustrated with a design case study exploring the potential for DRT to act as social capital by enhancing social interaction, engagement and community building.

KEYWORDS

Demand Responsive Transport, comfort experience, design, Purpose Built Vehicles

Introduction

The work presented here formed part of a wider project funded by the UK's Economic and Social Research Council (ESRC) entitled "*Gong Yu! - Designing shared mobility across cultures*" (Grant Ref: ES/W011239/1). The project explored the role of culture and design in enhancing the acceptance and uptake of shared mobility, specifically, Demand Responsive Transport (DRT). As part of this international collaboration between the Royal College of Art (London) and Kookmin University (Seoul), DRT design was explored from four different perspectives in four separate work packages: wellbeing, inclusivity, cultural-sensitivity, and sustainability. In this paper we focus on the design of future DRT from the perspective of wellbeing.

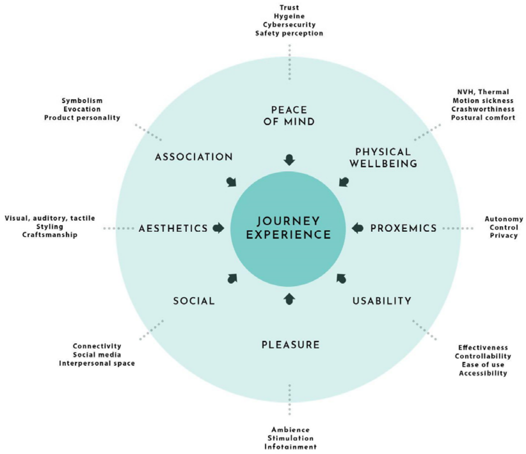
Demand Responsive Transport (DRT) refers to flexible services that provide shared transport to users who specify their desired location and time of pick-up and drop-off (COMOUK, 2023). It typically complements fixed route public transport services and improves mobility in low-density areas and at low-demand times of day. Furthermore, DRT can also contribute to decarbonisation by replacing private car journeys and facilitating multi-modal travel. DRT can therefore play an important role in our transition towards more sustainable mobility futures. To realise its potential, DRT services need to be integrated into the local transport network, optimise routes in real time, and consist of lower or zero tailpipe emissions vehicles that need to be run at high passenger occupancy levels.

Whilst these factors are relatively well understood, the focus on optimisation and efficiency has typically come at the expense of the passenger experience. Yet, the passenger experience has been found to deter people from choosing DRT as a compelling alternative (e.g. Shovlar, 2022). In part, this may be explained by the relatively low comfort levels provided by the typically standard 8-16 seater mini buses or vans employed. In recognition of this, DRT service providers such as MOIA have started to move towards Purpose Built Vehicles designed to provide more appropriate and premium experiences (https://www.moia.io/en). This approach has the potential to also reach "choice users", i.e. those people who use DRT even though they have a car available. Attracting this group in particular is more likely to relieve congestion and contribute to decarbonisation (KonSULT, 2014).

Based on the premise that with more appeal comes more usership, we asked the question how design can contribute to more comfortable and even joyful journeys. To this end, we identified relevant DRT vehicle and service design features to develop an initial conceptual design framework. The framework was subsequently used to guide a three-day creative event exploring particular design challenges and opportunities.

Method

Conceptual design framework: Vehicle and service design features were identified by reviewing characteristics of current DRT schemes (e.g. Gilibert et al., 2019; Mueller et al., 2020; Westtrans, 2022) as well as those anticipated to be important in future applications involving autonomous vehicle operations, i.e. robotaxi and shuttle services (e.g. Sanguinetti et al. 2020). The framework was derived from Ahmadpour et al.'s (2016) model on the aircraft passenger comfort experience and its subsequent adaptation for shared autonomous vehicle journey experience by Diels et al.'s (2017). The framework consists of eight factors associated with the journey experience.



Whilst acknowledging that feelings of comfort and discomfort can occur simultaneously and are not polar opposites, for simplicity, we consider the journey experience as a point on a fragmented continuum between comfort and discomfort whereby comfort can be defined as "*a pleasant state of well-being, ease, and physical, physiological and psychological harmony between a person and the environment*", while discomfort refers to "*a state where one experiences hardship of some sort which could be physical, physiological or psychological*" (Vink, 2005). Note that we use the term "journey experience" to include the experiences pre- and post-boarding.

Creative event: In May 2022, a three-day creative event was held at Kookmin University with a team of academics and students from both institutions and included: 1) a discovery phase where wellbeing in DRT was explored using the conceptual framework; 2) a definition phase identifying a specific focus for subsequent design activities; and 3) a development and delivery phase where designs were developed in more detail and presented back for reflection.

Results

Due to space restrictions, we here present a selection of design challenges and opportunities for each of the factors.

Peace of mind: In contrast to the safety concerns in autonomous taxis in the absence of a driver, DRT is appreciated for being a safe evening / night transport, and a safe transport for children to travel alone. Yet, there still is the need to feel safe and secure during the whole customer journey, from the booking to reaching the final destination. This may include to the provision of safe physical or virtual stops or adjoining spaces.

Physical wellbeing: In contrast to public transport with its focus on maximizing occupancy, vehicle comfort is an important factor DRT is expected to offer. This refers to an appreciation of human body dimensions (e.g. more personal space), motoric capabilities and the luggage carried, cleanliness and hygiene, and access to individual climate controls. Driving style and outside visibility should be considered to prevent carsickness.

Proxemics: Regarding a sense of autonomy, control, privacy, prominent features include the ability to and to ensure that seats of companions are together, or reserving the whole vehicle; increased personal space; enhancing perceived control by providing personal climate controls, lighting and ports for personal electronics, real time navigation information, reliable reservation of features that support riders with varying needs, and easily accessible and secure interior storage space.

Usability: Design considerations included easy vehicle access via tall frames, low floor heights, and sliding doors; easy storage and retrieval of luggage during entry / exit; availability of tables, personal lighting, charging ports, and internet access; optimised waiting and travel times; accessible online portals; short distances to pick-up/drop-off points; and the ability to carry bicycles on board.

Pleasure: Referring to features related to ambiance, stimulation, and services, DRT can provide restorative environments providing relief from stress, a welcoming and comfortable atmosphere for all via sociopetal seating orientations, use of natural materials, personal lighting and climate controls, comfortable seating, accommodations for food and drink, and promoting social interaction and community identity via a shared stimulus (e.g. in-vehicle art, local trivia as conversation prompts).

Social: Management of infringement of personal space includes the avoidance of extended eye contact (i.e. “civil inattention”) via seating configurations and territorial props such as physical or perceived barriers as well as offering more personal space compared to public transport, or reserve the entire vehicle. Conversely, however, DRT may also act as “social capital”, facilitating social networks providing ”third places”, public spaces where social interaction occurs (see also *pleasure* features).

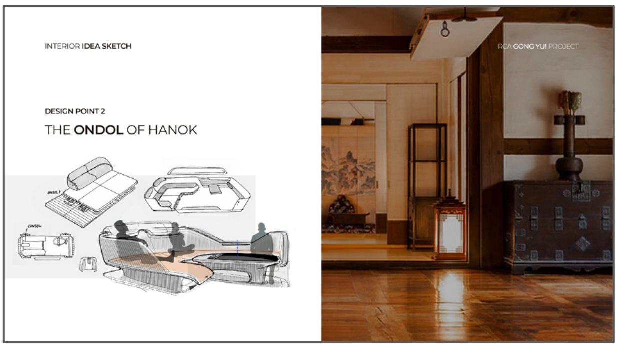
Aesthetics: With reference to DRT providing restorative environments, third places, and more premium journey experiences in comparison to most public transport, aesthetics qualities referred to include the use of wood surfaces and natural elements, ambient lighting, noise cancellation technologies, and thematic designs.

Association: This factor is concerned with evocation of familiar memories and symbolism. Association did not explicitly emerge as a factor within the reviewed literature but may be linked to the abovementioned social and pleasure factors.

The above findings from the literature were collectively discussed with a team of academics and students from both institutions. It coincided with a recent shift in the South Korean Government's COVID-19 policy from "UNTACT", i.e. aimed to spur economic growth by removing layers of human interaction from society (Guardian, 2021), to "RETACT", the reinstatement and promotion of social interaction recognising the unintended consequences of the "UNTACT" policy including corroding social solidarity and isolation.

In response, the focus moved to the potential for DRT to play a role as "social capital", i.e. its ability to create social networks characterized by mutual trust, cooperation, and reciprocity that contribute to community, culture, and economy (Putnam, 2000). Indeed, as pointed out by Sanguinetti et al. (2021), casual social interactions on public transit have been noted as "*society's most extensive opportunities to interact with people outside the individual's common social circles*" (Currie and Stanley, 2008). A more recent study found that nearly a third of pooled ride-hailing services customers made useful social connections (Safa, 2018).

The team subsequently explored how future DRT vehicles and services may facilitate or enhance social interaction, engagement and community building with a specific focus on Korean culture and the local context of the city of Seoul. Three design themes were chosen to direct the subsequent design activities. "Tools for conviviality" referred to design features that enable or facilitate interactions. The theme "Slowness & connectedness" emphasized the joy of travel and connection to fellow passengers but also the outdoors. Finally, "Shifting mode" was intended to explore how a passenger's psychological state could be prepared to enter and actively engage with DRT as a "third space" for example via rituals or routines. For illustration purposes, below figure shows design outputs of the themes of shifting mode and tools for conviviality design outputs with reference to the Korean custom of *hyun-gwan*, the entrance of Korean traditional housing (left), and sociopetal seating orientations (right), respectively.



Conclusion

Demand Responsive Transport (DRT) has the potential to significantly assist in our transition towards more sustainable transport but suffers from a relatively poor passenger experience. The work presented here shows the value of applying the conceptual design framework around the journey experience to identify design opportunities and challenges related to DRT vehicle and service design features. In turn, these can provide designers and transport operators tangible, relatable anchors to direct design activities and inform vehicle fleet choices, respectively, and ensure prospective DRT passengers' needs and motivations are better met to ultimately promote the desirability and uptake of DRT.

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Virtual Analysis of Dynamic Seat Comfort

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ABSTRACT

This study presents a simulation approach to examine dynamic seat comfort using finite element analysis (FEA). The result of an occupied seat from the static body pressure distribution simulation is used as input for the dynamic analysis, both approaches are presented. A test-method to derive the required material properties is introduced together with the material-card generation for the simulation. The simulation method is successfully validated by comparing the simulated and experimental seat transfer functions.

KEYWORDS

Comfort, Simulation, FEA, Seat transfer function, frequency response

Introduction

The comfortability of car-seats is gaining more and more interest in the automotive industry while the subjectivity of “what is comfortable” remains. Besides derived criteria to evaluate seat comfort physically, finite element analysis (FEA) methods have been established to support the development process of car seats providing objective evaluation criteria. Along with static seat comfort, which includes the body pressure distribution of the passenger while he/she is sitting in the seat, it is of great importance that the seating comfort is maintained when the car is in motion. This is designated as dynamic comfort and is related to the frequency response of the complete seat with the occupant while an excitation is induced to the seat track mounting points. Such excitation could be caused by unevenness of the road, vibration of the car’s structure etc. While the virtual analysis of static comfort using the finite element method has already been widely established in industry, the dynamic comfort analysis is still at a research and developmental level. A simulation method for the dynamic analysis of seat comfort is presented. The CASIMIR/Automotive software (Wölfel GmbH, Höchberg, Germany) offers the opportunity to conduct both static and dynamic comfort analysis with Abaqus being used as the FE-solver. In this study, the procedure to conduct virtual analysis for dynamic comfort is presented.

A front seat of a full-size pick-up truck is used. First, the Polyurethan (PU)-foams of the seat are characterized with both static and dynamic test procedures, and the material cards are generated via the experimental data. Then, the simulation procedure is further developed which includes two simulation steps: First, the CASIMIR -manikin is placed into the seat in a static implicit analysis. The result is an occupied seat which is used as input for the dynamic analysis. Subsequently, the dynamic frequency response analysis is accomplished by applying a harmonic excitation in a defined frequency range in z-direction (vertical) on the seat track mounting points. The resulting acceleration on the cushion surface under the buttock of the manikin is analyzed.

To ensure the validity of the simulation method, the simulation is compared to experiment. The seat is tested on the shaker table to analyze the frequency response while it is occupied by human participants. The frequency is measured on the cushion surface under the buttock of the occupant. It is ensured that the position of the accelerometer during the experiments and the evaluation point of the simulation are exactly at the same location on the seat cushion. The seat transfer function is calculated by the ratio of input and output accelerations. A comparison of experiment and simulation is conducted, and the simulation approach is successfully validated.

Method

The finite element approach used for static and dynamic comfort analysis is described in the following. The CASIMIR/Automotive software (Siefert et. al., 2009) provides the manikins for both analyses. The three standard CASIMIR -manikins of 5%-tile female (F05), 50%-tile male (M50) and 95 %-tile male (M95) are shown in Figure 1.

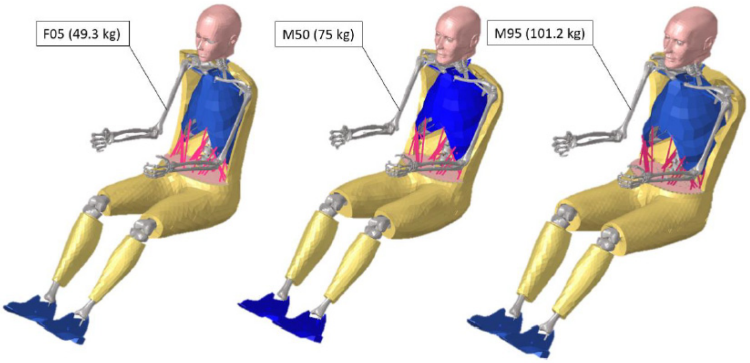

Figure 1: CASIMIR manikins (Hassas, 2022)

These manikins are used in an Abaqus standard implicit for static comfort simulations and in an Abaqus steady state dynamic analysis for dynamic comfort simulations. A complete seat model is setup in Abaqus. For static analysis, the manikins are positioned directly over the seat and the earth acceleration (measured by the unit of gravity “g”) is applied on the complete model which induces the sit in of the manikin in the seat. Figure 2 shows the complete seat model of the analyzed full size pick-up truck seat in different states unoccupied and occupied. The resulting Body Pressure Distribution (BPD) is the evaluation criterium for the static comfort analysis, an exemplary BPD is given in Figure 3.

The occupied seat resulting from the static analysis is used as input for the dynamic comfort analysis. The deformed shape of the seat together with compression states of the foams are considered. A harmonic excitation load at a frequency range is applied to the seat mounting points of the seat in vertical (z-) direction. The resulting ratio between amplitude at the evaluation point under the buttock bones and the excitation amplitude is derived over the excitation frequency range. This ratio describes the seat transfer function which represents the evaluation criteria of this study.

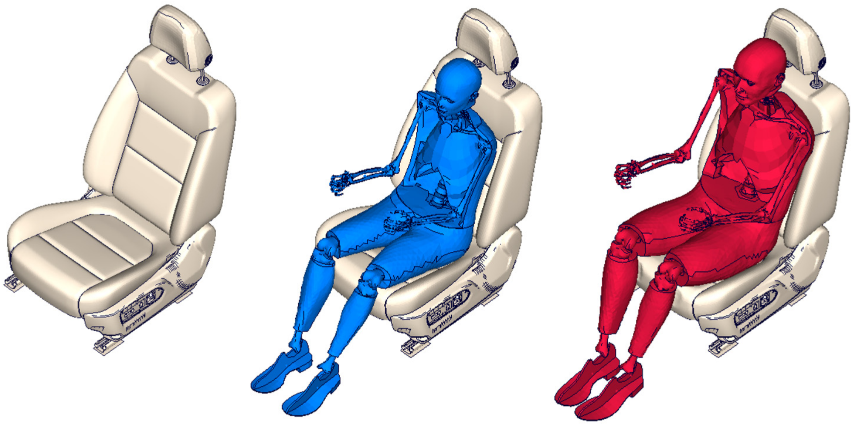

Figure 2: Complete seat model unoccupied (left), occupied with F05 (middle) and M50 (right).

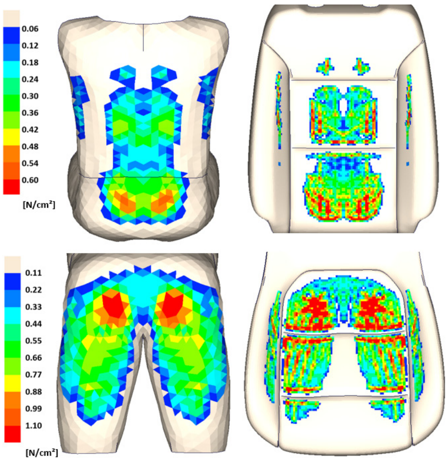

Figure 3: Exemplary body pressure distribution (M50).

A detailed material characterization is conducted to consider the dependency of the foam material properties on precompression state, the frequency, and the amplitude of the vibration. A compression test-setup, exemplarily shown in Figure 4, is used for both static and dynamic testing. The static test is conducted corresponding to (ISO 3386-1). The sample is cut to a rectangular shape having a quadratic cross-section and half height of the ground edge, 100x100x50 mm in this case. The skin of the foam is removed on all areas to allow the air in the foam cells to escape under compression. The foam is compressed in four cycles, with three pre-flex cycles and the load deflection curve of the fourth cycle is used as input for the material card generation (Figure 4, center). The CASIMIR/Automotive software is used to identify the parameters of the * HYPERFOAM material-law in Abaqus describing the compression behavior.

The same foam sample is used for dynamic testing. The foam is characterized in a fully factorized test program using a sinusoidal displacement signal while varying the precompression (10-60%), the frequency (1-20 Hz) and the amplitude of the signal (1 mm, 2 mm, 4 mm). The CASIMIR/Automotive software is used to identify a combined * HYPERFOAM, *VISCOELASTIC material-law in Abaqus.

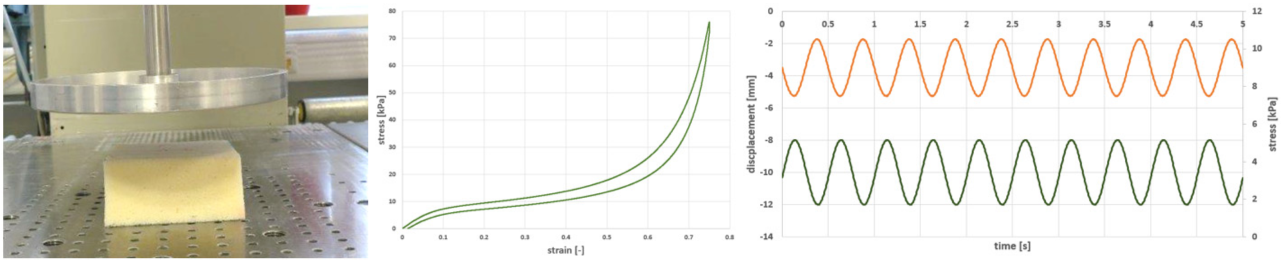

Figure 4: Foam compression test setup (left), stress-strain curve from static test (center) and exemplary displacement and stress progression in dynamic test (right).

The simulation results are further compared to physical test-results to ensure the accuracy of the simulation method. The test-data determined in the prior publication (Zagorski et.al., 2022) are used. The pick-up truck seat exemplarily used in the FEA is mounted on a motion platform applying an oscillation while the seat is occupied by a human test subject.

Figure 5: Shaker tests: A seat occupied with a human test-subject is accelerated by a motion platform (Kim et. al., 2021).

Results

The seat transfer functions for both simulation and experiment are calculated by the ratio of amplitudes between evaluation point (under the buttock bones) and excitation. It needs to be emphasized that an exact agreement of the location is required for achieving a good correlation. The results are shown in Figure 6. The curve-progressions of simulation and experiment are very well correlated. Moreover, a good correlation of the frequency of amplification (amplitude peak) as well as the attenuation behavior is achieved. Both are key evaluation parameters for the dynamic comfort performance of seat structures and complete seat systems.

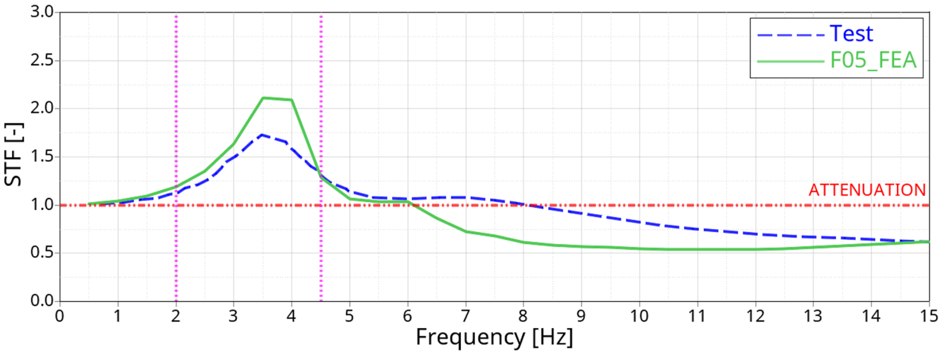

Figure 6: Seat transfer function comparison

The peak value at amplification is higher in the FEA while it also attenuates faster for frequencies above 6 Hz. Root-causes for these differences are related to the deviations in dimensions of CASIMIR -manikin and test-subject. Moreover, the differences in initial conditions between experiment and FEA have to be reported as the test-subjects were instructed to move the seat to a comfortable position (height, backrest angle etc.) while it was modeled in design position in the simulation model.

Conclusion

The main outcome of the presented study is that a good agreement between experiment and simulation can be achieved by the proper procedures. This study proved the validity of such method for evaluating dynamic comfort. The analysis provided by CASIMIR software is found to be reliable and stable. A good correlation between experiment and simulation in the amplification frequency and the attenuation behavior is achieved. A higher frequency peak and a faster attenuation at higher frequencies have been reported in the simulation results. These deviations between simulation and experimental results are related to differences in test and simulation. For example, the manikin represents standardized 5%, 50%, and 95%tile human being, whereas the anthropometries of the participants vary (i.e., a 50%tile height and weight person does not necessary warrant a 50%tile leg length). Moreover, it is of great importance to ensure the seat position and seat contents/components are consistent between experiments and simulations as deviations have been seen when consistency is not maintained. A limitation worth pointing out in this type of virtual analysis is that the dynamic characterization of foams as well as the material card generation is quite time-consuming. The applied test frequency and amplitude of the sinusoidal loading signal and the applied pre-load need to be varied in a wide range resulting in more than 300 tests for each foam type.

This study was the first to establish a procedure that could achieve a good predictivity level for virtual dynamic comfort analysis. To ensure the comfort of car seats while the car is in motion, the simulation is a powerful tool to support the seat development in early structural design engineering as well as in later prototype phase to avoid relatively costly shaker experiments with human participants and change of design in late development status close to start of production.

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Estimation of occupant comfort using driving behavior and seat pressure distribution

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ABSTRACT

Driving skill is the one of important factors connected with the relief feeling and comfort of vehicle occupants. The aim of this study is to evaluate occupant comfort using indices of passengers' body motion and driving behaviors. The driving experiments had done at the test course, and the relationship between indices of driving skill, body motion, and seat pressure distribution was analyzed. Using the data, estimation formulas for passenger comfort using pressure measurement data were established.

KEYWORDS

Passenger comfort prediction, Seat pressure distribution, Driving evaluation, Body motion

Introduction

The seat has the largest area in contact with the occupant of any vehicle component and can be said to be the largest human-machine interface. Body pressure distribution sensors can measure the contact condition between the occupant's body and the seat and are widely used as a tool for evaluating static seating comfort (Zemp et al. 2015). Recent improvements in sensor technology have enabled dynamic measurement with a short sampling time, and there are examples of applications other than seat comfort such as the pressure center of displacement for occupant arousal level (Gwak et al. 2020) and detecting occupant behavior (Zhao et al. 2021). During driving, the contact state between the upper body and the seat changes due to the body motion caused by the vehicle. It is known that the vehicle acceleration is sensed from somatic sensations caused by the body being pressed against the seat and the information about the road surface is obtained through the seat. However, there have been few studies that have evaluated occupant comfort based on body pressure distribution during the ride. In this study, we used this pressure distribution sensor to measure information on body motion and examined whether objective measurement data could explain the subjective evaluations of comfort.

Measurement Method

Driving behavior (skill): The driver's driving behavior was obtained via the vehicle CAN by sampling data from onboard sensors at 10 Hz. Vehicle motion: vehicle speed, acceleration (longitudinal, lateral), Driving operation: brake pedal opening, acceleration pedal opening, steering angle. The following driving skill indices were calculated. Vehicle: longitudinal acceleration, lateral acceleration, vehicle speed jerk, Operation: steering jerk, steering entropy (Nakayama et al. 1999).

In calculating the indices, each measured data was smoothed by a moving average filter. In the calculation of the jerk, the derivative values were also smoothed.

Body motion: Microsoft Azure Kinect camera was installed on the instrumental panel in front of the front passenger seat to capture the upper body motion. The coordinates of the body landmarks were measured at 30 Hz using the function of the Body Tracking Toolkit. Using the measured time-series 3D coordinates of the head and thorax, the displacement of each characteristic point was calculated.

Passenger body motion was also measured using inertial measurement units (IMU, XSENS MtW Awinda) mounted on the center of the thorax (above the sternum) and forehead by belts. The accelerations of the body in the longitudinal and lateral directions were used.

Pressure distribution: Pressure distribution was measured by the SR Soft Vision half-body version (Sumitomo Riko) installed on the front passenger seat. The total body pressure, the total contact area, and the displacement of the Center of Pressure were calculated.

Subjective evaluation: After the end of each driving condition, we obtained 7-point evaluation ratings of “comfort” (1: not comfortable at all - 3: neither good nor bad - 7: very comfortable). The Z-scores calculated using the mean and standard deviation of all evaluation scores of each participant were used in the analysis.

In this paper, all indices were calculated from the time-series data, and the maximum and minimum peak values were used as indices for analysis.

Experimental Method

The experiment was conducted on the AIST test course using a medium-sized sedan (Toyota Prius ZVW51). The driver was instructed to perform the following driving tasks, and an experimental participant was seated in the front passenger seat.

Curve driving task and Turn left/right driving task shown in Fig.1 were performed on a test course skid pad (200 m x 100 m). Data from a total of 16 runs were obtained for the tasks, twice for each of the two conditions of normal and quick driving operation.

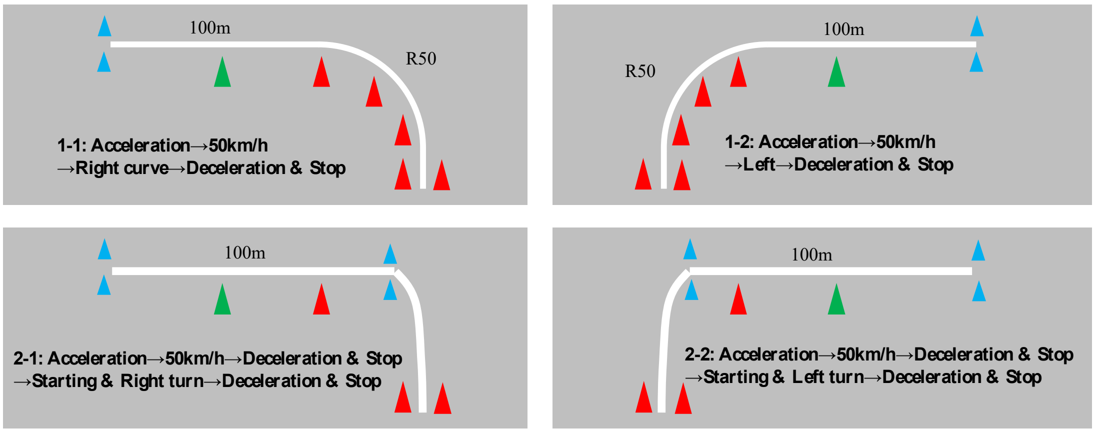


Fig.1 Curve course and driving conditions

A skilled driver was used, and 30 healthy adult passengers (15 males and 15 females) aged between 21 and 58 (an average of 40.3 years) who drive a car daily were recruited as participants.

All experiments in this paper were approved by the National Institute of Advanced Industrial Science and Technology (AIST) Safety and Ethics Committee and were carried out only after each of the participants had provided their informed consent.

Results and Discussion

Correlations between the indices and subjective evaluation of "comfort" were analyzed. For the driving skill indices, in the fore-aft direction, the correlations were observed in the vehicle's longitudinal acceleration and deceleration, and the vehicle's speed jerk (Table 1). In the right-left direction, only a very weak correlation was observed. Therefore, it was suggested that "comfort" in the fore-aft direction was evaluated based on vehicle motion, but in the right-left direction, "comfort" was evaluated based on body motion that did not necessarily coincide with vehicle motion.

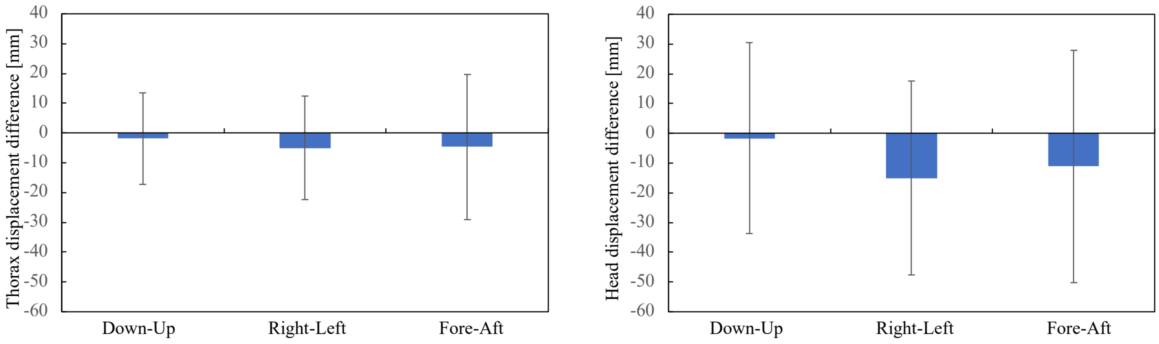
No clear correlation was observed between the thorax and head displacements (Table 2). Fig.2 shows the differences in the displacement of the thorax and head between quick and normal driving. The displacement of the upper body did not increase in the case of quick operation but rather tended to decrease. This suggests that when lateral acceleration is applied to the body, the subject may use their muscles to resist the lateral acceleration and stabilize the upper body.

Table 1 Correlation of skill indices

Direction	Skill index		Correlation coefficent	p-value
Fore-Aft	Longitudinal acceleration	Maximum	-0.707	<0.0001
		Minimum	0.682	<0.0001
	Speed Jerk	Maximum	-0.630	<0.0001
Right-Left	Lateral accelaration	Maximum (right)	-0.096	0.004
		Minimum (left)	0.133	<0.0001
	Steering jerk	Maximum	0.034	0.451
	Steering Entropy		-0.154	0.0006

Table 2 Correlation of body displacement

Direction	Maximum lateral body displacement	Correlation coefficent	p-value
Fore-Aft	Thorax	-0.009	0.841
	Head	-0.122	0.009
Right-Left	Thorax	0.125	0.007
	Head	0.107	0.021



(a) Thorax displacement (b) Head displacement

Fig.2 Body displacement difference

Table 3 Correlation of seat pressure indices

Direction	Pressure index		Correlation coefficent	p-value
Fore-Aft	Change of total pressure	Backrest	-0.435	<0.0001
	Change of contact area	Backrest	-0.440	<0.0001
Right-Left	Maximum CoP lateral displacement	Backrest	-0.227	<0.0001
		Seat	-0.132	0.003

Table 4 Correlation between body acceleration and seat pressure

Direction	Pressure index		Correlation coefficent	p-value
Fore-Aft	Change of total pressure	Backrest	0.188	<0.0001
	Change of contact area	Backrest	0.199	<0.0001
Right-Left	Maximum CoP lateral displacement	Backrest	0.331	<0.0001
		Seat	0.204	<0.0001

For the pressure distribution, in the fore-aft direction, the correlations were observed in the total pressure and change in the contact area of the backrest, and in the left-right direction, the correlations were observed in the amount of Center-of-Pressure displacement of the backrest and seat cushion (Table 3). It can be said that changes in body balance that did not appear in the upper body displacement appeared in the contact state between the seat and the body. In other words, it is thought that the pressure sensor can capture the load balance that does not appear on the external body surface.

In the fore-aft direction, the correlations were observed in thorax acceleration and the total pressure and change, and in the left-right direction, the correlations were observed in the amount of Center-of-Pressure displacement of the backrest (Table 4). This indicates pressure distribution seems an effective measurement for including the information on body segment acceleration that cannot be observed from actual body displacements.

Although skill indices measured by the vehicle and body pressure indices can be used to predict occupant comfort, the prediction equation constructed using only the body pressure indices is highly convenient because it can be used without relying on the vehicle system if the body pressure sensor is available.

$$\begin{aligned} &Passenger\ comfort\ evaluation \\ &= -1.964 \times 10^{-6} \times Change\ of\ total\ pressure_{backrest} - 0.001 \times Change\ of\ contact\ area_{backrest} \\ &\quad -0.124 \times Lateral\ CG\ displacement_{backrest} + 0.152 \times Lateral\ CG\ displacement_{seat} + 1.314 \end{aligned}$$

(R=0.483, p<0.0001) (1)

This study has the following limitations. The peak value of the time-series data was used due to no time synchronization between measurement systems. Only one skilled driver was used. Therefore, the results were based on a narrow range of driving variations. The test course experiment was conducted with front-seat passengers, who can predict the future driving and vehicle trajectory, which is different from rear-seat passengers who have limited forward visibility. These are to be solved in the future study.

Conclusion

In this paper, we conducted an evaluation experiment for a specific driving task and obtained the following findings.

- In the fore-aft direction, “comfort" can be evaluated by the vehicle acceleration or the contact pressure of the backrest, and the vehicle speed jerk. In the right-left direction, it can be evaluated by the amount of lateral displacement of the Center of Pressure distribution of the backrest and seat cushion, regardless of the vehicle motion.

- Pressure distribution is effective that includes the information of body segment acceleration that cannot observe from the actual body displacement.

- The above results show "occupant comfort" can be predicted only using body pressure distribution sensors.

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Development of sitting behavior modification system using an infrared depth camera

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ABSTRACT

Sedentary behavior is known to cause a variety of diseases and chronic physical disorders, including low back pain. In the past few years, the rapid spread of Covid-19 has forced workers to work remotely. With the change from the office work to a remote work, the decrease of walking, and the lack of supervision by surrounding humans are concerned to make it easier to continue working in an improper posture for extended periods of time. This study proposes a posture behavior modification system to prevent improper postures and to encourage desk workers to modify their behavior spontaneously without interfering with their work. The proposed system mainly consists of a sensor part and a feedback part. The sensor part acquires a two-dimensional sitting posture in a sagittal plane, and the feedback part induces the worker to modify his/her postural behavior. In this work, Microsoft Azure Kinect DK (depth camera) was used for the marker-less posture acquisition as a sensor part. The feedback part of the system is realized with a multiple-joint-robot that imitates the acquired worker's sitting posture in real time, thereby presenting their own sitting posture in an objective and intuitive manner. The two-dimensional sitting posture can be analyzed using a musculoskeletal model, and further effectiveness in preventing body loads is expected by adding information to the feedback in the future system expansion. We plan to conduct verification experiments using the proposed system in the future.

KEYWORDS

Behavior modification, Sitting posture, Depth camera

Introduction

Low back pain (LBP) is one of the most common modern diseases and habitual prolonged sitting posture is thought to be one of major risks. In addition, the rapid spread of Covid-19 has forced workers to work remotely, and their work environment has changed from the traditional office environment to personal spaces, such as home. Thus, the change of the workstyle has led to a decrease in the frequency of walking and lack of properly equipped environment for working, such as monitors, desks, and chairs. Those problems are also concerned to be causes of LBP (Butte et al., 2022). In addition, the lack of supervision by surrounding people in a personal work environment makes it easy to continue working in an improper posture for long periods of time.

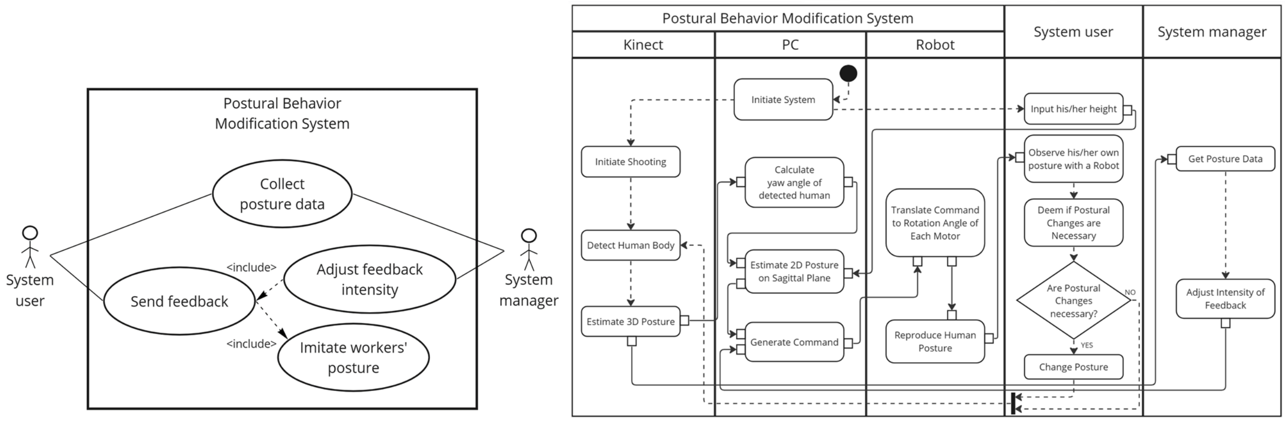
Research on the development of systems to promote postural improvement for LBP prevention has examined various methods, such as chair-type devices and visual changes on a PC screen (Ishac & Suzuki, 2018; Haller, 2011). However, there are concerns that direct interventions for working posture are likely to be cumbersome for workers, and may reduce work efficiency (Cutrell et al., 2001; Haller 2011). Additionally, uniformly set alert based on arbitrary rule such as time or single posture for a moment is often taken annoying and ignored by users. Therefore, we aim to design a monitoring system for sitting posture and to realize more comfortable sitting for a long time by proposing and constructing a sitting behavior modification system that is expected to reduce the annoyance and effectively prevent LBP.

In this study, we designed the concept of the sitting behavior modification system using the model-based systems engineering (MBSE) method, which can clarify the function of complex systems by using several types of system model diagrams to describe multiple components (e.g., hardware, software, people, and facilities) related to the target product or service (INCOSE, 2015).

Method

System concept definition

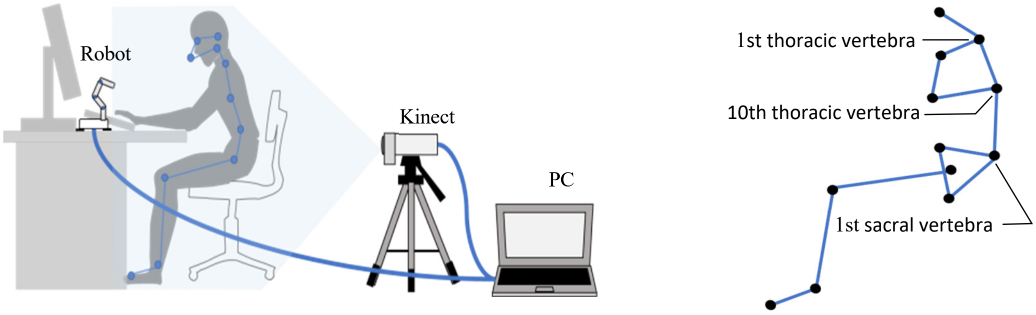
We studied operational scenarios and functions of the sitting behavior modification system using the MBSE method. The use case diagram and activity diagram were used to define the operational scenario and function, which are shown in Fig.1(a) and (b), respectively. The proposed system uses Microsoft Azure Kinect DK (Kinect) as an input device to provide feedback to the worker's posture. The device is capable of continuously detecting human posture as the 3D coordinates of 32 joint points using an infrared ToF (Time of Flight) depth camera. In the conventional studies, various devices such as webcams and wearable devices were used to acquire the posture information on workers（Kim & Jin, 2019; Shin et al., 2019; Zaltieri et al., 2020）. However, webcams are only capable of obtaining images of upper body and wearable devices are often disturbing for users. Thus, we adopted the device that can acquire information on the entire body without any devices attached to users. The designed concept includes functions of collecting the posture information and providing a feedback to the user. Based on the issues in the conventional research described in Introduction, we devised a method of imitating and presenting the worker's own posture using an multiple-joint-robot-arm as an indirect and intuitive manner to provide feedback. The robot does not instruct the user (worker) to modify his/her posture, but rather reproduces it based on the worker's posture acquired by Kinect. The intensity of the feedback, such as the inclination of the joint angle and the feedback interval, is adjusted by the system manager, such as the user itself, worker's superior or employer,



(a) Use case diagram

(b) Activity diagram

Fig. 1 Design of proposed system using MBSE method



(a)System components (b) Sagittal posture estimation

Fig. 2 Outline of implemented system

thus providing effective feedback to the individual worker to encourage voluntary posture modifications. Furthermore, the proposed system is expected to enable workers to evaluate their own posture and spontaneously improve their posture even in an environment where they lack supervision from their surroundings.

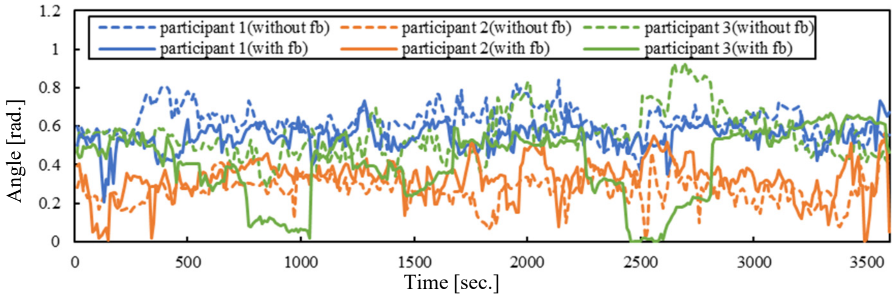
Proof of concept

Based on the above model, we implemented the proposed system. Figure 2(a) shows the outline of the system. The posture was recorded by Kinect, and the data was converted into skeletal feature points in the sagittal plane of the human body (Fig. 2(b)), and the joint angles of the lower back, upper back, and head were calculated at 5 second intervals. The robot then presents the feedback as imitation of the worker’s posture during the work. Due to the lack of accumulated data of worker's habitual posture change, adjustment of feedback intensity was excluded from the system in this stage.

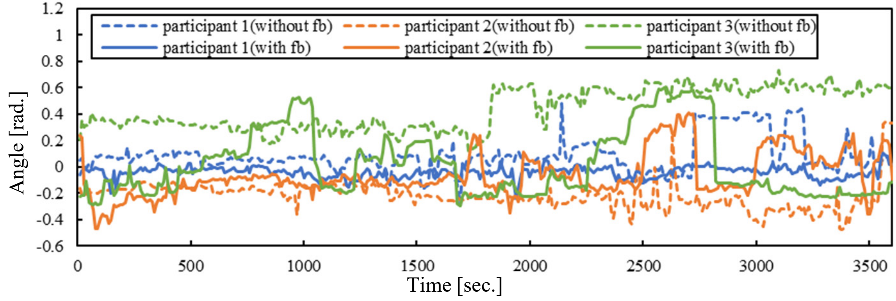
We conducted verification experiments of the system. Three participants (age: 22, height: 1680, 1760, 1820 mm) were sitting on a chair to perform their own tasks, such as creating slides and writing reports with laptop PC, assuming that they were performing their normal work. The duration of the experiment was one hour and was conducted two times with and without the system for each participant. Postures during the experiment were captured with Kinect, regardless of whether with or without feedback.

Results

Figure 3 shows the changes in the joint angles of the upper back (Fig.3(a)) and of the lower back (Fig.3(b)), with or without feedback. The lower back joint angles and the upper back joint angles were estimated as the inclination of the straight line connecting the first sacral vertebra and the tenth thoracic vertebra, and as the inclination of the straight line connecting the tenth thoracic vertebra and the first thoracic vertebra, respectively. Note that, the positive value and the negative value in the estimated angles corresponds to flexion and extension, respectively. In this figure, a significant increase or decrease of the joint angles corresponds to the occurrence of a postural change. For each participant, postural changes occurred more often in the condition with feedback (solid line), compared to that without feedback (dashed line). To investigate how the participants’ posture was modified, we calculated the mean values of the joint angles for each participant during the experiment (Table 1). As shown in Table 1, except for participant 2, both joint angles were smaller with feedback, indicating that the feedback alleviated the slouching. On the other hand, as for participant 2, the mean value of the upper back joint angle slightly changed in two conditions with and without feedback and



(a) Upper back



(b) Lower back

Fig. 3 Comparison of postural changes in experiment with or without feedback

Table 1 Mean value of joint angles

	participant 1		participant 2		participant 3	
	Upper back	Lower back	Upper back	Lower back	Upper back	Lower back
without fb	0.625	0.087	0.271	-0.221	0.552	0.436
with fb	0.548	-0.042	0.330	-0.065	0.406	0.014

that of lower back joint angle was larger in negative value, suggesting that the feedback induced participant 2 to straighten its posture.

Conclusion

We developed a concept of the system that promotes spontaneous posture modifications of workers. Then, the effectiveness of the developed system was partly confirmed by the experiment involving three participants.

At the present stage, the implemented system is able to acquire posture information and mimic posture by the multiple-joint-robot-arm, but the adjustment of feedback intensity in the proposed system has not yet been implemented. Future tasks include (1) long-term experiments to further verify the effectiveness of the system, including adjustment of feedback intensity such as feedback intervals and enhancement on robot joint angles; (2) implementation of musculoskeletal evaluation to the proposed system with a musculoskeletal model (Hirao et al., 2023); (3) experiments to confirm and improve the system behaviors in relation to other factors in the work environment (e.g., co-workers, indoor positioning system, health management system, etc.).

Acknowledgement

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Development of a passenger comfort model for turboprops

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ABSTRACT

A quantitative comfort model will aid in evaluating comfort levels of various target groups before the actual flight of an airplane. However, constructing the model always presents a challenge due to the complexity of the phenomenon. This paper presents recent efforts in modeling comfort for turboprop passengers. Ninety-seven participants took part in two flights, during which forty of them had full environmental and personal factors recorded using different measurement tools. The experimental data were analyzed, highlighting the effects of different factors. Subsequently, a preliminary comfort model based on Gaussian Processes is introduced. The outcome of the model shows that we are able to take a step towards modeling the human comfort experience using objective measurements, with anthropometry (including age and gender), seat positions, time duration, and row (noise) are leading factors that influence the feeling of (dis)comfort in turboprop planes.

KEYWORDS

Comfort, Model

Introduction

Modeling passenger comfort is essential in aircraft interior design, encompassing different aspects such as optimizing space utilization and crafting ergonomic seat designs. However, the subjective comfort/discomfort feelings of passengers involve complex constructs (Mansfield et al., 2020). Researchers have begun to interpret this phenomenon using a series of qualitative models (De Looze et al., 2003; Mansfield et al., 2020; Moes, 2005; Naddeo et al., 2015; Vink & Hallbeck, 2012; Zhang et al., 1996), and it has been proposed that the factors influencing comfort can be categorized into the users' backgrounds, the physical properties of their bodies, their expectations, the (social) environment(s), the product(s) they are using, the interactions between the users and the product/environment, and the duration of the use.

Although the factors that may influence the comfort feelings are relatively clear, constructing a comfort model for an individual in the cabin remains a challenge due to the complexity of the environment and the differences among individuals. Meanwhile, research in relevant fields, e.g. thermal comfort modeling (Zhao et al., 2021), has encountered similar complexity. Among different types of modeling tools, the potential of using machine learning in modeling has been highlighted due to its ability to address the various factors of complex phenomena.

In the European project COMFDEMO, researchers were engaged in modelling the (dis)comfort experience of passengers seated in the aircraft cabin. In this paper, we outline the experiment conducted for modelling, the data collection tools, the modelling tools and the initial model. The outcomes of the model suggest the potential, along with a notable degree of uncertainty, in modeling comfort using objective measures.

Materials & Methods

Experiment: An experiment was carried out with two flights, one in the morning and another in the afternoon, each lasting about 70 minutes. The flights were conducted at Rotterdam Airport using an ATR72-500 turboprop (Fig.1). The flight altitude was approximately 17,000 feet, and the cabin pressure was around 900 hPA during the cruising stage, as measured by (Müller et al., 2022)).

Measurements: A wearable measurement tool, called the jacket (Fig.1), was developed to gather data on passengers' physical movements and local environmental parameters (Yao et al., 2023). Twenty jackets in four different sizes were manufactured to capture posture changes (acceleration of the left/right shoulder, left/right waist), light intensity, CO_2 levels, humidity, and temperature near the passengers. Additionally, a series of measurement tools were utilized to measure environmental factors, including noise (Müller et al., 2022).

Fig.1: The flight, the Jacket and the layout (From top to bottom)

Participants: Among all participants on each flight, 20 of them were chosen to wear the jacket, resulting in a total of 40 datasets. The mean age of the 40 participants is 35.15 ± 15.08 years old, with a mean stature of 174.2 ± 8.6 cm. The mean body mass is 74.0 ± 13.9 kg. In terms of gender distribution, there are 26 males and 14 females. During the participant selection process, our aim was to minimize the specificity of the population in relation to key anthropometric parameters associated with (dis)comfort.

Layout: In the seating arrangement, the consortium discussed several options, and it was concluded that a relatively sparse and uniform distribution of jackets across the rows and seat directions in the cabin would be most helpful in understanding the influence of environmental parameters on the passengers. Therefore, passengers wearing jackets would be seated in Rows 3, 7, 11, and 16 (Row 13 was unavailable on the plane). Furthermore, participants occupying Seats 2C, 5C, 9C, and 14C also wore the jacket, as illustrated in Fig. 1. Among these 20 designated seats, participants had the freedom to select their seat positions according to their preferences.

Protocols: Upon signing the informed consent, participants received a briefing about the procedure and donned a jacket that corresponded to their body size. Once onboard the aircraft, they completed questionnaires on various (dis)comfort aspects (Anjani et al., 2021) at different flying stages, including taxiing, takeoff/climbing, cruising, descending, and taxiing after landing.

Data Analysis Methods: Data gathered from various measurement tools underwent pre-processing. The slight variations in the starting times of the jackets (1-2 minutes) were minimized by synchronizing the CO_2 concentration level peaks just before engine start. Among all the data, data from Jacket No. 5 (Seat 2C), Jacket No. 10 (Seat 3D) in the morning, and Jacket No. 9 (Seat 11C) and No. 18 (Seat 5C) in the afternoon were missing, most likely due to a power management issue in the embedded system. Physical activities of the left/right shoulders and left/right waists were extracted from the four accelerometers and then pre-processed using the sensor motion package (Simonho, 2022) for the three axes, respectively. CO_2 concentration levels were adjusted using the pressure data reported in the study by (Müller et al., 2022).

All collected data were scaled to the range of {0,1} using the min-max scaler (Scikit-learn, 2019). Concurrently, the questionnaire data on comfort and discomfort were normalized using the POMP method (Cohen et al., 1999). Linear interpolation methods were employed to sample all parameters and comfort scores at 60-second intervals. Correlations between each parameter and the (dis)comfort scores were computed. Parameters with correlations ($p<0.1$) to (dis)comfort were selected as inputs for the Gaussian Processes model, establishing relations with (dis)comfort scores. The most significant contributors to (dis)comfort were identified by assessing their contributions through the permutation importance method (ELI5 package, 2022).

Table 1 Parameters and their correlations with (dis)comfort

Parameters	**P value of correlations with comfort**	**P value of correlations with discomfort**
Time	**p<0.01**	**p<0.01**
Row	**p<0.01**	**p<0.01**
Seat (A, C, D or F)	**p<0.01**	**p<0.01**
Morning or Afternoon	**p<0.01**	0.2
Gender	0.04	**p<0.01**
Age	0.09	**p<0.01**
Stature	**p<0.01**	**p<0.01**
Body Mass	**p<0.01**	**p<0.01**
Popliteal height	**0.03**	0.21
Buttock popliteal depth	**p<0.01**	**p<0.01**
Hip width	**p<0.01**	**p<0.01**
Noise	0.73	**p<0.01**
Right shoulder X-(contra)Lateral	**p<0.01**	0.23
Right shoulder Y-Anterior/Posterior	0.76	**p<0.01**
Right shoulder Z-Superior/Inferior	**p<0.01**	**0.03**
Left shoulder X-(contra)Lateral	**p<0.01**	0.11
Left shoulder Y-Anterior/Posterior	**p<0.01**	**p<0.01**
Left shoulder Z- Superior /Inferior	**p<0.01**	0.58
Right Waist X-(contra)Lateral	**0.04**	0.19
Right Waist Y- Superior /Inferior	0.25	0.82
Right Waist Z-Anterior/Posterior	**p<0.01**	0.44
Left Waist X-(contra)Lateral	**p<0.01**	0.77
Left Waist Y-Superior/Inferior	**0.02**	0.16
Left Waist Z-Anterior/Posterior	0.26	**0.03**
CO_2 level	**p<0.01**	0.11
Temperature	**0.02**	0.53
Humidity	**p<0.01**	**p<0.01**
Red light intensity	**0.01**	**0.09**
Orange light intensity	**0.02**	0.18
Yellow light intensity	0.62	**p<0.01**
Green light intensity	0.25	**p<0.01**
Blue light intensity	0.27	**p<0.01**
Violet intensity	**p<0.01**	0.26

*p-values in bold indicate that the parameter is selected

Results

Table 1 displays all parameters along with their correlations with (dis)comfort. In total, 17 and 15 parameters exhibit significant correlations ($p<0.01$) with comfort and discomfort scores, respectively. To ensure that all (dis)comfort-related factors were included, a threshold of $p=0.1$ was utilized to select parameters for modeling the comfort experience. This increases the number of parameters to 26 for comfort, and 19 for discomfort.

The identified parameters were employed as inputs for the Gaussian Processes model. A 10-fold cross-validation method was utilized to validate the model's accuracy (Scikit-learn, 2022). The results of cross validation indicated that the root mean square errors (RMSE) of the model for predicting comfort and discomfort are 0.11±0.03 and 0.21±0.04, respectively. This implies that the RMSEs represent a variation of 11% in comfort changes and 21% in discomfort changes, considering that the (dis)comfort scores are normalized using the POMP method.

Using the model and the permutation importance method, we ranked the contributions of various factors concerning the model's outputs. It was found that for comfort, the row number (closely linked with noise levels) is the most important factor, succeeded by hip-width, left waist superior/inferior movements, age, right waist superior/inferior movement, time, seat location (windows/aisle), and left waist lateral movement. Conversely, for discomfort, the prominent factors are time, seat location (windows/aisle), the row, right shoulder superior/inferior movements, buttock popliteal depth, popliteal height, gender, and left shoulder superior/inferior movements. The magnitudes of these contributions are displayed in Fig.2.

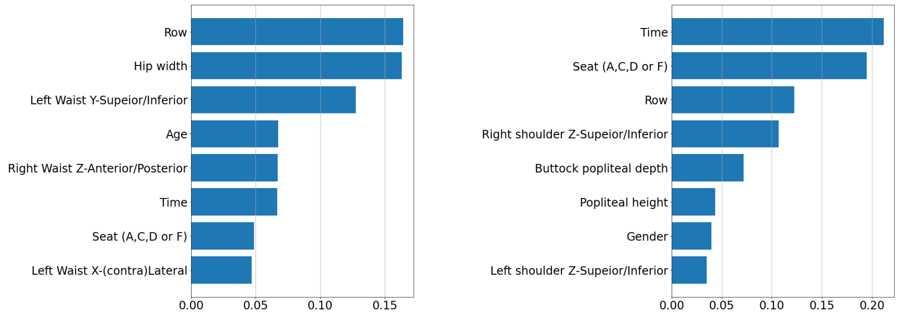

Fig.2 The importance of factors regarding (dis)comfort (left comfort, right discomfort, horizontal axes represent the amplitude of the contribution)

Discussion

The sensation of comfort results from the interplay of psychological, social and physical aspects in humans. For instance, despite over 99% of the population being fitted by modern airplane seats, individuals still desire greater space for movement. This desire is reflected in the significance of hip-width, which stands as a pivotal comfort factor. Human perception additionally exerts a potent influence over comfort, with both the row and seat playing vital roles in shaping this perception. Conversely, discomfort primarily stems from physical interactions between users and their environment/products. Time, seat selection, and anthropometry emerge as the dominant discomfort factors, in accordance with existing literature (Sammonds et al., 2017). Notably, the row number exhibits a strong correlation with noise in the ATR 72-500, ranking as the top factor influencing both comfort and discomfort, highlighting noise's impact on passenger comfort in turboprop airplanes.

Accuracy: The model's accuracy is not considerably high, with RMSE at 11% for comfort changes and 21% for discomfort changes. Several potential reasons contribute to this outcome: 1) The dataset comprised only 36 sets (with 4 missing); acquiring more data could potentially enhance the model's accuracy. 2) We utilized the min-max scaler and the POMP method for data normalization, and employed a threshold of p=0.1 to select significant factors for the model. Further investigation into both data pre-processing techniques, e.g. using the z-score method (Gopal Krishna Patro & Sahu, 2015), and modeling methods, e.g. network pruning (Yang et al., 2021), might yield improved results.

Limitations: Ethical considerations prevented the measurement of noise and vibration in the user's micro-environment. Technical challenges also hindered the measurement of micro-environmental vibration. As a result, the model does not incorporate these factors, despite their significance according to the literature. Moreover, the specific ATR72-500 used has a relatively large seat pitch of 34 inches, potentially influencing the importance of other anthropometric measures like stature.

Conclusion

Outcomes of the model indicate that we were able to make a step towards modelling the human comfort experience using objective measurements. Anthropometry (incl. age and gender), seat positions, time duration, row numbers (correlated with noise) are the leading factors that influence the feeling of (dis)comfort in the turboprop planes. Shoulder movements can be important indicators of discomfort and waist movements may reflect the levels of comfort of the user.

Ethical statement

The experiment was approved by 1) the Human Research Ethical Committee (HREC) of Delft University of Technology under file number 1823; 2) in compliance with the foreign guidelines of the Ethics Committee at the Faculty of Medicine, Ludwig-Maximilians-University, Munich, under ID 21-1010. Consent forms were signed by all the subjects.

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Prediction model for the analysis of the haptic perception of interior textiles

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ABSTRACT

To stand out from the competition, the quality of a product as subjectively perceived by the customer is becoming increasingly important. If one wants to meet the comprehensive customer requirements, it is no longer sufficient today to develop a product that focuses only on the functional aspects, but it must also fulfil the sensory requirements at the same time. In this paper, a systematic approach is described that first describes the objectification of customer language for describing the textile haptics of automotive interior materials (11 headliners and 15 seat materials). For this purpose, ten textile-specific descriptors were developed in an expert panel. The descriptors used and the measurement of the human-haptic system are summarized in 4 main groups: 1. warmth/cold sensation, 2. friction properties, 3. deformation, 4. surface/topography. Furthermore, the human-tactile parameters (pressure, speed) that humans exert when touching textile surfaces were determined. The human-sensory product evaluation of the textiles was carried out with 116 test persons. Comparative statistical analyses of the technical parameters (e.g., roughness, friction coefficient, wetting index, deformation) and the human characteristics made it possible to create a prognosis model for determining the quality perception of textile car interior materials.

KEYWORDS

Haptic, Perception, Prediction model, Tactile parameters, Human sensory

Introduction

The development of high-quality products that simultaneously meet the needs of customers is a central challenge for companies today. Before a customer buys a product, he often tests its characteristics by extensively recording the different sensory modalities (visual, acoustic, and haptic perception) [1, 2, 3]. The quality of a product is therefore not only influenced by its technical and functional properties, but also by the subjective impression resulting from the sensory analysis. One aspect in this area is the haptic perception of quality, which determines the customer's appreciation and acceptance [4]. Therefore, customers' haptic preferences and desires need to be identified. However, it is difficult to quantify and model human haptic perception with suitable test methods. This is because the sense of touch is a highly subjective sensation that combines different stimuli and is thus multimodal [5, 6].

Due to the rapid development of autonomous driving, occupants have more and more time to occupy themselves with other things, including the haptics of the materials used. The vehicle interior is increasingly becoming an "oasis of well-being" and the haptics contribute a great deal to the sense of well-being. Until now, there was no technical measurement that could objectively capture and represent this sensory impression. Today, the assessment of product quality is largely carried out via test person studies with subjective results. As part of the publicly funded research project of Hohenstein together with FILK Freiberg Institute gGmbH and Laboratory for Machine Tools and Production Engineering WZL of RWTH Aachen, a new prediction method was developed so that the haptic parameters relevant for the purchase decision can already be considered during the development of products.

Method

Twenty-six materials from the automotive interior sector were used for the investigation: 17 knitted fabrics, six woven fabrics, three nonwoven fabrics and one knitted fabric. The selection was based on various comparison criteria: weaves, yarn or fiber fineness, number of filaments in the yarn composite. Laminated and non-laminated materials were also selected to determine the extent to which lamination influences the subjective impression in terms of softness and hardness.

The methods listed in Table 1 were used to determine the objective, haptic properties of the materials. The skin sensory measurements (surface index i_O, wet cling index i_K, sorption index i_B, stiffness s and contact points n_K) and the measurements on the rheometer were performed at standard climate of 20°C and 65% relative humidity. The remaining measurements were carried out at specific standard climate for leather, 23°C and 50% relative humidity.

Table 1: Methods/Measuring devices/ Characteristics/ Measuring parameters/ Descriptors

Method/Measuring device	**Characteristic**	**Measuring parameter**	**Descriptor**
1. Thickness/ DIN EN ISO 5084	thickness	weight 180 g; measuring area 20 cm²	hardness, elasticity
2. Roughness/RoughTec	roughness parameters	normal force: 10; 3000 mN, velocity: 0.3, 0.99 mm/s; 40 mm travel; ball stylus: 1, 20 mm; angles: 0°, 30°, 60°, 90°, 120°, 150°	roughness, directional difference's structure height, structure regularity, structure contour
3. Static and sliding friction/SSP-03	static/ kinetic	2.4, 6.6 N; 1, 80 mm/s; 20 mm; haptic standard leather	slipperiness
4. Deformation/SoftTec	penetration depth	3 N; 0.3, 2 mm/s; 20 mm ball stylus; with/without 4 mm foam	hardness, elasticity
5. Haptic touch temperature/HapTemp	sensotact value		touch temperature
6. Stiffness	stiffness	sample: 2 cm x 10 cm	hardness, elasticity
7. Surface index	surface index	sample: 1 cm x 10 cm	quality impression
8. Contact points/Textile topograph	number of contact points	sample 6,25 cm²; rotation angle 0°, 90°, 180°, 270°	quality impression
9. Wet cling index	wet cling index	speed: 3 cm/min	quality impression
10. Sorption index	sorption index	measuring duration 600 s	quality impression
11. Rheometer/HAAKE MARS	coefficient of friction	ring turning body: 35 mm, speed: 1 mm/s, normal force 1-20 N speed: 1 mm/s	slipperiness

In total, two empirical studies were conducted on the textile surfaces with identified descriptors (see Table 1). The first study was the main study to build a model between subjective and objective data, the second was the validation study. The descriptors were introduced to all subjects prior the evaluation. Extreme examples were used to illustrate a descriptors maximum and minimum value to guarantee the realization of its actual span. The surfaces were spanned on a hemisphere with foam patting underneath. The hemisphere was designed to induce a 5 % surface expansion to the material, which is the usual elongation of textiles used in cars. In addition, the three-dimensional presentation enables the subject to provide a more realistic judgment. The evaluation of the surfaces was done by means of digital questionnaires. For this purpose, each descriptor had to be rated on a 7-point scale by the test persons. Throughout the studies a total number of 26 textile surfaces (11 Headliner, 15 seat Material) were presented and evaluated out of a total of 116 subjects.

Results

The thicknesses D of the used materials without lamination range from 0.5 mm - 1.68 mm. For the materials with lamination, the thicknesses are highly dependent on the lamination material, such as foams, nonwovens and range from 0.55 mm - 4.43 mm.

The stiffness s was determined according to the Hohenstein test specification. In each case, the right and left side as well as the wrap/weft direction are considered. For the unlaminated materials, values between 11.9° and 64.2° were measured, laminated materials again show higher values overall and lie between 49.0°and 90°. The higher the value, the stiffer the material. The bending angle 90° represents the maximum value of this measurement.

During the investigations with the rheometer model HAAKE MARS, the friction force F_f and the friction coefficient μ_f of the materials can be determined. To investigate the friction behavior of the materials, ring rotors were rotated on the materials at loading pressures of 1 N, 5 N, 10 N, 15 N and 20 N for 60 seconds at a speed of 1 mm/s. Friction is lower on materials with longer protruding fibers, such as the nonwovens, than on "smoother" materials. This could be due to the protruding fiber ends, which move somewhat with the rotation of the measuring geometry and thus provide lower friction. At higher loading pressures, the coefficients of friction are lower than at lower loading pressures. For example, at load pressures of 1 N, the coefficients of friction average 0.426 for fabrics and only 0.193 for a load pressure of 20 N.

With the SoftTec, it is possible to recreate the hardness that a person feels when touching surfaces. A ball stylus (20 mm diameter) is applied vertically to the specimen. The material thickness, the penetration depth and a force-displacement diagram are output. The measurement parameters of 3 N normal force and 2 mm/s velocity were chosen based on the results of the exploration movement tests. Penetration depths between 20% and 75% were measured for the different textiles.

The measuring principle of the RoughTec is based on the stylus method. The surface of the specimen is traversed with different probes, loads and speeds. The measurement was carried out in accordance with DIN EN ISO 4287. The slowest speed, the lowest load and the smallest stylus can be used to record the actual roughness of the material most accurately. For the roughness parameter Rt, values were measured in a range from 100 to 600 µm. However, this roughness does not necessarily have to correspond to the perceived roughness. For this reason, further roughness measurements were carried out with a stylus like the fingertips (20 mm ball stylus), the maximum measuring speed of the instrument of 1 mm/s and a load of 3000 mN. These measurement parameters were chosen based on the results of the exploration motion studies. During these measurements, some materials experienced snagging of the sample with the textile. Thus, these measurement settings are not to be considered as purposeful. In total the correlation between subjective and the objective parameters lead to good relationship between the variables.

Conclusion

Overall, the results achieved in the research project represent progress for the objectification of subjective surface descriptions. Each subjective description of a surface could be assigned to one or more objectively measured technical parameters. For several descriptors, a correlation was found between the objectively measured technical parameters and the evaluation of the test persons. This approach can be used in the product development process to predict and validate the haptic surface perception of e.g., newly developed products. This kind of surface validation of textiles helps manufacturers to predict the acceptance of the material by the customer before it reaches the market. Consequently, this information could create added value for the manufacturer.

However, it is important to remember that the best haptic surface does not directly mean that the customer will want to buy the surface. Human perception is inherently multisensory, so in the future, a multisensory data-based model that incorporates the auditory and visual senses should be considered to predict human surface perception.

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Effects of hand support to reduce carsickness caused by smartphone use

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ABSTRACT

When passengers look at the scenery ahead through the windshield while driving, they are unlikely to get carsick, but when they gaze at a hand-held smartphone in the vehicle, they are likely to get carsick. In general, passengers hold their smartphones at chest or stomach level and look downward. This prevents them from seeing the scenery outside the vehicle and from obtaining visual information about the vehicle's movement, which is thought to increase the risk of carsickness. In addition, the relative motion between the smartphone and the occupant's head due to the sways of the hand-arm system may also be related to sickness. We have therefore developed a new hand support that supports the occupant's elbow and hand back at two points and holds the smartphone at shoulder height so that the forward scenery can be seen in the occupant's field of vision. To verify the effectiveness of the hand support, the experiment participants were seated in the second-row seats of a minivan and experienced 30−minute journeys in an urban area. The results of the experiment with twelve healthy participants showed that the use of the hand support reduced the amount of carsickness during smartphone use by about half. Furthermore, the use of the hand support also significantly improved readability of the smartphone screen and significantly reduced neck, shoulder and arm fatigue.

KEYWORDS

Motion sickness, Ride comfort, Readability, Fatigue

1. Introduction

Vehicle drivers rarely get carsick, but passengers sometimes experience it. Researchers have reported that the passenger in the front passenger seat or in a rear seat often experience aggravation of carsickness when his/her forward view was limited or while reading or watching television (e.g. Griffin and Newman (2004)) in the cabin. Also, it is reported that carsickness worsens with the use of smartphones, tablets and other mobile terminals. Additionally in the case of automated driving there are growing concerns that hands-freed drivers, just like passengers, may suffer carsickness by busying themselves with non-driving activities, pointing to a need to prevent carsickness in automated as well as conventional driving (Diels and Bos (2016)).

The main cause of carsickness is considered to be discrepancy between visual information and vestibular sensation as proposed by the sensory conflict theory (Reason & Brand (1975)). Various studies have been conducted to find ways of resolving these perceptual discrepancies, reporting that carsickness was effectively alleviated when the passenger was prompted to perceive in his peripheral visual field the outside view through the windshield. In this regard, Kuiper et al. (2018) reported that when the display was set at a windshield height level, carsickness was abated by over 40% as compared to when the display was set at a glove box height level. According to van Veen et al. (2014), an armrest that they had developed to support both upper and lower arm prevented neck bending effectively, improved the passenger's sitting comfort during the use of a smartphone. Although their study was performed in a static setup, it is predictable that ride comfort also can be enhanced for passengers operating a smartphone while driving.

The authors have therefore developed a new hand support capable of relieving carsickness during the use of a smartphone in a running vehicle. Reported in this paper are carsickness measurements under the test condition of using a smartphone in a running vehicle and the effect of the new hand support on carsickness, fatigue, and ease of viewing the smartphone display.

2. Hand Support

Figure 1 shows a hand support that enables the passenger to see the outside view in his peripheral visual field, hold up the smartphone at a higher position to moderate neck bending, and suppress the sways of the smartphone by supporting the passenger's arm at two points: at a back of a hand and at an elbow. The height of both parts were adjustable according to the passenger's body size and preference.


a) Handrest part b) Armrest part

Fig.1 Hand support

3. Method

3.1. Vehicle and journey

This experiment employed a minivan as test vehicle. For each test the minivan was driven for 30 minutes along a circuit of urban roads. Each participant was seated in the second row seat and asked to read an e-book in the display and conducted sensory evaluations. The participants experienced only one condition per day, and the order of the seating conditions was counterbalanced.

3.2. Participants

Twelve healthy males aged 21 to 58 yr participated in the study. 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.

3.3. Sensory evaluation and data analysis

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. After the end of the test, the participants were each requested to evaluate the readability of letters in the smartphone display and fatigue in the neck, shoulder and arm in terms of seven levels. [Readability → 3: Very easy, 2: Easy, 1: Slightly easy, 0: Neither, -1: Slightly difficult, -2: Difficult, -3: Very difficult] [Fatigue in body regions → 0: No fatigue, 1: Minimum fatigue, 2: Moderate fatigue, 3: Medium fatigue, 4: Definite fatigue, 5: Heavy fatigue, 6: Extreme fatigue.]

Within-subjects statistics were used and data was analyzed using a non-parametric statistical method. Multiple Comparison Procedure was applied for significant tests (Wilcoxon signed-rank test (two-tailed)) and p-value adjustment using the Holm-Bonferroni Method (Holm (1979), Wright (1992)).

3.4. Experimental conditions

As shown in Figure 2, a total of four test conditions were applied in this experiment.

a) “Outside view”: Passenger looked at the forward outside view through the windshield, not holding a smartphone.
b) “Without armrest”: Passenger held his smartphone in front of the chest without the support of the armrest.
c) “With armrest”: Passenger held his smartphone in front of the chest with elbow supported by the armrest.
d) “With hand support”: Passenger held his smartphone at a shoulder height with arm supported by the hand support at the back of hand and the elbow.

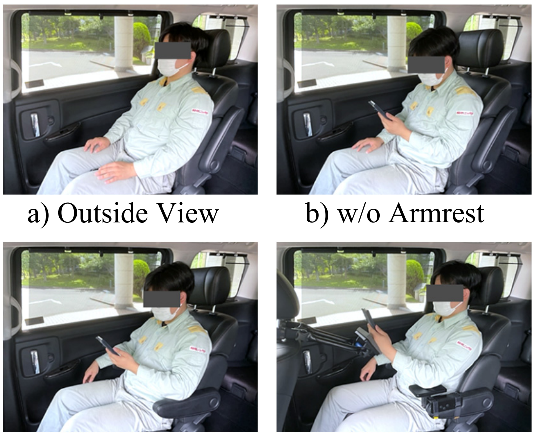
a) Outside View b) w/o Armrest
c) w/ Armrest d) w/ Hand support

Fig.2 Experimental conditions

4. Results

4.1. Carsickness ratings

The mean ratings of carsickness every minute of the 30-minute ride are shown in Figure 3, and the accumulated illness ratings are compared among the four test conditions in Figure 4. As compared to the “Outside view” condition, the use of a smartphone aggravated the carsickness ratings of passengers by about 3 times. Compared to the “Without armrest” and “With armrest” conditions, the use of the new hand support halved the ratings. In addition the mean ratings indicated that the time required to reach an equal level of carsickness was prolonged 2 times by the use of a hand support.

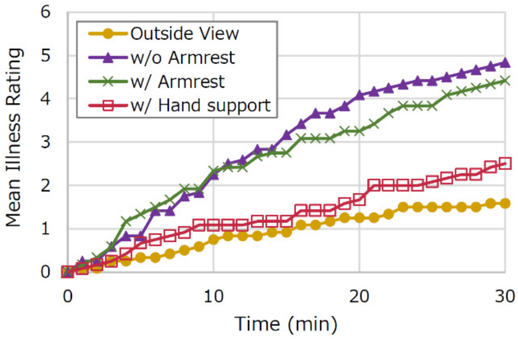

Fig.3 Mean illness ratings during the 30-min

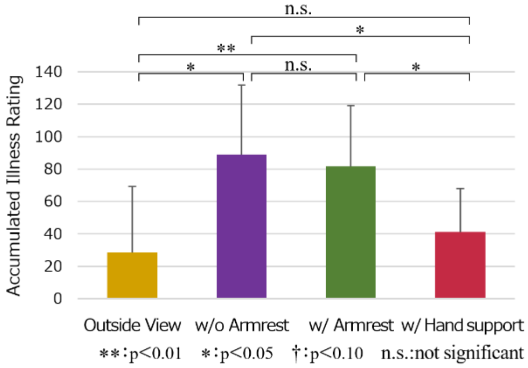

Fig.4 Comparison of means of accumulated illness ratings

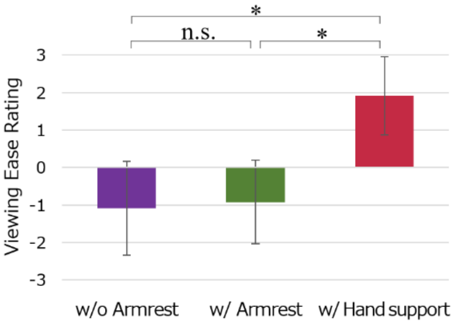

Fig.5 Comparison of means of display viewing ease score

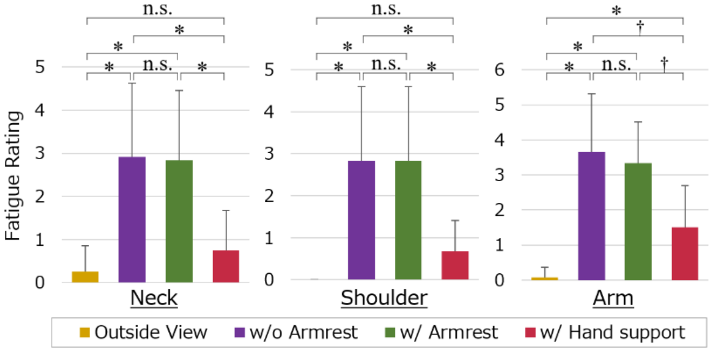

Fig.6 Comparisons of means of fatigue score

4.2. Display visibility and fatigue

The mean ratings of display visibility are shown for the three smartphone viewing conditions in Figure 5. Indicating a marked improvement of display visibility through use of the hand support. Ratings of the fatigue sensed in various body regions are compared among the different conditions in Figure 6. These fatigue ratings in neck and shoulder when reading an e-book with the help of the hand support were respectively less than one-fourth of the ratings in other e-book reading conditions.

5. Discussion

As shown in Figure 4, the order of ratings is considered identical with the order of the estimated amount of discrepancy between visual information and vestibular sensation. In the “Outside view” condition, carsickness is minimized because it is easier for the passenger to perceive his own motion against the motionless ground. However, in the e-book reading conditions with or without the use of the standard armrest, his access to the outside view is limited while his vestibular information on moving himself is not limited. This generates a discrepancy between visual and vestibular information, resulting in carsickness. In the “With hand support” condition, the amount of visual information through the windshield is increased, resulting in the moderation of carsickness.

Figure 7 shows the power spectral density (PSD) values of the smartphone’s lateral acceleration measured in the experiment. The lowest power spectral density (PSD) values were recorded in a 0.3~3.0 Hz frequency range in the “With hand support” condition. This suggests that, in cornering and similar driving situations where low-frequency inertia force occurred, the hand support most effectively reduces hand sways and minimizes the relative motion between the smartphone and the subject’s eye, leading to a reduction of sensory discrepancy and abatement of carsickness. In this regard, Tsubaki et al. (2006) reported that when images were oscillated sinusoidally in the lateral direction, the motion sickness reached its maximum at a 2.5 Hz frequency. Since in the present experiment the vibration level at a 2.5 Hz frequency proved the lowest in the “With hand support” condition, it is possible to conjecture that the newly developed hand support also reduces visually induced motion sickness caused by swaying of the smartphone.

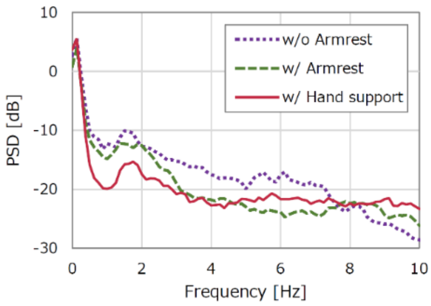

Fig.7 Comparison of PSDs at the smartphone in lateral direction

6. Conclusion

A hand support aimed at reducing carsickness and neck fatigue from the use of a smartphone during car ride was trial-manufactured, and its effect was examined in the present experiment. The test results indicated that carsickness was reduced to a half level partly because the new hand support increased the forward outside view in the passenger’s peripheral visual field by raising the smartphone holding position to a shoulder height and partly because its handrest part decreased the sways of the hand-held phone during car ride. In addition, the hand support improved the passenger’s sitting posture and reduced the sways of the hand-held phone, resulting in a substantial abatement of neck and shoulder fatigue and in greater ease of viewing the smartphone display.

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Train Passenger's Needs for the Seating Environment

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ABSTRACT

The number of train passengers using smartphones continuously increased. This situation could influence their comfort while traveling long distance. To study the needs of passengers thirteen participants who had experience in long distance train travelling were invited to join an experiment. Three groups participated: a student, employee, and elderly group. The experiment consisted of exploring problems, and a co-creation session on how to improve the seat. The results showed that the passengers were mainly using a smartphone on the train, especially the younger group and the employee group. They performed activities like listening to music, watching a video, reading, and chatting. The elderly group were doing mainly the other activities such as, gazing window, reading, and working on a laptop. The participants mainly used the right hand. While chatting they used both hands on the smartphone. The co-creation sessions showed the need for more support for a smartphone use. This research is useful for the train, car, bus, or airplane seat provider company to consider the new design for the passenger's comfort fitting to their performed tasks.

KEYWORDS

Train passenger, comfort, seat, activities, postures

Introduction

Passengers frequently use a smartphone while travelling by public transport (Lyons & Davidson, 2016). Previous studies found that the percentage of the train passengers using the smartphone during the trip was3.8%, 12.1%, 48.8%, and 57%, respectively (Kamp et al., 2011), (Groenesteijn et al., 2014), (Kilincsoy & Vink, 2018), (Udomboonyanupap et al. (2021) However, the activities passengers do on their smart phone differ. Most activities are listening to music, chatting, looking at a video, and reading from the phone ((Udomboonyanupap et al., 2021). This smart phone use might cause upper body pain (Honan, 2015). Also, because a train seat is not designed for using a smart phone for a longer period of time. There are many studies that recommend that a comfortable passenger's seat design should be based on the activities and corresponding posture of the passengers (e.g., Hiemstra-Van Mastrigt et al., 2016). The question is what the passengers' needs are regarding the interior. This study aims to gain insight in the needs of the train passengers' activities including the use of smartphones. These data might be used to design a comfortable train seat, which might attract passengers in the future.

Method

Generative techniques like context mapping can be rich sources of information in designing a product (Stappers and Sanders, 2003) and were therefore applied. Three sessions were organized with groups of 4 to 5 participants (a student group (18-25), an employee group (25-60), and a group of elderly (60 up)). The groups were seperated as Rüger et al. (2013) showed that the age is an aspect influencing the activities performed during a long-distance train trip. The informed consent was signed after the introduction. After that, the respondents are asked to sit in a train interior and recall their latest journeys to express their needs regarding the interior. To this purpose a part of a train interior was built in which participants could indicate their needs. A green sticker was used for nice comfort and for low comfort a pink sticker had to be used and placed on the seat part corresponding to the experience. After that, the researcher distributed a toolkit including the activities stickers as show in figure 2, and 3. The first part started by recalling the travel purposes of the long-distance train trips. The 2nd phase concerned the activities performed during a long-distance train trip. The 3rd phase was about the details of the activities done. Then the other activities were discussed such as, sleeping, talking/ discussing, reading from book, watching/ window gazing, working using large electronic devices eg. Laptop, eating/ drinking, standing, writing, or other activities. The 4th phase was about the body postures corresponding to the activities. The results from the first session were then summarized and discussed. Then they were asked in a cocreation session on how to improve the interior or specific seat parts to increase the passenger's comfort. Descriptive statistics are used by the research team to analyse the data from the first part. For example, the percentages of the travel purposes, activities performed on the train, and corresponding postures were calculated. The second part included the interpretation of the data from the co-creation by theme analysis (Rosmalen et al, 2010).

Results and discussion

The main activities of the the student and the employee groups were using smartphone on the train: (61.7%, and 57.9%, respectively. While the elderly performed other activities (74.4%) in the long-distance train. They did use the train for visiting their friend and family, commuting to work or study, and holidays as is mentioned in figure 1.

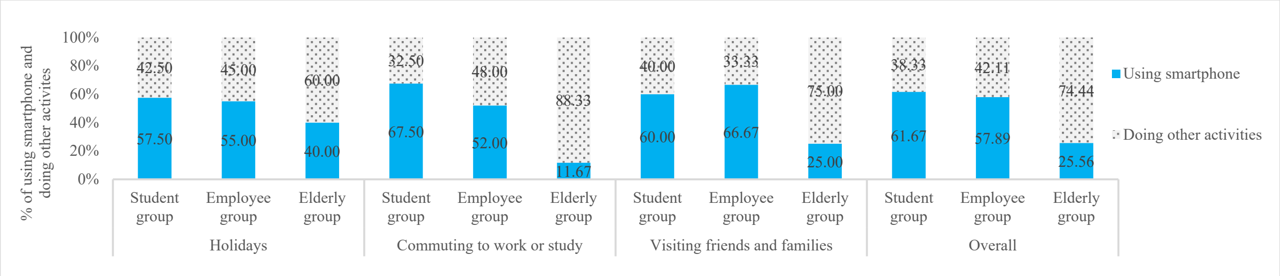

Fig1: The main activities of the long-hour train passengers

The studies by Kilincsoy & Vink. (2018) and Udomboonyanupap et al. (2021) showed that the smart phone is used by the train passengers. This smart phone use is in agreement with the group students and employees in this study. The study by Rüger et al. (2013) showed that the age is an aspect related to the activities performed during the long-distance train trip. Elderly use the smart phone a lower percentage of the time than younger travelers. Figure 2 shows that the students, mainly use a smartphone for listening to music (25.7%), followed by watching videos, reading, and chatting with a percentage of 24.8%, 21.8%, and 12.6%, respectively. While the main activities on the smartphone by the employees are reading, watching videos, and chatting with a percentage of 48.5%, 25.6%, and 13.4%, respectively. The elderly use the smartphone 25.6% of the time on the train, while the other groups use it at least twice this percentage (figure1). The elderly mainly use a smartphone for chatting (32.6%), reading (30.5%) or making a phone call (22.5%).

The postures are influenced by the performed activities with the smartphone. When the passengers listen to music, they sometimes put the smartphone on their lab, put it in their pocket, or hold the smartphone in the right hand while selecting the music on the phone. Passengers mainly held a smartphone in the right hand while watching the videos, followed by putting the smartphone on the lab, holding it by both hands and used their knee to support the elbows, hold it in the left hand, both hands, or hold the smartphone in the right hand and used the left hand to support the right hand. The positions that the passengers performed while using a smartphone for reading are holding the smartphone by the right or the left hand, followed by holding the smartphone by both hands or lean on the armrest or with a hand on the window, holding a smartphone by one hand while looking down on the phone. When the train passengers were texting on the phone, they were mainly holding the smartphone by both hands and used the armrest. Sometimes they held the smartphone with both hands, or by the right hand without the armrest used. The main observed postures by Liu et al. (2019) and Udomboonyanupap et al. (2021) when holding a smartphone, were with their head free from the support, their trunk against the backrest, and their arms put on the lap, which is also found in this study.

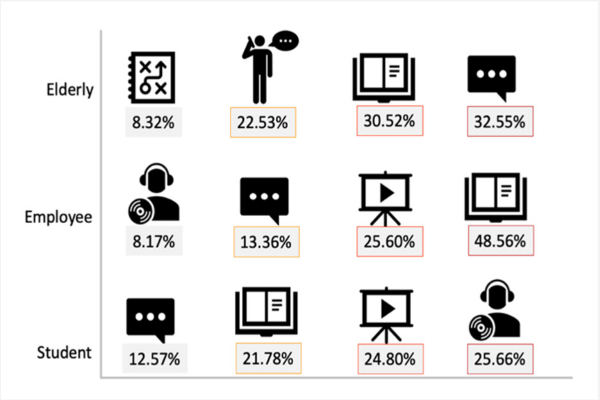

Fig 2: The smartphone used activities of the train passengers.

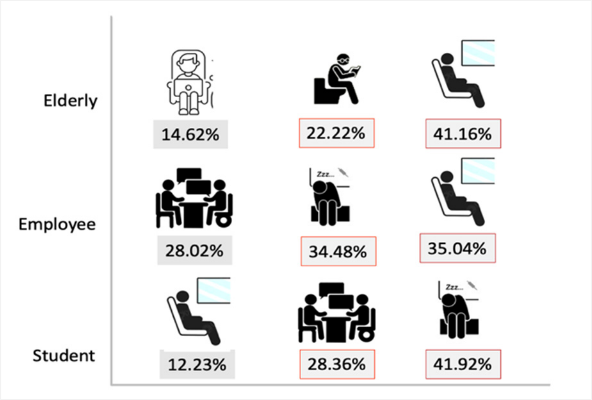

Fig 3: The other activities performed by the train passengers

In the co-creation session, the students suggest that a smartphone stand located at the backrest in front of them could help them while watching a video. The employees, and elderly selected the arm support to rest both elbows helping them to improve comfort while reading. This result is in alignment with the study by Veen et al. (2012). They found that the armrests were used by the users while using the smartphone. It is aiming and neck flexion reduction, which is also suggested by Liu et al. (2019; Veen et al. (2014) and Tapanya et al. (2021).

Fig 4: Suggestion to improve the smartphone stand by the students.

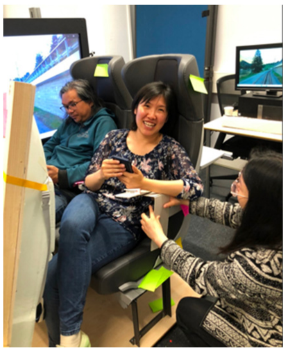

Fig 5: The special arm support suggested by the employee

Fig 6: The special arm support suggested by the elderly.

The posture of the activity gazing out of the windows (figure 3). were with their back against the backrest and the head bent to the window side. While sleeping, passengers try to recline their back as much as possible and that is why they prefer an adjustable backrest. Sometimes their head rotated due to the fact that the headrest does support the head properly. The previous studies by Kamp et al. (2011) and Groenesteijn et al. (2014) also show that the passengers place their head and trunk against the headrest and the backrest, respectively for sleeping and window gazing.

Conclusion

This research focused on the train passenger’s need for the seating environment. The participants mainly used a smartphone during the train trip, especially the student, and the employee. The different activities such as watching the videos, reading, and texting on the phone influenced the posture changed. The passengers mainly held a smartphone in their right hand while watching video or reading. While chatting, they were typing on the phone with both hands. When they use the smartphone for listening to music, they performed like the posture that they are doing the other activities. However, the participants tried to use the armrest or the other body, and also the wall of the train bogie that can help to support their arms while using the smartphone. This means, they need some parts or equipment that can help them to hold the smartphone to improve their comfort. This research could be used as the inputs to design the seat to improve the passenger’s comfort while using a smartphone by train, automotive car, bus or coach. The limited number of the participants is the limitation of this study. Also, the unbalance between men and women in each group. Next study should be setup with more participants, and also the special group of the passengers, that we need to pay attention such as the disability groups. About 50-60% of students and employees use a smart phone while travelling long distances by train, while elderly use the smart phone about 25% of the time. To prevent discomfort while using the smart phone the interior of vehicles could be optimized. For watching a video in a vehicle, a holder could be useful at the backrest in front of the traveler and for texting the arm rest can be used. However, it should be at the right height to prevent neck flexion. For listening to music no adaptations are needed in the interior.

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Is neck flexion angle a good indicator to explain perceived discomfort while doing non-driving related activities in reclined seating?

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ABSTRACT

The study aimed to investigate the effect of seating posture more specifically neck angle on discomfort while doing different non-driving related tasks in highly automated vehicles (HAVs) for reclined seats. This is important for interior design of future HAVs so that they can accommodate non-driving related activities. Thirty-three participants performed four tasks with different vision requirements (relaxing, looking forward, watching on a tablet, working with a laptop) while sitting in a reconfigurable experimental seat. Three different seatback angles (20°, 40° and 60°) were tested with a fixed seat height. Other seat parameters such as seat pan angle, seat pan length, headrest position, etc. were self-selected. The CP50 discomfort rating scale was used to evaluate subjective perception. The postural parameters such as neck, trunk-thigh and knee angles, etc. were obtained by an inverse kinematics method. Results showed that seating discomfort increased for activities that required a more flexed neck such as laptop use or looking forward as the seat back reclined, while it decreased for relaxing activity with no specific visual requirements. A relatively high discomfort level was found for tablet use, probably due to holding an object of non-negligible weight in the hands. Among the postural parameters, only neck angle was significantly correlated with the discomfort ratings.

KEYWORDS

Non-driving activities, Autonomous vehicles, Reclined seating, Neck angle, Discomfort rating

Introduction

In highly automated vehicles (HAVs), i.e. automation level 3 or above, drivers do not need to constantly monitor the road and control the vehicle. This allows drivers to adopt more reclined seating positions for doing non-driving related activities (NDRTs). Commonly expected NDRTs include reading, smartphone use, working with a laptop, relaxing and sleeping (Detjen et al., 2020) . These activities involve different visual demands compared to the driving task, leading drivers to adjust their head orientation accordingly. However, adopting a neck posture that significantly deviates from the neutral position can result in discomfort in the neck and head, thus impacting the overall user experience of HAVs. While digital human models are used in current car interior design process requiring the knowledge of comfortable postures, these postural comfort models primarily focus on driving-related activities. To predict comfort levels for other activities, new insights regarding non driving postural comfort are necessary. Vision requirement is one of the most important factor affecting in-vehicle seating posture especially the neck angle in reclined seating positions. We hypothesize that neck posture could serve as a good indicator for assessing non-driving postural comfort when using a digital human model (DHM).

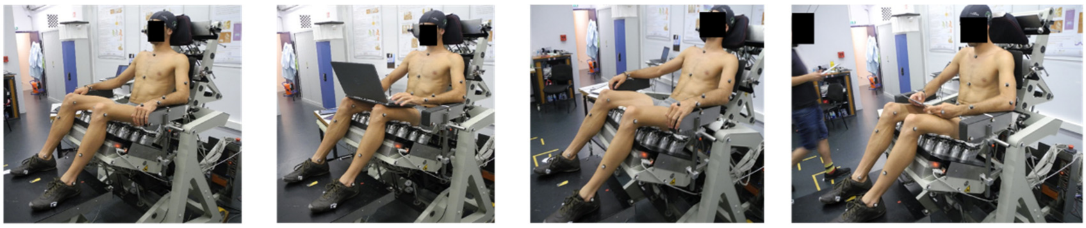
A limited number of investigations were conducted on the comfort of non-driving activities, particularly on reclined seats. Caballero-Bruno et al. (2022) investigated the impact of seat back angles (60° and 87°) on perceived comfort during a relaxing activity in self-driving vehicles. They found that 40% of participants reported discomfort in the head/neck area with an 87° seat back angle. Similarly, Zhang et al., (2021) compared a vertical and a reclined (20°) seat back for sleeping in economy class air seats without head support, and found that a reclined backrest could increase cervical fatigue. The discomfort experienced in both studies with a more reclined seat backs may be attributed to a bad neck posture. Similarly, using an autonomous driving simulator, Mansfield et al. (2021) examined the effect of seat back angles (15° and 37°) on perceived comfort in different body regions. They found that discomfort in the neck area slightly increased as the seat reclined in case of non-use of neck rest. Adding a neck rest significantly reduced discomfort at a 37° seat back angle.

Several studies show that head/neck rest can affect the overall comfort perception for either drivers or passengers (Franz et al., 2012; Coelho & Dahlman, 2012; Bouwens et al., 2018), specially for more reclined seat angles (Mansfield et al., 2021; Smulders et al., 2019). Smulders et al. (2019) found that a headrest enhanced the expected comfort of passengers watching in-flight entertainment in a 40° reclined business class airplane seat during a long-haul flight. This highlights the importance of neck/head support use and appropriate neck posture to ensure comfort, particularly in reclined positions. Additionally, aside from seat back angle, engaging in non-driving tasks with different visual demands can influence neck posture and subsequently affect comfort level. Using a kyphometer, Nijholt et al. (2016) observed the upper back, neck, and head tends to bend forward when using a laptop compared to watching in-flight entertainment on aircraft seats with seat back angles of 10° and 0.5°, suggesting that seating activities are also an important factor affecting neck angle thus overall comfort. However, few studies have investigated the effects of vision demands of a NDRT on neck posture and its relationship with perceived discomfort.

Therefore the headrest is important for ensuring comfort during NDRTs with different seat back angles. They support the preferred neck posture and meeting visual requirements. This study aims to investigate the effects of NDRTs on neck posture and on perceived comfort with seat back angles ranging from 20° to 60°.

Methods

Data were collected from thirty-three participants aged from 21 to 56. The participants, included 15 males (Stature: 1767±91; BMI: 25.4±5.5kg/m²) and 18 females (Stature: 164.2±79; BMI: 27.2±6.6kg/m²), all having a driving license for more than one year. Ethics committee of Gustave Eiffel University approved the experimental protocol and a prior consent was obtained for each participant. Four non-driving related tasks (**Fig. 1**) were selected based on vision requirement: 1) Looking forward (*LFW),* 2) Watching a short movie (<1 minutes) on a tablet while having the tablet in their hands (*TBL or tablet),* 3) Typing a short sentence on a laptop (*LPT or laptop),* 4) Relaxing with closed eyes (*RLX)*. A multi-adjustable experimental seat developed (Beurier et al., 2017) was used to simulate different seat configurations (**Fig. 1**).



Looking forward (**LFW**) Typing on a laptop (**LPT**) Relaxing (**RLX**) Watching on a tablet (**TBL**)

Fig. 1. Illustration a participant doing the tasks on the experimental seat

To better representing automotive environment, seat height, defined as the height of the seat reference point close to SAE H-point with respect to the footrest support, was set to 300mm (±10mm). Three seat back angles or A_SB (from vertical) of 20, 40 and 60 degrees were tested for each task. In total, 12 conditions (4 tasks × 3 seat back angles) were tested for each participant. The armrest heights were fixed during the whole experiments for all of the subjects. Other seat parameters such as seat pan length, seat pan angle, lumbar support position, dorsal support height, headrest position were self-selected by participants to adopt their preferred postures.

Prior to the test, participants were asked to familiarize the use of the experimental seat. More specifically, they were asked to choose their preferred seat parameters for the three seat back angles. For each seat back angle, the seat pan angle was set to zero (horizontal) initially. Once a comfortable seating was obtained, the corresponding seat parameters were saved as the initial seat configuration for each A_SB. After this first phase of familiarization, main anthropometric dimensions were measured and 3D body surface was scanned in a standing posture. A set of 39 surface markers were attached to the body for motion capture.

Trial order was determined by randomizing the three seat back angles at first and then the four tasks. To reduce adjustment time, prior to conducting the four tasks associated with each seat back angle, the corresponding initial preferred seat configuration obtained during the familiarization phase was recalled as starting seat parameters. Participants were re-asked to choose their preferred seat parameters except for seat height and middle back support (front-aft direction) to reach a comfortable seating. After these preliminary adjustments for each A_SB, the four tasks were performed randomly. For each task, participants could adjust all non-controlled seat parameters as before. They were allowed not to use the headrest if it made them feel uncomfortable. Once a comfortable position (suitable for doing the requested task) obtained, 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 comfortably for doing the required task. Vicon motion capture system was used to measure the position of markers for each trial. Finally, the participants rated the perceived seating discomfort, using CP50 rating(Figure 2) from 0 (imperceptible) to 50 (extremely strong) or more (Shen & Parsons, 1997). Furthermore, a multiple choice question was asked to know how long they could continue doing the task for the self-selected seating configuration: A) less than 30 minutes, B) between 30 minutes and 1 hour C) more than 1 hour.

A personalized articulated skeletal model was defined from a 3D standing body scan and a set of anatomical landmarks manually palpated on the scan. Joint centers including spinal and pelvis joint centers were obtained using the methods by (Peng et al., 2013) and (Nerot et al., 2018). To reconstruct the postures for each trial, an inverse kinematic algorithm was used to match the position of the markers attached on the body with those attached on the model. Once the postures reconstructed, postural parameters (**Figure 2**) were defined relative to the standing posture for each participant. To reduce the individual effects on discomfort scores (CP50), the average score was calculated for each participant. CP50 scores were centered relative to each participant's mean score (CP50_C). General linear models were performed using STATGRAPHICS Centurion 18 to study the effect of seatback angle (A_SB) and tasks on CP50_C. Effects of independent variables were considered 'significant' when $p<0.05$

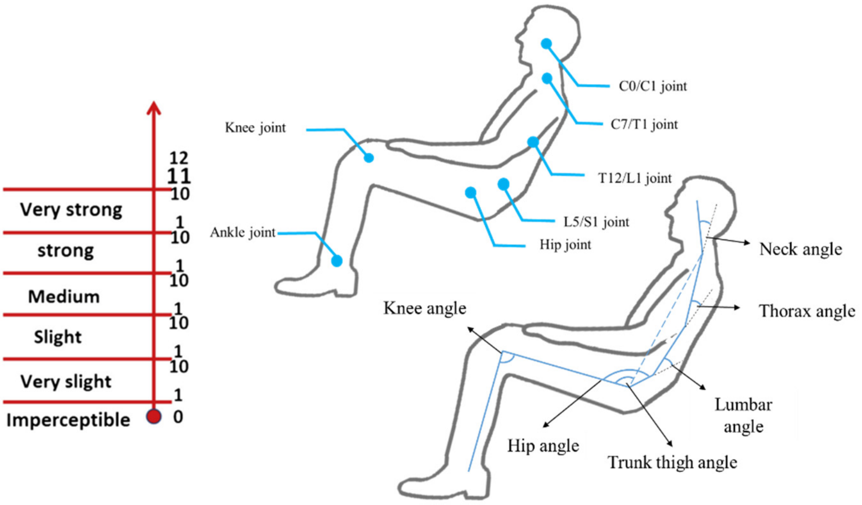


Figure 2 CP50 discomfort rating scale (left) and definition of postural parameters (right)

Results and discussions

Figure 3 compares neck angles (relative to standing) and centered CP50 (CP50_C) of the four tasks in the three seating conditions. Relatively lower discomfort scores (negative CP50_C) were observed for LFW for all three seat back angles, for RLX in 40° and 60° seat back angles as well as for LPT in 20° seat back angle. This indicates that participants were able to engage in these activities without experiencing significant initial discomfort perception in these seat back angles. A positive CP50_C was observed for TBL across all of the seat back angles and for LPT in 40° and 60° seat back angles, suggesting higher discomfort perception for these two tasks.

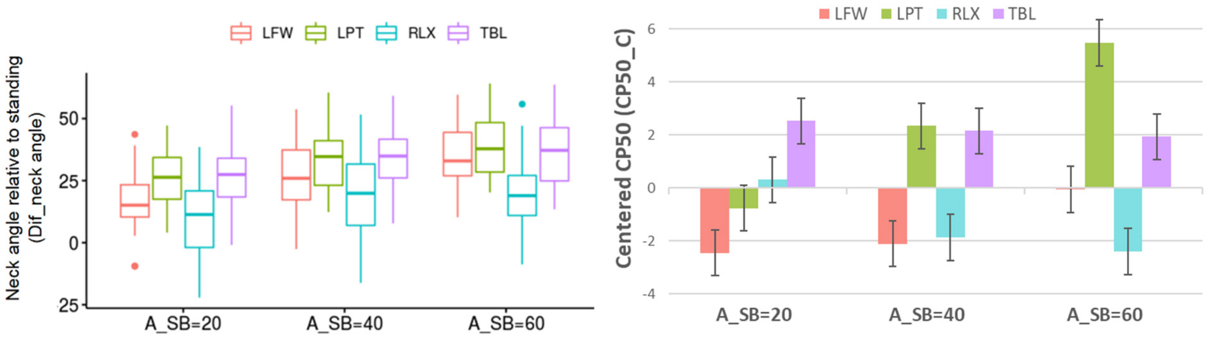


Figure 3. Neck angles (relative to standing) and CP50_C for the four tasks (Task) and three seat back angles (A_SB)

In general, the laptop and tablet use activities were more uncomfortable especially for reclined seats than the looking forward and relaxing activities. This was consistent with the responses to the question about the expected maximum task duration. One possible explanation for this is that laptop and tablet activities require the neck to be more flexed. Among the various postural parameters, only neck angle was found significantly correlated with CP50_C with a coefficient of correlation of 0.16.

In summary, results showed that seating discomfort increased for activities that required the neck to flex such as laptop use or looking forward as the seat back reclined, while it decreased for the relaxing activity with no specific visual requirements. The discomfort rating for tablet use was relatively higher for all three seat back angles. One explanation could be that holding an object of 0.5kg for a while may generate discomfort in addition to higher neck flexion due to vision requirement. In fact, participants sometimes put the tablet on their thighs or held it in their hands. Results from the present study will be useful for predicting non driving related postures and corresponding discomfort ratings when using a DHM to assist future vehicle interior design.

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In-seat movements: a literature review on categorizations and patterns over time

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ABSTRACT

In recent years in-seat movements (ISM) have been a focus of attention in discomfort and comfort studies, but the role of these movements in preventing and/or alleviating discomfort remains unclear. Also, differences in study setup and ISM-measurement make comparison of different studies difficult. This paper describes a literature review of 19 papers that include empirical measurements of ISM over time. Results show that despite a general trend of ISM increasing over time, nuances may be placed. Several studies show that small-size and large-size ISM patterns overlap in time and differ in ISM amplitude. Also, the difficulty of interpreting posture change becomes clear, e.g. slumping over time, as this is explained both as ISM as well as a separate, underlaying, movement dynamic. Altogether this gives a mixed view of ISM patterns over time and should bring caution when interpreting ISM studies, calling for a focus on ISM patterns or behaviors in future research. Furthermore, this paper brings new questions on the study of ISM especially in relation to other discomfort factors such as seat characteristics, performed activities, anthropometrics, and contextual factors.

KEYWORDS

In-seat movements, ISM, ICM, fidgets, seating discomfort

Introduction

The relationship between in-seat movements (ISM) or in-chair movements (ICM) and (dis)comfort is under debate (Lampe & Deml, 2022). (Dis)comfort is related to for instance seat characteristics, user characteristics, context, expectations and sitting duration, as explained in the discomfort model of Vink and Hallbeck (2012). An earlier literature review by Song and Vink (2021) gave an overview of objective measures related to these factors to assess discomfort. Studies have indicated that ISM might be a way of managing or coping with perceived discomfort (Anne Fenety et al., 2000; Baker et al., 2018; Bendix & Bloch, 1986; Callaghan et al., 2010a; Maradei et al., 2015; Sammonds et al., 2017; Telfer et al., 2009). For instance, Bhatnager et al. (1985), and Karwowski et al. (1994) proposed that ISM may be a sign that the person is "trying to alleviate musculoskeletal discomfort", and the number of ISM has been shown to increase with fatigue (Arippa et al., 2021), where others could not establish a correlation between fatigue and ISM (Furugori et al., 2003). Thus, ISM could be argued as a measure of discomfort. Yet, other studies have argued ISM to be a tool to prevent discomfort, such as exercising (Bouwens et al., 2018; P. P. A. Fenety et al., 2000). This "two-fold" relation between ISM and discomfort was also recognized in earlier literature reviews (Hiemstra-van Mastrigt et al., 2017).

Furthermore, several papers have stated that in-seat movements (ISM) are partly driven by tasks (Andersson, 1985), e.g. sorting papers on a desk (Bendix et al., 1985; Groenesteijn et al., 2011) or typing on the keyboard (Liao & Drury, 2000).

Despite this attention to ISM, recent papers have acknowledged that categorizations of ISM are ‘undecided’ (Lampe & Deml, 2022). These differences in categorizations bring an additional difficulty in comparing studies. Furthermore, due to different thresholds, measurements, and study setup, as acknowledged in the review of Hiemstra-van Mastrigt et al., (2017), there is no consistent correlation established.

This paper is an enquiry aiming to provide an overview of ISM over time, in terms of progressions, characteristics, possible patterns as well as types of ISM that are distinguished. It aims to build towards a more common understanding of ISM-types and patterns which would be constructive in the search for possible relationships with factors of discomfort.

Method

A search on databases Scopus, PubMed, and Web of Science was followed by a structured literature review. The search terms were organized in five groups; #1: (dis)comfort; #2: seating #3: industry; #4: Body movement/body posture change; #5: Exclusions. Database searches were performed on November 12th, 2022. Inclusion criteria were: 1) The study involves real humans as subjects; 2) The study focuses on everyday sitting contexts, e.g. occupational or transit (bus, truck, office worker) or touristic travel; 3) The study concerns in-seat movements, ‘sitting posture-changes’ over a certain sitting period, or similarly regards movements while sitting, as a factor in the study; 4) The paper/study describes or contains an empirical element, reporting empirical results. For this paper, a selection criterium of describing ISM over time was added. The paper selection process is shown below.

Identification (performed on 12-11-2022)	141 records identified through Scopus search	115 records identified through Web of Science search
	27 records identified through PubMed search	
Screening	230 records after removing duplicates	169 records excluded based on title and abstract
Eligibility	61 full text records assessed for eligibility	27 records excluded, based on full text
	5 records added by experts	
	39 records assessed on measurement of ISM over time	20 records excluded, based on inclusion of time-based variable
Included	19	

Figure 1. Paper selection process

Results

In total 19 papers were included for this review. The results are divided into three parts: results regarding ISM frequency over time, results regarding ISM amplitude and results regarding posture change.

ISM frequency

Out of 19, 16 papers report on overall time effects in ISM. Nine out of 16 (56%) show an increase of ISM over time (Callaghan et al., 2010; Cascioli et al., 2016; A. P. Fenety et al., 2000; Furugori et al., 2003; Jin et al., 2009; Maradei et al., 2015; Na et al., 2005; Tanoue et al., 2016; Telfer et al., 2009b). Of these, Cascioli et al. (2016) note that this increase is significant after 100 mins, and similarly, Furugori et al. (2003) note a peak in ISM at 70 mins. A time effect was also found by Na et al. (2005) although different per seat element, i.e. the seat-pan pressure change variable reaching significance after 23 minutes, while pressure change in back rest reached significance after 41 minutes, the authors also noting a ‘come-and-go’ oscillation of ISM frequency.

Also, Maradei et al. (2015b) report an increase of ‘Macro-ISM’ over time but note that ‘combined pelvis and trunk’ ISM occur more frequently than ‘trunk-only’ ISM. Regarding ISM progression over time Wang et al. (2021) bring an additional nuance with ISM frequency decreasing in the first 15 minutes of the experiment, followed by an increase towards the end of the 50-minute experiment.

Four out of 16 (25%) papers report a partial time effect on ISM. A comprehensive field study involving bus drivers by Arippa et al. (2022) took a dynamic approach involving several pressure variables based on the center of pressure (CoP) over time. In their study, ‘velocity’ in anterior-posterior direction and ‘sway area’ increased over time with significance after 100 mins. Yet, other variables as ‘sway path’, ‘overall velocity’, and ‘velocity in mid-lateral direction’ as well as ‘maximum displacement value’ in anterior-posterior direction proved not significant over time. A following study by Arippa et al. (2022) involving office workers gives a similar mixed picture with, remarkably, a decrease of ISM over time, but ‘sway area’ and ‘sway path’ did not differ significantly over time. In line with this, Sammonds et al. (2017), using the term ‘seat fidget movements’ report an increase of ISM over time, attributed to movement of the ‘limbs’, where ‘torso’ ISM or ‘full body’ ISM proved not significant over time. Similarly, thigh ISM and lower limbs ISM were more frequently observed over time in the study of Jensen and Bendix (1992), where it should be noted that the seats involved had a slightly inclined and reclined seatpan, ISM only decreasing in the last measurement before the end of one hour experiment. Yet, also like Sammonds et al. (2017b), trunk ISM nor head ISM frequencies proved not significantly changing over time.

Remarkably, three out of 16 papers (19%) report no significant increase of ISM over time in any ISM variable. Studying pelvis ISM, Baker et al. (2018) did not find an increase in ISM. Also, a study of Hermann (2005), despite taking a dynamic approach to pressure data similar to Arippa et al. (2022), did not find an increase in ISM over time, however noting two different ISM strategies existing and overlapping in time. Pinto et al. (2022) distinguished ‘posture shift’ as a change from back flexion- to extension or vice versa, and ‘fidgets’ as a change in lumbar angle, based on earlier ISM categorization by Dunk and Callaghan (2010). Despite this definition, Pinto et al. (2022) also found no increases over time in ISM number and duration.

In conclusion, the time effect in ISM shows a mixed image regarding frequency. A large range is shown by papers and note the increase in time reaching significance after 23, 41 (seat pan and backrest respectively (Na et al., 2005), 50, 70 (Furugori et al., 2003) or 100 (Arippa, Leban, et al., 2022; Cascioli et al., 2016) minutes. However, the beforementioned range concerns all studies studying seat pan. A closer inspection of the sensitivity of the method for ISM measurement, could be recommended to investigate the influence of these methods on when and at which amplitude and frequency ISM is reported. Furthermore, the fact that some papers do not mention an increase over time, brings caution to interpreting overall time effects, as well as the understanding of possible correlations between ISM and discomfort.

ISM amplitude

Five of the included 19 papers (26%) report on ISM amplitude over time. The study of Arippa and Leban (2022) involving bus drivers shows that maximum displacement in medio-lateral (ML) direction increased, especially after 70 minutes, whilst the amplitude in anterior-posterior (AP) direction, proved not to change significantly. Yet, another study by Arippa et al. (2022) on office workers reports a seemingly opposite effect, with ISM amplitude in AP direction decreasing over time, and amplitude in ML direction not changing over time. Na et al. (2005) reports an increase of ISM amplitude over time based on pressure-ratio variables.

Two of the five (40%) papers report no change of ISM amplitude over time, despite defining different types of ISM. Distinguishing fidgets and posture change, Pinto et al.(2022) report no changes over time. Also, Sammonds et al. (2017b), distinguishing limb-, torso- and whole-body ISM, conclude that ISM amplitude did not change over time, but frequency did.

In conclusion, despite a small number of included studies discussing amplitude, results show a mixed image of amplitude over time related to direction of movement. The seemingly opposite effect regarding changes in AP and ML direction between studies on office workers and bus drivers, may indicate an effect of task on ISM amplitude as well.

Posture change

Ten out of 19 papers (53%) report on posture change over time. Furugori et al. (2003) report a slumping over time based on CoP position in backrest and seatpan. Furthermore, their study defined pressure ratio variables indicating the relative amount of pressure on the buttock and upper back areas compared to the total pressure on seat pan and backrest respectively. These ratios showed CoP on backrest moving downwards and moving forwards on the seatpan, towards the edge of the seat, indicating slumping. Yet, the authors note inter-subject differences, some subjects slump over time, and some subjects move to more leaning forward (Furugori et al., 2003). Similarly, slumping over time was also reported based on decreasing pressure ratios in the study of Jin et al. (2009), and based on marker data by Kleine et al. (1999), it could be seen that slumping was compensated by a relative lift of the shoulders. A different effect was described by Callaghan et al. (2010). In their study, on the one hand hip- and knee joint angles increased over time indicating a more kyphotic posture over time, similar to slumping (Callaghan et al., 2010). Yet, although the CoP position in backrest and seat pan changed significantly in their study, the seat-pan CoP moved to the back of the seat and the CoP moved upwards in the backrest (Callaghan et al., 2010), not in line with the results of Furugori et al. (2003).

Another effect that was noted by Callaghan et al. (2010) regarding posture change, based on pressure area, is that the area on the seat pan increased. The authors attributed this to a 'sinking' of participants into the cushion over time, due to visco elastic behavior of body tissues and seating foam deformations.

Several studies noted partial postural effects. Beforementioned 'slumping' results were also noted based on CoP anterior-posterior position (Arippa, Leban, et al., 2022) and in a following study on office workers reaching significance after approximately 42.5 minutes (Arippa, Nguyen, et al., 2022). Moreover, in both papers from Arippa et al., the pressure coordinate in mid-lateral position did not change significantly over time, where ISM frequency in that same ML direction proved to change significantly.

Furthermore, Arippa et al. (2022) noted a decrease of mean pressure in gluteus region and an increase in the thigh region, similar to the pressure results of Furugori (2003). Interestingly, the mean pressure change reached levels of significance sooner in the thigh region (after 57.5min.) than in the 'gluteus region being significant after approximately 2 hours (117.5min.). Another partial time effect regarding posture was found by Na et al. (2005), who report next to slumping, an increase of peak pressure on ischial tuberosities and moreover an asymmetric effect. Yet, based on video analysis the hip joint angle did not significantly change over time during the experiment. Interestingly the hip angle was significantly larger during the experiment than before the driving simulation, showing an effect of task in posture (Na et al., 2005). Asymmetry was also noted by Herman (2005) regarding changing pressure on ischial tuberosities.

Lastly, 3 out of 10 (30%) papers reported no posture shift over time. Low back angle did not change over time in the study of (Baker et al., 2018) and, based on accelerometer data, Pinto et al (2022) found no increase in amplitude or direction of posture shifts. Studying shoulder, neck and head posture in specific, Szeto et al. (2002) also reported no posture change over time.

In **conclusion**, interpretation of postural change is mainly based on pressure mat data i.e. CoP position. Seven out of 10 papers mention slumping over time, of which 3 contain variables that proved not significant over time such as joint angles (Na et al., 2005), or direction (Arippa, Leban, et al., 2022; Arippa, Nguyen, et al., 2022).

Discussion

The goal of this paper was to build a more common understanding of ISM-types and patterns. A few patterns are found in a majority of papers: more movement in the course of time and a change to a more slumped posture in the course of time. However, there are also studies who did not find these effects and differences in the way of recording making a general conclusion difficult. Further emphasis was given to distinguishing different movement patterns in both frequency and amplitude as well as duration of each ISM. Together this asks for a further study of ISM types, especially the distinction of ISM and posture change.

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Sleep quality in Noisy Aircraft Cabins

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ABSTRACT

This exploratory study has investigated the effects of cabin noise on passenger sleep length and quality, because the influence of cabin comfort and particularly cabin noise levels on sleep length and quality is not yet fully understood. Therefore, a feasibility study was conducted to explore the possibilities for a more extensive laboratory sleep study that will be executed later. In this feasibility study two groups of four 'passengers' slept under different circumstances. To simulate an immersive experience, these 'passengers' were seated on real aircraft chairs and slept in a semi-noise-controlled environment. Each group faced different variances of cabin noise loudness. The effects of these different conditions on sleep length, quality and comfort levels were measured and compared with each other, and with a control condition where subjects slept in their own bed at home. Demographic factors and general sleep quality were gathered to account for individual differences.
The results show that sleeping in the own bed at home is related to better sleep quality and less subsequent fatigue. However, no significant results on sleep and fatigue were found between the different noise conditions.

KEYWORDS

aircraft cabin noise, sleep quality, comfort, fatigue, sleepiness

Introduction

This study investigates sleep comfort in aircraft cabins in relation to experienced noise. Depending on the aircraft type and isolation of the cabin, a different noise level is experienced, which in turn can impact the sleep quality of a passenger. Short term sleep deprivation can lead to different adverse health effects, such as daytime sleepiness, cognitive impairment and gastrointestinal disturbances (Sack, 2010). This study aims to provide insight into the most comfortable noise level for an optimal sleep experience, which may especially be helpful for long-haul flights to reduce fatigue. In turn, airlines and Original Equipment Manufacturers (OEMs) can gain insight into the required noise reduction within cabins to improve passenger sleep quality. Eventually, being able to offer passengers a flight experience with good resting opportunities may be a solid marketing instrument for airlines.

Studies into aircrew (pilots and/or cabin crew) show that they are often subject to high fatigue, due to scheduling and time zone crossings (Sallinen et al., 2020). These high levels of fatigue are, in turn, associated with a higher risk of incidents and accidents (Avers & Johnson, 2011). However, the passengers in the back of the plane may also suffer from fatigue affecting their ability to work or operate a vehicle following a flight. The risks they face may be of another nature than aircrew, but the consequences can also be substantial (Sack, 2010). Thus, it is important to use the knowledge from other sleep and fatigue research to learn how disturbances and time zone crossings may affect these professionals as well.

Globally, it is estimated that around 20% of all global tourism expenditure in 2021 was business travel related (Statista Research Department, 2023), with Europe ranking as the second region worldwide in terms of business travel (López, 2022). Just before the COVID pandemic hit, the number of outbound business trips in the EU was estimated to be over 37.5 billion (Statista Research Department, 2021). These numbers warrant more research into the consequences of disturbed sleep for passengers.

Aircraft noise, such as that experienced in the vicinity of airports, has a general negative impact on sleep (Basner et al., 2010). Local residents shows a higher probability of awakenings throughout the night with an increase of aircraft noise levels, especially during the most vulnerable stage of sleep. However, the experience of aircraft *cabin* noise differs from aircraft noise as it is a constant noise at a relatively high sound level. Studies show that the continuous noise level (LAeq) during commercial aircraft flights ranges from 69.5 to 74.9 dB(A) for long haul flights (Lee et al., 2022). Continuous noise levels differ per aircraft type. For example, the noise of a Boeing 787 is 72.7 dB(A) and that of an Airbus A320 is 69.5 dB(A). Noise in an aircraft cabin can also be divided in continuous and discontinuous in-cabin noise. Continuous noise levels during cruise flight do not vary much. However, overall noise levels can increase to 81 and even 88 dB(A) when considering instantaneous noise sources, such as mechanical noises for take-off and climb, miscellaneous noises during warning signal, announcements from pilot and flight attendants, and brakes, as measured in an Airbus A321 commercial passenger plane (Ozcan & Nemlioglu, 2006).

Like air quality and humidity, noise in an aircraft is an important variable that has a negative impact on subjective passenger comfort and crew's performance (Mellert et al., 2008; Weber et al., 2004). For example, the study from Pennig et al. (2012) shows that increasing in-flight noise levels resulted in less pleasant and calm feelings in aircraft passengers. Aircraft cabin noise thus can have a negative impact on the comfort of passengers, however its impact on sleep during a long haul flight is not yet clear. This feasibility study was performed to determine all relevant considerations necessary for a study into the effects of different noise levels on sleep quality in aircraft cabins. A higher noise level is expected to be related to lower sleep quality and comfort, more activity during the sleep period, and higher levels of fatigue after sleep.

Method

A laboratory study was executed with a total of 8 subjects. Nine economy class aircraft chairs were placed in a darkened room in three rows of three chairs each. Per test night, four subjects slept in these chairs, each in one "aisle" chair with an empty chair in the middle. The front row was empty. All subjects were employees of NLR.

The experiment was designed as a mixed model with two levels of loudness condition (Loud (L) versus Soft (S)) as between subject factor and two levels of sleep condition (Experimental and Control) as within subject factor. The noise level of condition L was 83dB(A), which is comparable to a louder average noise level, such as an Airbus A350 (Lee et al., 2022). The noise level in condition S was 67dB(A), comparable with an Airbus A380-800 (Lee et al., 2022). For both condition L and S, the sound recording of a Boeing B787 commercial passenger aircraft was used. This sound was recorded on an earlier measurement flight with no passengers onboard. Sounds from other passengers, as well as alerting sounds for the flight crew, or announcement by purser or captain were therefore not included in this recording. The control condition was a normal sleep measurement at home, and was used as a baseline. Subjects were assigned to one of the two experimental conditions, and were not aware of the noise level they would experience during their simulated flight. A pair of dedicated (tweeter) loudspeakers was mounted around the subjects to produce the noise, and a subwoofer was also placed in the room to support the low-frequencies in the sound.

A scenario of a normal night flight of 10 hours was mimicked. Therefore, subjects were asked to remain in their chairs as they would during a normal flight. They were instructed to behave as they would in an actual aircraft. They reported for the flight at 21:00 where they were briefed and requested to take their seats at 21:30. At 23:00 the light was dimmed and subjects prepared for the night. At 06:30 the light was turned on and at 07:30 subjects were allowed to leave their seats.

Data regarding sleepiness and fatigue were recorded before and 45 minutes after the ‘flight’. The Karolinska Sleepiness Scale was used to measure subjective sleepiness (Kaida et al., 2006). Alertness was measured by means of the 3 minute Psychomotor Vigilance Task, an objective measure for fatigue (Basner et al., 2011). To diminish the effects of differences in speed, the morning PVT scores were divided by the preceding evening scores. Furthermore, subjects were asked to rate the quality of their sleep and level of comfort during the night. During the entire simulated flight, subjects’ activity level was recorded with an ActiWatch2 activity tracker (Weiss et al., 2010).

Results

The two experimental groups were comparable for gender and mean age. Each group consisted of two male and two female subjects. The mean age of the group in condition L was 37.8 years and condition S 38.3 years. None of the subjects had children under the age of 4, and all considered their health to be at least good. One participant in condition L scored higher than 11 on the Jenkins Sleep Scale, which is indicative of frequent sleep disturbances (Juhola et al., 2021). All other subjects scored lower than 12 on this scale. No significant differences were found between the normal sleep length of the groups in both conditions. However, on the individual strength questionnaire, a significant difference was found on the concentration scale ($t = -1.32$, $p < .05$), where the S group indicated to have more problems concentrating than the L group (Beurskens et al., 2000).

An independent sample t test showed no significant difference in average noise sensitivity scores between the both groups ($t(6) = -2.38$, $p = .055$). Even though not significant, a trend was seen where the S group reported slightly higher average noise sensitivity scores ($M = 3.93$, $SD = 0.76$) than the L group ($M = 2.68$, $SD = 0.73$). No significant differences were found between the groups on the realistic experience of the simulated aircraft ($t(5) = 2.39$, $p = .062$).

The data from one subject (L group) were not recorded correctly and were therefore not included in the analysis. The results from the other subjects show that they slept significantly longer in the control condition in the own bed compared to the experimental condition in the aircraft chair ($F(1) = 6.54$, $p <.05$). No interaction effect was found between the two experimental conditions and the control condition ($F(1) = 1.177$, $p = .320$). Also, a significant effect was found when focussing on the sleep quality as measured on a 4-point Likert scale ($F(1) = 50$, $p <.01$), but no interaction effect was visible ($F(1) = .000$, $p = 1$).

KSS scores measured at least 45 minutes after waking showed no significant differences ($F(1) = 3.191$, $p = .124$), nor trends between experimental and control conditions ($F(1) = .511$, $p = .502$).

The reaction times recorded with the PVT were significantly faster after the control condition compared with the experimental conditions ($F(1) = 11.635$, $p < 0.05$). Furthermore, a trend was found for the interaction between both experimental conditions and the control condition ($F(1) = 3.819$, $p = .098$), indicating that, contrary to expectations, the S group performed worse after sleeping in an aircraft chair than the L group.

Conclusion and discussion

The results show that indeed sleeping in the own bed at home is related to better sleep quality and less subsequent fatigue. However, no significant results on sleep and fatigue were found between the different noise conditions.

The main goal of this feasibility study was to assess the possibility to conduct a realistic aircraft cabin set up suitable for a simulated night flight. Expectations were met, as 8 test subjects slept in an either a louder or quieter sound condition of a simulated Boeing 787. It was expected that both groups would have a longer actual sleep duration (percentage of time spent ‘resting’) as measured with the ActiWatch during the control condition in the own bed compared to the experimental condition in the aircraft chairs. The results show that the subjects indeed slept significantly longer in the control condition. Additionally, the group that was exposed to loud noise was expected to have a lower sleep duration than the group that was exposed to lower noise levels in the experimental condition. Unexpectedly, no difference between the groups was found.

Furthermore, contrary to expectations, a trend was found where the group in the louder experimental condition showed a faster response time, measured with the PVT than the group in the quieter experimental condition. One possible explanation could be found within the groups. Even though the subjects were divided over the two groups as equally as possible, the results from the baseline questions showed that the group in the quieter experimental condition reported more troubles on concentrating than the group in the louder experimental conditions. Another explanation might be that the S group was slightly more sensitive to higher noise, compared to the L group. Even though this effect was not significant, it should be studied further in the following study.

Since this study was a feasibility study, the number of participants was kept low. Therefore, results should be interpreted cautiously, while focusing on improvements for future sleep studies. A possible improvement is that more instantaneous noise should be added in future studies. This study only presented continuous noise to the subjects and no instantaneous noise, such as pilot and flight attendant announcements that can bring noise levels up to 88 dB(A) (Ozcan & Nemlioglu, 2006), and in turn decrease comfort of passengers (Pennig et al., 2012).

Aside from noise and aircraft seating, no other factors were measured that may impact comfort. For example, subjects commented on the lack of aircraft movement (vibration) during the experiment. The study from Quehl (2001) showed a contribution of approximately 70% of noise and about 30% of vibration magnitude to the comfort assessment in their study. Even though aircraft noise contributes more to the (dis)comfort of subjects, future studies should consider adding vibration. Other factors reported by subjects that may impact the sleep quality include air pressure, humidity, chair position and recline (including the difference between business class and economy class), smaller space surrounding the chairs to mimic the space of an aircraft cabin, and illumination levels.

Overall, this study offers an initial insight in a realistic sleep experience in an aircraft night flight and provides preliminary results on sleep quality and fatigue, as well recommendations for a more realistic study set up with the purpose of an aircraft sleep study.

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Inflight service optimization for a better comfort experience

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ABSTRACT

Comfort can affect the passengers' overall travel experience. A comfortable flight can turn a long and tiring journey into an enjoyable one, leading to increased customer satisfaction and loyalty. Environmental factors including aircraft interior and past experience of passengers and service influence this comfort. In this study, co-creation sessions were conducted to find out which services are valued by the passengers most and what is the suitable amount of different services in flights with different durations. The results show that in general, catering service is considered to be the most important service, especially for long-haul flights. In a flight with a duration of 12 hours, 3.7 meals and 5 times of drink service are preferred on average. Next, passengers perceived entertainment and offering blankets during the flight important services to improve their comfort level. Helping with carry-on luggage and flight information service are only valued a lot during short-haul flights under 4 hours. Finally, the results also indicate some services desired by passengers in their future flights, e.g. massage, a silent zone and pets allowed in the cabin. The insights of this study could be beneficial in establishing a better inflight service scheme to improve passengers' perceived comfort and overall satisfaction.

KEYWORDS

Passenger experience, comfort, inflight service

Introduction

Inflight comfort could influence the overall travel experience. Comfort is correlated to choosing an airline (Bouwens et al., 2018). Vink & Hallbeck (2012) define comfort as "*a pleasant state or relaxed feeling of a human being in reaction to its environment*" and built a comfort model of how interactions between persons, products and tasks in the environment cause human body effects and finally have a perception of their comfort status. Comfort can be viewed as the result of both physical stimuli and the various states of the subject over an extended period, including their physical, mental, emotional, and social states. Song & Vink (2021) also confirmed the impact of intangible factors including mental aspects, social aspects, expectations and culture backgrounds.

Inflight service by crew triggered the most common human interactions in air trips and it is easy to adjust without any changes to the hardware requirements in an airplane. It is confirmed that service quality could directly influence passenger satisfaction (Hapsari et al., 2017)(Saleem et al., 2017) and high-quality service is essential for airlines' survival in industry competition (Park et al., 2004). Yao

& Vink (2019) found that positive changes of emotion often occur when the service starts. Vink & Brauer (2011) showed comments of 10032 trip reports of passengers and mentioned that warm, smiling flight attendants and service of newspapers are appreciated by passengers.

Due to variety in airlines and durations of the flights, the service frequency and type can be diverse. However, they all include the basic elements for passengers to form comfort. Every time passengers receive service, there are interactions. The interactions could be with the flying attendants and products (pillows, blankets, food, drinks and etc.). These interactions lead to physical (e.g. posture change with pillows and blankets) and physiological (e.g. body temperature, water content and digest process) changes. After weighing between the current service quality and expected service quality, passengers perceived comfort can increase or decrease. It is important to understand passengers' expected service quality and how they value different types of services, especially in economy class, where less service types and lower service quality are usually provided. In addition to service type, service frequency also plays a role in comfort change during the flight. Since perceived comfort decreases over time (Anjani et al., 2020)(Yao et al., 2021) and discomfort starts to develop after 40 minutes of sitting (Sammonds et al., 2017), applying different service frequencies to disrupt the development of discomfort can make an impact on the overall experience.

Many researchers stated the importance of improving service quality to increase passenger satisfaction (Hapsari et al., 2017)(Saleem et al., 2017)(Namukasa, 2013), retain passenger loyalty (Jiang & Zhang, 2016)(Etemad-Sajadi et al., 2016) and increase the chance of being selected as an airline (Adeola & Adebiyi, 2014)(Chen et al., 2017). However, knowledge on the passengers' preferred amount of different types of service still remains scarce, especially on how people value different service during the trip with different durations. This leads to the research questions of this study: 1) What are the most valuable services that make the greatest impact on passenger comfort experience? 2) How many times different services are needed?

Method

The study was conducted in three co-creation sessions with 4 participants and 1 host in each session. In total 12 participants (6 males and 6 females) aged 26-33 were invited to this study. All participants have experience in both regional and long-haul (>=12 hours) economy class air travels. The shortest flight the participants experienced is about 30 minutes and the longest is about 16 hours. Only services in economy class were studied in the sessions. Materials used in the session included markers, pens, paper, stickers, post-its, papers with the flight timeline were printed before the sessions. All the sessions followed the same procedure.

1. Researchers welcome participants and participants sign consent forms.
2. Participants write down the service they have experienced on post-its.
3. Participants discuss to rank the importance of services in a flight of 2 hours regarding how this service quality influence their comfort experience and have an agreement on the discussion.
4. Repeat step 3 for all the other flight durations (4 hours, 6 hours, 8 hours, 10 hours and 12 hours).
5. Participants write down additional services they want to have and the reasons.

The frequency of service types mentioned in step 4 were counted. Since the top three important services had to be ranked by the participants, the importance ($\overline{\mathrm{Im}}$) of each service was computed as

$\overline{\mathrm{Im}} = \sum_{i=1}^{3} w_i n_i/3$, where w_i stands for the weight applied to the rank and n_i stands for the times of a service showed up in different importance rank. According to the Pareto principle (Dunford et al., 2014), few key elements could make the greatest effects. The weights w applied to the most, second and third important services were decided to be $[80\%, 16\%, 4\%]$. The mean of desired times of important service types were calculated. Due to the unequal needs of food and drinks, the desired times were summarized separately. Since eating preference is very personal and varies a lot between cultures, specific food or drinks were not the focus of this study.

Results

The service types mentioned as important by the participants are: catering, helping with luggage, wifi, seat change, information, offering blankets, waste collection and IFE. Table 1 shows the number of groups that rank the service types with the top three importance for their comfort experience during flights with different durations. Figure 1 shows the importance ($\overline{\mathrm{Im}}$) of the service types in flight with different durations. Catering service was ranked within the top 3 importance by all the teams regarding flight duration ranging from two hours to 12 hours and the importance during long-haul flights is more prominent compared to short-haul flights (see fig. 1). Helping with carry-on luggage and information service were only considered important in short flights. Wifi connections are always preferred, especially during flights of 6 hours and 8 hours. Participants prefer wifi more than IFE as entertainment since wifi connections provide more possibilities. The possibility to seat change is also important but the importance decreased in flights over 10 hours. As flight duration increases, passengers produce more waste and the need of waste collections becomes stronger.

Table 1 numbers of different services ranked with top 3 importance during the flight.

	catering	helping with luggage	wifi	seat change	information	offering blanket	waste collection	IFE
2h	3	3	1	1	1	0	0	0
4h	3	1	1	1	1	2	0	0
6h	3	0	2	1	0	1	1	1
8h	3	0	2	1	0	1	1	1
10h	3	0	1	1	0	3	1	0
12h	3	0	2	1	0	1	2	0

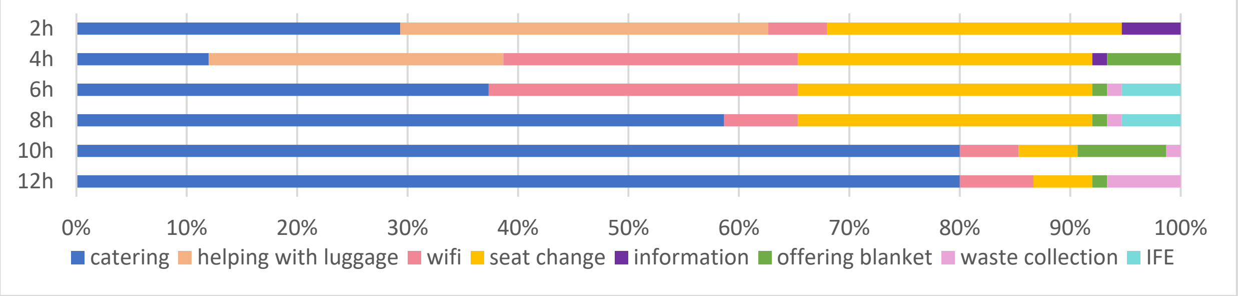

Figure 1 Importance of different services during flights with different durations.

Figure 2 shows the average numbers of service times of different service types regarding flight duration from 2 hours to 12 hours. The service amount varies a lot between short haul flights and long haul flights, especially for food and drinks. With a flying duration of 2 hours, service times for food and drinks are not more than other services. For a flight of 12 hours, 3.7 meals and 5 times of drink services in average are preferred by the participants. The entertainment including wifi and IFE are not shown in the figure because passengers expected them to be accessible throughout the journey.

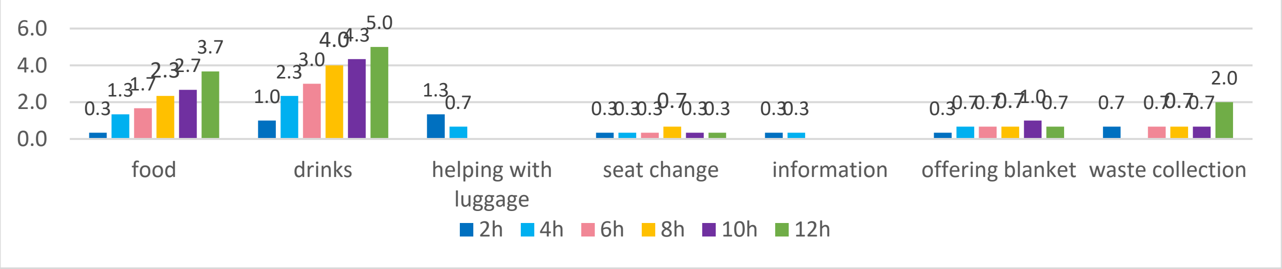

Figure 2 average numbers of preferred service times of different service types regarding flight duration from 2 hours to 12 hours.

The desired services mentioned in the session were also summarized. There were three services that mentioned by all the groups participating in this study. Due to the physical discomfort in prolonged sitting during the flight, massage to relax the muscles and reduce edema can be very helpful in improving comfort experience. A silent zone is wanted to separate people travelling alone and group travelers or provide a quieter environment for passengers who have to work in the economy class. Also, having a pet in cabin can create huge comfort and feeling of secure for passengers taking their pets with them.

Discussion & conclusion

The results reflect that among all the services, catering is considered to be the service influencing the comfort experience the most in cabin. This is in accordance with the study of Hiemstra-Van Mastrigt et al. that passengers feel most refreshed after food (Hiemstra-Van Mastrigt et al., 2016). According to Bouwens (Bouwens, 2018), the feeling of boredom can cause low comfort ratings. The interactions during catering service could break the situation of being bored, thus improving the comfort experience. This indicates that, separating the food for one meal into a main meal service and a snack service could help to increase passengers' perceived comfort without additional budget. For flights with different flying durations, the desired amount of catering services grows when the flying duration increases. This is associated with people's diet habit. According to Meessen et al., in general, people take three meals with snacks in between during 12-16 hours every day (Meessen et al., 2022), which is comparable to the results regarding the desired amount of food service. Water intake can be more frequent than food. The needs of other services only have a few changes with the change of flight durations since other resources will not be 'digested' over time.

In this paper, with co-creation sessions, the importance of different services during flights with different durations was investigated. Catering service is the most important, especially for long-haul flights. Passengers prefer wifi as entertainment over IFE devices. Entertainment influences passenger comfort more in long-haul flights (over 6 hours) compared to short-haul ones. Helping with luggage and information service are only important during short flights under 4 hours. With the increase of flying duration, the service amount of food and drinks should increase to satisfy passengers while the requirement of the amount of other services will not be influenced. Perceived comfort of passengers can be improved by better planning of catering services without extra expense. Besides current services offered during flight, massage, silent zone and pet in the cabin are the most wanted services in the future. The results of this study addressed the importance of inflight service schemes for a better comfort experience.

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comfort congress
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Effectiveness of earplugs and noise cancelling headphones to improve turboprop acoustic comfort.

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THE WORK IN CONTEXT

Current jet airplanes are not sustainable. As a good alternative to regional jet engine aircrafts, turboprop aircraft can be used. It is found that noise is the largest contributor to discomfort in turbo propeller aircraft. The noise levels in turboprops can range from 83 to 92 dB(A) depending on the seat location in the aircraft, flight phase and aircraft type. A good comfort rating is related to passengers' willingness to fly with a certain airline or airplane. Therefore, the aim of this study was to evaluate the performance of different noise cancelation methods (active noise cancelling headphones and earplugs) to reduce noise for passengers and to see how they affect the passengers (dis)comfort in turbo propeller aircrafts.

In this study 24 participants experienced the conditions: Boeing 737 sound, ATR 72 sound, ATR 72 sound with active noise cancelling headphones and ATR 72 sound with earplugs. The sound level was for all conditions between 84.2 and 86.3dB(A). The study took place inside a grounded airplane fuselage with the sound source on the inside. Passenger experiences were measured using questionnaires. The use of ANC headphones and earplugs have a positive effect on the passenger discomfort and comfort. The comfort and discomfort scores become better when wearing these two solutions compared to jet engine sound and turboprop sound.

KEYWORDS

Sound, aircraft, comfort, discomfort, noise cancellation

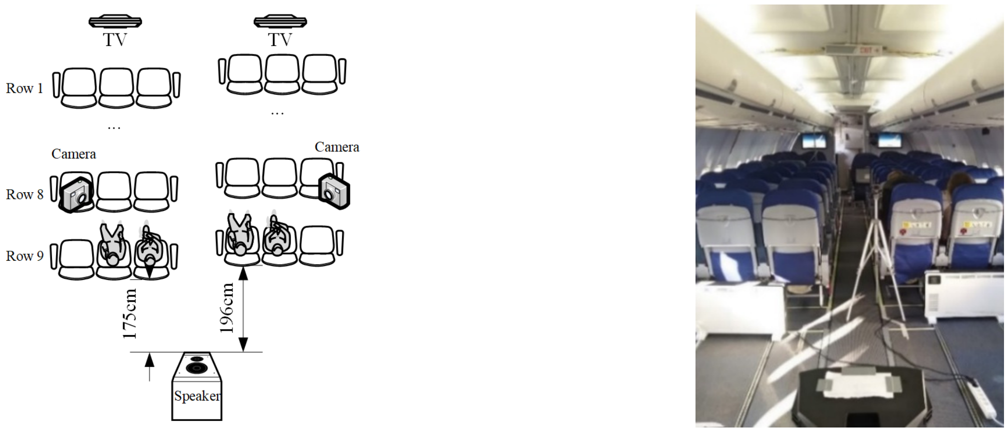
Introduction

Turboprop airplanes can play an important part in enabling an all-electric aircraft system with almost no emissions (Schäfer et al., 2018). Even in their current configuration turboprop consume 10-60% less fuel compared to jet regional flights (Babikian et al., 2002). A good comfort rating is related to passengers willingness to fly with a certain airline (Vink et al., 2012). According to Bouwens (2018), comfort in a jet engine airplane is dependent on the seat, noise, light, temperature, vibrations and smell. Vink et al. (2022) found that noise is the largest contributor to discomfort in turboprop aircraft.

From a physical viewpoint there is no difference between sound and noise, although the distinction is relevant for the human listener (Berglund & Lindvall, 1995). “Noise is unwanted and/or harmful sound” Fink (2019), emphasizing the harmful effects noise can have on people and animals, which cannot be ignored. The threshold for physical discomfort (loudness discomfort level) is in the range of 80-100 dB SPL (Berglund & Lindvall, 1995).

The noise levels in turboprops can range from 83 to 92 dB(A) depending on the seat location in the aircraft, flight phase and aircraft type (Zevitas et al., 2018). Aircraft manufacturers have quieter turboprop aircrafts in development, but until these new aircraft are on the market it is relevant to look into other options, such as passive or active noise cancellation. Passive hearing protection is not a new invention as well as active noise cancelling (ANC) headphones. Stephenson (2009) describes: “Consider that in the 1970s there were 100 different models of earmuffs and earplugs on the market. By the early 1990s there were more than 200 types of earmuffs and earplugs, and today, there are almost 400 different models available.” and “active noise reduction (ANR) headsets were developed by the U.S. Air Force more than 50 years ago”. In general there are 5 main barriers for the use of hearing protection on the work floor: comfort, convenience, cost, communication and corporate climate/safety culture (Stephenson, 2009). For willingness to use hearing protection for passengers in transportation, there might be similarities and differences, which is worth looking into. The aim of the study is to evaluate the performance of different noise cancelation methods in turboprop flights to reduce noise for passengers. This lead to the RQ of this paper: What is the effect on passenger (dis)comfort in turboprop airplanes of noise cancelling headphones compared to earplugs?

Method



(a) (b)

Figure 1: Experiment setup

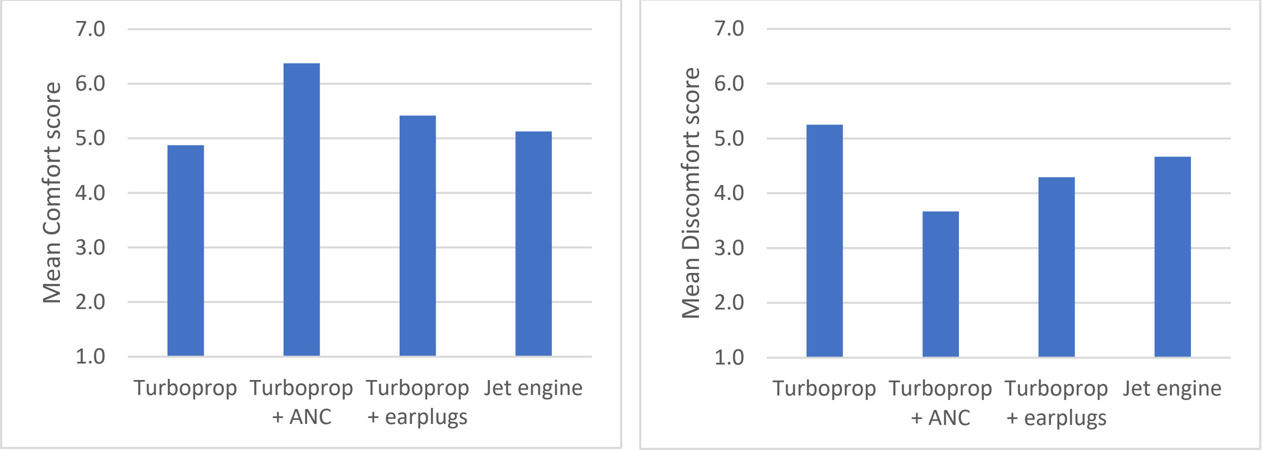
In order to compare noise cancelling solutions 24 Participants (12 Male, 12 Female, mean age: 26.96, sd=4.016) went through four conditions (1. Boeing 737 sound, 2. ATR 72 sound, 3. ATR 72 sound and Active Noise Cancelling (ANC) headphones type: Bose® NC 700, and 4. ATR 72 sound with earplugs type: Mack’s® Slim Fit Soft Foam earplugs) of each 45 min with 15min. break in between. All participants experienced traveling by air before, but not all had experience with turboprops (experience: 37.5%, no experience: 16.7%, don’t know: 45.8%). Figure 1 shoes the experiment setup, max. 4 people were tested simultaneously. The average Sound Pressure Level (SPL) distribution across the seats is shown in table 1. The questionnaire was filled out at t0,t15, t30, t45, and contained multiple choice and open questions about their comfort/discomfort level and condition preference, also including Ear Local Discomfort (ELD) score specifically for the ear and area around the ear (based on Stavrakos et al. (2015) and Anjani et al. (2021)). Data analysis was done using SPSS and open question text results were analyzed using ATLAS.ti®. The Wilcoxon signed rank test was used to test for statistical difference between conditions in the multiple choice questions. The setup of the experiment, the used questionnaires, the use of the measurement devices and the protocols were approved by the human research ethics committee (HREC) of Delft University of Technology (ID:1953).

Table 1: Average SPL of each seat. Unit is in dB(A), measured by B&K® 2270 Sound Level Meter

Seat Number	9B	9C	9D	9E
Recording of Boeing 737	84.6	86.1	86.0	84.2
Recording of ATR 72 Turboprop	86.3	84.9	84.8	86.3

Results

We have found that the conditions with ANC headphones and earplugs have a better comfort and discomfort score over the condition with only turbo propeller (turboprop) sound (p<.05)(fig. 2). This is in accordance with Bouwens et al. (2021) who states that being in control of noise levels can improve airplane seat comfort. Additionally the condition with ANC headphones scores higher (p<.05) as jet engine sound in comfort and discomfort. In comfort, ANC headphones scores better as the earplugs (p<.05). For discomfort, this is the same but the difference is not significant.



a b

Figure 2: Comfort (a) and discomfort (b) rating per condition after 42min., 1=no comfort, 7=extreme comfort, 1=no discomfort, 7=extreme discomfort

The ELD score shows that although the overall discomfort scores are quite low, there are some differences in the scores between the headphones and the earplugs. Interesting are significant higher scores for the Earplugs in the areas of the inner ear (p<.05) *Concha, Tragus, Anti-tragus* and the higher scores for the ANC headphones (p<.05) in the area around the ear *Helix, Lobule, Around the ear, Above the head.*

Table 2 shows the outcomes of the open question text analysis. The outcomes show that noise is mentioned more as cause for discomfort while wearing earplugs compared to ANC headphones. But when looking at discomfort caused by the earplugs or headphones itself, the ANC headphones develop more discomfort over time. Specific things mentioned as disadvantage of ANC headphones are *pressure on the head, weight, neck pain, vibration is noticed more, sweating,* and *a feeling of low air pressure.*

Table 2: Causes for discomfort: count of coded words

	T1 (N=40)	T14 (N=42)	T28 (N=39)	T42 (N=39)
'Headphone' while wearing ANC	1	4	3	7
'Earplug' while wearing earplugs	1	2	3	3
'Noise' while wearing ANC	7	4	6	6
'Noise' while wearing earplugs	12	11	13	14
'Vibration' while wearing ANC	7	8	6	5
'Vibration' while wearing earplugs	7	7	7	6

Discussion and conclusion

The use of ANC headphones and earplugs have a positive effect on the passenger discomfort and comfort. The comfort and discomfort scores become better when wearing these two solutions compared to jet engine sound and turboprop sound. There is a preference of ANC headphones over earplugs, but this difference is not significant for the preference and discomfort score (it is significant for comfort). The discomfort in local ear areas and general comments suggest that there are more factors at play and earplugs cannot be discarded that easily.

The better comfort and discomfort scores for the conditions with Earplugs and ANC headphones compared to jet engine sound and turboprop sound are an indication that they help make the turboprop airplanes a more competitive option compared to jet engine airplanes.

Between earplugs and ANC headphones there is a general preference for the ANC headphones. But it cannot be concluded if this is because of the comfort of the wearable or because of the better blocking of the sound. The preference is personal and individuals can have strong reasons not to wear headphones or earplugs. Thus providing a choice to passengers would be preferred.

The findings from the ELD and text analysis correspond with proposed guidelines from Hsu et al. (2004) to improve design of hearing protection. Hsu et al. (2004) proposes the following attention points to improve comfort: Airtightness, weight, heat sinking ability, texture, headband force, improving possibilities to converse. Another factor mentioned as a disadvantage of the ANC headphones was 'a feeling of low air pressure'. Butterworth & Dragan (2019) describe this phenomenon as "eardrum suck". In their test 52% experienced this effect. This effect is psychosomatic, there is no measurable air pressure difference. This is something to consider when providing ANC headphones to passengers.

The choice to use ANC headphones and compare them with earplugs was made to give a comparison of the best noise cancelling performance (ANC headphones are better than ANC earbuds) with an easy to implement earplug option. Additionally, in the research of Bouwens et al. (2021) earplugs were used, creating comparability between studies. In future research a larger set of options might be included, using ANC earbuds, and passive noise cancelling headphones. ANC earbuds might combine the noise cancelling qualities of the ANC headphones with less wearable specific discomfort.

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Preferred environmental conditions and products for comfortable nap in vehicles

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ABSTRACT

In this study 40 participants (30 female, 9 male and 1 other) were asked to take a nap three times at the same time of the day in three different backrest angles, and were asked which products they add for a good nap, what environment they prefer for a good nap and how they want to be awakened. The participants were free to choose three different back rest angles. The discomfort was lowest at the most reclined back rest angle, which had an average of 125 degrees. On preferred products for a good nap, most participants mentioned "blankets/sheet" and "pillows" and regarding the nap conditions, *"dark"*, *"silent"*, *"warm"* and *"cool"* were mostly mentioned. For awakening by *"alarm"*, *"light"* and *"natural awakening"* were mentioned as most preferred.

KEYWORDS

Nap, upright sleep, vehicle, comfort

Introduction

Research shows that in long-haul flights nearly 80% of the passengers like to sleep (Bouwens et al., 2017). They showed that among other activities sleeping had the lowest comfort in flights. However, also in other vehicles people like to sleep. Groenesteijn et al. (2014) observed that sleeping is among the four most observed activities in trains. In automated driving cars, Wilson et al. (2022) showed that passengers also like to take a nap or sleep while travelling. Although information on sleep medicine is vast, and there is some extensive research on ideal sleep environments, there is not much information available on sleep ergonomics for upright sleeping (Smulders and Vink, 2021), let alone for vehicle interior designers on the most important factors influencing sleeping in transit.

In this study an attempt has been made to gain information on environmental conditions and products for comfortable nap in vehicles. The term nap is chosen as Faraut et al. (2017) define nap as any sleep period with a duration of less than 50% of the average major sleep period of an individual. Usually in vehicles the sleeping time is no longer than 50% of the average major sleep period.

Method

To gather information about preferred environmental conditions and products that support a good sleep quality during a nap, 40 participants (30 female, 9 male and 1 other; age 21-31 years) were asked to take three times a nap. The 40 participants were asked to take a nap three times at the same time of the day in three different back rest angles, which they could choose themselves and was dependent on the available seat. The participants were asked to record the back rest angle with their mobile phone or a geo-triangle for each condition. For each of the three conditions participants had to rate their sleep discomfort on a 5-point scale ((1= No discomfort, 2= Some discomfort, 3= Medium discomfort, 4= A lot of discomfort, 5= Extreme discomfort) after the sleep. The average back rest angle was calculated for each discomfort score and differences between the angles for each discomfort score were tested using the t-test for paired comparison (p<.05). In addition, questions were asked on environmental preferences for a nap, how they want to be awakened, and what additional products they prefer to add for a good nap.

Results and discussion

The discomfort was lowest at a back rest angle average of 125 degrees and highest (score 4) at 108 degrees (see fig. 1). Between 1 and 2 the difference was not significant, between 2 and 3 it was significant (t-value 3.02083; p-value .00171). Between 3 and 4 the difference was also not significant.

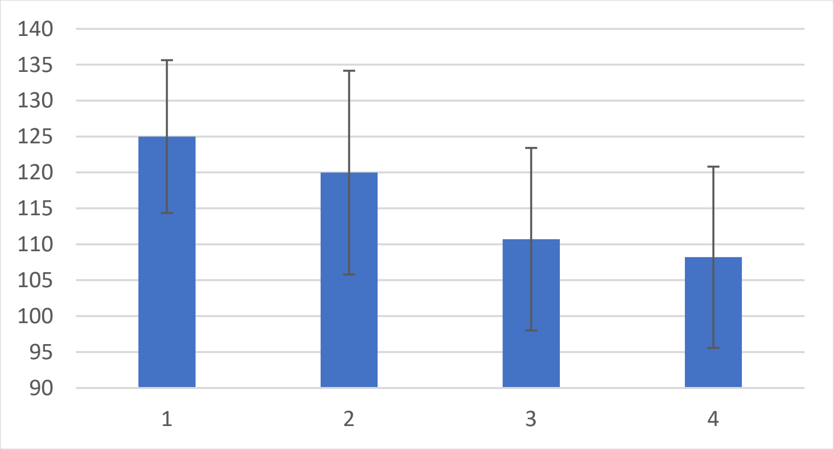

Fig. 1. The average back rest angle for each discomfort score on a 5-point scale (1= No discomfort; 5= Extreme discomfort). The score 5 was never given by the participants.

On the questions regarding products for a good sleep, most participants mentioned *"blankets/sheet"* and *"pillows*". Also, *"earplugs"*, *"blindfolds"* and *"socks*" were mentioned (see table 1). It is clear that it differs per person what they see as important. Vink et al. (2022) also state that providing passengers with the right means to control their body temperature (e.g. blankets) might contribute to a better comfort experience. The fact that travelers have a choice might be very relevant in this case.

Considering the environment most participants mentioned *"dark"*. "*warm*" was also mentioned a lot, but surprisingly *"cool"* was also mentioned by four of these 13 participants. In asking to three participants how this is possible, they reported all three that they like a cool environment for their head and like it warm under the blankets. A *"silent"* room was also often mentioned for a good sleep. On long haul flights 25% mentioned that the environment (temperature, light and engine noise) is the dominant factor for a good sleep (He and Vink, 2020). This means that attention is needed for the temperature, light and noise in vehicles. The temperature in flights needs attention as it differs at different heights in the cabin. It can be cold at feet level, but warm at head level. That is why simultaneously cold feet and hothead discomfort is a frequent complaint (Park et al., 2011). Also, in other environments ambient conditions, such as air temperature and air flow, are known to affect sleep comfort and quality (Lan et al., 2017).

Table 1. number of participants answering to the question "what product do you prefer for a good upright sleep?"

Blanket/sheet	10
Pillow	5
Blindfold	4
Socks	4
earplugs	4

Table 2. number of participants answering to the question "what do you need for a good upright sleep?"

Dark	22
Warm	13
Silent	11
Cool	10
Music	5

Table 3. number of participants answering to the question "how do you want to be awakened?"

alarm	18
light	18
coffee smell	1
bird singing	1
no awaking	3

For awakening *"alarm"* or *"light"* were mentioned as most preferred. The *"light"* could be natural awakening by natural light from outside, a lamp or a relax light. Waking up can be unpleasant, like being awoken by the alarm clock during deep sleep (Kuijsten, 2010). It might even cause general fatigue during the day (Kuijsten, 2010). Therefore, modern awakening techniques in which the depth of sleep is recorded and pleasant sounding alarms or light certainly have potential.

Conclusion

Having a good nap is not only influenced by the physical support or angle of the back rest – although these are important. Factors like blankets, sleep environment and way of awakening have an influence as well on the perceived sleep quality.

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Professional and inexperienced cabin crew evaluate aircraft interiors in XR

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ABSTRACT

Designing aircraft interiors is a complex task. While ensuring safety remains the top priority, it is equally important to create a cabin environment that can cater to the diverse needs of its users. Hence, the active participation of diverse types of users in the design process is crucial. This paper aims to evaluate the contributions of different types of users in co-creation within an eXtended Reality (XR)-based environment for aircraft interior design evaluation. Two platforms were employed: a traditional and an XR-based platform. Two distinct user groups utilized these platforms: 32 inexperienced participants and 2 experienced flight attendants. The evaluation outcomes revealed an interesting observation. While the inexperienced participants performed better in the XR-based environment, the outcomes achieved by the two professionals were significantly more fruitful, especially in professional tasks. This finding underscores the value of XR technology in creating immersive environments and emphasizes the importance of incorporating both professional expertise and crowd wisdom in the co-creation process.

KEYWORDS

participatory design, co-creation, XR, user experience

Introduction

Extended Reality (XR) technologies are being explored as a tool to provide immersive experiences to end-users in the conceptual design stage of aircraft interiors (Vink, 2016). One of the key advantages of using XR technologies in aircraft interior design is the ability to create realistic and immersive virtual environments in which users can navigate and interact with objects, thereby improving decision-making during the design process. Participatory design (PD) approaches have emerged, involving end-users in the design process. "Co-creation" is defined as collaborative development of new value, the value being products, solutions, concepts, services, etc. (Santhosh et al., 2022) (Patricio et al., 2020). In this regard, XR technology can enhance co-creation sessions by providing immersive environments that facilitate collaboration and idea generation (Fleury & Richir, 2021) (Kohler et al., 2011). Moreover, the choice between involving professional or non-professional stakeholders can be challenging, and a hybrid approach that combines both methods can leverage the strengths of both methods while mitigating limitations (Zafar et al., 2016), fostering innovative solutions that may not have been considered by experts alone (Weststrate et al., 2019).

This paper aims to explore how XR technology can enhance the design process for aircraft interiors by engaging both non-professionals and professionals in the field. The research questions are outlined as follows: 1) Do the co-creation sessions with XR help participants identify more critical issues than conventional sessions? 2) Do professionals/stakeholders produce more relevant issues than inexperienced participants in the co-creation sessions?

Materials & Method

Setup: An experiment with multiple co-creation sessions and different types of users was designed to answer research questions. Besides a traditional co-creation setup (Fig.1a), which serves as a baseline, an XR system-based co-creation platform (Fig.1b) was also designed. In both platforms, the interior design of the Flying-V (TU Delft, 2021) was used for the evaluation. The design featured an oval cabin configuration with staggered seats to provide more legroom and shoulder space (Vink et al., 2021). The evaluation focused on assessing the new design's impact on passenger and cabin crew comfort. Three tasks were proposed for the co-creation sessions 1) Assessing the visibility of life vest checks under the seat; 2) Evaluating the visibility of seat belts (whether fastened or not); and 3) Testing the reachability of the meal tray. Among these tasks, Tasks 1 and 2 were specific to flying attendants, while Task 3 required cooperation between passengers and flying attendants.

A. Conventional sessions with 2d pictures of the design and 3D models on the desktop

B. XR sessions with two physical seats

Fig.1 Set-up of the co-creation sessions

Participants were divided into two groups: non-professional (32) and professional (2). Among the 32 participants in the non-professional group, 16 joined the conventional sessions, while the other 16 participated in the XR sessions. The majority of the non-professional participants were design students with an average age of 27. None of them had cabin crew experience. The professional group consisted of 2 experienced cabin crew personnel who participated in both sessions.

Protocols: Participants joined the experiment in a duo setup, with one person playing the role of a flying attendant and the other as a passenger. In the conventional co-creation setup, traditional tools such as pens and sticky notes were provided for participants to provide their comments. They were presented with 2D pictures of the design and a 3D model on the desktop application to view from different angles (Fig. 1a). For the XR-enabled co-creation session, a 1:1 real-scale environment was created, allowing participants to walk through the cabin as if they were in real life. To enhance participants' perception, two physical prototypes of the new seat design were included in the virtual XR environment, providing a more immersive experience. Digital interaction features, including virtual sticky notes and a meal-tray, were also introduced in the XR session to support the tasks and enrich the interactions. In each co-creation session, participants were asked to collaborate with each other and interact within the setup to perform the three given tasks. They were also required to provide their feedback using the Think-out-loud method. Two facilitators were present during the study: one engaged the participants by asking a set of pre-fixed questions to elicit their responses, while the other observed and took notes.

Data analysis: All the sessions were video recorded, and the voices were transcribed. The transcriptions, along with the written notes from the facilitator, were analyzed using a narrative analysis approach. This approach aimed to examine the key findings and themes that emerged from the different sessions. Specifically, it involved exploring the similarities, differences, and unique aspects between professional and non-professional participants, as well as between conventional and XR setups. The identified issues and/or suggestions were then summarized, and the researchers ranked their importance using the Delphi technique with experts.

Results

The data analysis using narrative analysis reveals insights (Table 1) regarding the tasks and setups.

Table1: Key finding of the experiment

Task	Setup	Findings
Visibility of life-vests checks	Con.	Professional stakeholders highlighted the procedure for checking life-vests under the seats and the location of life-vests in existing aircraft. They provided their input on staggered seats, expressing that the storage location of life vests is too low. On the other hand, non-professional participants during conventional sessions had varying opinions on visibility. Some mentioned, "I should bend a lot" or "easy to see." Additionally, certain participants suggested the idea of incorporating "transparent seats" to enhance visibility.
	XR	Professional stakeholders were observed navigating through the environment and identifying a turnaround solution where walking from the back to the front of the aisle made life-vest checks easier. Some non-professional participants eventually shared the same opinion, while others mentioned that they might have to bend a lot and noted variations in visibility across different aisles. At times, it proved challenging to see the life-vests.
Visibility of Seat Belt checks	Con.	In the preliminary interview and conventional sessions, professional cabin crews were observed mentioning their best practice of checking seatbelts. Specifically, they expressed uncertainty about the visibility of seatbelt status from the pictures used in the conventional session. Among non-professional participants, 90% of them mentioned that it might be difficult to determine whether the seatbelts were fastened or not.
	XR	Professionals were observed to provide straightforward answers regarding the visibility of seat belts. They mentioned that seat belt checks are easy to perform, especially considering there are only two seats per flight attendant across two aisles. On the other hand, non-professional stakeholders had varying opinions on the visibility from both aisles in XR sessions. Most participants expressed that walking on one aisle was easier than the other in terms of visibility.

Reachability of meal tray:	Con.	Professionals stated that reachability would not be an issue. However, for non-professionals, most participants mentioned having less space to handle the meal tray from any aisle.
	XR	Professionals commented that serving from one side of the aisle was better than the other because the passengers were facing towards them. Non-professionals also mentioned that the task felt different when approaching from different aisles.

Discussion & conclusion

Co-creation sessions, designed to gain a better understanding of the problem statement and provide practical solutions, aim to improve interactions to meet specific customer or stakeholder needs. The participants' experience depends on the tools and platforms used for collaboration. The real-scale XR sessions generated more consistent and valuable feedback from participants compared to using conventional platforms. Moreover, inexperienced participants can also easily engage in the design and the context using the XR technology despite their lack of experience. Participants in XR sessions offer turnaround solutions for improvements and design ideas, while participants in conventional sessions often have diverse opinions, making it challenging to converge on a solution.

In comparing experienced and non-experienced participants, those who participated in XR sessions identified more critical issues than those using conventional tools. Compared to the broader crowd, professionals generate more relevant and significant aspects of design development in a shorter time frame. This may be attributed to professionals' background knowledge of the context in which the design will be used, leading to a quicker understanding and alignment of mental models.

On the other hand, insights from the crowd tend to be more unconventional and explore aspects that professionals may have overlooked due to being limited by their "in-the-box" thinking. When suggesting design ideas, such as changing materials and forms or introducing new seat configurations, the crowd offers suggestions that professionals might not have considered. This could be attributed to the fact that inexperienced participants are more flexible in their thinking and can approach the design process from the passengers' perspective rather than solely focusing on the operational aspects of the cabin crew.

In summary, XR can be a valuable tool for researchers and designers in co-creation by providing a more immersive environment for understanding and evaluating designs than conventional tools. While inputs from professionals are highly valued, despite their smaller numbers, inputs from a larger pool of inexperienced participants also hold significance. Inputs from professionals yield practical design aspects that can significantly impact, while inputs from the inexperienced group offer inspiration and fresh perspectives. Furthermore, XR technology can provide inexperienced participants with a realistic design experience, filling the gap caused by their lack of experience. In conclusion, involving both professionals and inexperienced participants in co-creation is beneficial for generating more meaningful outcomes in co-creation.

This study shows that in future research co-creation using XR tools is useful. While XR traditionally requires a physical environment, the exploration of using digital twins of humans and objects in remote co-creation is underway to enhance the efficiency of the co-creation process and achieve more fruitful outcomes.

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Standards on standing - the influence of posture on comfort and health effects of whole-body vibration

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ABSTRACT

Human vibration is classified into hand-arm (HAV) and whole-body vibration (WBV). The standard assessing the methods for the evaluation of the exposure severity is the ISO 2631-1 (1997) and provides guidance on the effects of the mechanical stimuli on health, comfort, perception and motion sickness. Here, we briefly set out the particular limitations of the current Standard related to the role of posture on both comfort and health effects. Regarding comfort, responses of seated and standing people differ for horizontal vibration; current frequency weightings are inconsistent with discomfort caused by horizontal vibration on standing subjects; and discomfort experienced by standing subjects increases instability impacting health and safety. Health effects are well documented for seated subjects, but the effects of vibration on standing and walking subjects (known as Foot Transmitted Vibration, hereinafter FTV) or on recumbent subjects have to date only marginally been considered. Directions for future research and suggestions for revisions of current Standards are provided.

KEYWORDS

human vibration, comfort, health effects, standing posture, standards

1. Introduction

In this paper, we briefly outline the need to revise and update the framework for the evaluation of the effect of human vibration exposure. To date, human vibration is classified into hand-arm and whole-body vibration. Hand-arm vibration (HAV) normally derives from the use of hand-held power tools and refers to the vibration entering the body at the hands. Whole body vibration (WBV) occurs when the worker is standing on vibrating surfaces or when driving vehicles over uneven surfaces. Here, the word vibration may be somewhat ambiguous. In a most generic sense, it refers to any kind of variable motion. Intuitively, it may also suggest cyclic motion at a relatively high frequency as typically caused by machinery. The latter excludes occasional or repeated shocks i.e., relatively high acceleration peaks lasting (fractions of) seconds. The Standard assessing the methods for the evaluation of the exposure severity of whole-body vibration are the ISO 2631-1 (1997) and ISO 2631-5 (2004). ISO 2631-1 provides guidance on the effects of the mechanical stimuli on health, comfort, and perception in the frequency range between 0.5 and 80 Hz, and between 0.05 to 0.5 Hz for motion sickness. While ISO 2631-1 excludes the effects of occasional shocks, defined as events resulting in peak accelerations exceeding nine times the RMS acceleration, ISO 2631-5 (2004) focuses on multiple or repeated shocks and their effects on the lower back. A detail concerns the fact that ISO does not have a legal status. The EU directive 2002-44-EC does have a legal status and returns to the ISO2631-1, including the Vibration Dose Value (using the root mean quad frequency weighted acceleration) to set specific legal limitations on these shocks. In the below, we briefly set out the particular limitations of the current Standard ISO 2631-1 (1997) related to the role of posture on both comfort and health effects.

2. Posture and Comfort

Various evaluation methods have been proposed to quantify the subjectively perceived vibration comfort from the physical quantity of vibration. Current standard ISO 2631 considers the effect of vibration characteristics (frequency, magnitude, direction, etc.) on comfort and tries to establish a relationship between subject comfort and vibration dose value based on experimental lab data. However, it has been suggested that current evaluation methods cannot accurately predict the ride comfort, especially under practical field validation conditions. In part this may be explained by the fact that there are many uncertainties when applying the current evaluation methods to predict ride comfort: 1) variation on measurement locations used for comfort evaluation. The Standard falls short of providing guidance as to the most appropriate motion measures for comfort prediction. Different measurement points should be suggested by the standard, since establishing appropriate measurement points is crucial for representing the vehicle and passengers' six degrees of freedom motion, to facilitate comparisons across studies and comfort prediction; 2) appropriate objective and subjective measures that provide a better prediction of vibration comfort, considering the precision, repeatability, accessibility, and their mutual (cor)relations; and 3) the impact of body movement, posture, and secondary activity on comfort evaluation. The use of head-mounted sensors has relevant advantages also in the quantification of comfort and on the possibility of quantifying the difficulty in reading, writing or using a laptop, that is strongly influenced by both vibration frequency and acceleration amplitude.

The influence of the posture of the legs and the vibration magnitude on the dynamic response of the standing human body exposed to vertical whole-body vibration has been investigated (Matsumoto and Griffin, 1998, 2003; Subashi et al, 2008; Kiiski, et al., 2008; Tarabini et al., 2013). Studies suggested that the main resonance frequencies of the apparent masses at 1·0 ms^{-2} r.m.s. differed between postures: with 5.5 Hz in the normal posture, 2.75 Hz in the legs bent posture and 3.75 Hz in the one leg posture. Research into vibration discomfort induced by lateral and vertical vibration on standing subjects indicates that for vibration at horizontal direction and at frequencies between 0.5 and 3.15 Hz, discomfort was similar when the vibration velocity was similar, whereas at frequencies above 3.15 Hz, discomfort was similar when the vibration acceleration was similar (Thuong and Griffin, 2011a, b; Shibata, 2015). More importantly, with frequencies below 3.15 Hz, the subjects experienced problems with their stability, whereas at higher frequencies vibration discomfort was mostly experienced from sensations in the legs and feet. Further research on postural stability has demonstrated that at the same velocity between 0.5-2 Hz lateral vibration, postural instability was almost independent of the frequency of oscillation (Sari and Griffin, 2014). It is concluded that r.m.s. measures of acceleration are insufficient to predict the postural stability of walking passengers exposed to mediolateral oscillations and that peaks in the oscillations should also be taken into account (Ayık and Griffin, 2019).

The results suggest that the responses of seated and standing people are similar with vertical vibration, but differ for horizontal vibration, partly due to greater instability in standing. The frequency weightings currently proposed in ISO 2631-1 for comfort evaluation have been greatly influenced by research based on seated subjects, studies have shown that the weightings are inconsistent with the experimentally determined frequency-dependence of discomfort caused by horizontal vibration on standing subjects. The discomfort experienced by standing subjects will increase the instability which is an important factor contributing to the health and safety, specific guidance is required on stability/balance under the motion environment.

3. Posture and health effects

While the adverse effects of vibrations transmitted to the whole body through the seat are well documented in the scientific literature, at the moment, the effects of vibration on standing and walking subjects (known as Foot Transmitted Vibration, hereinafter FTV) or on recumbent subjects have only marginally been considered. To date, epidemiological data has not classified FTV independently from WBV and published exposure data have not been reported for worker exposure to FTV. However, several worker categories are exposed to FTV, but to our knowledge there are just 2 studies on the vibration-induced white finger. ISO 2631-1 standard states that health effects are related only to seated persons, as the effects on standing, reclining or recumbent subjects are not known (clause 7.1, first paragraph). Laboratory studies evidenced the great effect of not only acceleration levels, but of jerk levels as well on posture and the transmission via the spine to the different body segments and jerk should therefore be included in the metrics for the evaluation of the health effects. As noted, ISO 2631-5 only deals with part of these effects.

The effect of frequency is important too. The low-frequency vibration transmitted to standing subjects may lead to motion sickness, while the vibration alters the patterns of standing (posture) and walking (gait) subjects, increasing the risk of musculoskeletal disorders and falls (Chadefaux et al., 2021; Moorhead et al., 2021). The high-frequency vibration transmitted to standing subjects through the feet may lead to toes vascular disorders, with greater similarities with HAV rather than with WBV.

Although frequency weighting can be used to predict high frequency effects crucial in single shocks, in public transportation jerk is also considered in certain criteria. The latter offers the advantage of defining simple limit values, rather than applying the more complex frequency weighting as applied in ISO 2631-1.

Currently, the ISO 2631-1 mainly focuses on the musculoskeletal effects of the WBV on sitting, supine and standing subjects; neither vascular nor neurological effects are considered. The frequency limitation (0.5 - 80 Hz for health and 0.05 to 0.5 Hz for motion sickness) should be revised. In particular, considering the anatomical, biomechanical and occupational exposure symptoms similarities between the hand and foot, also the upper frequency of 80 Hz should be increased. Literature studies (Goggins et al., 2019a,b) evidenced that the toes resonance occurs at frequencies between 90 and 160 Hz; the values are larger than the fingers resonance frequency (10-60 Hz) and suggests that the measurement chain for FTV should be at least similar to the one used for HAV and to extend the upper frequency limit to 2000 Hz. Furthermore, also vibration with frequencies between 0.5 and 1 Hz also have the potential to induce motion sickness.

The location of sensors is also an open issue: placing sensors inside the shoes would have relevant advantages for the assessment of risk related to vascular pathologies deriving from FTV exposure, while locating sensors at the abdomen would better quantify the gait alteration deriving from the exposure to medio-lateral vibration.

5. Discussion and conclusion

To date, we do not have sufficient guidance and insight on the impact of standing and more research is required in this field. In particular, related to comfort, future research should focus on the definition metrics related to the perceived discomfort in different body areas, derived from experiments performed on a large population, and should be specific for standing subjects (not derived from sitting ones and adapted with coefficients kx, ky and kz). This may lead to the definition of new frequency weighting functions. The comfort might be related to quantities not derived from the RMS of the vibration but may depend on the acceleration peaks, jerk or other quantities. The instability experienced with standing/walking passengers should be taken into account and this will contribute to the overall riding comfort but may also lead to serious health and safety risk. Regarding health effects, our understanding is limited to foot pathologies or to low back pain, depending on the stimulus frequency. In the field of FTV it is necessary to extend studies performed on the hand (vibrotaptile perception, cold response) to the foot.

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A method to improve seating comfort based on 2-D pressure sensitivity distribution

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ABSTRACT

To explore more comfortable seating, we confirmed the comfort of the body pressure distribution which passengers felt uniform pressure. Firstly, we measured two-dimensional pressure sensitivity distributions at the buttocks to the thighs using three types of experimental seats and obtained equivalent pressure functions for each measurement point based on Stevens' power law. The results suggested that the pressure sensitivity changed depending on the presence or absence and intensity of pressure around the sensitivity measurement area. Next, we calculated the body pressure distribution such that the sensory intensity was theoretically constant using the equivalent pressure functions and reproduced it on our original experimental seat to confirm the actual comfort. The results of the subjective evaluation showed that the pressure distribution was felt more uniform, and that the seating comfort was improved compared to a standard car seat.

KEYWORDS

Seating comfort, Body pressure distribution, Stevens' power law

Introduction

The pressure distribution on the seat surface (body pressure distribution (BPD)) is widely used as an index for comfort evaluation, and in seat design, the shape and hardness are adjusted to avoid severe pressure concentrations that cause strong pressure feeling and pain on the seating surface. However, the optimal BPD is not fully understood.

Yamazaki et al. (1992) and Hirao et al. (2022) seated experimental participants on vehicle seats with the seat surface cut in half in the front-back direction, and measured pressure sensitivities along the femur by applying pressure with a rubber ball to the lower surfaces of the buttock and thigh of the half body not in contact with the seat surface. Vink et al. (2017) measured pressure sensitivity during seating using an experimental seat with a seat surface and backrest made of a plate with a number of 20 mm diameter holes for pressure measurement.

On the other hand, it has been reported that sensory intensity varies with the size of the applied pressure area (Goonetilleke & Eng(4)). Since the pressure during the experiments in the studies mentioned above was significantly different from that when seated on a soft seat, it is unclear whether the measured BPD is suitable for evaluating automobile seats.

In this study, we measured the two-dimensional pressure sensitivity distribution in the buttocks and thighs under the BPD similar to that of actual seating, using an experimental seat in which the BPD, the seat surface shape, and spring constant during seating can be freely changed. And based on the results, we created a BPD that provides a uniform pressure feeling across the entire seat surface to evaluate comfort.

Method

Equivalent pressure function

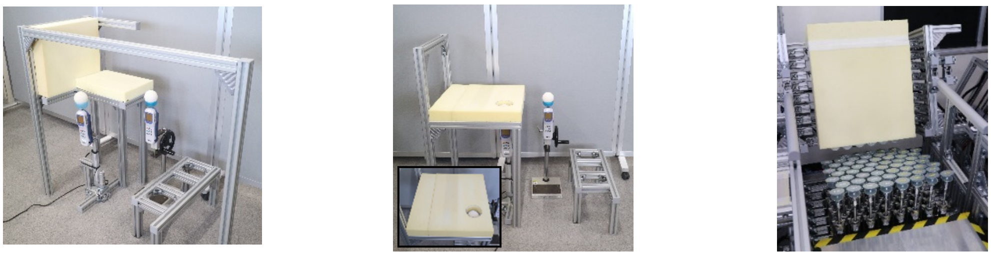
It is known that the relationship between the intensity of a physical stimulus and the perceived intensity of the stimulus follows a power law (Stevens (1957)). In this study, instead of having the participants directly report the sensory intensity, we applied a specified pressure to the reference site, measured the pressure at the evaluation point that produced an equivalent pressure sensation (subjective equivalent pressure), and obtained the following equivalent pressure function using the measurement data.

$$\phi_{REi} = k_i \phi_{EQi}^{a_i}$$

where ϕ_{REi} : pressure at the reference point relative to the pressure at evaluation point i, ϕ_{EQi} : subjective equivalent pressure at evaluation point i, k_i : constant at evaluation point i, a_i : power index at evaluation point i.

Experimental seats

Figure 1 shows the three types of experimental seats used in this study. In Seat 1, a 50 mm-thick polyurethane foam pad was placed only on the left leg side, and the right leg side was seated in the same way as in the previous studies (Yamazaki et al.(1992) and Hirao et al.(2022)), and the pressure sensitivity was measured by applying pressure to the reference and measurement positions with a rubber ball from the bottom. Seat 2 was made of a 50-mm-thick polyurethane foam pad. The seat was made of polyurethane foam with a thickness of 50 mm and a hole of 90 mm in diameter on the right leg side, through which pressure was applied to the measurement position. Seat 3 was an experimental seat designed to reproduce the load-deflection characteristics of various seats. The seat consists of 58 air cylinders with a pressure plate of 60 mm in diameter, and the air pressure of each air cylinder and the total volume of the air circuit can be adjusted to generate various BPDs and stiffness. During the experiment, a seat surface was covered with 20 mm-thick urethane foam and a pressure mat LX100 (XSENSOR Technology Corporation, Calgary, Canada) for pressure measurement. The seat was adjusted in advance to obtain the same pressure as that of a standard vehicle seat.



(a) Seat 1 (b) Seat 2 (c) Seat 3

Figure 1. Experimental seats

Reference pressure

As the reference load on the sensory reference position for Seat 1 and 2, the upper limit was set at 20 N (13.6 kPa), which provides a higher pressure sensation than when seated on a standard automobile seat. The lower limit was set at 5 N (7.6 kPa), which provides a clear pressure sensation even at low loads. In Seat 3, sufficient pressure sensation was obtained even below 7.6 kPa, which is equivalent to a 5 N load, so the reference pressure was set to fall within the range of pressure sensation felt when sitting on a general seat (2.5 – 4.0 kPa).

Measurement and evaluation

The sensory reference position was the anterior left thigh, and the sensitivity measurement positions were 12 locations on the right half of the body, from the buttock to the anterior thigh, as shown in Figure 2. In the experiment, subjective equivalent pressure was measured using the adjustment method. From the measurement results, each coefficient of the equivalent pressure function for each evaluation site was identified. Next, the BPD that provides a uniform pressure sensation was calculated using these functions, and the BPD was reproduced on Seat 3 and evaluated for the intensity (weak – strong) and preference (poor – good) of the buttock and thigh pressure sensations using the 9-level semantic differential method to compare seating comfort.

Figure 2. Sensitivity measurement points (12 white dots)

Five healthy males aged 26 to 52 yr participated in the study. They all gave their informed consent to participate in the experiment, which was approved by the Ethics Committee of the Seating Division, NHK Spring Co., Ltd.

Results

Figure 3 shows examples of equivalent pressure functions just below the ischial tuberosity for each experimental seat. The mean reference pressure subjectively equivalent to 10 kPa, which is close to the pressure that occurs at the ischial tuberosity when sitting on a conventional vehicle seat, was 7.48 kPa for Seat 1, 4.74 kPa for Seat 2, and 6.80 kPa for Seat 3. The results showed that the pressure sensitivity varied depending on the experimental seat used.

Figure 4 shows examples of BPDs with theoretically uniform sensory pressure, created using the equivalent pressure functions for Seat 1 and Seat 3. Figure 5 shows the means of the sensory pressure

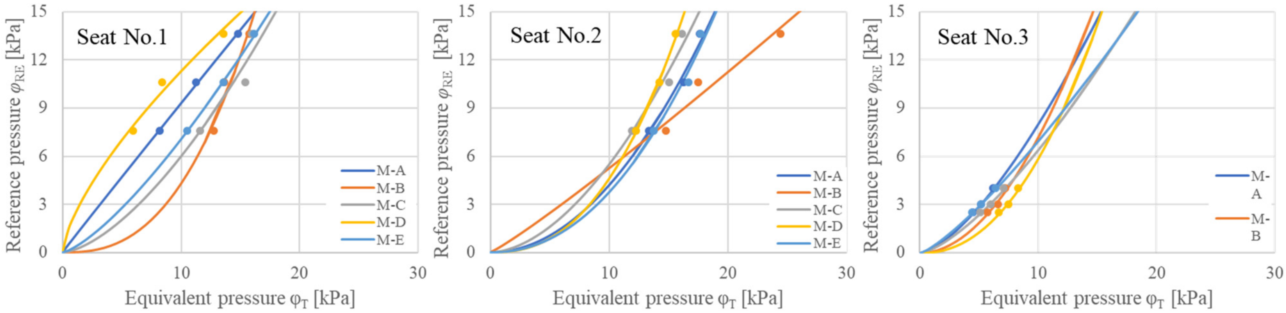


Figure3. Equivalent pressure functions just below the sciatic tuberosity under 3 seat conditions for five participants (M-A ~ M-E)

intensity scores for all participants. The BPDs created from the results of Seat 3 showed a smaller difference in scores between the buttocks and thighs than that of the Seat 1, indicating a more uniform pressure sensation. Next, looking at the means of the preference scores for all participants shown in Figure 6, the BPDs created from the results of Seat 3 had a better feeling of pressure sensation in both the buttocks and thighs than the one created from the results of Seat 1. Furthermore, compared with the results of sensory evaluation using a conventional car seat, the BPDs created from the results of Seat 3 were found to provide a more favorable pressure feeling in both the buttocks and thighs.

Participant： M-B

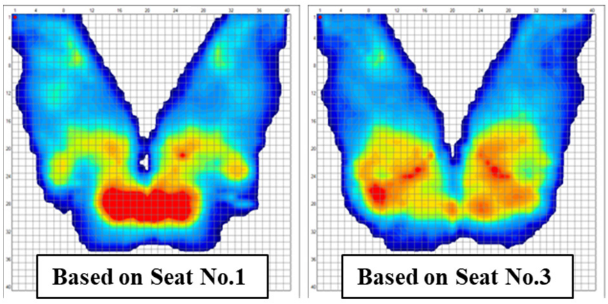


Figure 4. Body pressure distribution with uniform sensory intensity

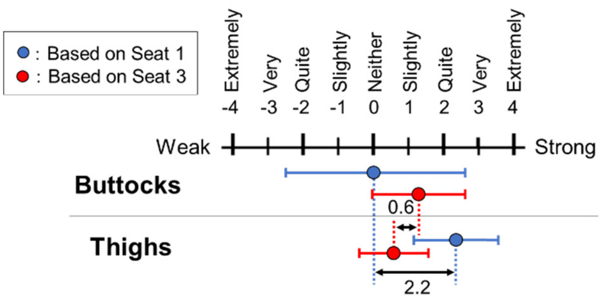


Figure5. Comparisons of means of pressure intensity scores of the unified pressure distribution based on Seat 1 and Seat 3

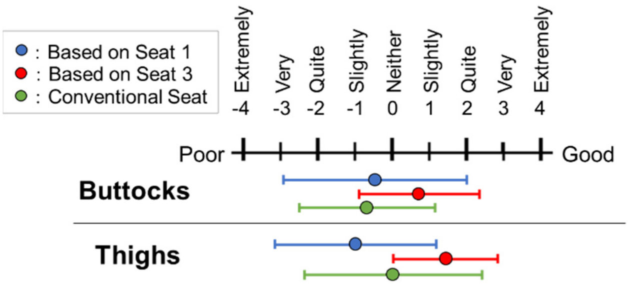


Figure 6. Comparisons of means of preference scores of the unified pressure distribution and a conventional seat

Conclusion

Using three types of experimental seats, we measured pressure sensitivity distributions at 12 locations on a two-dimensional plane from the buttock to the thigh, to create BPDs on the experimental seat that would produce uniform pressure sensations. The pressure sensitivity measurement results suggest that the sensitivity to human contact pressure changes depending on the presence or absence and intensity of pressure applied around the sensitivity measurement area. Next, we evaluated the seating comfort of the BPDs in which the theoretical sensory pressure was uniform, which was calculated using the equivalent pressure function obtained from the experiment. The results revealed that the pressure in the buttocks and thighs is felt more uniform, and that the seating comfort is improved compared to a conventional car seat. In the future, we will measure more data to search for seat characteristics that fit more occupants and verify whether this seating comfort improvement method is also effective in improving seating comfort during long rides.

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A novel experiment to unravel fundamental questions about postural stability and motion comfort in automated vehicles

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THE WORK IN CONTEXT

Automated vehicles (AVs) are one of the major automotive technological developments of the last two decades, due to their associated enhancement of safety, environmental impact and accessibility. Using automation, the driving time can be used for work or leisure creating a demand for high comfort levels. However dynamic driving will challenge postural stabilization and can cause motion sickness when taking the eyes off the road. Multiple theories, such as sensory conflict theory, postural instability theory, and neural mismatch theory, explain the occurrence of motion sickness (MS). These theories are not mutually exclusive but rather complement each other, as indicated by conceptual MS models. However, current state-of-the-art MS models primarily focus on the sensory conflict theory and neglect visual anticipation and postural control. Efforts to incorporate these aspects remain unvalidated due to the lack of proper experimental data. As a result, fundamental questions regarding occupants' postural adjustments (when and how they are activated) in AVs and their impact on MS are unclear. Nevertheless, literature lacks experimental data to unravel all the above, thereby efficient mitigation strategies cannot be designed. Hence, this paper describes an on-going novel experiment to investigate postural stability and motion comfort (ride comfort + MS) in AVs.

KEYWORDS

Biomechanics, Posture, Stabilization, Comfort, Seating.

Introduction

Over the last two decades, automated vehicles (AVs) have emerged as a notable technological progress within the automotive sector. They bring various benefits such as enhanced safety, decreased environmental impact, and improved accessibility. However, AVs envisaged designs can provoke motion sickness (MS) in occupants, jeopardizing their engagement in non-driving related tasks (NDRT), a key driver of their adoption. Yet, insufficient consideration has been given to MS, despite 2/3 of passengers having experienced MS while being driven in conventional vehicles. There are multiple explanations for why MS occurs. According to the sensory conflict theory [1], MS is caused by the mismatch between sensed and anticipated (based on prior experience) sensory (visual, vestibular and somatosensory) inputs. On the other hand, the postural instability theory [2] attributes MS to prolonged uncoordinated motion of the body and its segments. However, this theory has been supported with limited empirical studies. Conceptual MS models [3] propose that these theories are not mutually exclusive but rather complementary to each other. Nevertheless, current state-of-the-art

MS models primarily focus on the vestibular system, neglecting visual anticipation and postural control. Although there have been initial efforts to incorporate head and body dynamics, these attempts still lack validation through proper experimental data especially in dynamic driving scenarios. Despite the profound importance of postural stability on motion comfort, empirical evidence supporting its importance remains limited. This overall lack of understanding leads to the absence of reliable human body models (HBMs) or MS models capable of accurately predicting human body motion and MS accumulation, thus hindering the development of effective strategies for mitigating MS.

To address these gaps, this paper introduces a novel experiment aimed at investigating postural stability and motion comfort (motion sickness and ride comfort) in AVs. Specifically, the experiment is designed to provoke postural instability and MS in an AV while occupants are driven in a realistic environment and engaging in non-driving activities. The overarching objective is to unravel the fundamental relationship between sensory integration, postural control (including body posture and head rotation), and motion sickness, while exploring how occupants control their bodies during expected and unexpected events and under different postures 4]. The current experiment is designed to provide insights into the following fundamental research questions: (1) How are postural control, sensory integration and motion sickness related? (2) How do occupants adjust their body segments and activate their muscles to anticipate and compensate expected and unexpected road events while adopting different postures? (3) To what extent does our human body motion adapt to repetitive and prolonged exposures to self-enhance motion comfort?

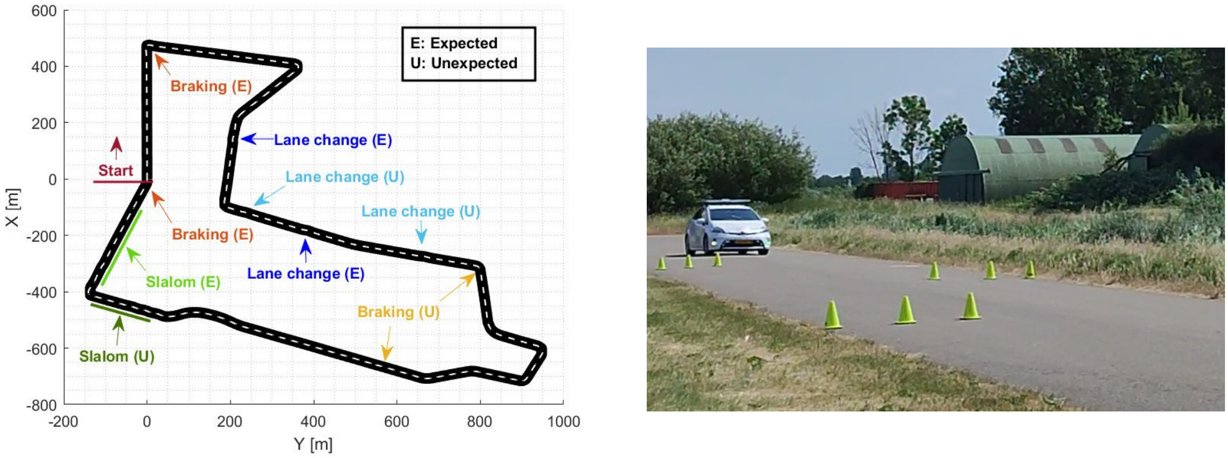
Methodology

To achieve the above, the experiment includes the following driving scenario and testing protocol (equipment, questionnaires, instructions, etc.).

Driving scenario: The driving scenario (Figure 1a) was recorded during manual driving and consists of a 4 km long path including various events, such as slalom, obstacle avoidance with double lane change, and braking. The intention of the manual driver was to generate a naturalistic drive while provoking occupants' postural instability and motion sickness through abrupt and intense accelerations (longitudinal and lateral accelerations of up to 8 m/s^2 and 6 m/s^2, respectively). Both expected and unexpected events were included. Expected events, such as the slalom event depicted in Figure 1b, provided occupants with indications (e.g., cones) to anticipate the event. On the other hand, unexpected events occurred randomly along the path, without any indication given to the participants. Thus, the occupants were not able to anticipate these upcoming disturbances. The expected and unexpected events induce anticipatory and compensatory postural adjustments to the maximum, respectively. During the experiment, the recorded scenario was replayed using the driving robot. The robot accurately tracks the recorded (by the human driver) path and velocity by controlling the vehicle's steering wheel, braking, and accelerating pedals.

Variations: The conditions studied are described in Table 1 systematically varying vision and execution of the NDRT(Variations 1-3) and posture and seat (specials A-C within Variation 4).

Equipment: To capture body kinematics, we use the XSENS suit, which is equipped with IMUs placed on certain body landmarks. The XSENS measures body kinematics, including orientation, angular and linear velocity, and acceleration of body segments. Meanwhile, to validate the data obtained from the XSENS suit, we also use Optitrack, a system that provides ground truth data with high accuracy. The Optitrack setup involves four infrared cameras placed on the front glass of the passenger seat. Wireless passive markers are placed on different body segments (head, torso, and pelvis) to enable precise tracking of body movements in three dimensions. Furthermore, muscular activity (EMG) are recorded. We apply EMG electrodes to measure the activity of specific muscles, including the longissimus muscles (1) in the upper back, trapezius muscles (2) between the shoulders and neck, oblique muscles (3) on the sides of the mid-belly area, and quadricep muscles (4) in the upper front leg. An electrode is also placed to the chest to record the heart rate, allowing us to remove the noise from the EMG data. These sensors provide valuable data on the muscle activation and body kinematics during anticipation and compensation of expected and unexpected events while being driven in automated vehicles.



(a) Path trajectory with the designed expected an unexpected events (slaloms, lane changes and braking)

(b) Our experimental platform Toyota Prius during the slalom event. Cones are used to indicate the upcoming perturbation.

Figure 1. Path for assessing motion comfort while being driven.

Table 1. Visual, task, and posture variations

	Variations			
#	**Vision**	**NDRT**	**Posture**	**Laps**
1	No	Without	Standard	3 Laps x 8 min/Lap
2	External	Without	Standard	3 Laps x 8 min/Lap
3	External	With	Standard	3 Laps x 8 min/Lap
4	External	Without	Special A Special B Special C	3 Laps x 8 min/Lap Different posture per Lap

To understand how postural stability is affected during the ride, displacement of the centre of pressure is assessed by measuring interface pressure between seated participants and the front passenger seat. The interface pressure mapping system (XSENSOR Technology Corporation, Calgary, Canada) is used and consists of two sensing elements that are placed over both the seat pan and back. The contribution of the lower limbs in stabilizing the body during dynamic driving conditions are examined using foot pressure insoles placed in the passenger's shoes. Using this advanced equipment, we are able to determine applied vertical ground reaction forces and analyse anterior-posterior and medio-lateral displacement of the foot centre of pressure. The Smart Eye system is used to measure the gaze and head motion of the participants. This system consists of three infrared cameras placed on the front-most part of the vehicle at different orientations to capture a wide field of view. By tracking the coordinates of eye gaze during the drive, we can gain insights into where the subjects were looking before certain events occurred. This analysis helps us understand when participants identified the events and anticipated them or not, and could provide valuable information on the relationship between optical flow, gaze behavior and motion sickness. Another physiological indicator recorded is the Galvanic Skin Response (GSR), which has been proven to correlate with motion sickness. For this, we have equipped the participants with Mind Media's Nexus 4, connected using BioTrace+ software. This device is capable of measuring skin conductance at a sampling rate of 32 Hz. The electrodes used to measure skin conductance were placed on the index and middle fingers. Lastly, throughout the drive, participants are asked to verbally rate their level of motion sickness using the MISC scale. Ratings are collected every 30 seconds, and a rating of 6 or above indicates a significant level of motion sickness. If participants reach this threshold, the experiment is immediately terminated to ensure their well-being and safety.

Questionnaires: At the end of each variation, the participants are asked to answer subjective questionnaires about motion sickness (MSAQ), body discomfort, and trust (feeling safe or not).

Procedure: Participants were selected based on their body mass index (BMI) to ensure that individuals with excessive body fat, which could potentially affect the quality of electromyography (EMG) measurements, were excluded. Written informed consent was signed from participants, after they were debriefed in detail about the experimental procedure and were familiarized with the sensor equipment. Prior to the experiment, participants were also asked to familiarize themselves with the NDRT (a racing game controlled by tilting a tablet). At the start of each experiment, participants were introduced to the MISC scale and received training on its usage. For ethical reasons, two stopping criterions were considered. In the variations without NDRT, the experiment was immediately terminated if a participant reported a score of 6 or higher on the MISC scale, indicating severe nausea. At the same time, in the variations with the NDRT, the participants paused the NDRT when reported a score of 4 on the MISC scale until they return to 2. Participants had the right to request the termination of the drive at any time, without the need to provide reasons. Taking into consideration the Helsinki Declaration, written consent, data collection procedures, and respect for participant privacy were all adhered to ensure the research was ethically acceptable. The procedure was recognized and approved by the Human Research Ethics Committee of the Delft University of Technology (HREC), under application number 3111.

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Motion Sickness Symptoms in Underwater Robot Operator in Low Visibility Environment

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ABSTRACT

This study focuses on motion sickness of underwater robot operators caused by operating the robot in low visibility environments. The low visibility of underwater environment leads to operational challenges for operators. We hypothesized that one of these challenges is presumed to either originate from or contribute to the difficulty in maintaining their gaze fixation. Therefore, we proposed using a fixation point on the center of the display to reduce the strongness of motion sickness symptoms during operating the underwater robot. To simulate the low visibility environment, a digital semi-transmittance filter overlaps the camera images. In an experiment, i.e., five participants controlled an underwater robot in the low visibility environment, we found that the participants' motion sickness symptoms decreased in condition with the fixation point compared to condition without fixation point.

KEYWORDS

Underwater Robot, Motion Sickness, Visually Induced Motion Sickness, Fixation Point of View

Introduction

In recent years, demand for fish reef and facility surveys by using wired or remotely controlled underwater robots is increasing (Bingham et al. 2010; Maslin et al. 2021; Hotta et al. 2023). However, the onset of motion sickness in underwater robot operators may decrease their operating performance and increase the risk of accidents. Many studies focused on motion sickness moldering and its improvement methods for boat crews, car drivers and passengers (Wertheim et al. 1998; Wijlens et al. 2022). However, as far as the authors are aware, no comprehensive studies have been conducted to investigate the onset conditions, underlying mechanisms, and mitigation methods of motion sickness during the operation of underwater robots. It is important to consider various potential factors, including body motion such as swaying with a boat or ship, visual stimuli from a monitor, and control of the underwater robot. Among these various complex factors, the present study primarily focuses on the visual stimuli from a monitor. The low visibility of underwater environment leads to operational challenges for operators. One of these challenges is presumed to either originate from or contribute to the difficulty in maintaining their gaze fixation. We consider that visibility of the images affects the severity of motion sickness. In addressing this issue, Webb et al. (2002) reported that the gaze fixation as a potential solution could reduce motion sickness symptoms when the optokinetic stimuli received. Therefore, we proposed using a virtual fixation point placed on the monitor to reduce the motion sickness symptoms of underwater robot operators. To verify the proposed method, a within-subject experiment was conducted with controlled visibility conditions.

Method

In this experiment, a BlueROV2 underwater robot was used in an indoor pool (W5.4 x D2.7 x H1.6 m) at Nara Institute of Science and Technology, Japan. The underwater robot communicated with the control computer through a tether cable. The BlueROV2 was equipped with a front-facing camera that enabled the transmission of captured images to the control computer. To ensure that the participants did not have direct visual observation of the robot's motion, they were positioned at a distance from the pool. A 15.6-inch laptop was utilized as the control computer. The Sony DualShock 4 was employed as the control interface for the robot. The participants were able to control the underwater robot and perform various maneuvers, including surge, heave, sway, and yaw rotation.

To simulate the different visibility levels of an underwater environment, we superimposed a digital filter in the RGBA color space onto the camera's image. This filter allows for adjustable transparency levels, ranging from 0 to 255. To identify the conditions most likely to cause motion sickness due to visibility, we conducted an examination. We utilized four green color filters (r=0, g=255, b=100) with different transparency levels: 41% (a=150), 22% (a=200), 14% (a=220), and 6% (a=240) which are shown in Fig. 1. In our statistical analysis of motion sickness symptoms reported by the 11-point Misery Scale (MISC) (see Fig. 2) from four participants, i.e., the median of the accumulated MISC of the four participants during 10 mins operating the underwater robot and 5 mins rest, we observed relatively intense symptoms when they operated the underwater robot for an object searching task with the filter's transparency level set to 14% (see Fig. 3).

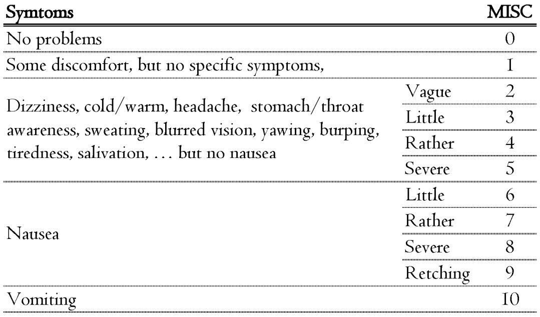
(a) 41% (a=150) Median($MISC_{sum}$)=2.5

(b) 22% (a=200) Median($MISC_{sum}$)=7.5

(c) 14% (a=220) Median($MISC_{sum}$)=9.0

(d) 6% (a=240) Median($MISC_{sum}$)=4.5

Fig. 1 Conditions of translucent filter. Condition (c) was used in the experiment.



Symtoms		MISC
No problems		0
Some discomfort, but no specific symptoms,		1
Dizziness, cold/warm, headache, stomach/throat awareness, sweating, blurred vision, yawing, burping, tiredness, salivation, … but no nausea	Vague	2
	Little	3
	Rather	4
	Severe	5
Nausea	Little	6
	Rather	7
	Severe	8
	Retching	9
Vomiting		10

Fig. 2 MIsery SCale (MISC) (Bos et al 2005)

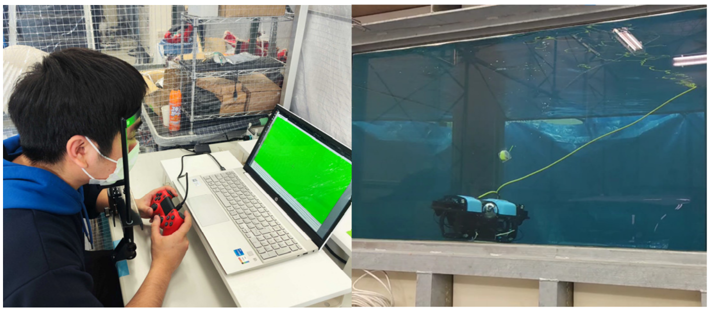


Fig. 3 Scene of the experiment: a participant controls an underwater robot to search an object.

Therefore, we conducted an experiment with five other participants using the 14% filter to assess the effectiveness of reducing motion sickness symptoms for underwater robot operators through a fixation point. Specifically, two experimental conditions were set, i.e., w/ fixation point and w/o fixation point (see Fig. 4). In each condition, participants were instructed to place their heads on a head fixture to restrict head movement while controlling the underwater robot for an exploration task in 10 mins. After that, they got 5 mins to rest. During the total duration of 15 minutes, participants reported their motion sickness symptoms every minute using MISC scores (see Fig. 2). Each condition was administered with intervals of approximately 24 hours or longer to minimize the possibility of order effects. It is important to note that the experiment was immediately terminated if participants reported a MISC score of 6 or higher.

(a) without fixation point

(b) with fixation point

Fig. 4 Conditions of fixation point.

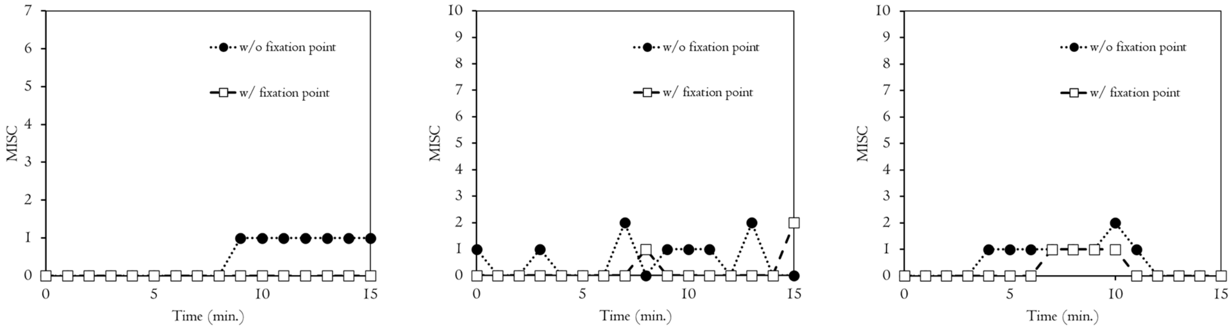
Result

To assess the impact of the underwater robot operator on motion sickness symptoms, the MISC results for each condition, i.e., w/ fixation point and w/o fixation point, were compared among five participants: #1, #2, #3, #4, and #5. Figure 5 (a) to (e) shows the results of MISC score reported in each minute under those two conditions. In Fig. 5 (a) to (e), the vertical axis represents the MISC scores, and the horizontal axis indicates the timeline. To provide a clearer comparison between the MISC results under the w/ and w/o fixation point conditions, the average MISC scores over time were calculated for each trial. Figure 5 (f) shows the average MISC score of each participant.

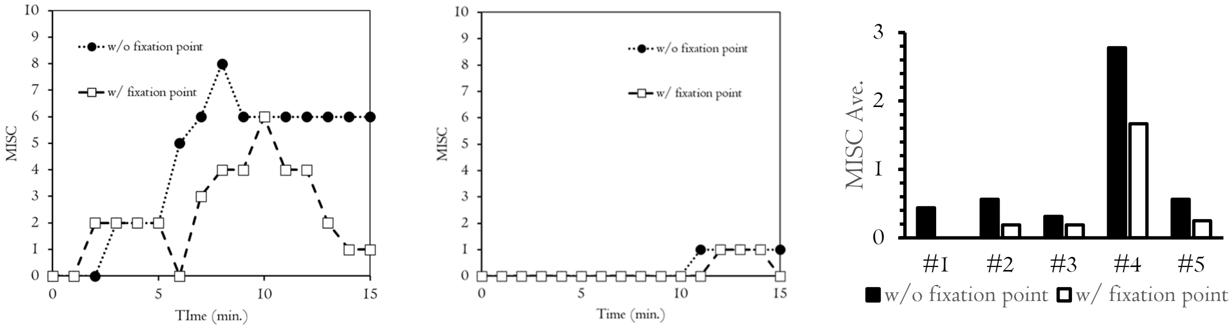
Discussion

From Fig. 5 (a) to (e), we found that there are individual differences in the onset time of motion sickness symptoms and maximum MISC scores among participants. For instance, participants #2 and #4 reported the onset of their first motion sickness symptoms, indicated by a MISC score of 1, earlier than participants #1 and #3. Furthermore, participant #4 reported a MISC score of 6 at the 7th minute, leading to the termination of the experiment. Within the following minute, the MISC score continued to rise, reaching a maximum of 8. As a result, the maximum MISC score of 8 reported by participant #4 was notably higher than the maximum MISC score reported by participants #1, #3, #2, and #5. From Fig. 5 (f), comparing the average MISC scores, w/ fixation point of view exceeded w/o fixation point of view. Across all conditions, the MISC exhibited an ascending trend during the task, but in experimental participants #1, #2, #3, and #4, a decline in MISC persisted even after task completion.

Figure 5 (f) illustrates a comparison of the average MISC scores between participants controlling the underwater robot with and without the fixation point. It was found that the average MISC scores decreased when the fixation point was used. This demonstrates that the presence of a fixation point helped mitigate motion sickness in the participants.



(a) MISC score of #1 (b) MISC score of #2 (c) MISC score of #3



(d) MISC score of #4 (e) MISC score of #5 (f) Average MISC scores of each participant

Fig. 5 MISC scores reported from 5 participants. The (a)~(e) show the progress of each participant's MISC on the timeline. The (f) shows the average MISC scores of each participant.

Conclusion

The present study can be regarded as the first systematic experimental study on motion sickness during the operation of underwater robot. In addition, this study first showed that there exists a potential risk of motion sickness with low visibility for the operation. Moreover, this study proposed a method displaying a fixation point was demonstrated to reduce the motion sickness in underwater robot operators. The method is expected to contribute to the reduction of the operator's burden and increase work efficiency in tasks with remotely operated underwater robots.

Acknowledgments

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Guidelines for adapting the vehicle interior for comfortable smart phone use.

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ABSTRACT

Passengers often use a smartphone while traveling in the train, airplane, bus, and perhaps in the future in the automated driving car. Ideally, future designs should support this smartphone use to prevent discomfort. The smart phone is often used with two elbows on the armrests. However, the armrest height could be too low and cause neck flexion. This study focuses on a guideline for the appropriate height level of the armrest while using the smartphone. Participants performed four main smart phone activities: listening to music, texting, watching, and reading on the phone in a train seat. The anthropometric data, and the neck, trunk, and elbow ankle were recorded. Based on these data the height level of the armrest was calculated. The results show that the height level of the armrest should be adjustable between 184-295 mm. above the seat pan. If there is no possibility to make it adjustable 243 mm is advised. Future steps could be the design and mechanism of the armrest, or another tool that can help to hold the smartphone.

KEYWORDS

Comfort, seat, armrest, smartphone, passenger

Introduction

Smartphones have become an inseparable part of our daily lives. People use it for many different purposes, such as, talking to someone, chatting, listening to music, reading or watching videos (Udom booyanupap et al., 2021). Observations by Kilincsoy & Vink (2018) showed that 48.3% of train travellers used a smartphone, and the study by Udomboonyanupap et al. (2021) reported that 57.4% used a smartphone. This growth in the use of mobile computing devices might have comfort and health implications. When people use a smartphone, they usually stress their upper body (Groenesteijn et al., 2014). The upper, lower arm, wrist, and fingers could potentially get overused, due to holding the smartphone for a long period of time (Honan, 2015). The head is bent forward when people use a smartphone on the lap, which could increase neck discomfort and eventually pain compared with holding the smartphone in front of the head by leaning the arms on an armrest resulting in a more upright position of the head. Some studies report even 7 hours of use of mobile devices during the day (Damasceno et al., 2018). Using the smartphone for an extended period of time can lead to more pain and fatigue, as described by Kim & Koo (2016). Redesign of the vehicle's interior might be useful to prevent these problems to some extent. Previous anthropometric data (Dined, 2004) are based on the height level of the armrest measured by the elbow height above the seat pan with a 90 degrees angle. However, the posture of the passengers while traveling is more reclined. The angle of the trunk and elbow influence where the armrest should be positioned to give support to the elbows. In the literature it is not reported yet what the armrest height should be to support smart phone use. To support the redesign of vehicle interiors (like trains, buses, cars and airplanes), armrest design guidelines could be helpful. The main goal of this research is to study the elbow and the neck postures of the passengers while performing various activities on a smartphone on the seat with the aim to provide guidelines for interior design supporting comfortable smartphone use.

Method

Thirteen female and fifteen male aged between 22 to 25 years volunteered to join the experiment. Their stature varied from 155 to 191 cm. Their nationalities varied (Thai, Italian, Dutch, Spanish, Chinese, Greek, and Colombian, Mexican/Peruvian, Taiwanese, and United State Dominican Republic). They had no musculoskeletal disorders or injuries in the last 6 months. Their elbow rest height at 90 degrees of upper arm and lower arm ankles were 17.91(P5) to 20.89(P95) cm, respectively.

After arriving at the lab, the participants were informed on the protocol and signed the informed consent. After that, they were asked to sit in the train seat. Fourteen participants were sitting in the seat and used the smartphone to perform four activities: listening to music, texting, watching and reading on the phone as these were the most observed activities in a previous study (Udomboonyanupap et al., 2021). While the other fourteen passengers started by reading, followed by watching, texting, and listening to music. They performed each activity for 15 minutes. After completing the test, the anthropometrics was measured as presented in table1. During the session the video recorded laterally on 2 sides of the seat to define body angles, such as, the neck, trunk, upper arm angles. The angle between the trunk and the elbow, and the neck angles were recorded by the video camera.. For each activity the pictures of the postures were recorded while holding a smartphone at the 1, 7.5 and 15 minutes (using Kinovea program version 8.5) as shown in figure 1. The position of the armrest was recorded as well. Based on these data, the elbow height was calculated by using the equation ((the shoulder sitting height*sin (angle)) - (elbow sitting height* sin(angle)). From DINED the P5, and P95 percentile of shoulder sitting height were derived (532 to 664 mm.) and the elbow sitting height (203 to 301 mm.). These data were confirmed the normality test. After that the P5 and P95 of the armrest height were calculated. Moreover, the descriptive statistics (percentages) were used to explain the neck flexed and the armrest used.

Fig1: The trunk, elbow, neck ankles calculation

Results

This research aimed to develop the guidelines for the armrest design while the passengers using a smartphone to increase their comfort. The previous publication showed the anthropometric data with the ninety degree of the elbow and the trunk ankles (Dirken et, al, 2004). However, the passengers in the train seat and using the smartphone had different angles than the ninety degrees. This experiment conducted with the three main activities (Listening to music, Texting, Watching, and Reading) while people holding a smartphone on the train seat (Udomboonyanupap S., 2021). The angles of the trunk and upper arm are shown in table 2. The activity listening to music is not seen as relevant for defining the arm rest height as the elbows are usually not on the armrests. For watching a video, a holder at the backrest is preferred. Therefore, the armrest height is based on the other two activities texting and reading. The sinus of the maximum and minimum trunk angle varies between .69 and .98. The sinus for the upper arm varies between .56 and .98. The p5 shoulder height sitting (Dutch adults 20-60 mixed 2004) is 538mm. and the upper arm length 335mm. This means for the smaller persons and largest angles the arm height should be: .69x538-.56x335=184mm. and for the p95 and smallest angles (close to vertical) .98x664-.98x363=295mm. This means that the armrest should be adjustable between 184 and 295mm. (figure 2). It is interesting to see that for all activities the average trunk angle is approximately the same and that is true for the upper arm angle as well. The average trunk angle is in all activities around 62 degrees and the average upper arm angle is 55 degrees. Combining this with the p50, the average arm rest height is 243 mm.

Table 2: the recorded angles of the trunk and upper arm of the 28 participants

Activities	**trunk angle**			**upper arm angle**			**trunk**		**upper arm**	
	Min.	Avg	Max.	Min.	Avg	Max	sin min	sin max	sin min	sin max
Listening	46	61	85	30	54	81				
Texting	44	62	78	34	56	75	0.69	0.98	0.56	0.97
Watching	39	63	126	30	55	88				
Reading	50	63	80	36	55	80	0.77	0.98	0.59	0.98

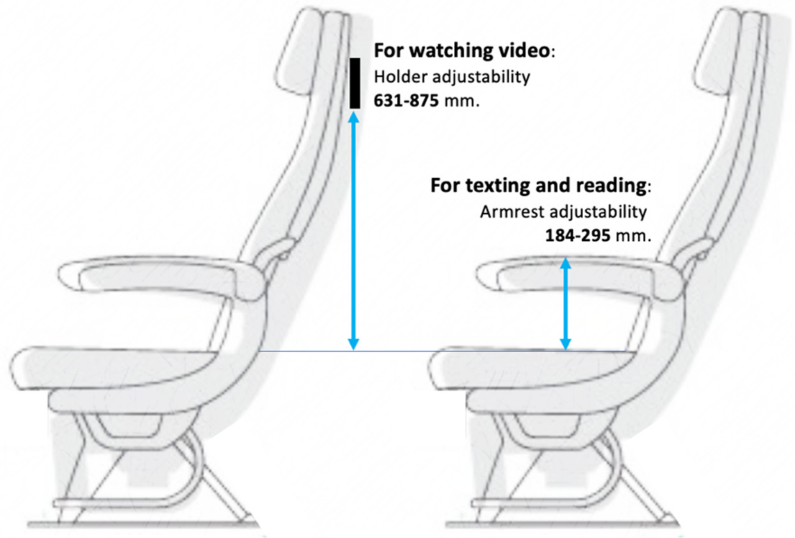

Fig 2: Guidelines for adapting the interior design for comfortable smart phone use.

For watching video, a smartphone holder should be set up at the eye height levels. The recommendation of the international people referred from Dined database showed that 5, and 95 percentiles of the eye height levels from the above of the seat pan are 631, and 875mm., respectively. However, an average eye height level of the smartphone holder for watching activity is 753 mm.

Discussion on the guideline

Based on these data the guideline for using a smart phone differs per activity. For listening to music no guideline is needed as the smart phone is not linked to the eyes and hands and can be placed anywhere. For watching a video the hands are not linked to the smart phone and this study does not give clues. Perhaps it is better to base the guideline on the study of Smulders et al (2019). In this study a viewpoint (middle of the screen) between 0-15 degrees under the horizontal line through the eye is defined based on studies of Delleman et al. (2004) and Psihogios et al. (2001). Suppose we use the 0 degrees, then for a 30"pitch (760mm) aircraft seat and a smart phone with a width of 75mm the lowest point of the holder should be at the height 718mm above the seat pan for p5 and 872 mm above the seat pan for p95 (DINED, 20-60 male and female). For the tasks texting and reading where hands are on the smart phone and persons have to watch on the screen the armrest should be adjustable between 184-295 mm. above the seat pan. If there is no possibility to make it adjustable an armrest height of 243 mm above the seat pan is advised.

These guidelines are based on observations of 28 participants, anthropometric data of other persons in DINED in combination with literature. This means that verification is needed. It is advised to perform future empirical research to test the guidelines in practice and compare these with other conditions. Another limitation of this study is that privacy is not considered. It might be that postures are different trying to avoid that the neighbour is following your smartphone activities. The seat design in our case had only one armrest in the middle between two seats, and the elbow breadth was rather wide which could have influenced the postures. Future studies should be focused on how to design the arm support as the hardness could also influence the comfort. Also, the actual size, the mechanism of the adjustment and cover and cushion materials should be studied.

Conclusion

The vehicle interior can be improved to prepare for smartphone use. In this paper an indication for a guideline is made based on observations, anthropometric data and literature. This guideline is a first indication to help improving the interior. For watching a video the height of the holder on the backrest in front of the person should vary between 718-872 mm above the seat pan. For texting and reading is the armrest should be adjustable between 184 and 295mm. The average trunk angle is in all activities around 62 degrees and the average upper arm angle is 55 degrees. Combining this with the p50, the average arm rest height is 243 mm.

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Clear preference for a seat and almost no difference in comfort: the basics for further development of an aircraft seat

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ABSTRACT

Passenger space in long haul flights is limited, but by using the vertical space, more personal space can be created. In this study a new concept of an aircraft seat making use of the vertical space in the aircraft cabin was tested. The research question is whether passengers see and experience the advantage and experience differences in comfort. To test the potential, 29 participants were asked to sit for 40 minutes in the new and in a traditional aircraft seat. Every 10 minutes they were asked to fill in a questionnaire regarding comfort and discomfort. The Wilcoxon signed-rank test ($p<.05$) was used to check differences of comfort and discomfort scores between different sitting conditions. Afterwards the participants were interviewed on their experience. Only a few significant differences in comfort or discomfort could be found. However, 76% of the 29 participants preferred the new seat and 90% see potential in this seat. It was preferred because of the extra space and the potential to sleep better. A clear preference of the new developed concept was shown. The research also shows that in testing a low-fidelity prototype, results of closed comfort questions provide limited information. On the contrary, answers of open questions and in interviews are essential to gather the users' opinion.

KEYWORDS

Aircraft interior, passenger experience, low-fidelity prototype

Introduction

Improving seat comfort in aircrafts is relevant as passengers' comfort is important to airlines, as it is one of the decisive factors for passengers to "fly again with same airline". Ahmadpour et al. showed that seat comfort is one of the most influencing factors in overall passenger comfort(Ahmadpour et al., 2014). However, due to the limited space, passengers can not move freely and the prolonged sitting time may cause discomfort (Hiemstra-van Mastrigt et al., 2015). To explore whether creating extra space by using the vertical space could provide an acceptable comfort experience, new design 'chaise longue' aircraft seats were made in a previous study (Nuñez Vicente et al., 2021). The design is shown in fig.1. The recline was made possible up to 15 degrees in both the upper and lower row (larger recline angle than current 32" aircraft seats). Footsteps were made to get into the upper row and the neck rest was engineered.

Fig. 1. The CAD model of the new design, left: an overview with mannequins, middle left: recline in the upper row, middle right: showing the sliding of the seat pan backwards, right: showing the neck rest and recline of the lower seat.

To check how passengers experience this completely new way of seating in an aircraft, a test was done. The research questions for this test are: 1) Is the 'chaise longue' using the vertical space in a new way preferred above a traditional aircraft seat positioned at 32" pitch? and 2) Is the comfort and discomfort improved by the chaise longue compared with a traditional aircraft seat positioned at 32"?

Method

To check how passengers experience this completely new way of seating in an aircraft, the prototype was made and a test was done. 29 participants including 15 males and 14 females aged 20 to 49 (28.03 ±6.33) were asked to sit in both seats. The BMI of the participants ranged from 15.78 to 34.15 (23.86 ±4.17). Considering the shortest cruising time of flights is around 40 minutes, the duration of each scenario is set to be 40minutes. The participants were asked to sit 40 minutes in the upper and lower row of the "chaise longue", (see fig. 2) and in the traditional aircraft seat placed at 32" pitch. All three conditions were the reclined conditions. Permission was given by the ethical committee of the TU-Delft. After welcoming the participants, they completed the informed consent and were instructed on where to sit and how to complete the questionnaires. The participants were studied in groups of 3. The order was arranged by the Latin square method. Comfort/discomfort questionnaire and local postural discomfort (LPD) questionnaire (Anjani et al., 2021) had to be completed every 10 minutes in each condition. The comfort/discomfort questionnaire had an 11-point Likert scale (0= no comfort at all; 10= extreme comfort). During the test, the participants were asked to behave just like in an aircraft and they were allowed to use mobile phones and listen to music. After experiencing each condition, participants were asked to have a break to reset their bodies. Sitting during the break time was not allowed.

Fig. 2. The chaise longue prototype used in this test

Results

Fig.3 shows the that the majority (76% of the participants) prefers the chaise longue seat. Also, for reclined sitting, sleeping and watching IFE the chaise longue has most preferred scores. However, for using the smart phone and for in- and egress the majority prefers the traditional seat. Table 1 shows that most participants experience the upper row as spacious and comfortable.

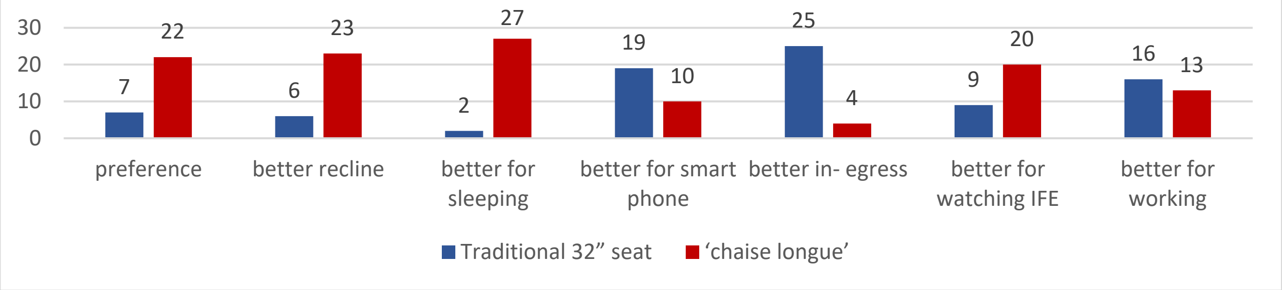

Fig. 3. preference of the 29 participants for the seat after experiencing 40 minutes each seat

Table 1 preference of the 29 participants for the seat after experiencing 45 minutes each seat

	traditional	Upper row	Lower row
more spacious	1	20	8
more comfortable	6	14	9

The open questions and interviews gave more understanding for this phenomenon. Most participants (26 out of 29) see potential in the chaise longue, but they also see the need for improvement. Four mention that much is to be improved, one mentions that the armrest needs to be added, one mentions that the footrest is too high and one that legroom needs improvement. The potential is having more living space creating comfort in a long journey. For the three participants that see no potential in the chaise longue (see table 2), two mention that the seat is inconvenient and one mentions that in- and egress is an issue, claustrophobia could be a problem for the people sitting in the lower row and no windows is an issue as well (while in reality windows might be possible).

Table 2. Points mentioned on the question whether the participant thinks the Chaise Longue has the potential to be the next generation of airline economy seats in the answer no (3 participants)

not convenient	2
high row difficult to access	1
claustrophobia	1
upper row has no window	1

The comfort and discomfort scores during the seating did not differ significantly among the three conditions (see fig. 4). This was surprising as there is a clear preference for the "chaise longue". Fig. 4 shows the change in perceived comfort and discomfort in 40 minutes duration. Most differences were not significant. There is a trend that comfort is not dropping that much in general and the least drop of comfort happens when participants sitting in the upper row reclined seat. No significant difference was found among comfort ratings over 40 minutes. The upper row reclined seat was rated with the least discomfort from the beginning to the end of the test. It is also the only seat has a slight drop at the end of the experiment. A significant difference in discomfort was found between the normal economy aircraft seat and the upper row reclined seat at 30 minutes (p=0.043). Besides, the figures also suggest large standard deviations in the ratings on both comfort and discomfort in three conditions. Few differences regarding scores of the LPD are found. Compared with the discomfort (0.028±0.08) when sitting in the lower row reclined seat, a higher discomfort (0.166±0.306) on the right shoulder was reported when sitting in the upper row reclined seat at the beginning of the test. Another significant difference was found on the right upper thigh of participants between the economy seat (0.161±0.248) and upper row reclined seat (0.075±0.213).

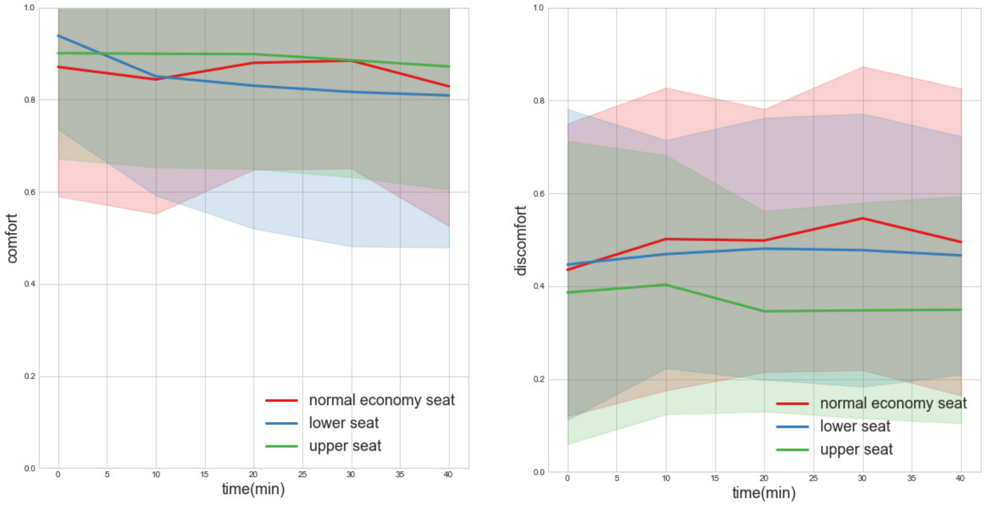

Fig. 4. comfort and discomfort ranking in time (40 minutes), with the standard deviation in a lighter colour.

Discussion & conclusion

The chaise longue is preferred by 76% of the participants and 90% see potential in this seat. However, the effect of comfort and discomfort did not affirm this difference between the chaise longue and the traditional seat. There could be different reasons for this. The participants already mentioned points of improvement, like the addition of armrests and improvement of the leg space. It could also be that the cushions were not optimized for the chaise longue as existing cushions were taken. The cushion is among the top five elements of the seat regarding seating comfort (Bouwens, 2018)(Fiorillo et al., 2021)(Wang et al., 2021).

Lim et al. already showed that the validation of low-fidelity prototyping test results is difficult, because it is unknown whether the results are the effect of the prototype itself or the essence of the design concept(Lim et al., 2006). Therefore, the answers to open questions might be more valuable as these show that participants were able to look beyond the existing low-fidelity prototype, which was far from optimized yet. However, the "chaise longue" concept has a clear potential for giving more personal space and using the vertical volume in an aircraft cabin. Although the comfort and discomfort scores are mostly not significant, a potential for improvements for a better comfort experience is seen in chaise longue, especially the upper row seats. As a design in an early stage, involving users is helpful to find problems and make space for further improvement.

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A case study of the effects of foam properties and support surface on seat pressure distribution

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ABSTRACT

Lightening seat cushions while enhancing seating comfort is a compelling area of research for seat manufacturers. Past studies showed that pre-shaped support could reduce weight and improve comfort. However, the influence of cushion foam properties, including thickness and stiffness, remains relatively unexplored. This case study aimed to address this gap by examining two different foams (softer and harder) with varying thicknesses from 30 to 70 mm using a reconfigurable experimental seat. An eco-class passenger seating on an airplane was simulated. Two types of foam support, one pre-shaped and one flat, were also compared. One short male, one average height male, one tall male and one short female were selected to participate in the experiment. Results show that pre-shaped support significantly reduced the peak pressure and increased the contact area. Big differences in seat pressure distribution were observed between the four participants, suggesting strong effects of sitter's anthropometry. Results also suggest that a harder foam should be used when reducing cushion thickness. Further investigations with a larger sample size of participants and a longer sitting test are needed to confirm the findings of the present work.

KEYWORDS

Seat cushion, pressure distribution, foam thickness, foam stiffness, pre-shaped surface support

Introduction

Today, people spend most of their time seating for transportation, offices, and leisure activities (Le and Marras, 2016). Seat cushions, which bear a significant portion of the body weight (over 65%), play a crucial role in seating comfort. Lightening seat cushions while enhancing seating comfort is a compelling area of research for seat manufacturers. Recent studies by Wang et al. (2021) showed that pre-shaped support could be a solution to reduce foam weight and improve comfort. They compared two new airplane seats incorporating a pre-shaped foam support and an existing seat. The two new seats had better performance in terms of subjective comfort ratings and objective measures, such as peak pressure and number of large postural changes during nearly one hour sitting test. However, the optimization of foam thickness and stiffness in conjunction with the proposed pre-shaped foam support remains an open question.

In a previous study, Franz et al., (2011) developed a lightweight automotive seat by utilizing the contour of the seated human body. The effects of seat material properties, specifically cushion stiffness were not studied. Many other studies (Trewartha and Stiller, 2011; Bui et al., 2017) primarily focused on comparing different existing cushions, rather than investigating specific design cushion parameters like thickness and stiffness.

The primary objective of our study was to optimize the properties of seat cushions with a pre-shaped surface support. More specifically, the effects of foam thickness and foam stiffness on pressure distribution were investigated.

Materials and methods

As a case study, four subjects, representing different body sizes, large-sized male (LM), midsized male (MM), and small-sized male (SM) and small-sized female (SF), were selected. Their body heights were 187, 174, 164, and 150 cm respectively for LM, MM, SM and SF, and their weights were 105.4, 72.8, 69.0 and 55.6 kg. The corresponding BMIs were 30.1, 24.0, 25.7 and 24.7 kg/m2.

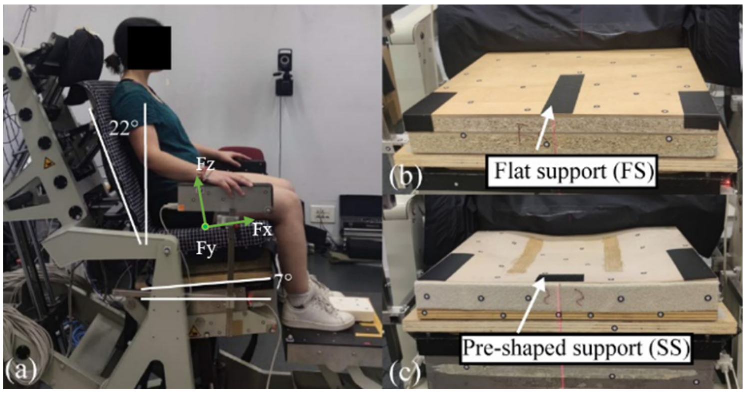

Figure 1. Experimental set-up showing the small sized female participant with the arms resting on the armrests (a). The soft cushions were fixed on two seat pan surfaces, one flat (b) and one pre-deformed (b) with help of double-sided scratches.

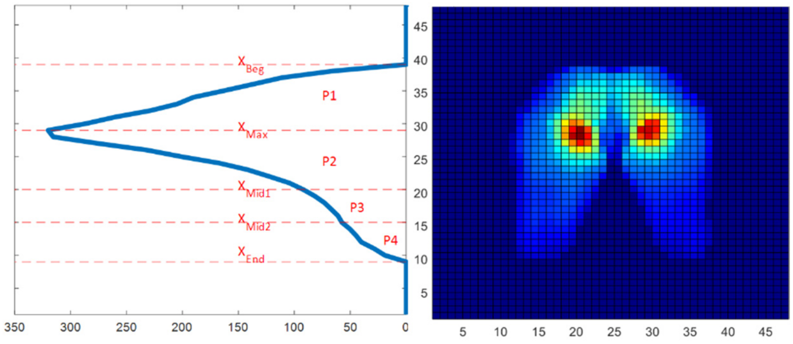

Figure 2 Definition of the four seat pan contact regions (P1 to P4) from the lateral pressure profile of pressure distribution. X_{Beg} is the first row where the buttocks contact the sensor mat, X_{End} is the last row where the thighs contacting with the sensor mat, X_{Max} is corresponding to the row of the peak pressure, X_{Mid1} is the middle between X_{Max} and X_{End}, and X_{mid2} is the middle between X_{Mid1} and X_{End}.

A reconfigurable experiment seat (Beurier et al., 2017) was used to simulate an airplane eco-class passenger seat (Figure 1) with a 7° seat pan and a 22° flat wooden backrest. Two types of foam were chosen: a softer (SF) with a density of 0.0497 g/cm3, and a harder (HF) with a density of 0.0612 g/cm3. Uni-axial compression tests were performed with a sample dimension of 50 x 50 x 50 mm and a loading speed of 100 mm/ min (ISO:2439). For 50% and 80% compressions, the forces were 14.2, 60.7 N and 36.9, 146.8 N respectively for SF and HF. For each foam, five different thicknesses (30 to 70 mm with an increment of 10 mm) were tested. Ten cushions of a same dimension (500 x 390 mm) were thus prepared. They were supported either on a flat (FS) or a pre-shaped (SS) surface which was obtained previously to better distribute the pressure (Wang et al, 2021). Combining them led to 20 different test conditions (5 thicknesses x 2 types of foam x 2 types of support). Trial order was determined as follows: the type of foam support was randomly selected at first, then ten test cushions were tested in a random order for each support surface. To look at the repeatability, the conditions with a 50 mm cushion were performed three times. Each participant performed 24 trials in total. For each trial, participants could adjust the seat height to a comfortable position.

Two sensor mats (XSENSOR, X3 PRO V6, Canada), attached to the seat and backrest, were used to measure the pressure distributions at a frequency of 25Hz. Measurements were made after 2 minutes sitting. Three pressure measurements were made for each test condition corresponding to three upper limbs postures: arms resting on the armrest, hands put on the thigh, and arms in the air. As upper limb posture had almost no effect on seat pan pressure distribution, three measurements were used as repetitions. The average pressure was calculated from these three measurements. Since our primary focus was on the seat cushion, we only analyzed the pressure parameters associated with the seat pan in the present study, including peak (P_max), mean (P_mean) pressures, contact area (A), pressure standard deviation (P_std), maximum (Grd_max) as proposed by Zemp et al., (2016). Furthermore, four sub-contact areas were defined based on the lateral pressure profile (Figure 3). The pressure proportions on these areas (P1, P2, P3, and P4) was calculated. To address potential measurement inaccuracies in pressure, a correction factor (fcorr) was applied using the trial-specific correction method as introduced by Zemp et al., (2016). The correction factors were determined by comparing the integration of the pressure map across the contact area with the corresponding normal force exerted on the seat pan, which was measured using load cells.

Results and discussions

Figure 3 shows the peak pressures (P_max), contact areas (A) and pressure proportions in the frontal thigh area (P4) for all participants and test conditions. Big differences were observed between participants. The small female (SF) had the lowest peak pressures for all test conditions and similar contact areas compared to the small and medium males (SM and MM). Though P_max tended to decrease with increase in cushion thickness, its effect on SF seemed very small.

As expected, the use of the pre-shaped support resulted in a lower peak pressure (P_max) and larger contact area (A) compared to the flat support regardless of participant, foam and cushion thickness. On average, peak pressure reduced from 12.6 to 9.4 kPa while contact area increased from 1190 to 1318 cm2. The frontal thigh area tended to support more pressure compared to the flat surface. On average, its pressure ratio increased from 7.07 to 8.31%.

The softer foam did not always result in lower peak pressure. This was observed for the participants SM and MM when the cushion thickness was less than 50 mm. For LM who had a high BMI, lower peak pressures were obtained for the harder foam especially when the pre-shaped support was used. The observations suggest that a harder foam should be used to reduce peak pressure when reducing cushion thickness.

Increasing cushion thickness tended to reduce the peak pressure and increase contact area. Its effects on P_max were less obvious when the thickness was higher than 50 mm for all participants.

In summary, the present study confirmed that the use of the pre-shaped foam support could reduce peak pressure and increase contact area. However, it also tended to increase the pressure proportion under the frontal thigh area. The results show big differences in pressure distribution between the four differently sized participants, suggesting strong effects of body size. The observations also suggest that a harder foam should be used when reducing cushion thickness. Further investigations with a larger sample size of participants and a longer sitting test are needed to confirm the findings of the present work.

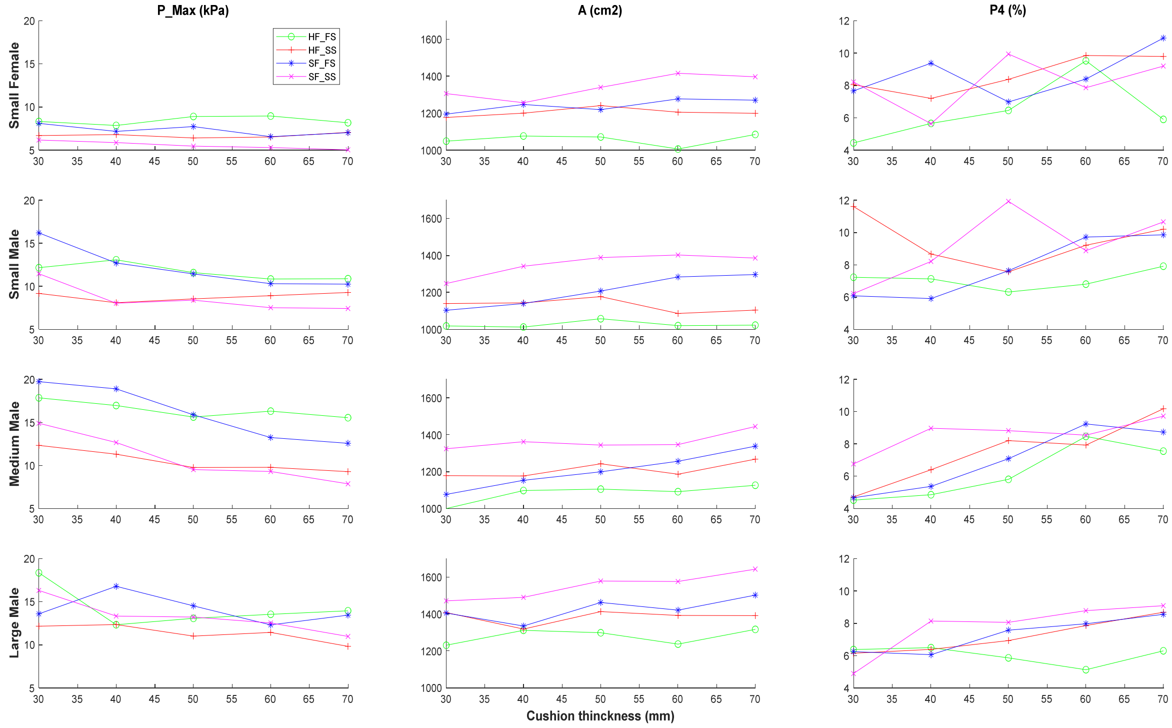

Figure 3. Means of peak pressures (P_max), contact areas (A) and frontal thigh pressure proportion P4 (%) for the four participants and four foam and support surface combinations when varying cushion thickness.

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Comfort of a reclined backrest with less leg space versus an upright backrest with more leg room

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ABSTRACT

In this project a second row of seats in a van is developed which has an extra recline function, but due to this the leg room is reduced. An experiment is done with 20 participants experiencing both seats for 45 minutes. The first results based on analyzing 8 participants show a slight preference for the reclined seat.

KEYWORDS

Back rest angle, leg room, comfort, discomfort

Introduction

In this project a second row of seats in a van is developed that has the same appearance as current ones, but adds extra flexibility, comfort and functionalities. The legislation reduces the design space as the cargo space should have a certain size. For instance, Bpm (=private motor vehicle and motorcycle tax) requirements for delivery vans state that the cargo area is at least 130 cm high over a width of at least 20 cm and over a length of at least 150 cm. Additionally, the front row can not be changed as these are determined by the van manufacturer. However, within the limited space it is for instance possible to add a reclining mechanism. The seat cannot go more backwards, which means that the reclined version of the seat will reduce the legroom. This principle has been applied in aircraft seats (e.g., Cascioli et al., 2011). According to Porta (2019) the minimum seat space should be between 68.1 and 70.1 cm. The relevancy for this research is that we preferably should not go past this value. Reclining could increase the comfort (Vink et al., 2023), but in our case it does reduce the leg room. There is literature which states that there is a difference in comfort and discomfort experience (Helander & Zhang, 1997). Therefore, in this study not only comfort is recorded, but discomfort as well. There is no literature studying the effect on (dis)comfort of improving the recline and reducing leg room.

Therefore, the research question is:

Does a reclined backrest with less leg room meet the same comfort or discomfort as an upright backrest with more leg room?

Method

Twenty participants are asked to sit 45 minutes in the upright seat with 8 cm more legroom and 45 minutes in the reclined seat. The automotive industry usually works with P50 male measurements. The users of the product (van) are usually craftsman, which are generally larger in size, and woman can also be handyman. Therefore, the experiment will be done with both P50-P95 male and females. Relevant anthropometric data were recorded at all 20 participants (Buttock knee depth, popliteal length, hip width, weight, stature and shoe size). The participants are divided into two groups, one starting on upright, finishing reclined and one starting on reclined. Four participants did participate in the somewhat more than 1.5 hour lasting test. The first two regular seats will have a seating angle of 116 degrees and a seat distance from the front of the knee to the back of the backrest of 75 cm. The second two adjusted seats will have a seating angle of 133 degrees and seat room 67 cm (8 cm less leg room). Research has shown that more than 5 degrees adjustment is needed to experience comfort (Helander et al., 2000). Therefore, an adjustment of 17 degrees might be sufficient to feel this difference. The participants will sit for 45 minutes on the first chair, walk 10 minutes and then sit 45 minutes on the other seat. Prior to the test the participants will not be told what will be measured just that they have to sit. There was a separation wall between the two participants to prevent that they would talk as talking influences the comfort (Hiemstra-van Mastrigt, 2015). In figure 1 an image of the user test can be found. The set up is positioned at the Applied Labs of the Delft University of Technology.

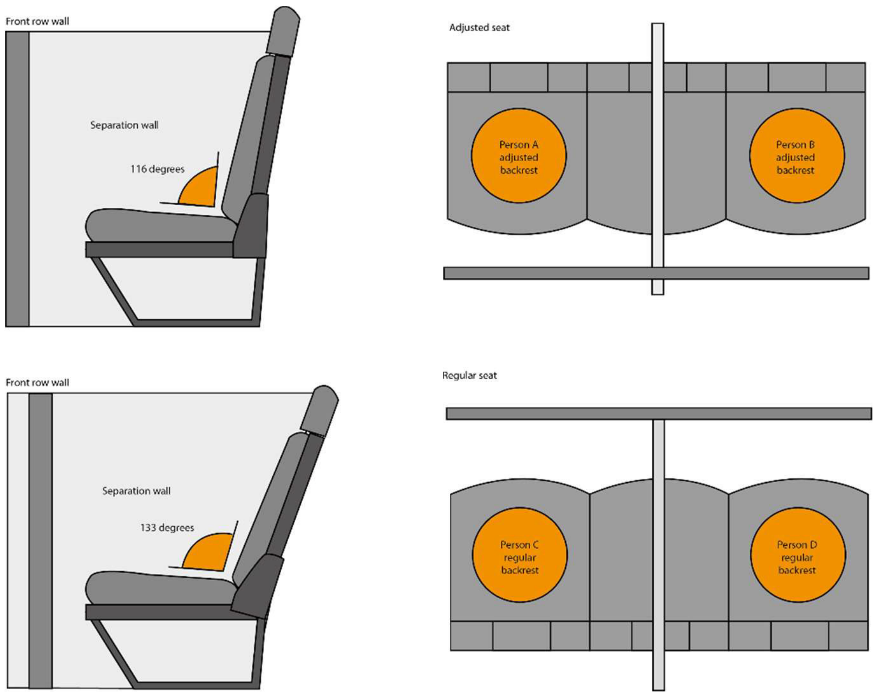

Figure. 1. The test set-up

The participants were asked to complete a questionnaire after 15 min, 30 min and at the end of the experiment (45 min). It consisted of questions on comfort and discomfort and how they feel and how they have experienced the seat. The user was allowed to do what he/she wants like reading or watching a video, but they should do the same activity in both seats. The participants were not allowed to talk to each other. They receive a voucher of 20 euro for participating. First, a pilot test was conducted using people that walked past the set up. In the pilot we measured if people felt which seat, was the reclined seat. Five persons sat down and were asked about the experienced seating angle. A difference was felt, which decided us to continue with the research. The less reduction in leg room was also noticed.

Participants had to rate the comfort and discomfort on a Likert scale 0 to 10. In this paper the preliminary results of the first eight participants will be presented.

Results

The upright seat scored on average lower (6.4 on a scale 1-10)) on comfort and higher at discomfort (6.8). The comments of the eight participants are shown in table 1. One participant did complain about the amount of leg room. This a person with a large buttock-knee length, which could explain the complaint.

Table 1. comments of the participants after the experiment.

upright	reclined
3 out of 8 liked the upright seat	5 out of 8 liked the reclined seat
The upright seat was to upright for me	Less discomfort in the back area, at my neck and feet
Lower back support was better to sit upright.	more comfortable for your back
For short moments I would prefer the upright backrest	Less comfort in shoulders
More room for movements	Relaxed more in the reclined sitting, which is nice for longer periods of time
More support for my lower back (in my opinion)	Too little leg room to enjoy the reclined sitting.
Enough legroom, I was able to choose if I want to sit upright or little reclined	At first the reclined position feels better
The upright position feels wrong at first but saves my back from fatigue	Discomfort up my back leading to more discomfort in the long run

Discussion

The effect of the reclining seems to have a slightly positive effect. The results of the 20 participants still need to be analysed. On average the reclined seat scored higher, but statistical tests are still needed. Other studies also showed an increase in comfort with more reclining (e.g., Vink et al., 2023). Although the comfort is also dependent on the task (Smulders et al. 2016). Further research is needed on this, and conclusions might drawn based on the result of the 20 participants.

Conclusion

This study indicates that a more reclined back rest is preferred and has limited effect on the discomfort caused by the reduced leg room.

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Explorative study for sleep conditions in sleeper trains.

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THE WORK IN CONTEXT

European night trains are being revived as a sustainable alternative to short-haul flights. Besides sustainability, sleeping on the train shows its competitive advantage by improving the perceived value of the efficiency of travel. Therefore, sleep comfort and quality on the night train is one of the keys to promoting the shift. This study aimed to explore the factors that may influence sleep quality in the context of the night train. Prior research was conducted where factors on environment, products, people, and social interactions were highlighted. Based on these findings, an experiment was conducted on a round trip from Amsterdam to Munich. The dimensions of the seats and possible backrest inclination angles were measured. Environmental factors, including sound, noise levels, vibrations, vehicle speed, and air quality, were collected. Researchers slept in the train in turns, self-reported their feeling using a questionnaire, and observed social factors. The study ended with a group discussion. It was found that for sleeping comfort and quality, vibration, vehicle speed/movement, and noise levels on sleep should be balanced, and abrupt changes of some factors, e.g. jerk or distinctive sounds should be avoided. The study provided the insights of travel experience in a night train and a better design can be made based on these insights.

KEYWORDS

Night trains, noise, vibration, comfort, passenger experience

Introduction

The European Environment Agency (EEA) (2021) suggested that rail travel is the best mode of travel regarding sustainability and night trains can be a way of dealing with longer rail travel times. However, it was addressed that "*Travel time cost and travel time reliability are the key parameters that influence modal choice. ... Factors such as convenience, comfort, quality of service and safety also merit additional attention*.". This is in line with findings of Heufke Kantelaar et al. (2022), who mentioned that besides travel time, the travel cost and the comfort level were found to be important in selecting the mode of transportation. The perspective of comfort in night trains, especially sleep comfort is therefore essential, as it is the competitive advantage of the train.

Research on sleep comfort in trains is limited. In different context several related inputs were found considering environment, product, people, and social interactions. Looking at the seat, passengers expect a higher long term comfort level in a reclined seat including a headrest while watching IFE (Smulders et al., 2019), neck support is also a relevant factor for sleeping in transit. Whole-body vibration (WBV) can have a positive and a negative effect on sleep comfort. exposure to WBV accelerates the development of discomfort (Mansfield et al., 2014), and involuntary turbulence is associated with sleep disruption (Caddick et al., 2017). On the positive side, vibration at a certain frequency and amplitude might increase sleepiness (Bhuiyan et al., 2022) and during rough seas duration of sleep increases (Matsangas et al., 2015).

Therefore this research aims to explore and define relevant factors influencing the sleep comfort in night trains. The research question is: what environment factors influence the comfort of passengers during sleep and influence the sleep quality?

Method

During a round trip Amsterdam-Munich several factors impacting sleep comfort were measured. The trip contained several planned/unplanned stops and included fast-breaking and coming to a halt. A six-person sitting compartment was reserved for 3 researchers. The seats had two possible backrest angle positions: upright 106° and reclined 159°. In the reclined position the two opposed seats would form a 'bed', with the feet going up as a result. The measurements consisted of Sound Pressure Level (SPL) measurements (B&K® 2270) and acceleration measurements (several random moments during the trip)(High-Sensitivity 2g USB Accelerometer X2-5), a complete speed recording (smartphone sensor logger) and a recording of the temperature, humidity and CO2 (TFA Dostmann AirCO2ntrol 5000). The trip concluded with a short discussion among the researchers about the impact of different factors on sleeping comfort, quality, and experience. Figure 1 gives an impression of the research setup.

Figure 1: research setup

Results

The following impacting factors were frequently mentioned during the discussion: Changes in vibration/movement and sound, Privacy, e.g. *"the feeling of people peeking through curtains from the hallway was very uncomfortable"*. This is in line with the findings of Heufke Kantelaar et al. (2022) that privacy is important in determining the passenger's comfort in sleeper trains. Additionally, it was observed that during long stops the air conditioning and train were switched off. This was accompanied by a switching on and off of the lights and a sudden stop of train background noise.

High acceleration and deceleration, i.e. "jerk", are confirmed by the measurement data. The maximum jerk during the outward trip was 0.9 m/s3 and during the return trip 0.5 m/s3 (Table 1). These speed fluctuations are also visualized in Fig. 2.

Table 1: Speed, Acceleration and Jerk data for Amsterdam (A) to Munich (M) and Munich to Amsterdam

	Mean		Std		Min.		Max.	
	A-M	M-A	A-M	M-A	A-M	M-A	A-M	M-A
Speed (m/s)	17.31	17.47	15.20	15.57	0.00	0.00	53.52	56.46
Acceleration (m/s^2)	0.53E-3	2.05E-3	0.28	0.20	-4.24	-2.37	4.93	3.03
Jerk (m/s^3)	-0.16E-3	-0.02E-3	0.04	0.02	-0.50	-0.29	0.92	0.45

Table 2: Temperature, CO2 and Humidity data for Amsterdam (A) to Munich (M) and Munich to Amsterdam

	Mean		Std		Min.		Max.	
	A-M	M-A	A-M	M-A.	A-M	M-A	A-M	M-A
temperature (Celsius)	23.46	23.73	0.76	0.77	22.10	21.10	24.70	24.60
CO2 (ppm)	1030.57	909.38	536.54	314.47	87.00	590.00	3320.00	2090.00
Humidity (%)	34.66	32.61	4.68	3.11	26.10	28.50	45.70	48.10

Besides the speed fluctuations/stops of the train, Fig.2 visualizes the climate factors temperature, CO2 and humidity. Around 22.00 and 00.00 on the outward trip from Amsterdam to Munich the train stopped and the air conditioning was switched off, this corresponds with the CO2, humidity, and temperature peaks.

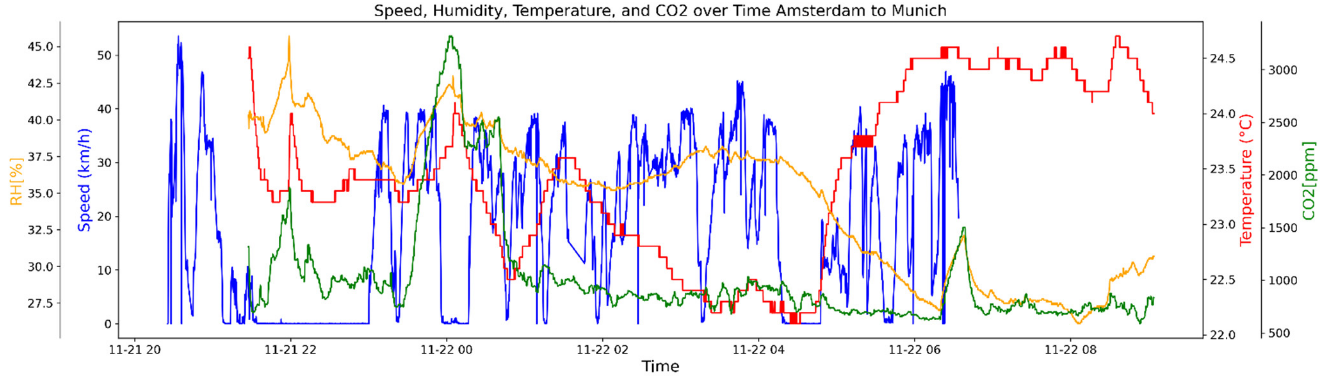

Figure 2: Visualization of the train journey, showing speed, humidity, temperature, CO2, and time (11-21 20= date hours)

Lower-frequency components were observed in the collected vibration data (see the Power Spectral density graph in Fig.3). Additionally, peaks at 48 Hz (0.05g) and 84 Hz (0.02g) were found.

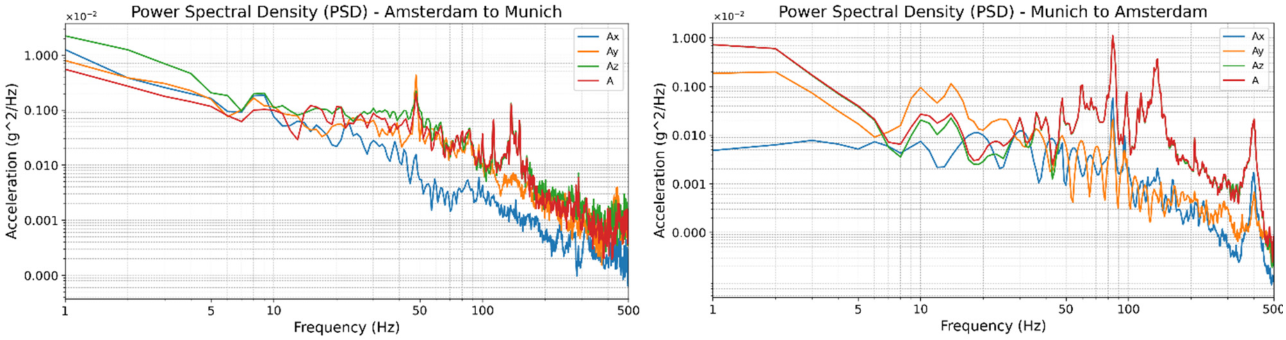

Figure 3: Vibration measurements combined in a PSD graph

On the inward/return journey on average, an LAeq of 57.9dB(A)/52.8dB(A) (max: 77.2dB(A)/ max: 79.2 dB(A)) was measured. Large standard deviations of the measurement data suggest high fluctuations during recording (Max. Std. 11.7/10.59).

Discussion and conclusion

The acceptability of acceleration strongly depends on the amplitude of the acceleration (jerk) (Powell & Palacín, 2015). Kimura et al. (2017) reported that jerk over 0.2 m/s3 disturbs sleep, In this study, multiple events of “jerk” over 0.2 m/s3 occurred, which might have negative effects on the sleeping quality and are related to the amount of experienced stops. This could be connected to the finding from Heufke Kantelaar (2022) who concluded that decreasing the number of stops would increase the comfort rating of a sleeper train.

The optimal sleeping environment should maintain ambient temperatures between 17 to 28°C and a relative humidity between 40 to 60%, in this case sufficient means should be available to facilitate an individual microclimate with e.g. blankets (Caddick et al., 2018). During this test the ambient temperature was within range, but bedding was absent. This will increase waking (Caddick et al., 2018).

With an average CO2 level of 2582 ppm a reduced sleep quality was experienced (Caddick et al., 2018), but a clear relation between CO2 and sleep quality is not reported. While some studies report changes in cognitive performances at 1000 ppm, others report that changes in CO2 are not noticed by passengers, the occupancy is noticed (Herbig et al., 2023). Suggesting more influence of the psychological effect of proximity to others or smell on passenger well-being.

Advices for sound levels in sleeping environments vary from 35dB(A) (Caddick et al., 2017) to 55dB(A)(Ozcan & Nemlioglu, 2006). During our test the values were above this. Next to this, Intermitted noise should be minimized to a 5dB variation from background noise (Caddick et al., 2017)(Parnell & Wassermann, 2014). Large sound changes were mentioned during the group discussion. We can conclude that for promoting sleep, overall SPL levels should be lowered, filtering peaks of the noise and minimize large fluctuations is important.

The seat is one of the most important factors influencing comfort (Bouwens et al., 2018). As the seat shape has a large influence on what activities are facilitated, this factor cannot be neglected. The test took place in a 6-person seating compartment, not facilitating flat sleeping. The greater the seat back angle the greater the quality and quantity of sleep (Caballero-Bruno et al., 2022). The seats in this test were not evaluated by participants, this is something to further consider in follow-up research.

In conclusion, speed, temperature, humidity, noise, and the seat influence the sleep comfort during a sleeper train trip. Especially, acceleration and sound can harm the sleeping quality. Abrupt changes in some factors, e.g. jerk or distinctive sounds should be avoided. Bedding should be available for personal temperature control and additionally, social factors cannot be neglected. These findings can serve as input for train operators and manufacturers e.g. to adopt their cabin or driving styles to best accommodate sleep.

The research gave inspiration for further testing of the importance of sound/movement/vibration on sleeping quality ‘from a comfort/discomfort’ perspective throughout multiple types of sleeper trains and in laboratory settings. Further research with more subjects, more train trips, and different operators is needed to define the relevance of different factors and their thresholds on sleeping comfort and quality. Additionally the factors vibration and light need to be expanded on, since vibration was not further discussed and light measurements were not included in this test.

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Kinematic body responses and perceived discomfort in a bumpy ride: Effects of sitting posture

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ABSTRACT

The present study investigates perceived comfort and whole-body vibration transmissibility in intensive repetitive pitch exposure representing a bumpy ride. Three sitting strategies (preferred, erect, and slouched) were evaluated for perceived body discomfort and body kinematic responses. Nine male and twelve female participants were seated in a moving-based driving simulator. The slouched posture significantly increased lateral and yaw body motion and induced more discomfort in the seat back area. After three repetitive exposures, participants anticipated the upcoming motion using more-effective postural control strategies to stabilize pelvis, trunk, and head in space.

KEYWORDS

Kinematic Body Responses, Biomechanics, Posture, Stabilization, Discomfort.

Introduction

Analysis of perceived discomfort is a complex and multifunctional problem that combines several crucial parameters. The variation of the road conditions, the whole-body vibration characteristics, the exposure, the postural adjustments, and the seat design have been extensively studied regarding their impact on occupant's perception of discomfort (Cvetkovic et al., 2021; Nawayseh et al., 2020). The road conditions (path, road profile and environment) can induce visual, vestibular, and muscular feedback, thereby provoking postural instability (i.e., more postural adjustments). The latter has a proven relation with local body discomfort, interfering with the center of mass' ability to sustain external perturbations (Mirakhorlo et al., 2022). To anticipate this, occupants' usually adopt different sitting strategies (re-posturing) while being driven (Cvetkovic et al., 2020). This greatly affects whole-body vibration transmissibility and perceived discomfort, but there is limited literature (Paddan & Griffin, 1994). Current works focus on either quantifying vibrational transmissibility (Nawayseh et al., 2020) neglecting the perceived comfort, or vice versa (Lecocq et al., 2022). To that end, this research quantifies the impact of adopted sitting strategies on kinematic body responses and perceived discomfort while exposed to intensive pitch vehicle motion through longitudinal perturbations. In particular, the research uncovers whether test subjects can reduce pelvis, trunk, and head angular rotation by adopting various sitting postures, and through anticipation.

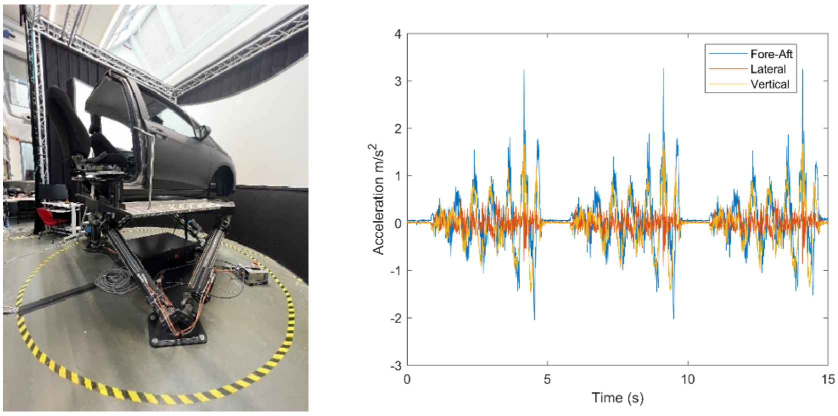
Methodology

The data collection included twenty-one test subjects, consisting of nine males and twelve females. The average age of the participants was 28.2 years (± 4.7), with an average height of 170.6 cm (± 7.5) and an average weight of 68.0 kg (± 11.18). Prior to the experiment, all participants were informed of the experimental procedure and study via informed consent. Test subjects were offered a voucher for 20 EUR as compensation for participating in this study. The experimental design and procedure were in accordance with the Declaration of Helsinki. The procedure was recognized and approved by the Human Research Ethics Committee of the Delft University of Technology (HREC), under application number 962.

The participants were placed in a driving simulator (Figure 1a) with a standard passenger seat and exposed to intensive pitch motion representing a bumpy ride, and filtered to fit within the range of the motion platform. The perturbation was combined with modest fore-aft and lateral motion. More specifically, the input signal (Figure 1b) contained three bumps, with 0.55 m/s^2 rms power, separated by one second and lasting 15 seconds. Each test subject performed three experimental trials with different sitting strategies (i.e., preferred, erect, and slouched). The preferred posture aimed to achieve relaxed upper body muscles with an erect posture. In erect, the participants placed the buttocks at the most anterior position on the seat, pressing the abdomen and shoulders outwards, and keeping the back in an arched position. For the slouched posture, the participants moved their pelvis to the anterior seat pan position, flexing the lumbar spine towards a C-shape curvature. The upper arms stayed relaxed in the lap while keeping the chest and head straight. Table 1 lists the recorded posture for these 3 conditions.

Table 1. Flexion – Extension angles between the body segments (mean degrees ±standard deviation) and perceived comfort

	Postures		
	Erect	Preferred	Slouched
Head – Thorax	13.7 ±10.7	13.0 ±8.7	23.1 ±11.1
Pelvis – Thorax	30.5 ±9.0	36.9 ±8.6	42.0 ±9.7



a) b)

Figure 1. a) Delft Advanced Vehicle Simulator; b) recorded platform signal

Perceived motion discomfort was assessed using an 8-item questionnaire after each posture condition. The first item assessed motion sickness using the misery scale (MISC). The 2nd to 8th item addressed perceived discomfort in different body areas.

Kinematic 3D full body responses and adopted sitting strategies were captured using a motion-capturing system (MTW Awinda, Xsens Technologies, Enschede, The Netherlands). For the purpose of this work, the root mean square of the body segments (head, trunk, and pelvis) rotational kinematic responses (roll, pitch, and yaw) were calculated to estimate the effect of the adopted sitting posture (i.e., preferred, erect, and slouched) on the different body segments. Thus, we could quantify the variation in acceleration between the three different sitting strategies and determine whether the participants anticipated the bump after the repetitive exposure, by reducing the kinematic body responses.

Two-Way Repeated Measurements Analysis of variance (ANOVA) was conducted including three within-subjects factors (three postures, three body segments, and three bumps) to uncover the differences within dependent variables and its interactions. Additionally, an One-Way Repeated Measures ANOVA was performed to reveal differences between three bumps (B1, B2 and B3) for specific posture and body segment. The same method was performed to expose differences between perceived body discomfort and sitting postures. If criteria did not meet the Mauchly's Test of Sphericity (>0.05), Greenhouse-Geisser adjusted p-value was taken into consideration. A post hoc test, the Bonferroni adjustment, was utilized to reveal differences between collected variables and to determine between and within subject variation (B1-B2, B1-B3, and B2-B3).

Results and Discussion

Twenty-one participants completed the experiment, reporting acceptable motion comfort (Table 1) and negligible motion sickness (median, overall body comfort level, was 2.65 out of 10, with an Inter Quartile Range, IQR, of 0.36; median, MISC, was 0.38, IQR = 0.08). Due to insufficient and deviant kinematic data, two participants (males; mean age= 25.6 years; mean weight=77.5 kg; and mean body height = 177.5 cm) were excluded from further analysis.

As far as the perceived comfort is concerned, re-posturing from erect to slouched, resulted in more discomfort ($p=0.008$) in the lower back region (perceived comfort level/slouched = 3.14 ±1.06, and perceived comfort level/erect = 1.76 ±0.9). The postural effect on perceived discomfort was also reflected in reporting the backrest as the least comfortable in the slouched posture ($p<0.001$).

The kinematic body responses are displayed in Table 2. Regarding sitting postures, they substantially affected the pelvis, trunk, and head, roll and yaw responses ($p=0.001$ and $p=0.043$, respectively), while the pitch body rotational acceleration did not differ. Sitting erect and maintaining active posture resulted in lower roll and yaw rotational acceleration compared with more extensive pelvis-thorax angle – slouched posture (p-value for the roll = 0.004, yaw $p=0.025$). The erect sitting posture produced a stable center of mass and better posture alignment, resulting in lower body rotational acceleration versus slouched posture. As the participants were subjected to three perturbations, their body responses did not differ in the first two, but illustrated significant variations compared to the last perturbation. The repeated measurements ANOVA tests did not indicate significant differences between the first two consecutive bumps (B1-B2), except from pelvis pitch angular acceleration which differed ($p=0.036$) when participants adopted the preferred posture. According to the assessment of all body segments kinematic responses, the participants did anticipate the third motion by significantly reducing their roll, yaw, and pitch motion ($p<0.001$). The participants struggled more to stabilize their head (i.e., higher magnitude roll, pitch, and yaw responses than the other segments – Table 2) when exposed to the pitch platform motion. Meanwhile, more effective trunk-in-space stabilization was identified at the third bump (B3), where significantly lower roll, pitch, and yaw responses (Table 2) were measured for all sitting postures. Furthermore, the trunk illustrated more roll ($p=0.008$) and pitch ($p=0.002$) rotation compared to the pelvis, while the trunk was dominant over the head motion in yaw rotational acceleration (p=0.010). Similar to the trunk responses, the participants demonstrated improved stabilization of the pelvis during the third bump (Table 2).

Table 2. Mean rotational responses (± standard deviation) of body segment (head, trunk, and pelvis) in three sitting postures (erect, preferred, and slouched) during intensive-pitch platform motion. Analysis of significant differences and post hoc test of kinematic body responses in the three consecutive motions (B1, B2 and B3).

Body segment	Posture	Bumps [deg/s^2]						
		B1	B2	B3	*p-diff*	B1-B2	B1-B3	B2-B3
Roll kinematic responses								
Head	Erect	182.4 ± 63.0	179.2 ± 66.4	168.2 ± 67.8	*0.041*^{b}	*n.s.*	*n.s.*	*0.006*
	Preferred	193.5 ± 105.6	188.7 ± 109.9	187.4 ± 96.2	*0.853*^{a}	*n.s.*	*n.s.*	*n.s.*
	Slouched	246.4 ± 245.7	227.9 ± 248.6	220.6 ± 202.3	*0.232*^{a}	*n.s.*	*n.s.*	*n.s.*
Trunk	Erect	233.8 ± 145.7	241.6 ± 147.7	192.3 ± 99.7	*0.001*^{a}	*n.s.*	*0.005*	*0.007*
	Preferred	281.9 ± 180.3	279.8 ± 191.0	221.4 ± 118.6	*0.002*^{b}	*n.s.*	*0.004*	*0.014*
	Slouched	276.2 ± 148.8	272.2 ± 139.7	244.5 ± 122.5	*0.011*^{b}	*n.s.*	*n.s.*	*0.022*
Pelvis	Erect	100.4 ± 35.6	99.1 ± 34.7	92.4 ± 37.5	*0.018*^{a}	*n.s.*	*0.050*	*n.s.*
	Preferred	141.6 ± 66.8	139.6 ± 68.2	128.8 ± 61.0	*0.001*^{a}	*n.s.*	*0.011*	*0.004*
	Slouched	240.4 ± 80.2	245.9 ± 81.7	228.3 ± 78.1	*<0.001*^{a}	*n.s.*	*n.s.*	*0.004*
Pitch kinematic responses								
Head	Erect	455.9 ±132.1	463.2 ± 150.7	461.3 ± 155.6	*0.078*^{a}	*n.s.*	*n.s.*	*n.s.*
	Preferred	399.2 ± 97.5	423.1 ± 102.0	415.9 ± 75.1	*0.135*^{a}	*n.s.*	*n.s.*	*n.s.*
	Slouched	472.1 ± 356.7	475.9 ± 375.2	424.3 ± 224.4	*0.213*^{b}	*n.s.*	*n.s.*	*n.s.*
Trunk	Erect	339.3 ± 168.9	375.7 ± 199.9	303.4 ± 140.8	*<0.001*^{a}	*n.s.*	*0.036*	*0.001*
	Preferred	411.2 ± 245.2	411.3 ± 243.3	332.1 ± 176.1	*<0.001*^{a}	*n.s.*	*0.002*	*0.001*
	Slouched	376.8 ± 215.3	385.2 ± 222.4	313.3 ± 132.9	*0.015*^{b}	*n.s.*	*n.s.*	*0.050*
Pelvis	Erect	175.4 ± 37.4	170.5 ± 44.53	147.9 ± 23.6	*0.004*^{a}	*n.s.*	*0.013*	*0.050*
	Preferred	227.0 ± 107.0	236.0 ± 113.8	207.6 ± 100.0	*<0.001*^{a}	*0.036*	*<0.001*	*<0.001*
	Slouched	267.2 ± 109.1	272.6 ± 114.0	241.9 ± 110.1	*0.001*^{b}	*n.s.*	*0.019*	*0.002*
Yaw kinematic responses								
Head	Erect	142.7 ± 56.2	118.2 ± 31.7	112.3 ± 28.4	*0.056*^{b}	*n.s.*	*n.s.*	*n.s.*
	Preferred	138.4 ± 78.7	131.4 ± 74.8	123.4 ± 64.1	*0.018*^{a}	*n.s.*	*0.036*	*n.s.*
	Slouched	199.7 ± 155.3	165.0 ± 104.9	156.0 ± 83.8	*0.156*^{b}	*n.s.*	*n.s.*	*n.s.*
Trunk	Erect	280.2 ± 162.7	282.0 ± 187.6	213.0 ± 118.5	*<0.001*^{a}	*n.s.*	*<0.001*	*0.002*
	Preferred	308.2 ± 227.4	317.1 ± 270.8	244.5 ± 186.0	*<0.001*^{a}	*n.s.*	*0.001*	*0.008*
	Slouched	246.3 ± 129.8	248.0 ± 132.2	210.2 ± 90.0	*<0.001*^{a}	*n.s.*	*0.010*	*0.007*
Pelvis	Erect	170.3 ± 66.0	168.0 ± 64.3	166.0 ± 72.7	*0.477*^{a}	*n.s.*	*n.s.*	*n.s.*
	Preferred	198.0 ± 66.2	196.2 ± 67.5	188.6 ± 65.6	*0.002*^{a}	*n.s.*	*0.012*	*0.025*
	Slouched	259.0 ± 79.4	263.9 ± 79.1	247.9 ± 73.3	*0.001*^{a}	*n.s.*	*n.s.*	*0.008*

B1 – first bump; B2 – second bump; B3 – third bump; a - Mauchly's Test of Sphericity; b - Greenhouse-Geisser test;

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Passengers’ seat vibration exposure on turboprop aircraft flights

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THE WORK IN CONTEXT

Turboprop aircraft offer the possibility of lower emissions for regional travel in comparison to jet aircraft. Future low-carbon aircraft concepts include propeller-generated thrust powered from fuel cells, hydrogen, biofuel, battery or hybrid power. The noise and vibration experienced in a turboprop cabin is different to that experienced in a jet, with signals characterised by tonal components related to the blade pass frequency of the propellers. These components have been associated with more noise and vibration discomfort. There are few published studies of aircraft cabin vibration measured on the seat cushion surface according to ISO2631-1. This paper gives data from two turboprop aircraft flights with measurements made in three different seats. It shows how the vibration is highly tonal, and is affected by position and flight phase.

KEYWORDS

Turboprop, comfort, ISO2631-1, vibration, ComfDemo

Introduction

Demand for passenger air travel is expected to continue to grow despite the shift in working patterns and communication norms triggered by the global pandemic (International Air Transport Association, 2021). Regional passenger transport usually occurs on single aisle aircraft, including those powered by turbojet engines (‘jets’ such as Boeing 737 or Airbus A320 series) or turboprops (such as ATR 42/72 or Bombardier Q400/Dash 8). Turboprops generate power through rotation of the propeller, the wake from which interacts with the wing resulting in the tonal component related to the blade pass frequency. Future aircraft may use alternative power sources such as electric or hybrid systems also likely to use propellers. Passengers perceive propeller aircraft as being uncomfortable due the noise and vibration (Mansfield et al., 2021).

A review of the literature showed that there have been very few published studies of the vibration experienced by passengers in aircraft cabins (Mansfield & Aggarwal, 2022). Studies rarely conducted vibration measurements according to ISO261-1 or measured the entire flight from gate-to-gate.

This paper reports vibration data measured on the surface of seats in an ATR72 turboprop aircraft. Two fully occupied test flights were conducted as part of the ComfDemo project (Vink, et al., 2022).

Method

Data was collected on two flights of 70 minutes duration reaching a cruising altitude of 17,000 feet. Data was also collected during taxi. The aircraft was an ATR72-500 with a capacity of 60. The aircraft was configured in a 2x2 layout with 35” seat pitch.

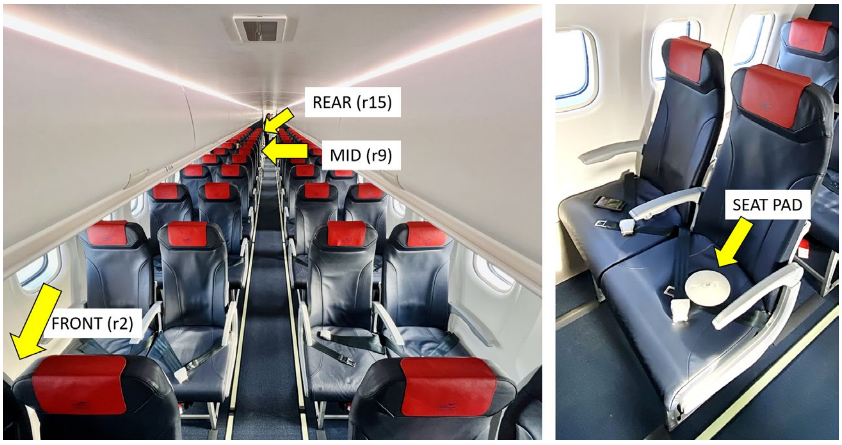

Figure 1. Position of accelerometers in the ATR aircraft.

Whole body vibration was measured on the surface of three occupied seats in the aircraft cabin. The seats were located on different rows representing front (p1), middle (p2) and rear (p3) positions. Measurements were made using Axivity AX3 triaxial accelerometer and data loggers which were mounted inside a seat pad (Figure 1). Calibration was checked before each flight (ATR01 and ATR02). The AX3s were configured to sample at 800 Hz with a range of 2 g. Measurements were conducted for the full duration of the flights. Data segments were extracted from the measurements for full analysis. The data segments were selected to represent the different flight phases.

Data analysis was conducted in MATLAB and included frequency weighted signals, in accordance with ISO2631-1, and the use of unweighted band limited signals.

Results

Samples of data were extracted based on the flight phase. Five-minute data samples were extracted for taxi, climb, cruise and approach/landing. Runway/take-off comprised a shorter sample (approximately 40s) starting from initial acceleration to take-off.

For most phases of the flight, the vibration was dominated by the main engine rotation and harmonics related to the blade-pass frequency (Figure 2). The first peak during the climb and cruise phase occurred at 16.5 Hz, with additional components at 35, 49 and 98 Hz. During landing the 16.5 Hz component is reduced but blade-pass harmonics are still present. Lower frequency components were increased due to air turbulence.

Frequency weighted vibration data showed that the highest vibration was experienced on the runway / takeoff phase, and the least during the cruise phase (Figure 3). Whilst the vibration was greatest during runway/takeoff, this was the shortest element of the flight with measurements lasting less than a minute. There was a greater variation with flight phase than with position on the aircraft. However, p3 at the rear of the aircraft showed a higher magnitude of vibration than p1 or p2 during takeoff and landing. During flight 2, there was more cloud cover and therefore more turbulence during the landing phase, as observed in the data comparing flights ATR01 and ATR02 ‘land’ data.

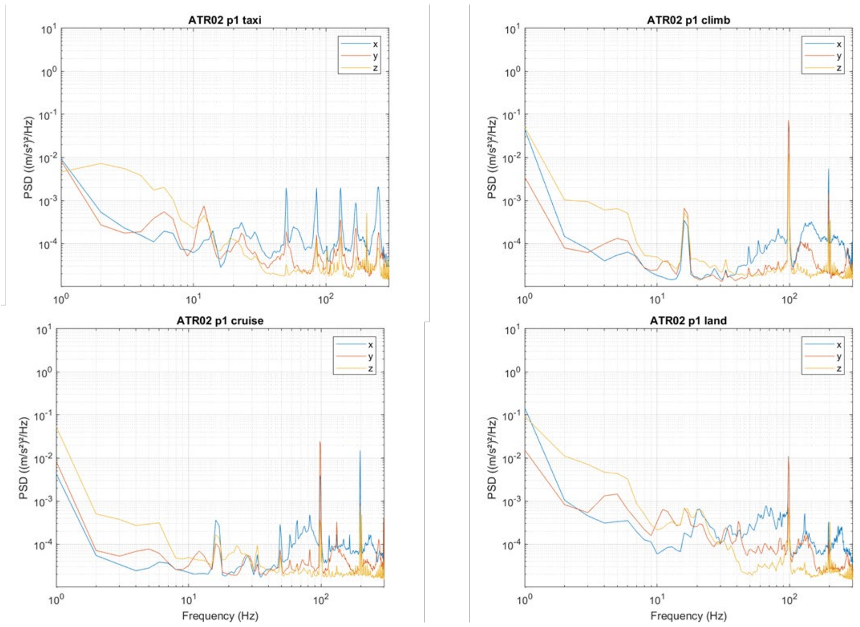

Figure 2. Power Spectral Density of vibration measured on the surface of an aircraft seat during four flight phases; flight 2.

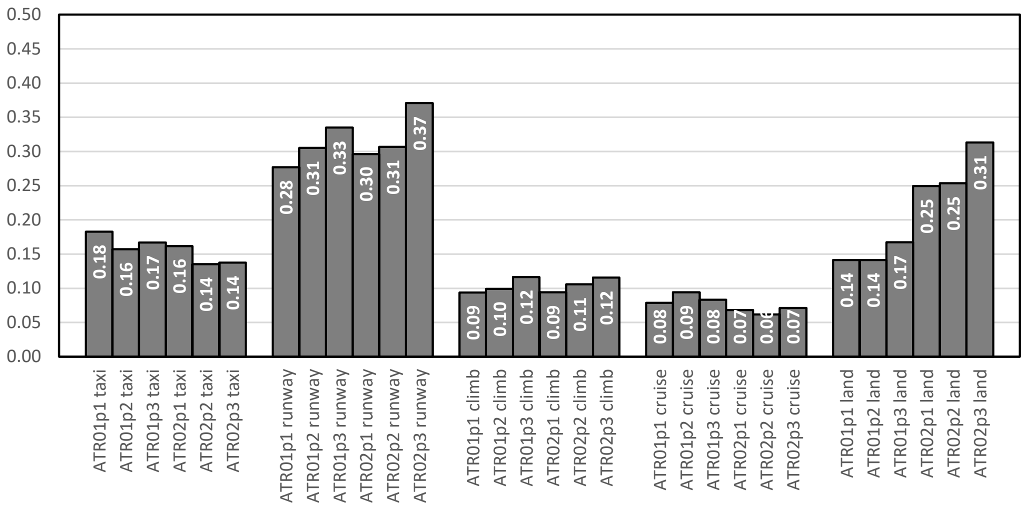

Figure 3. Frequency weighted vibration magnitude measured at each of three seat positions over two flights. Data show r.s.s. vibration including axis multipliers.

Turboprop aircraft have a reputation for exposing passengers to uncomfortable vibration that is not clearly supported by the frequency weighted vibration results. Some studies have shown that vibration that is highly attenuated by frequency weighting filters can be important for perception (Morioka & Griffin, 2006). Spectral analysis showed that there was significant vibration with high levels of tonality (e.g. Figure 2). To consider higher frequency vibration components in an overall analysis it is possible to use ISO 2631-1 band-limiting filters at 0.4 and 100 Hz. However, Figure 2 illustrates that there are several components of vibration that would be attenuated by a 100 Hz filter. To

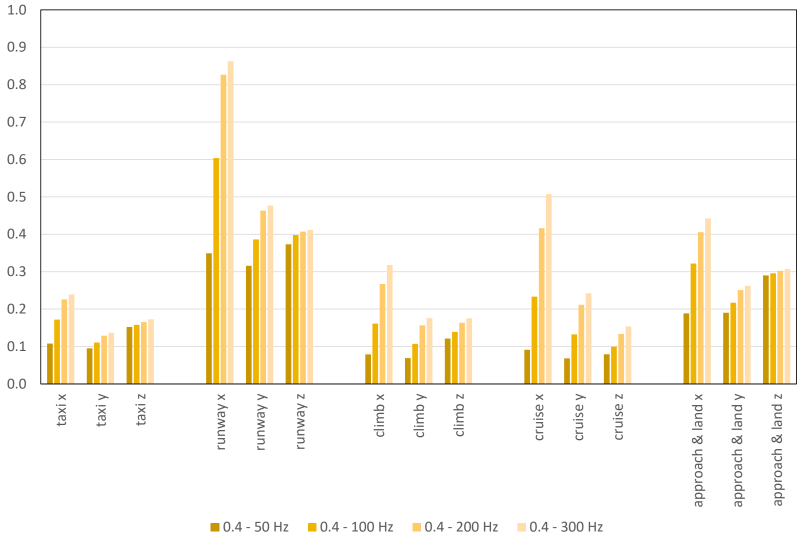

Figure 4. Effect of low-pass band limiting filter on r.m.s. vibration across all flight phases (ATR02p2).

investigate this effect, band-limiting filters were applied at the ISO 2631-1 frequencies, and also with a low-pass filter set to 50 Hz, 200 Hz, and 300 Hz. These data show that the dominant axis of vibration changes with selection of the band-limiting filter.

If the low pass filter is set to 50 Hz vertical vibration is dominant for most flight phases (Fig 4). As the filter frequency increases, fore-aft vibration becomes dominant. Therefore prioritization of the aircraft optimization strategy will be dictated by the selection of the filter. High pass filtering can also affect the overall assessment of vibration exposure. The greatest effect occurred for vibration in the vertical direction. This is what would be expected considering the spectral data in Figure 2.

Conclusion

Measurements of seat vibration according to ISO2631-1 have been successfully made from gate-to-gate on passenger seats on an ATR72 aircraft. Vibration was dominated by tonal components that are attenuated using the ISO2631-1 filters. Indications of the magnitude experienced by turboprop passengers is affected by the choice of digital filters applied to the signal. Studies of human perception of aircraft vibration should include frequency components up to 300 Hz.

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Impact of thinner seat foams in static and dynamic seating comfort simulation

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ABSTRACT

Foam costs and foam volume are a significant portion of the total seat manufacturing cost. One trend is to go for thinner foam pads for the cushion and backrest to reduce volume and gain design space besides saving material cost. Especially in battery electric vehicles there are more design constraints due to the volume of the batteries that has to be accommodated. In current discussions on sustainability, apart from the chemical composition of the material itself, the reduction of foam material used also plays a crucial role. In this study, the impact of thinner seat foams on seating comfort (static and dynamic) and H-point is investigated by means of simulation.

KEYWORDS

Virtual Human Body Model, Comfort, Body Pressure Distribution, Transmissibility, H-point

Introduction

Since there is a strong trend towards thinner seats, it becomes very important to maintain and increase comfort for these seats. Especially in autonomous vehicles, the perception of discomfort may be higher, so ensuring comfort is crucial. According to the trend of virtual development, virtual seat development is state of the art by now.

Due to the strongly nonlinear, frequency dependent behavior of the foam materials, a realistic loading of the seat with human body models is crucial. The virtual seating comfort tool CASIMIR offers the possibility to consider various comfort aspects with a set of manikins representing different human percentiles and anthropometries. Based on these combined simulations of the seat together with the manikin, it is possible to evaluate the seating comfort, H-point and seat design by having a deeper look into the seat and foam material stressing.

Method

To analyze the impact of different foam thicknesses (100 mm and 50 mm), two seat models are built up with the same A-surface and moving the B-surface upwards by 50 mm for the thinner foam.

A new approach is to visualize (cf. Figure 1) and quantify the volumetric strain distribution (VSD) to identify the regions with low foam utilization on an occupied seat. These regions may be shrunk without major impact on static comfort and H-point.

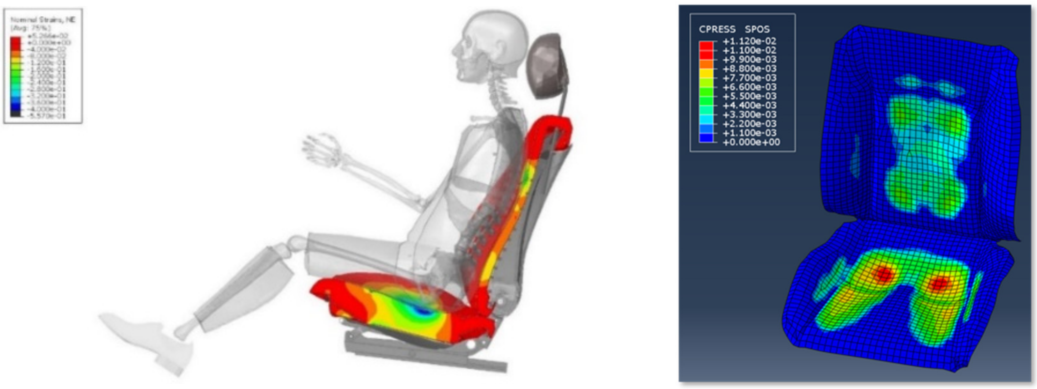

Figure 1: Example of an occupied seat and the strain distribution within the foam and body pressure distribution

After re-designing the foam pads, a re-simulation may prove that there is no or only minimal impact on static comfort for different percentiles.

In some cases, this may even increase comfort due to a larger portion of foam in the comfortable compression range between typically 10% to 40% foam compression.

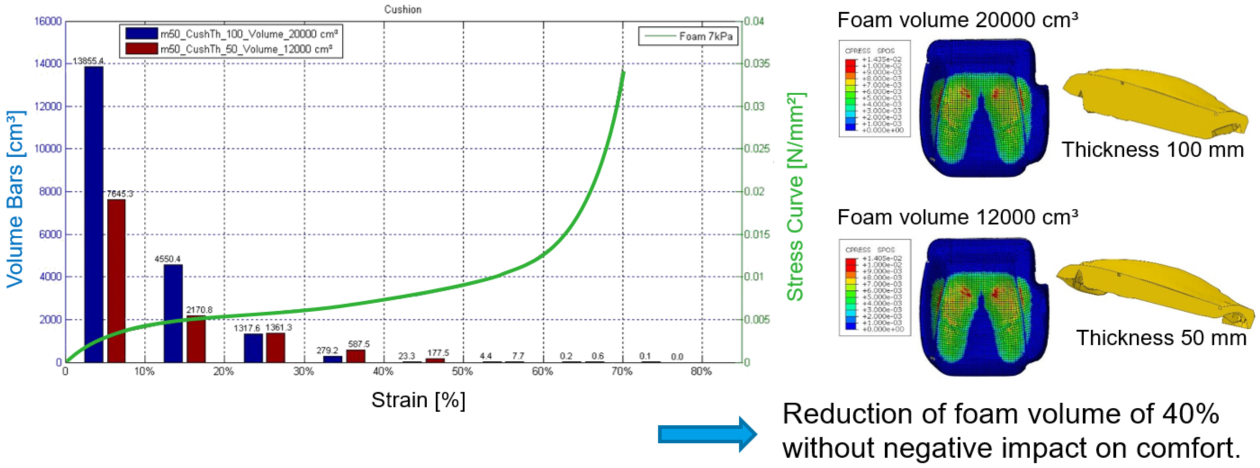

Figure 2: Reduction of foam Volume without compromising comfort for m50

Furthermore, dynamic seating comfort is evaluated by assessing the seat transmissibility. This is necessary to prevent a negative impact on dynamic seating comfort on the redesigned seat. Regarding the behavior at resonance, the thinner foam leads to a lower peak and a small upwards shift in frequency compared to the thicker foam. A loaded thinner foam has higher strains causing a higher stiffness (based on material curve). Due to the higher stiffness being excited with the same excitation energy, the thinner foam's cushion surface oscillates lesser than the thicker foam's, leading to a lower resonance amplitude for the thinner foam. Regarding the isolation behavior, with a thinner foam, isolation is worse (higher amplitude), which confirms the general expectation. However, the energy that flows through the foam into the occupant is similar, leading to the thicker and thinner foam resulting in similar amplitudes of the response at the torso.

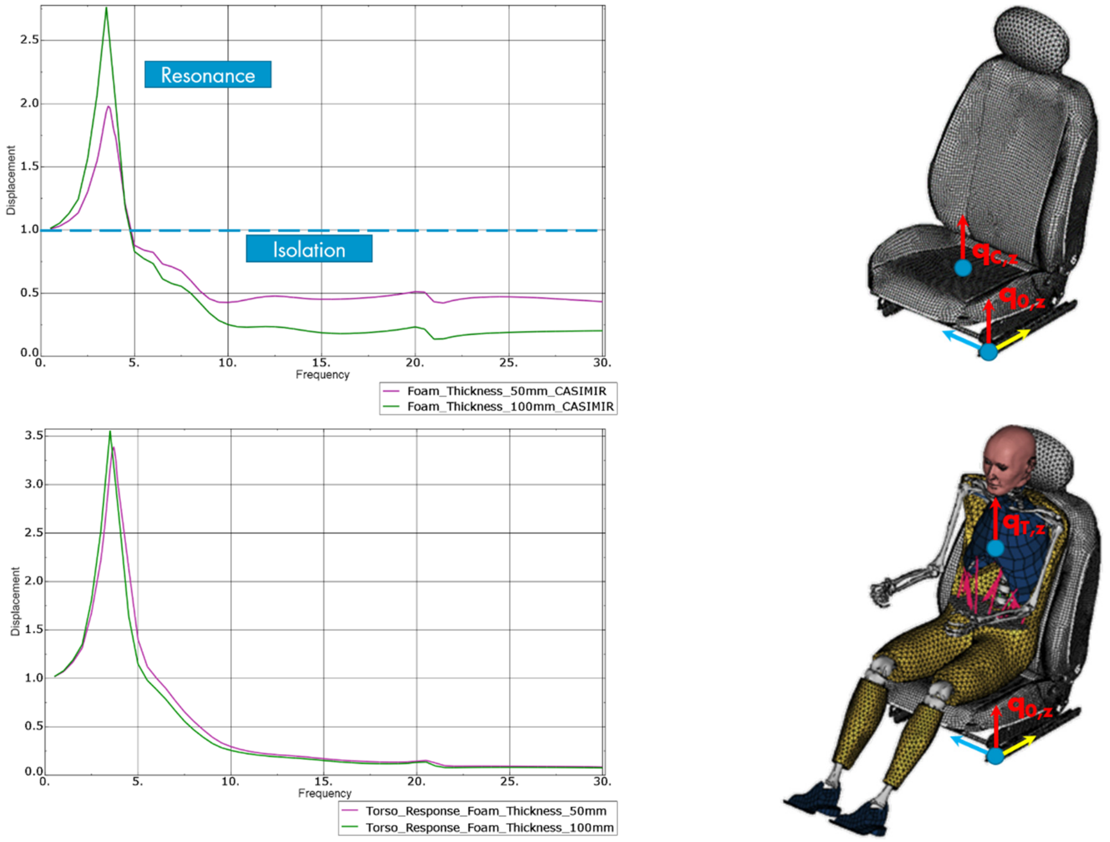

Figure 3: Comparison of Seat Transmissibility at Cushion Surface (top) and at Torso (bottom)

The change in foam thickness also affects seat transmissibility differently when CASIMIR human model is used instead of a rigid buttock shell, which underscores that the rigid buttock is not a suitable method to analyze the impact of foam thickness and that the human body model needs to be used.

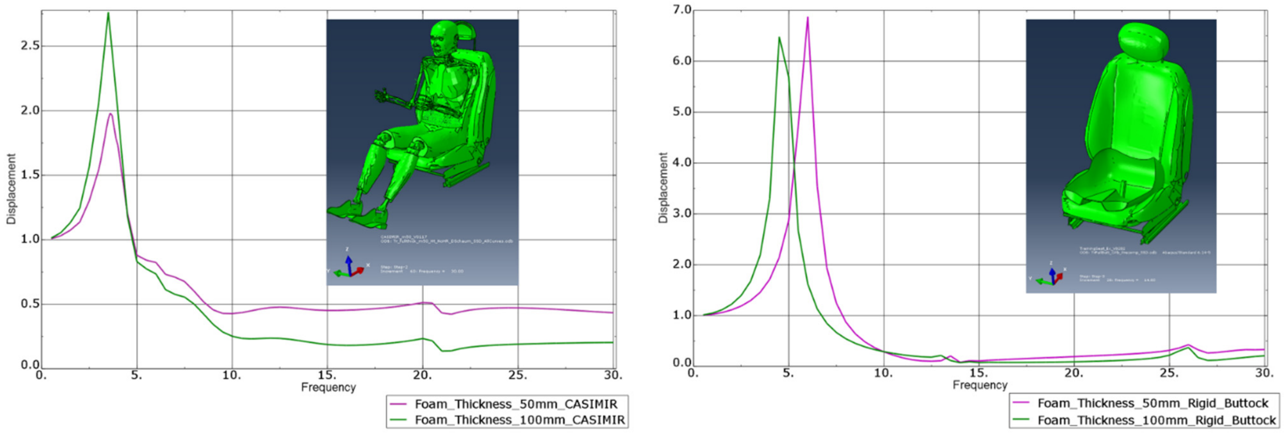

Figure 4: Comparison of Seat Transmissibility between CASIMIR and Rigid Buttock

To evaluate the change in H-point with redesigned foam pads, an H-point simulation is performed with a virtual representation of the SAE J826 manikin. The results of this analysis are as follows.

Table 1: Comparison of H-point coordinates and Torso angle for different foam thicknesses

Foam Thickness [mm]	X-Coordinate [mm]	Z-Coordinate [mm]	Torso Angle [deg]
50	11.82	40.32	23.30
100	10.99	36.18	23.24

Comparing the H-point results, the 50 mm foam results in a Z-Coordinate of only around 4 mm higher than the 100 mm foam, while the results of X-Coordinate and the Torso Angle are even more closer. This shows that to maintain the H-point location with thinner foams, it is possible to gain additional design space below the B-surface.

Results

As a result of this study, three major outcomes can be identified.

1. It was found that volumetric strain distribution is a useful measure to visualize and quantify the amount of foam in each compression state and to plot it over the material curve.

By the help of occupied seat simulation, it is not only possible to evaluate the seating comfort already in the virtual development, but also to identify unused and therefor unneeded foam regions.

2. Regarding the dynamic seating comfort it is found that depending on the seat design the effect of foam thickness variation can differ strongly. In this case, the resonance peak becomes lower and the isolation is less effective for the thinner foam. This underlines, that it is necessary to re-analyze also the transmissibility. The impact on the perceived vibration comfort depends on the response on the human body, at the buttock or the torso. This has to be studied further.

Furthermore, a rigid buttock cannot satisfactorily help analyze the seat transmissibility and therefore a human body model needs to be used to get reliable results.

3. The use of thinner foams has only small impact on the H-point, so more design space may become available in the car and the B-surface can be lifted upwards, eventually.

Conclusion

This study introduces an approach and a tool to analyze the volumetric strain distribution and its application for the comparison of different seat designs. In particular, this helps identifying the regions of low foam utilization and optimizing the seat ensuring static and dynamic comfort, and H-point compliance together with increased design space. This can be especially useful when designers try to allocate the battery volume for battery electric vehicles or some rotating or swiveling mechanism below the seat for future autonomous vehicles.

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Objective evaluation of seat discomfort on eRacing performance

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ABSTRACT

The study investigated the effect of perceived discomfort on perceived stress level and task performance during eRacing activities in a group of non-professional gamers. Objective evaluation of discomfort and stress were analyzed using electro-encephalographic (EEG), electrocardiographic (ECG) and galvanic skin response (GSR) data. Discomfort slightly increased with prolonged seating, and perceived task difficulty significantly increased stress and self-assessed task performance. While significant differences could be observed in EEG alpha-, low beta- and high beta-band activity and GSR data, these were not correlated to perceived stress, discomfort or performance.

KEYWORDS

Seat comfort, eSports, Driving simulation, Physiological measurement

Introduction

Racing simulations (eRacing) are a branch of eSports that are gaining momentum both at amateur and professional levels. Many participants will purchase racing chairs that allow them to experience the simulation as close to real life as possible (Furukado and Hagiwara, 2021). This experience includes vibrational effects, which may lead to discomfort, loss of attention and fatigue similar to real-life driving or driving simulators (Zhao et al., 2012).

Generally, research in objectively measuring eSports performance is lacking (Nicholson et al., 2020), and objective assessment on the effect of vibration and other conditions on gamers could help professional teams to coach and prepare members for competitions more optimally. This study evaluated the effect of vibration on eRacing performance by measuring behavioral, electrocardiographic (ECG) data, electro-encephalographic (EEG) data and galvanic skin responses (GSR) while subjects engaged in offline eRacing competitions.

Method

The study involved 17 participants (4 female) participating in two visits involving competing in racing simulations on Assetto Corsa (Kunos Simulazioni, Italy) while being seated in a Vesaro I Commercial VR Modular Series (Vesaro, UK). Each session lasted about 1.5 hours. The study was approved by the NTU Invasive Research Ethics committee. All participants provided informed consent prior to the study. Participants were informed they would be able to win an Amazon voucher of up to £30 if they managed to achieve the best lap time of all participants, with lap times only recorded during the second session.

Experimental Setup

Practice laps and races were driven on the default Asseto Corsa Vallelunga track using a Mazda MX-5. Participants were not allowed to modify the car settings. During races, AI raced with the same car but with different difficulty levels set for each race. AI difficulty was randomized in a Latin square design between three levels (80%, 90% and 98% difficulty), with each participant experiencing one race at a 90% difficulty for both visits. These difficulty values were specifically chosen in accordance with research by Solox (2022) to ensure participants with limited experience would be able to compete with AI in at least some of the races, while maintaining the environment challenging for experience eRacer participants. Weather conditions and driving aids were equal for all participants and for all races. These included automatic gearbox and clutch, optimal road and weather conditions, ABS, and high traction control.

Questionnaires

At the beginning of the first visit, participants completed a demographics questionnaire. This collected the age of participants, and their level of experience with driving, racing, gaming (competitively and non), and how often they play racing games.

A second questionnaire was given at the start, end and between each training and race session on both visits, asking the participants to evaluate their comfort level, current stress level, perceived task difficulty and task performance. The comfort questionnaire consisted of a section measuring comfort at different body parts using the scaling as per the ISO 2631-1 standard, alongside a scale to measure overall discomfort using a modified Borg CR100 scale (Sammonds et al., 2007). Stress levels, perceived difficulty and performance were evaluated using a 6-point Likert scale.

Physiological Data Collection

EEG, ECG and GSR data in rest were collected for five minutes at the start of each visit, with the participants keeping their eyes closed. Data were collected during each training and race session these sessions, with further data in rest collected for five minutes after each session. EEG data were collected at a sampling rate of 500 Hz using a 19-electrode EEG cap, with electrodes places according to the standard 10-20 system and reference against the right mastoid (Enobio 20, Enobio, Spain). Standard 3-lead ECG and 2-lead GSR data were collected at a sampling rate of 2000 Hz (BIOPAC MP160, Linton Instruments, UK). GSR electrodes were positioned at the tip of the index and middle finger of the left hand of the participant.

EEG and ECG Signal Processing and Analysis

EEG data were filtered using a 2001st-order FIR bandpass filter with 0.5 Hz and 48 Hz cut-off frequencies and re-referenced to the average. Data for each individual rest/race session were then resampled to 80 Hz before applying principal component analysis (PCA) to remove artefacts (e.g. blinking). The power spectrum for the delta (0.5 – 4 Hz), theta (4 – 8 Hz), alpha (8 – 12 Hz), low beta (12 – 20 Hz), and high beta (20 – 30 Hz) bands were analyzed by calculating the average, sum and standard deviation over each band's frequency range in the spectrum.

ECG signals were filtered using a 2001st-order bandpass FIR bandpass filter with 4 and 30 Hz cut-off frequency. After resampling to 80 Hz, ECG epochs were further filtered using at 2001st-order FIR bandpass filter (cut-offs 10 and 30 Hz) to highlight the QRS complex. ECG data were then visually checked and noisy segments (due to movement while steering) were discarded. Heart rate was measured by calculating the average time between individual QRS complexes using a previously described algorithm. Heart rate variability was both assessed as the standard deviation of heart rate and the sum of the root-mean-square of the time differences between successive beats.

GSR Signal Processing and Analysis

GSR data analysis followed the procedure described by Nourbaksh et al. (2012). Briefly, GSR data were low-pass filtered using a 4th-order Butterworth filter with cut-off at 1 Hz and resampled to 80 Hz. Signals for each session were normalized through dividing data by the average amplitude of the epoch. The GSR sum was then calculated as the sum of amplitudes over the entire epoch, with the GSR average being the sum divided by the number of samples.

Statistical Analysis

Results were statistically compared using analysis of variance (ANOVA) with post-hoc pairwise comparison (Bonferroni correction). Significance was assessed at an alpha level of 0.05. All statistical analysis was performed using SPSS 28 (IBM, USA).

Results

Questionnaires

The overall discomfort increased slightly as the experiment progressed, as expected from maintaining posture with increasing exposure to vibration, yet no trends were found for discomfort values at specific seat locations. Stress levels did not change with progression of the session, but a trend of increasing stress levels with AI difficulty was observed after race 1, independent of session number. Stress levels after race 2 were stable over all AI difficulty levels. The results indicate the potential need for participants to adapt to the environment in which they race against the AI, independent of previous experience. Stress levels were related to perceived task difficulty, with a significant increase in stress level with increasing perceived difficulty (Figure 1 left, ANOVA, p<0.001). Similarly, perceived performance significantly decreased with perceived task difficulty (Figure 1 right, ANOVA, p=0.009). These results are in accordance with previous literature suggesting higher perceived stress levels with increased working load (e.g. Kokoroko and Sanda, 2019), and a reduced perception of performance when perceiving a task as more difficult (Li et al., 2007).

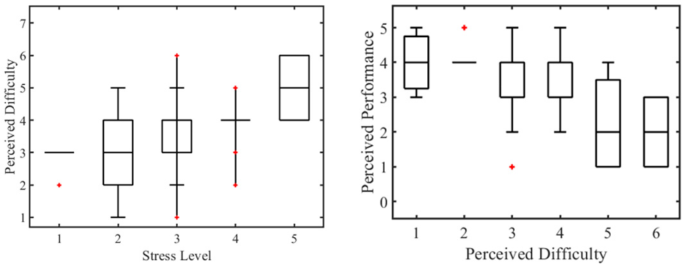

Figure 1: Perceived task difficulty significantly increases stress levels (left, p < 0.001) and reduces perceived performance (right, p = 0.009).

Physiological Data

Significant differences were observed in EEG alpha-, low beta- and high beta-band activities (Figure 2, $p<0.05$). Whereas post-hoc analysis for alpha and low beta activity showed significant decrease between rest session between races and the activity during race 2, high beta activity showed significant differences between the training and race sessions. Increased beta activity is related to active thinking process (Moini and Piran, 2020), which may explain its increase during eRacing activities. Zhao et al. (2012) further showed alpha activity might increase after completing a virtual driving task. Generally, no correlation was found between EEG activity and questionnaire data.

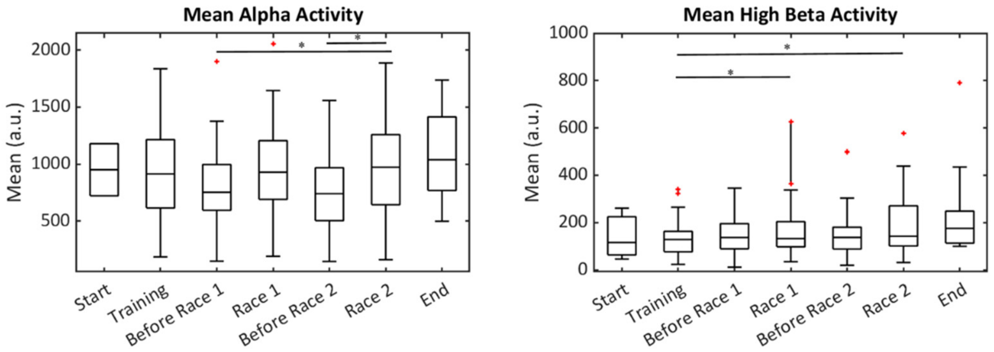

Figure 2: Mean power in alpha (left) and high beta (right) activity for individual tasks and rest periods. Low beta-activity followed a similar pattern to alpha activity. Significant differences are indicated with an asterisk.

ECG data did not show significant differences between tasks, but GSR showed an expected (Nourbakhsh et al., 2012) significant increase ($p< 0.05$) with progress through the session (Figure 3, left). Although showing an upward trend, GSR activity did not show a significant difference between different perceived stress levels (Figure 3, right).

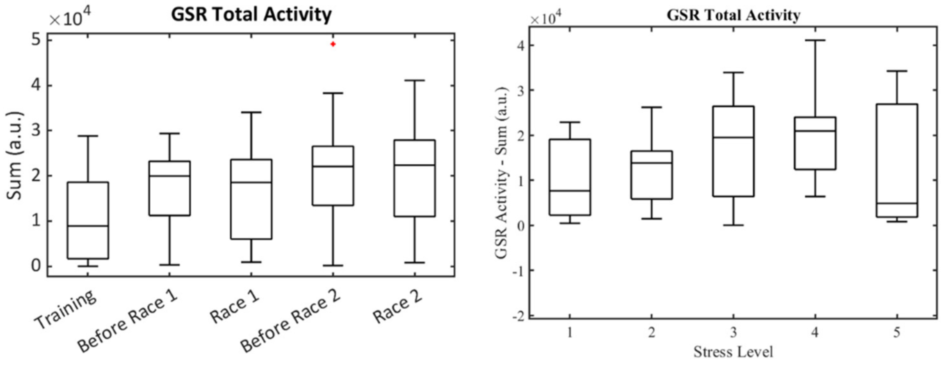

Figure 3: GSR activity significantly increased (ANOVA, $p<0.05$) throughout the session (left). While a trend with perceived stress is observed (right), no significant difference was found.

Conclusion

While no effect of discomfort could be measured on eRacing performance, the study showed the potential of using physiological measurements to evaluate eRacing activity and related stress levels. Further validation is required on larger sample cohorts, ideally within professional eRacing communities to establish the extent to which these measurements can be used for developing training schedules and wellbeing support for professional gamers.

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Thermophysiological studies of seat comfort – possibilities and opportunities of thermal manikins

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ABSTRACT

The comfort aspect of sitting, whether in the car, in the office or at home, is becoming increasingly important. By ensuring a high level of comfort, restrictions or reductions in attention can be avoided, allowing people to focus on their activities. An important part of comfort is the climatic aspect, in particular the microclimate that is created between the person and the seat. This depends on the environmental conditions as well as on the materials used in the layered structure of the seat. To determine and evaluate comfort while sitting, time-consuming and cost-intensive tests are often carried out on test persons. At Hohenstein, it was possible to develop a uniform, objective measurement scenario with a sweating, thermal manikin to determine the thermophysiological behavior of seats. In this way, the thermal insulation Rc, and the breathability Re of material structures or finished seats can be determined. The results could be validated by tests on test persons. Accordingly, conclusions can be drawn from the objective measurement data about the subjective sensation of people and a differentiated distinction can be made between different seats. The developed method can be used to investigate classic car seats or office seats as well as innovative systems with air conditioning.

KEYWORDS

thermophysiological comfort, car seat, office chairs, thermal manikin

Introduction

In-vehicle comfort has been of great importance to the automotive industry for years. [1] In this context, the seat is the most important and permanent contact surface between the driver or passenger and the vehicle. The seat design plays a key role in increasing seat comfort and is an important quality feature to increase the comfort level.

In general, a vehicle seat must meet many requirements and customer demands. Safety comes first, to help protect the driver or passenger in the event of an overturn. In addition, the seat must not restrict the driver when operating the controls. The seat position is responsible for an adequate field of vision. A high level of comfort provides a good and safe feeling and leads to less distraction from driving. Therefore, it has a strong influence on passive road safety. A driver who is under extreme stress and uncomfortable in his or her seat may react more slowly or carelessly.[2]

Furthermore, it has been shown, that driver performance decreases in extreme temperatures, even in young and healthy people. Therefore, it is crucial that cabin and seat temperatures are within the driver's comfort zone.[3] An important part of comfort is the microclimate (temperature and humidity) between the driver and the seat.[4] The balance of heat and humidity between the different materials installed and their layered structure can increase the driver's well-being. However, this does not only apply to automotive comfort, but can be transferred to other areas of seating, such as during office activities or at home on seating furniture.

So far, there is no standard scenario for determining the microclimate or the so-called thermophysiological behavior of vehicle seats. There are only standardized methods for measuring the thermophysiological comfort of clothing. As part of a doctoral thesis at Hohenstein, research was conducted to determine whether these measurement methods can be adapted for vehicle seats. The aim of the work was also to develop a novel measurement method for determining the thermophysiological comfort of vehicle seats that correlates with human perception.

Method

As part of a doctoral thesis [5], it was possible to develop a uniform, objective measurement scenario with a sweating, thermal manikin "Sherlock" at Hohenstein to determine the thermophysiological behavior of seats. In this way, the thermal resistance (thermal insulation R_c), and the water vapor resistance (breathability R_e) of upholstery materials or seats can be determined by measurement.

For thermal insulation R_c measurements, the ambient in the climate chamber is set to ambient temperature T_a=15 °C and relative humidity φ_a=50 %RH according to DIN 15831.[6] The test seat is conditioned under the measuring conditions 48 hours prior the measurement starts. The fully clothed sweating thermal manikin with the anatomical shape of a standard man (Newton type, Thermetrics; international size medium) is placed on the seat in a climatic chamber. The manikin’s weight is 30 kg and is therefore much lighter than a standard man. To get a more comparable pressure on the test seat a 15 kg extra load is set on the manikin’s thighs in sitting position. The surface of the manikin is controlled to a constant temperature (T_S=32°C). The electrical power that must be supplied to "Sherlock" to keep his body and skin temperatures constant is recorded as the measurand. It equals the heat loss from "Sherlock's" body through the seat to the environment. From this, the thermal insulation (R_c) of the seat can be determined.

In addition to these tests, realistic sweating is simulated while sitting with "Sherlock" to determine the breathability (R_e) of the upholstery. The ambient in the climate chamber is set to ambient temperature T_a=32 °C and relative humidity φ_a=40 %RH according to ASTM 2370.[7] The test seat is conditioned under the measuring conditions 48 hours prior the measurement starts. The fully clothed sweating thermal manikin with additional weight (15 kg) is placed on the seat in a climatic chamber. Sherlock’s sweating is realized with the aid of sweat nozzles distributed over the body. The surface of the manikin is controlled to a constant temperature (T_S=32°C). The electrical power that must be supplied to "Sherlock" during sweating to keep his body and skin temperatures constant while sitting on a seat. From this, the water vapor transmission resistance (breathability R_e) of the seat can be determined. In addition, temperature-humidity sensors are placed between the sweating thermal manikin and the seat to record the temperature and humidity in the microclimate.

Besides, objective and subjective data from test persons were obtained through wearer trials under controlled cold and warm conditions in a climate chamber. The subject trials were performed by five healthy men and one healthy woman. During the subject trials, physiological data of body functions like average skin temperature and humidity is obtained via temperature and humidity sensors (MSR Electronics GmbH), heart rate with the Polar T61-CODED pulse belt (Polar) and the data logger MSR 12 B10030 (MSR Electronics GmbH) and core temperature with the sensor SpotON (3M Medica). During the subject trials, the test subjects rate their microclimate sitting comfort regarding temperature and humidity on a rating box by a modified seven-point Bedford-scale.[8] The tested upholsteries contained four temperature and humidity sensors (MSR Electronics GmbH) placed on the trim as well as between trim and support layer to investigate the heat and moisture transfer through the seat layers.

Test set up under cold conditions (T_a=15 °C, relative humidity φ_a=50 %RH): Test subject enters the climate chamber and gets used to the ambient conditions for 15 minutes while sitting on a chair. To increase the metabolic heat production and to stimulate the heat release by evaporation, the test subject walks on a treadmill at 7 km/h for 5 minutes. Then the speed of the treadmill is increased until the test subject has a heart rate of 140 bpm for 2 minutes. The test subject settles in the test seat, installed in the driving simulator. The driving program is started and completed for 40 minutes.

Test set up under warm conditions (T_a=32 °C, relative humidity φ_a=40 %RH): The procedure corresponds with the experimental procedure under cold conditions, except some little changes The test subject walks on the treadmill only 6 km/h for 5 minutes, before the test subject sits down in the test seat, installed in the driving simulator. After 20 minutes of driving, the test subject takes a 5 minute’s break. Afterwards, the test subject continues a 20-minute driving task in the driving simulator.

Results

Based on objective data obtained during the subject trials a realistic test scenario with the thermal, sweating manikin “Sherlock” can be derived. The results are reproducible and valid. Different woven fabrics, knitted fabrics, leather as cover material, foam, fleece and 3D spacers for the middle layer and various types of foam for the padding were used for the investigations.

The tested seat constructions show thermal resistances R_c in the range of 0.26 to 0.36 m^2K/W. It could be shown that the thermal insulation has a dependence on the supportive layer. Higher thermal resistances are observed for combinations with the structured foam. Integrated holes and channels form air gaps, which are responsible for the higher thermal insulation. The influence of foam, fleece, or 3D spacers plus pads on thermal resistance is low. Foam and 3D spacers plus pads have a higher thermal resistance, fleece plus a lower thermal resistance. One reason for this could be the engineered air gaps in the 3D structure of the foam and 3D spacer. In cold environments, higher thermal insulations are recommended; conversely, in warm conditions, low thermal resistances are desirable. The breathability R_e on textile trim layers ranges from 35.69 to 71.20 m^2 Pa/W. For the trim layers with leather and leather-like face fabrics the water vapour resistances range from 63.57 to 129.42 m^2 Pa/W. The results lead to concrete recommendations for seat material selection, layer combination and joining technology with focus on microclimate sitting comfort. Face fabrics out of textiles have better breathabilities than face fabrics out of leather and leather-like materials. By using natural fibres, the moisture management can be improved.

In addition, the thermophysiological comfort of actively air-conditioned seat structures was researched. With active climate control at the highest performance level, the seat structure with artificial leather cover showed a good value from the clothing physiological point of view, which can be compared with values of seat structures with fabric cover. In general, the lower a chair's breathability Re, the better it can be judged physiologically. This ensures better moisture release from the sitter's body, resulting in better physiological seating comfort. From the clothing physiological point of view, the artificial leather-covered, actively climate-controlled seat structure showed good breathability, comparable to fabric-covered seat structures. Furthermore, the measurements recorded the temperature and humidity in the microclimate between the sweating thermal manikin and the seat structure. In the case of the thermal insulation measurements, significant temperature differences were detected between the measurement points positioned close to the active air conditioning and the measurement points positioned away from the active air conditioning. This means that the active air conditioning reduces the temperature in the microclimate. In the measurements of the respiratory activity, it was also possible to measure clear differences in the relative humidity in the microclimate between the sweating, thermal manikin, and the seat structure. The measurement points close to the active climate control have a lower relative humidity than the measurement points further away. Thus, the sweat produced is quickly removed from the microclimate by the active air-conditioning and directed into the seat structure.

Conclusion

The research work showed that the measurement scenario developed can be used to investigate both car seats and office chairs consisting of different materials. It was shown that the results are valid and reproducible. On one hand higher thermal insulation is recommended at lower ambient temperatures. On the other hand, lower thermal insulations are advisable in warm ambient conditions. The thermal insulation is mainly influenced by the supportive layer of an upholstery system. The breathability of an upholstery system should be as low as possible. This ensures better moisture release from the sitter's body, resulting in better physiological seating comfort. The main effect on the breathability has the face fabrics. Artificial leather shows the lowest performance due to breathability, textile face fabrics the highest performance. With active climate control, the seat structure with artificial leather cover showed a good value from the clothing physiological point of view, which can be compared with values of seat structures with fabric cover.

By elaborated measurement scenario with a sweating thermal manikin, objective measurement data for characterization of thermophysiological behavior of seats can be obtained in a simple way in the future. The measurement method enables a simple comparison of different seats. In addition, cost- and time-intensive wearer trials with test subjects or field tests can be reduced.

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A Framework on Aircraft Seating Comfort Research

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ABSTRACT

Presented in this paper is a framework being carried out at Toronto Metropolitan University (formerly Ryerson University) on aircraft seating comfort research. This program is centered on biomechanical modeling with three pillars. The first pillar is the creation of a database including seat parameters, human body parameters, and sitting postures. This database serves as the input to the second pillar on biomechanical modeling for two purposes, one being to study the contact pressure in the areas where the human body is in contact with the seat, and the other being to analyze the muscle strain in the areas where the human body is not in contact with the seat (such as the lumbar and neck). These two pillars set a base for the third pillar to ergonomically optimize the seat profile by minimizing contact pressure and muscle activation. Pressure sensor and electromyography sensor are used to validate the simulation of pressure and muscle activation based on the biomechanical model. Preliminary research results are included in the paper to demonstrate this program.

KEYWORDS

Seating comfort, biomechanical modeling, contact pressure, muscle activation, design optimization

Introduction

The aircraft seat, one of the most essential elements in the aircraft cabin, is particularly important, as it plays a crucial role in passenger comfort during long-haul flights. Therefore, the seat plays a key role in the competition between aircraft companies seeking to differentiate themselves in terms of cabin and customer experience. Comfort, referring to Anjani et al., 2021, is taken as subjective feedback associated with various states of the person over time by concept, and therefore important to the human-centered product design. Meanwhile, many seat-ergonomic studies also investigated objective measures to assess seating comfort (De Looze et al., 2003; Hiemstra-van Mastrigt et al., 2017).

The comfort-related objective indicators introduce more strategies and tools to evaluate the seat design and better improve the product. According to a review study (De Looze et al., 2003), it was concluded that the pressure distribution appears to be the objective measure with the clearest association with subjective ratings of comfort and discomfort. For the backrest specifically, (Carcone & Keir, 2007) found the tendency that participants referred backrest configurations that had lower pressure on the back. The contact loading and pressure distribution on the back constitutes essential parameters to assess the comfort of a seat's backrest and evaluate the seat design. In addition to external loading, internal reactions of the body, such as muscle activity, is also important for the overall sitting experience. In a long-haul flight, passengers may experience discomfort due to fatigue at some areas of the body. According to Jørgensen et al., 1988, a static isometric muscle contraction of 5-10% MVC (Maximum Voluntary Contraction) for 1 hour would cause fatigue in the muscles. Moreover, muscle force is also shown to be a predictor of occupants' seating experience based on previous studies (Gao et al., 2022; Majid et al., 2013; Smulders et al., 2019).

The seating studies that combine external support and muscle force measures are limited. Both aspects are included in the research by Li et al., 2020, who explored how different driving durations affect comfort based on both contact pressure and muscle fatigue. However, their work was based on real-person experiment tests using the pressure mat and electromyography (EMG) sensors. This paper aims to propose a framework based on 3D biomechanical modelling to evaluate, analyze and optimize the aircraft seat backrest, using contact pressure and muscle activation as the two main objective measures. The flexibility of the multi-body biomechanical model can also allow more comprehensive analysis considering multi-sitter and multi-activity scenarios for the seat design.

Method

The framework of the aircraft seating comfort study and seat optimization (focusing on the backrest area) contains three main stages. The core stage of the framework is the development of the biomechanical model simulating and evaluating both human-seat contact interaction and muscle activation. Multiple variables, including the seat-related parameter, body-related parameter, and posture-related parameter, must also be defined to describe the sitting condition of the analyzed body. Lastly, the backrest optimization can be achieved based on the first stage of the various parameters database and the second stage of the computation tool (biomechanical model). The overview of the presented framework is demonstrated in Figure **1**. Additional information on each mentioned stage is provided in the following paragraphs.

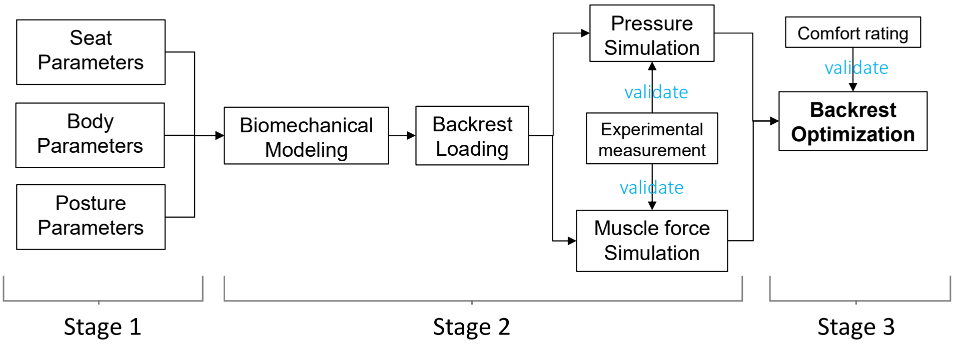


Figure 1. Roadmap of the presented framework for aircraft seating comfort and design optimization

For stage 1, the first three boxes on the left of Figure **1** list three types of input parameter to the biomechanical model, defining the sitting condition and environment. Seat parameters, such as backrest inclination, cushion size, and surface shape describe the seat condition. Among these parameters, the surface shape parameters are of special interest as they are the target parameters for backrest optimization, which is the ultimate objective of the study. We proposed a simple parameterized model to describe the backrest's geometrical shape, using three parameters for each transverse cross-section profile(Mistry, 2022). The three parameters are transverse centerline depth (TCD), transverse edge protrusion (TEP), and transverse curvature sharpness (TCS), as illustrated in Figure 2. Different backrest surface shapes can be formed, including surface protrusion of the neck and lumbar support, by changing the combination of surface parameters at different vertical levels, as shown on the left of Figure 2. The seat parameter also includes the backrest inclination, ranging from 20° to 60° to cover the activities from working to sleeping (Smulders et al., 2016). Regarding the body parameters, population anthropometric databases are available, such as Civilian American and European Surface Anthropometry Resources (CAESAR, Harrison & M, 2002). Figure 3 shows the demonstration of the seated body anthropometric dimension. In addition to literature, seating experiments can be conducted to investigate whether the selected anthropometric parameter plays a significant role in seating comfort. This step can be deemed as a process to reduce the number of body parameters or add additional body measurements, such as spine curvature, to be considered for comfort analysis and optimization. Lastly, posture parameters describe the spine's position under certain conditions, such as lateral bending and twisting (leaning to the side). The posture data, which can be understood as the spine position under different activities, can be found in literature (Kitazaki & Griffin, 1996), and experimental measurements using the motion sensor or magnetic resonance imaging (MRI). Various sitting postures were collected in previous studies based on experiment observation (Kamp et al., 2011; Liu et al., 2019), an example of which is shown in Figure 4.

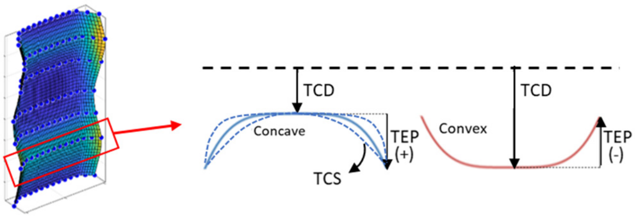


Figure 2. The fitted backrest surface with the transverse-plane profile defined by three key parameters of TCD, TEP, and TCS

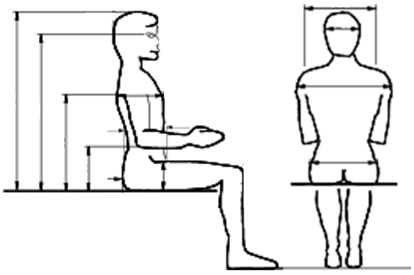
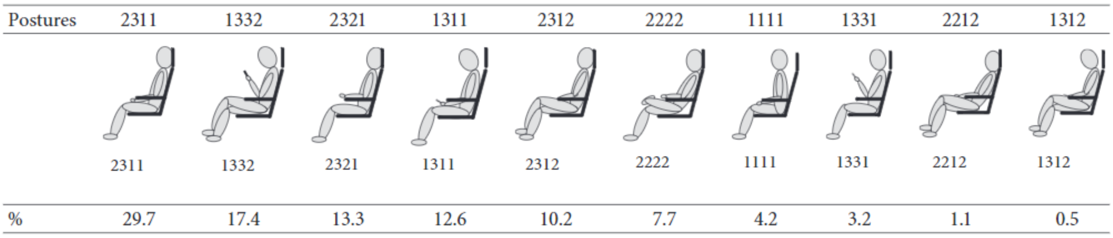


Figure 3. Upper body anthropometric dimensions



Postures	2311	1332	2321	1311	2312	2222	1111	1331	2212	1312
	2311	1332	2321	1311	2312	2222	1111	1331	2212	1312
%	29.7	17.4	13.3	12.6	10.2	7.7	4.2	3.2	1.1	0.5

Figure 4. Most observed postures in an aircraft cabin. The four-digit code represents the whole-body posture combined from those in different body parts (1st digit – head posture, 2nd digit – back posture, 3rd digit – arms posture, 4th digit – legs posture). The percentage means the recorded period of the corresponding posture

The second stage of our framework is associated with biomechanical modeling to simulate both the contact pressure and muscle activation. The external force on the backrest cushion must be evaluated first, based on which contact mechanics and inverse dynamics method can be applied to calculate the contact pressure and muscle force, respectively. In our biomechanical model (Zhong et al., 2022), the upper body is treated as a rigid multi-body system serially connected by spherical joints. For static seating, the supporting force on each segment can be determinately solved with the assigned joint conditions. The calculated contact force can be transformed into pressure distribution using contact mechanics based on the assigned material property and contacting surface geometry.

It is common to have some body areas unsupported due to sitting posture and lordotic body shape. In this case, the contact force and pressure become invalid in the gaped region. Muscle force is then introduced to evaluate the unsupported body region(s), as shown in Figure 5. With the previously computed backrest forces on the contacted body, inverse dynamics method is applied to calculate the joint moments in the gapped body region(s). Assuming the joint moment in the body is balanced by the surrounding muscles to maintain the body position, moment equilibrium can be established. Because the musculoskeletal system is highly redundant, static optimization method is used to approximate the solution of forces from each muscle. For finding the force generated from different surrounding muscles, the objective function to be minimized is chosen to be the sum of $(f_j/PCSA_j)^3$, where f_j is the muscle force, and $PCSA_j$ is the physiological cross-section area of the muscle (Crowninshield & Brand, 1981).

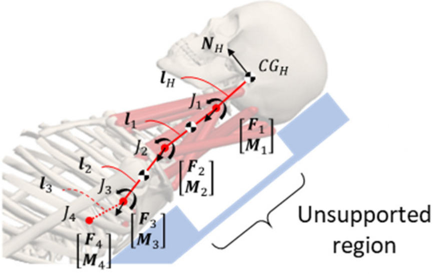


Figure 5. Musculoskeletal model of the upper body sections with its simplified linkage model for muscle mechanics in the gapped region at the neck

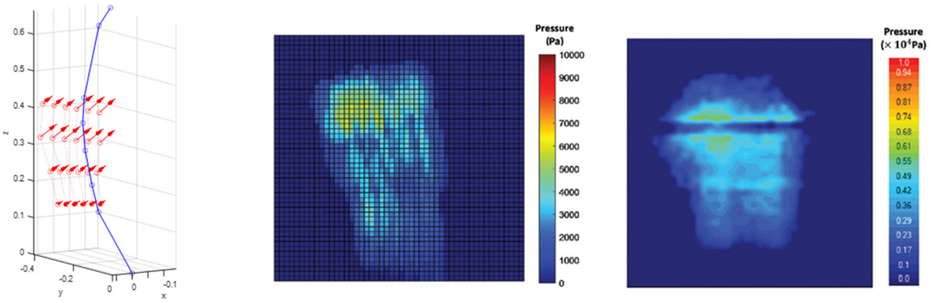
Stage 3, backrest optimization, can be reached depending on the first two described stages, where the contact loading and muscle reaction can be generated under a provided setting defined by the selected input parameter. The optimization aims to find a combination of backrest dimensional and shape parameters that can lower the muscle activation and average contact pressure. Minimized peak pressure and pressure standard deviation may also be considered additional objectives for the design optimization. Finally, seating tests will be conducted to collect the comfort rating on the prototype of the optimal design as well as the traditional seat with a flat backrest for validation.

Results

Some preliminary results related to contact pressure and muscle activity are presented. Contact pressure results have been obtained for different posture parameters (neutral sitting and leaning-to-side of 10°) and backrest inclinations (30°, 40°, and 50° from vertical direction) (Zhong et al., 2022). The pressure simulation is compared to the pressure sensor measurement; a good correspondence was found with a maximum simulation error of 11.5% on the average pressure. One example of the pressure result is shown in Figure **6**.

The muscle contraction within the unsupported neck region is evaluated to assess different headrest designs. Two types of designs: centered headrest (type A) and full-width headrest (type B) were introduced as case study (Zhong et al., 2021). The muscle force within the two main neck muscles, sternocleidomastoid (SCM) and upper trapezius (UT) were calculated for the backrest inclination of 20° (from the vertical), as shown in Figure **7**. In the unsupported neck region, distinctly lower muscle activation (63% on average) is observed in SCM compared to UT for both simulation and EMG measurement, corresponding to previous findings (Smulders et al., 2019). In addition, type B design increases the UT force by 6% and decreases the SCM force by 42%, noting that SCM is generally more relaxed. Meanwhile, the variation of EMG measurement for different designs is not as significant, although the same trend as the simulation occurs. Further validation and calibration would be needed for the muscle modeling of the biomechanical model.

The preliminary results are based on specific cases demonstrating the feasibility of the proposed biomechanical model for seating analysis. The backrest cushion shape being used at the current stage is flat. However, referring to the presented framework, the surface parameters will be introduced in future work to find the optimal backrest surface shape providing the theoretically best comfort.



(a) (b) (c)

Figure 6. An example of the (a) simulated contact force, (b) pressure distribution, and (c) experimental pressure measurement with backrest inclination of 30° (from the vertical) and lateral bending of 10°.

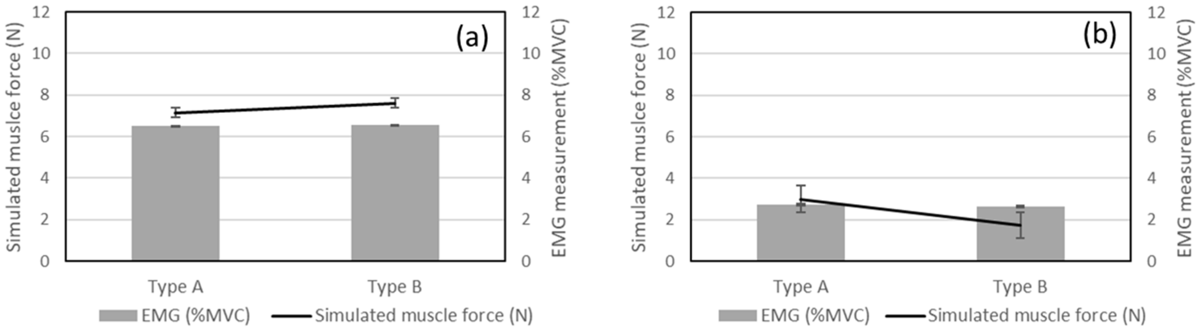


Figure 7. Simulated muscle force and corresponding EMG measurement for UT (a) and SCM (b)

Conclusion

This paper presents a framework for aircraft seating comfort evaluation and backrest optimization. The framework is based on a biomechanical model that can predict the backrest loading in the supported area(s) and muscle activity in the unsupported area(s), which are both considered as the objective indicators of comfort and thus to be used as the criteria for the design optimization. Preliminary results are presented to demonstrate the feasibility of the model. Further validation is needed for the muscle force modeling. In the future study, backrest surface parameters will be varied to find the backrest's optimal shape design. Additionally, a simulation package based on the presented framework will be integrated to facilitate future research for seating ergonomic analysis.

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Prediction Equations for Lower Leg Swelling in driving posture

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ABSTRACT

This study focused on the lower leg swelling as a typical physical load caused by prolonged sitting posture such as driving and aimed to obtain a prediction equation for the lower leg swelling based on the thigh pressure distribution, the participants' physical characteristics, and the seat tilt angle. In this study, the BI was defined as the ratio of the inverse of the measured impedance to the start sitting. The thigh pressure distribution was measured using an automobile seat that can change the thigh pressure by adjusting tilt angle of seat surface. Twelve male participants were recruited, and impedance in the lower leg, thigh pressure distribution, and sensory evaluation were measured during 90 minutes of sitting in four different tilt angles. The results reveal the followings. (1) Physiological state may have differed due to start time of the experiment and the influence of meals. After eliminating these data, a positive correlation was confirmed between the BI and the average thigh pressure normalized by the body weight. (2) The prediction equation for the lower leg swelling was constructed by multiple regression analysis. As a result, a prediction equation was obtained from the participants' physical characteristics, the thigh pressure distribution, and seat tilt angle.

KEYWORDS

Leg swelling, BIA(Bioelectrical Impedance Analysis) , Pressure distribution, Driving fatigue

Introduction

In recent years, the systems for detecting driver fatigue have attracted attention because of increasing traffic accidents (Choi et al. 2020) . The driving posture is a prolonged sitting posture, and the biomechanical load in the sitting posture is a direct cause of physical fatigue. The biomechanical load in the sitting posture can be categorized into musculoskeletal loads such as muscle and joint loads and contact loads by compression of soft tissue and blood vessels on the body surface (Hirao et al. 2019) .The lower leg swelling is a typical instance of contact loading and is affected by various conditions (e.g., sitting posture, chair shape, lower limb exercise, thigh contact area, thigh pressure distribution) (Fujita et al. 2010, Hitos et al. 2007) . This study measures the thigh pressure distribution and the impedance in the lower leg of the participants sitting on a car seat. The experimental purpose is to find a predictive method for the lower leg swelling. This paper is organized as follows. Section 2 illustrates the method to measure and analyze the lower leg swelling and the thigh pressure distribution employed in this study. Section 3 presents the experiment and the prediction formula for the lower leg swelling while Section 4 provides conclusions and future tasks.

Materials & Method

In this experiment, an automobile seat equipped with a tilt mechanism was used to change the pressure distribution on the seat surface. The tilt angle range was from 2 deg to 18 deg (with no mid-folding angle as the tilt reference (0 deg)), and three levels were set in the experiment: Lower tilt (-8 deg), Normal tilt (0 deg), and Upper tilt (0 deg). During the experiment, thigh pressure distribution and impedance in the lower leg were measured in prolonged sitting posture participants. The following sections describe each measurement method in detail.

Measurement of the lower leg swelling

In this experiment, BIA(Bioelectrical Impedance Analysis) is adopted to measure the lower leg swelling simply and non-invasively. In this experiment, and MLT550N (manufactured by Toray Medical Co., Ltd.) was used (Lukaski et al. 1987). BIA utilizes the increase in extracellular water content associated with the occurrence of the swelling and can measure impedance by applying a high frequency current (Chester et al, 2002). Since water allows an electric current to pass more easily than fat, a decrease in impedance indicates the occurrence of the swelling. In this experiment, R_t means the measured impedance, and R_i, indicates the initial impedance. Also, the measured data were standardized as shown in the following equation, and this was taken as the BI.

$$\mathrm{BI} = \frac{1/R_t}{1/R_i} = \frac{R_i}{R_t} \tag{1}$$

Measurement of the thigh pressure distribution

A pressure sensor sheet (SR Soft Vision, manufactured by Sumitomo Riko Co., Ltd.) was used to measure the thigh pressure distribution. The contact pressure and the area data measured by the pressure sensor sheet is displayed on the monitor in real-time. The measurement range is 320 mm × 250 mm, points number is 800. In this experiment, the thigh area was determined by estimating the ischial tuberosity position. In the pressure distribution, the greatest pressure area was taken as the ischial tuberosity. Also, the back side including the ischial tuberosity means the thigh area, and the other area indicates the buttocks area.

Participants

A total of twelve males (ages of 21.6 ± 0.9 years, heights of 1742 ± 48 mm, weights of 61.7 ± 4.1 kg, and right-handed) participated in our experiments.

Experiment protocol

To avoid the influence of the participants' previous posture, each participant first walked for about 5 minutes as a pre-measurement exercise to keep the physiological state constant. Then, they were seated on the car seat equipped with the body pressure distribution sensor and attached to the electrode of MLT-550N to the left lower leg. The experiment image is shown in Fig. 1. They were measured every 10 minutes for (1) lower leg impedance, (2) body pressure distribution, and (3)

Specification of MLT550N	
Measurement range	100 Ω~1 kΩ
Degradation ability	0.1 Ω
Accuracy	± 0.1 %

Specification of SR Soft Vision	
Measurement range	20~200mmHg
Measurement point	256 Point

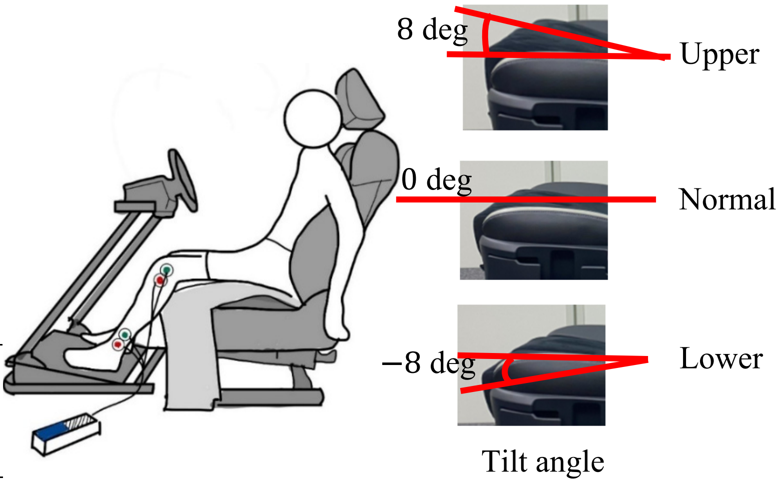

Fig.1 Experiment equipment and its specifications

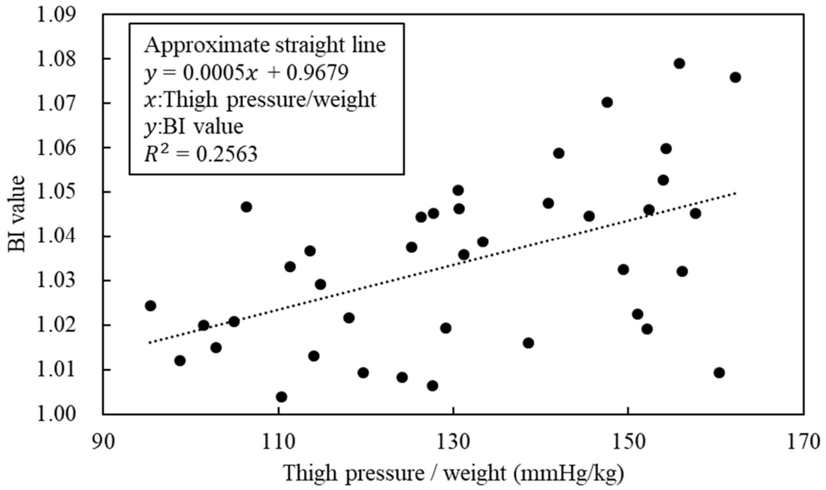

Fig. 2 Relationship of between BI value and thigh pressure/weight

sensory evaluation. The sensory evaluation consisted of a 6-point questionnaire (0: no sensation to 5: unbearable) for six items: thigh pressure, buttock pressure, thigh pain, buttock pain, leg swelling, and leg lethargy. The experiment was conducted four times, changing the tilt angle to the upper, normal, lower, and participants' free angle. The duration of each experiment was 90 minutes. Before the experiment, all participants were informed of the purpose, methods, and safety, and their informed consent was obtained. This experiment was conducted with the approval of the Bioethics Review Committee (2022-135) of the Faculty of Science and Technology, Keio University.

Result

Relationship between the lower leg swelling and the thigh pressure

Figure. 2 shows a scatter plot of BI after 90 minutes and the thigh pressure divided by body weight. Body impedance is affected by the participants' physical condition, state of fatigue, diet, time of day, and posture before measurement (Deurenberg et al. 1998, Slinde et al, 2001). Several data show a possible difference in the physiological state of the participants among the four experiments. The correlation coefficient $r = 0.506$ ($p < 0.05$) when they were removed. Also, some data indicates that the pressure distribution over the entire seating surface was asymmetric. When only the left leg pressure is focused, the correlation coefficient between BI value at 90 minutes and the left thigh pressure divided by the body weight was $r = 0.554 (p < 0.05)$.

The prediction equation for the lower leg swelling

A prediction equation for the lower leg swelling was constructed by multiple regression analysis. In this analysis, several data were excluded as data for different physiological conditions. The impedance is affected by physical characteristics such as height and weight (Deurenberg et al. 1998, Slinde et al, 2001). Multiple regression analysis was conducted using the stepwise method. The dependent variable was BI after t minutes. The independent variables were the following, t : the elapsed time from the start, P : the thigh pressure divided by body weight, w, h, f : the participants' weight, height, and body fat percentage, respectively, d : the tilt angle of the car seat. The following equation (2) was obtained.

$$\mathrm{BI(t)} = 0.036t - 12.7h - 0.021f + 0.095w + 0.019P + 0.103d + 115 \tag{2}$$

The adjusted correlation coefficient $r^2 = 0.540$, indicating a certain goodness of fit. The standardized coefficients indicated that time had the highest effect on the lower leg swelling. Furthermore, time, thigh pressure, and tilt angle were positively correlated with the lower leg swelling. As for physical characteristics, a positive correlation was observed for body weight, while a negative correlation was seen for height and body fat percentage.

Conclusion

In this experiment, a positive correlation was observed between the thigh pressure distribution and the lower leg swelling progression. Also, this study confirms that thigh pressure distribution affects the progression of lower leg swelling. Furthermore, multiple regression analysis derived a prediction equation in lower leg swelling of the participants sitting on a car seat. The future tasks include increasing the number of participants to improve the suitability of the prediction equation. Since impedance is affected by differences in physical characteristics and physiological state, it is necessary to clarify the relationship between the lower leg swelling and the thigh pressure distribution by analyzing the relationship taking participants' physical characteristics and physiological state into consideration. Moreover, examining the versatility of the equation by conducting measurements under different conditions, such as female participants and different chairs such as office chairs. Furthermore, the method of making the body pressure distribution variable should also be considered, such as image analysis or using only the tips of the thighs.

Acknowledgments

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Modelling human seat contact interaction for vibration comfort

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ABSTRACT

The seat to head vibration transmissibility depends on various characteristics of the seat and the human body. One of these, is the contact interaction, which transmits vibrational energy from the seat to the body. To enhance ride comfort, seat designers should be able to accurately simulate seat contact without the need for extensive experiments. Here, the contact area, pressure, friction and seat and body deformation in compression and shear play a significant role. To address these challenges, the aim of this paper is to define appropriate contact models to improve the prediction capabilities of a seated human body model with regards to experimental data. A computationally efficient multibody (MB) model is evaluated interacting with finite element (FE) and MB backrest models, using several contact models. Outcomes are evaluated in the frequency domain for 3D vibration transmission from seat to pelvis, trunk, head and knees. Results illustrate that both FE and MB backrest models allowing compression and shear provide realistic results.

KEYWORDS

Contact model, seat design, automobile, comfort, vibrations.

Introduction

Since occupants' well-being is directly affected by comfort, it is crucial to design automotive seating with the consideration of comfort. By simulating human body-seat interactions, designers can gather data and insights that inform the selection of materials, dimensions, ergonomics, and other design elements. These interactions can be modelled using multibody and/or finite element (FE) models. Finite element analysis (FEA) can provide detailed insights into the interactions between the human body and seating, including deformation in compression and shear. However, FEA can be computationally intensive and time-consuming, especially when simulating complex models with numerous elements and conducting multiple iterations (Roupa et al., 2022).

Contact interaction, which involves the transmission of vibrations from the seat to the human body, is a critical factor in determining ride comfort. Accurate modelling of contact interactions (Desai et al., 2021) is challenging due to the multiple characteristics involved, such as contact area, seat or body soft tissue deformations, dynamic friction, damping, pressure, and shear stress (Mirakhorlo, Kluft, Shyrokau, et al., 2022). The vertical forces are generated due to the weight of the occupant and the cushion (Papaioannou et al., 2020), while the shear forces, which can also cause discomfort, are affected by the interaction between the human body and the seat cushion. Therefore, to improve ride comfort, seats that effectively isolate shear forces to the occupant are needed. The aim of this paper is to explore appropriate contact models (capturing shear) that can (a) capture the dependency on various characteristics of the seat and the human body, (b) improve the prediction of body motion (seat-to-head vibrational transmissibility) in an erect seated position based on experimental vibration data (Mirakhorlo, Kluft, Shyrokau, et al., 2022).

Method

A computationally efficient human body model (EHM) (Desai et al., 2023) consisting of 12 segments is presented in Fig. 1. The seat-human body integrated system is modelled in MADYMO (Tass, 2019) and validated using 3D human response data (Mirakhorlo, Kluft, Shyrokau, et al., 2022). The (force-displacement/stress-strain comression) contact model is investigated using various combinations of multibody surfaces (ellipsoids), rigid 3D surfaces (facets) and deformable finite elements (FE). Three backrest models are investigated representing the two foam blocks of the experimental seat. An FE backrest was made up of 1523 four node tetra elements. The foam characteristics were defined using experimental load/unloading functions, hysteresis slope and density. Contact was established with a friction coefficient of 1.2. Two multibody (MB) backrest models are presented. The $MB_{friction}$ model applies standard friction which provides poor results in lateral loading in particular. The model drifted in lateral loading and this was resolved by adding weak springs preventing lateral drift at thighs and pelvis. However the friction still prevented a realistic shear deformation of seat and human which was well captured by the FE backrest. This was resolved in the model MB_{shear}, where contact friction was removed and replaced by 2D point restraints acting in the contact plane at thighs, pelvis and back with linear stiffness and damping. The human model postural stabilization parameters for the three backrest models were obtained using optimization, where for model MB_{shear}, also the point restraint stiffness and damping were tuned.

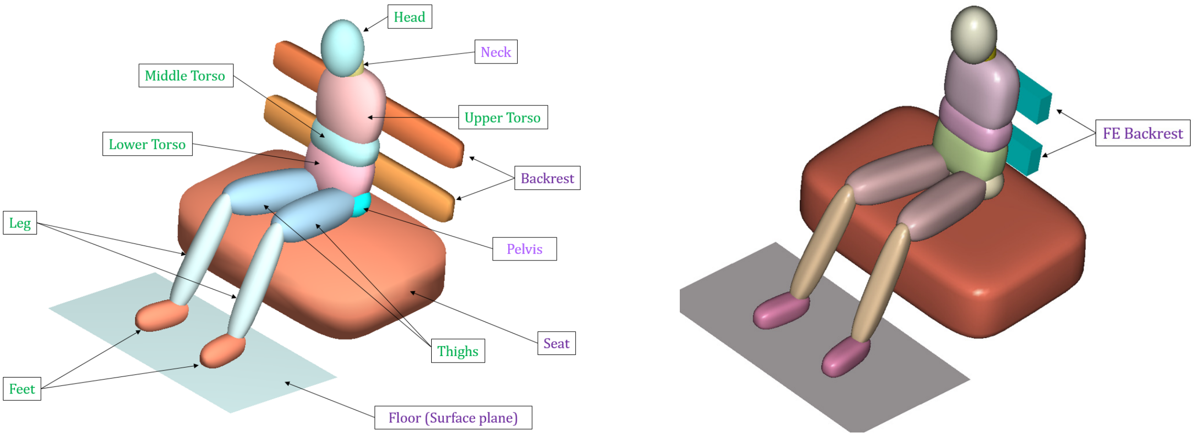

Fig. 1 Human body model (left: MB backrest, right: FE backrest)

Results

The experimental and model results are presented in Fig. 2 - Fig. 4. In comparison to the FE backrest, the MB backrest with shear can achieve comparable outcomes with less computing effort. The computational time required for simulating 35 seconds perturbation (with time step of 1E-3s) was 3.5 times more in the EHM with FE backrest compared to the EHM with MB backrest, which runs almost in real time. During vertical excitations, such as vibrations or impacts acting vertically on the seat backrest, the deformations in the FE elements can lead to the generation of higher forces. As a result, the FE elements may experience larger deformations, leading to higher forces being transmitted from the backrest to the torso, and consequently resulting in higher seat-to-head transmissibility (Fig. 4). Lower angular rotations are present in fore-aft and lateral excitations with the $MB_{friction}$ model which allows insufficient trunk motion (Fig. 2-3). The results of MB_{shear} and $MB_{friction}$ in the vertical loading case are comparable, showing a small influence of shear.

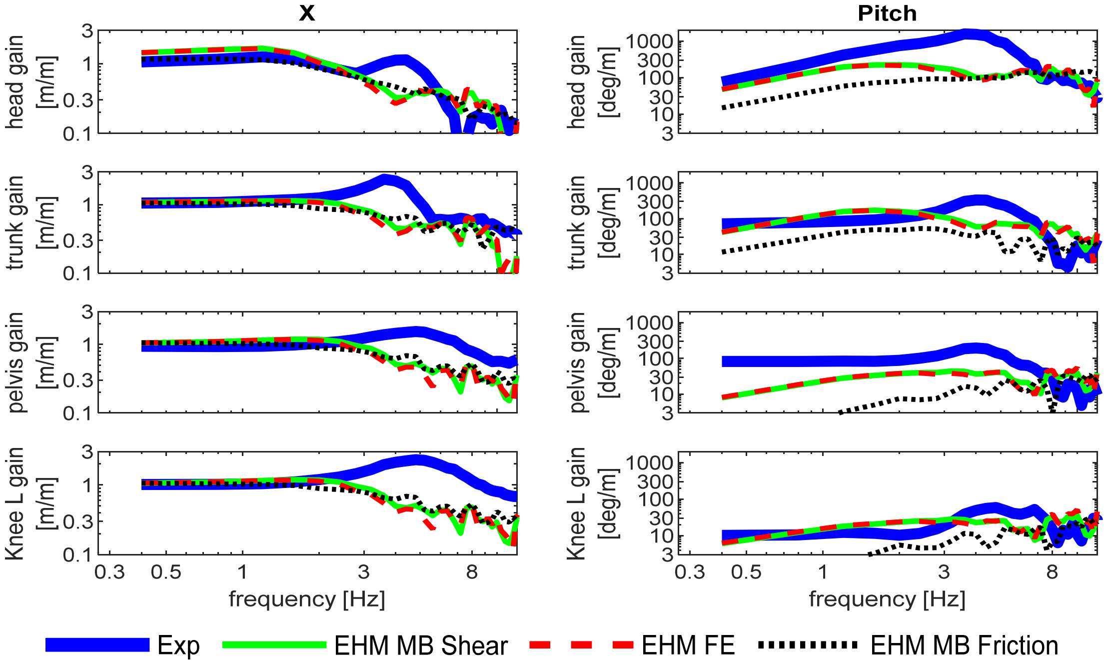

Fig. 2: Model simulation results in fore-aft loading (EHM MB: EHM with Multibody backrest, EHM FE: EHM with Finite Element backrest).

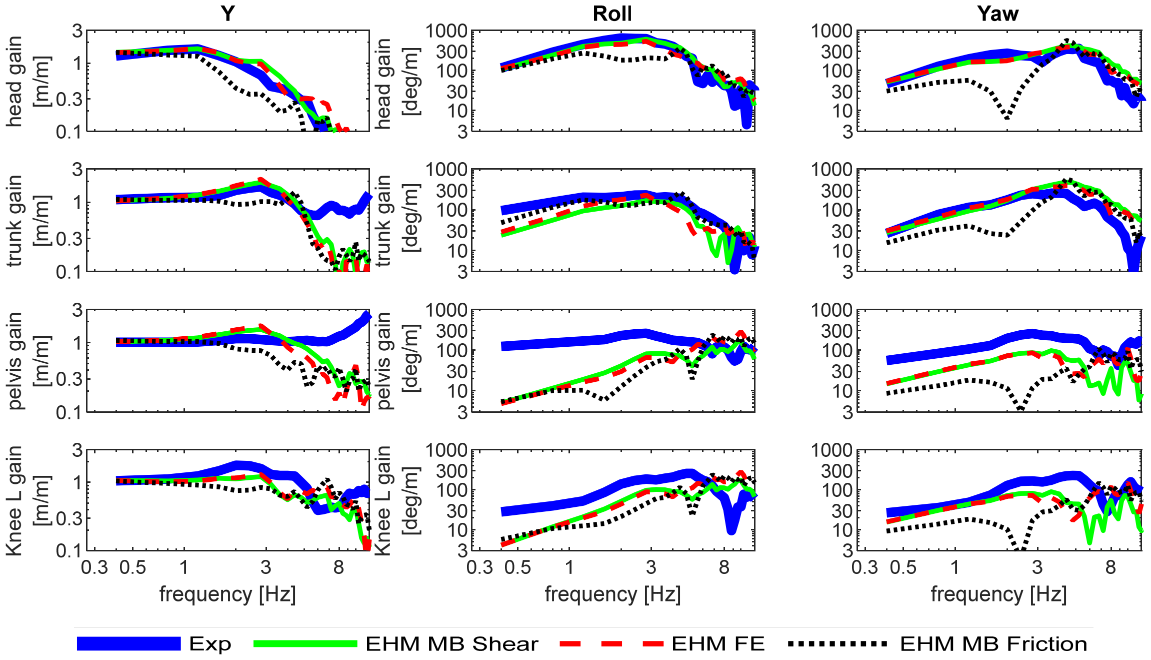

Fig. 3: Model simulation results in lateral loading.

Conclusion

The results show that the vibration transmissibility to the occupants is significantly influenced by the contact model. This paper investigates the characterization of the physical interactions between the human body and the seat backrest during motion precisely. The force-type contact model is the most efficient in enhancing the model's body motion prediction with respect to experimental data. Although using FE backrest increases model accuracy, it also increases computing load. The MB model with point restraint contact model allowing shear captures the interactions efficiently and accurately. By studying the interaction between the human body and the seat backrest, the paper provides valuable insights into how to efficiently capture the shear interactions. The findings of this study may also be used to guide the design of seats for improved comfort. In the future, we intend to precisely model interactions while taking into account the geometry/shape of the seat, buttocks, and backrest using pressure data.

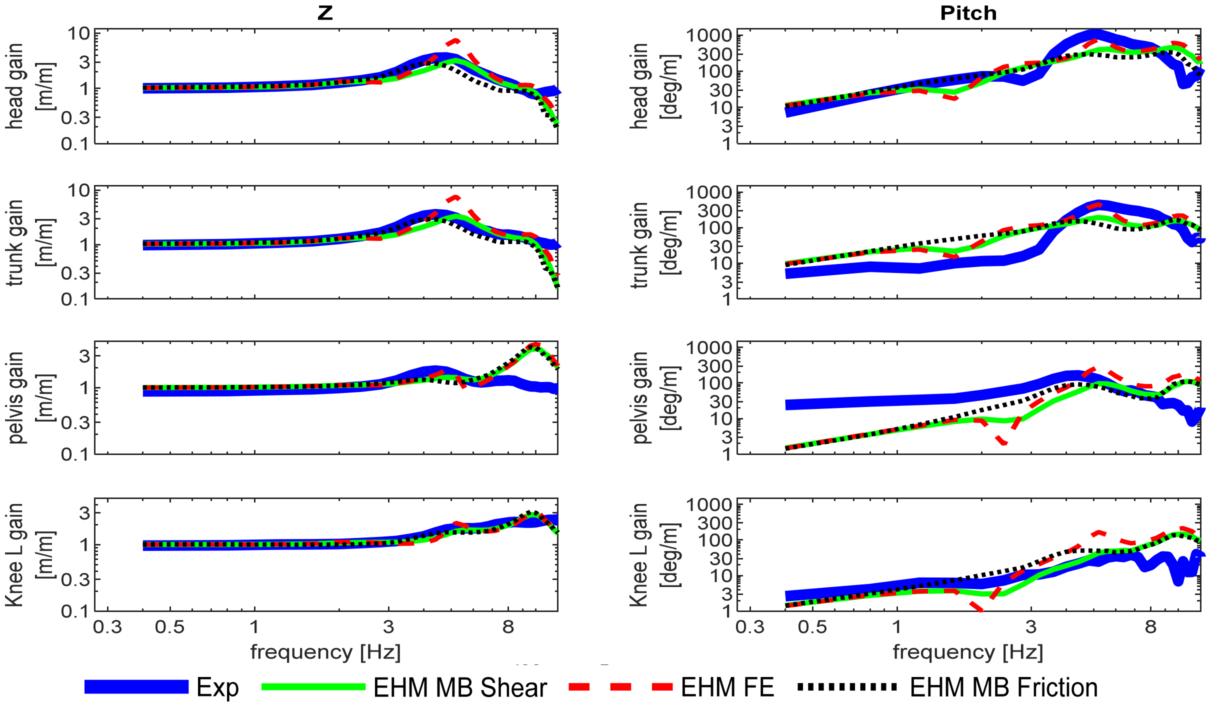

Fig. 4: Model simulation results vertical loading case.

Acknowledgement: We acknowledge the support of Toyota Motor Corporation.

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Challenges of females in menstruation calling for comfort design in working environment

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ABSTRACT

Sitting comfort is crucial for the health and working efficiency of office workers. The changes within female bodies during menstruation, as well as the use of menstruation products, might lead to different feelings of comfort. A better understanding regarding the feelings of the female population on comfort during menstruation is necessary for seat comfort design. An online survey was developed and conducted with 123 women with experience of menstruation to collect the female perspective on symptoms and sensations of the seat during this period. The preferences for seat cushion features were also collected. The results revealed that most females experience both physiological and mental issues of varying frequencies and severity. Additionally, it was found that lying is the most comfortable posture for the majority of women during menstruation. Due to these changes, a more female-friendly working environment should be built to improve comfort. The most desired changes regarding seat cushions are improvements in ventilation and darker cushion covers. The study also emphasized the necessity of designing with considerations of the female menstrual process to maximize comfort during menstruation.

KEYWORDS

Menstruation, comfort design, working female

Introduction

Sitting comfort is a crucial factor for comfort experience in office (Fujimaki & Noro, 2005). As a complex multi-factorial model, perception of (dis)comfort depends on physical, physiological, mental as well as environmental status (Song & Vink, 2021). The changes of female bodies in menstruation might lead to different perceived comfort levels, even health issues. For instance, high level of moisture concentration in the genital area can be a cause for women to seek for clinical help (Hainer & Gibson, 2011). To improve sitting comfort for female workers, it is important to have a deeper understanding of the challenges females are facing in their menstruation period.

Females experience menstruation from puberty (average onset of menarche declining worldwide rapidly to an average below 13 years at the moment (Leone & Brown, 2020)) to menopause at an average age of 51 (Rosner et al., 2022)(Pan & Li, 2019)(Coast et al., 2019). The normal menstruation can last 1-8 days (Thiyagarajan et al., 2021). It is a complex process with interactions of hormones, tissues, and molecular signalling (Smith, 2018). Avoiding or wanting to avoid working during menstruation can be difficult for many women. Besides the physiological changes within the female body during menstrual period (Smith, 2018), the sensory function (Swanson & Dengerink, 1988) (Navarrete-Palacios et al., 2003) (Giamberardino et al., 1997), emotion and cognition of females might change as well (Farage et al., 2008); accordingly, changes are required on the working environment. This leads to the research questions of this study: 1) what are the general experiences of working during menstruation? 2) what changes could be made to the seat cushions/ seating surfaces to improve comfort In sedentary work during menstruation?

Method

Based on the menstrual practices questionnaire(MPQ) (Hennegan et al., 2020) and Menstrual Distress Questionnaire (MEDI-Q) (Vannuccini et al., 2021), a questionnaire in the form of online survey was designed to collect data on females' perspectives on their daily work during menstruation,. The questionnaire consists of three parts. The first part is about general background, the used menstruation products and overall attitude regarding menstruation. The second part focuses on the symptoms and emotions during menstruation period. The preference of different elements of seat (cushions) of their working chair is asked in the last part. Since this study is a long-term study and large amount of data are required to draw universal conclusions, only preliminary results are reported in this paper.

The preliminary period of data collection involved 123 females who have experienced menstruation. An overview is given. The change of their sensations, attitudes towards working and desired cushion changes in period are summarized.

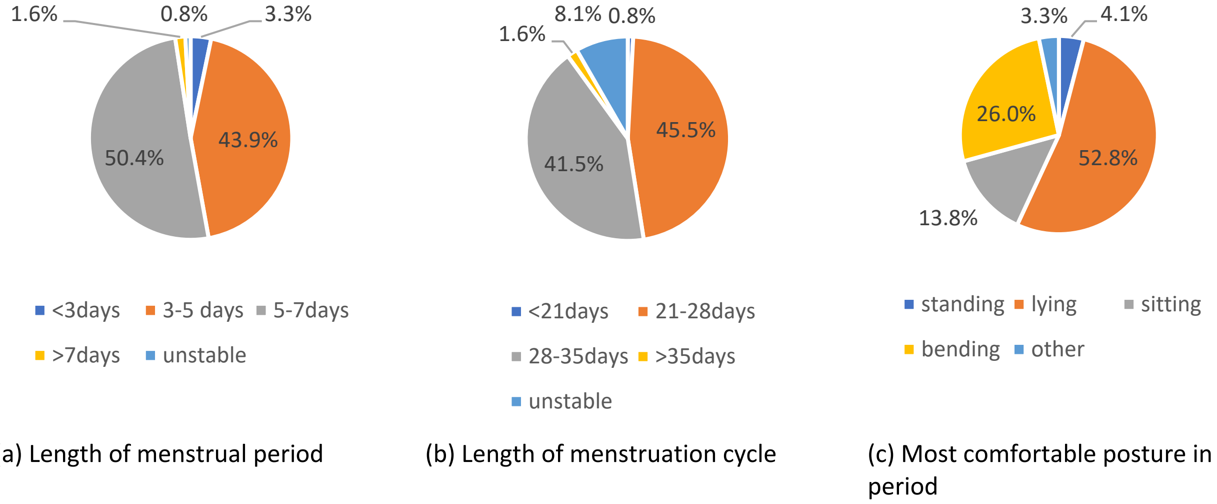
Results

The basic information of the population is shown in Table 1. Among the 123 females, 92.74% reported sitting positions as the most common posture during work. Disposable sanitary pads were the most frequently used product (74.19%) among this group during work, with some individuals using tampons (15.32%) and menstrual cups (8.02%). Out of the 123 females, 51 (41.5%) reported taking medication to relieve menstrual symptoms. Figure 1 displays the length of the menstrual period, the menstruation cycle, and the preferred posture during menstruation for the participating women. The majority (87%) experiences menstruation every 21-35 days, while over half (52%) of the participants have menstruation lasting over 5 days. Lying is considered to be the most comfortable posture by 52.8% of the women.

Table 1 Basic information of the sample.

	Minimum	Maximum	Mean	SD.
Age	20	62	31.70	8.66
Age of menarche	9	19	12.55	1.39
Height (cm)	152	187	165.87	6.74
Weight (kg)	45	100	62.97	11.28
BMI	16.65	36.73	21.96	3.78

The most often mentioned menstrual symptom is lower abdominal pain, with 91.9% of the tested population reporting its presence. Among the 123 females, 29.3% ranked the severity of the lower abdominal pain as high and unbearable. Fatigue was reported by 89.4% of females, and 20.3% considered the severity of fatigue as high and unbearable during menstruation. Emotional lability was reported by 87.8% of females, with 17.9% considering it to be very severe and unbearable.



(a) Length of menstrual period (b) Length of menstruation cycle (c) Most comfortable posture in period

Figure 1 Overview of menstruation of the participants.

Figure 2 shows the answers to five key questions related to work and sensations during menstruation. The questions were asked with 11-point Likert scales, with '0' representing largely decreased/large negative changes, '5' representing indifference compared to the non-menstrual period, and '10' representing largely increased/large positive changes. Compared to the non-menstrual period, females reported using the toilets with slightly higher frequency. They also sensed higher humidity and temperature around the perineal area. On average, working during menstruation was disliked and sleeping quality was slight worse than usual.

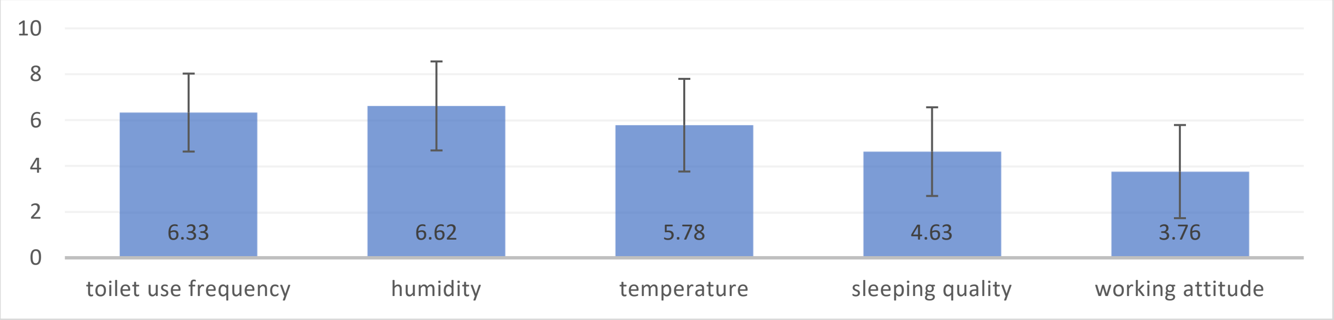


Figure 2 Average sensation changes and attitude (±1/2 SD) towards working during menstruation compared to non-menstrual period (0=largely decrease/large negative changes, 5=indifferent, 10=largely increase/large positive changes)

Figure 3 displays the desired changes to the cushions/seating surface of the working seats during the menstrual period. It appears that, over half of the participants preferred to keep the width and depth of the seat cushion the same. 77.2% of the tested population showed the preference towards a better ventilation. At the same time, 65.6% of the tested population prefer darker colors of the cushions (cover) in case of leakage. 63.2% of the tested population would like to have a softer cushions. The preference for thickness varied, with a majority opting to keep them the same but with notable percentages indicating a slight increase or decrease. Significant Pearson correlations ($p<0.05$) of -0.23 and -0.24 were found between height and seating area depth, cushion softness, respectively.

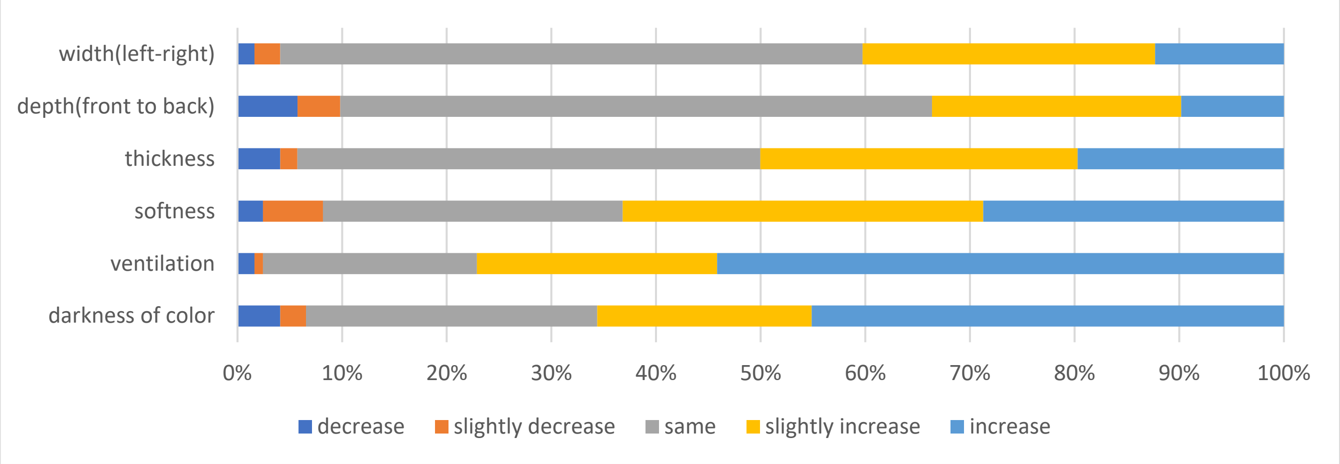


Figure 3 desired changes of the seat cushions/seating areas.

Discussion & conclusion

According to previous literature, the cardiovascular system, the central nervous system, the digestive system, the endocrine system, the female reproductive system, the immune system, the integumentary system and the skeletal system were confirmed to include estrogen receptors (Hall & Phillips, 2005)(Sekigawa et al., 2004)(Brincat, 2000)(Millikan, 2006)(Tamer et al., 2003)(Suzuki et al., 2001)(Thornton et al., 2006). The systemic process within body leads to the discomfort, pain and mental/emotional issues during menstrual period. The majority of females consider lying down as the most comfortable posture during menstruation. The preference of lying down can be a reason why females dislike working during their menstrual period. It is necessary to build a friendly working environment. Since the most common posture during work is sitting (92.74%), the seating surface (cushions) can have the most significant impact on the human body in the environment. The most crucial change in the cushion should be improving the ventilation of the cushion material, considering the increased humidity and temperature around the perineal area. A darker cover for the cushion is also preferred in case of leakage.

In conclusion, this study used online questionnaires to collect data regarding females' challenges and experiences with daily work during menstruation. A preliminary analysis was conducted with 123 females, focusing on their general background, menstrual symptoms and preferences regarding seating surfaces (cushions) during menstruation. The findings revealed that lower abdominal pain, fatigue, and emotional lability were the most commonly reported symptoms. The study also highlighted the influence of sensation changes, leading to discomfort and mental/emotional issues during menstruation. Although this study provides preliminary results, further research is needed to draw more comprehensive and universal conclusions.

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Improve comfort using a sensor-link between a sitter and a seat

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ABSTRACT

People might not be interested in seat comfort unless they are researchers in the related academic field. Nevertheless, however, we are living in an age when we tend to be seated almost all the year around. This situation often causes a raised sense of problems with relationships between seating and health maintenance, leading to a growing interest in seat comfort. This paper describes developmental process of a counseling support device coupled with creating dialogues. We report on results of experiments using the device and system. The device in question is composed of a sensor-link system and a D-A convertor, being designed to help a sitter enhance his or her own seat comfort as well as to function as such a counseling device as bringing awareness of relationships between seat comfort and health maintenance. Two kinds of chair were used for our research: one was for household use and the other for work. Using a household-use chair, we compared between cushions with different hardness, with relationships between subduction depth, sitter's weight, and seat comfort investigated. Individual subjects compared seat comfort between several cushions. Adopted as a chair for work was a chair used for ophthalmic surgeries as sitters. This chair was equipped with a structure in which the backrest could slide 6 cm back and forth to take such three positions as front, middle, and rear. In our experiment, surgeons were required to compare seat comfort between the three positions of the backrest in such a manner as "this position is too poor in seat comfort to conduct a surgery". We aimed to utilize the gained results to clarify sitter's preference on cushions and backrest, resulting in the development of a counseling system with creating dialogues.

KEYWORDS

comfort1, counseling 2, dialogue, 3sensor 4, device 5

Introduction

Concept of a counseling system leading to personal comfort.

Noro et. Al.2012 proposed an approach that incorporates physiological and objective data for evaluating seat comfort so called Zen sitting model. According to this model, the experiment measures both subjective evaluation and objective evaluation. Both data are recorded via a multi-channel DA converter. Next, we analyze the data to identify the comfort parameters. For a household chair, body weight is selected as the parameter. For a chair used for ophthalmic surgeries, sliding position of chair back is selected as a parameter. Once parameters are obtained, The user is invited to the communication space to get comfort. Characters and avatars play the necessary roles in that space.

Method

Design and development of chairs for experiments

Two types of chairs were used for the research. One is a versatile chair used for working from home. The other is a chair used by ophthalmic surgeons during their clinical work. Both chairs were designed and manufactured by our research team with help from factories. The surgical chair was also designed and prototyped by our team. The prototyping process has already been reported in detail. (Oyama、2022)

1 A household chair with replaceable cushions

Result of past experiments (Sato et al., (2020) and Hyodo et al., (2022) show that body weight is affected to comfort. A household chair with replaceable cushions was developed. Two types of slab urethane foam (9cm thickness) with different hardness were selected after examining the hysteresis curve. The chair has four replaceable cushions shown in Fig. 1. The picture on the right in Fig. 1 shows a sitter replacing cushions for comparison. Sitters can choose from many combinations among those cushions.

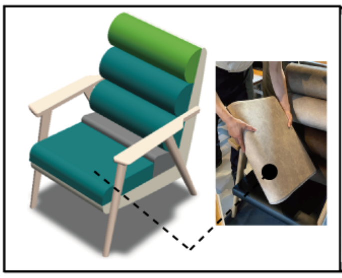


Fig.1 A household chair with replaceable cusshions

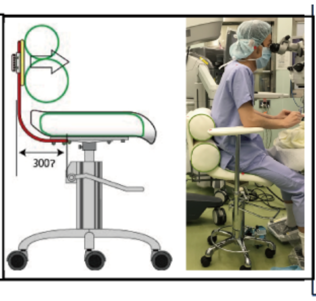


Fig.2 A proto type chair for surgent

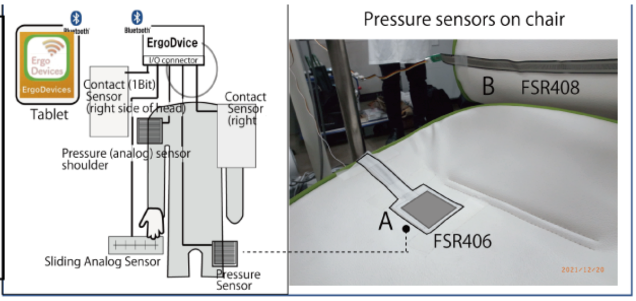


Fig.3-1 Sensor link with ErgoDevice Fig.3-2 Chair only needs two small sensors

Fig.3 Sensor link with ergodevice with sensors

2 A chair used by a surgeon for ophthalmic surgery

The prototyping process of the surgical chair has already been reported in detail.（Oyama, 2022） Left side of Fig. 2 shows the backrest of the chair slides back and forth 6cm to increase upper body stability. In a preliminary survey, high stability of upper body has been shown to have a positive effect on surgical procedures. Fig. 3 shows examples of these chair-mounted devices and sensors. Details are given in a later section.

Experiment for a household chair

Since 2019, Sato, Hyodo and others have been conducting research based on the ergonomics of sofas, especially the development of a method for measuring the amount of cushion sinking (subduction depth) and the relationship between the amount of displacement and sitting comfort. Hyodo et al. (2022) had a completed device and conducted experiments on 13 Japanese individuals (53.3 kg to 85 kg). The results obtained are shown in Fig.4.

Experiment for a prototype chair used for ophthalmic surgeries

Purpose of the experiment: The backrest of the prototype chair : slides back and forth 6cm. We will check the effect of this function, especially whether it makes easier to operate. Subjects: 8 people with sufficient surgical experience. Set the backrest of the chair to 3 levels: 3 cm in front, 3 cm in the middle, and 3 cm in the back. At each level, subjects were given a grid plotting test (Menozzi, M., et al 2019). Evaluation 5-point method Items for evaluation: -2 : The comfort of the back support is very bad (Surgery cannot be performed in this state).+2:The backrest is very comfortable (it seems to have a very positive effect on surgery).Rating was performed using SAS(see next column) immediately after the subject completed each of the three conditions. The results obtained are shown in Fig.5

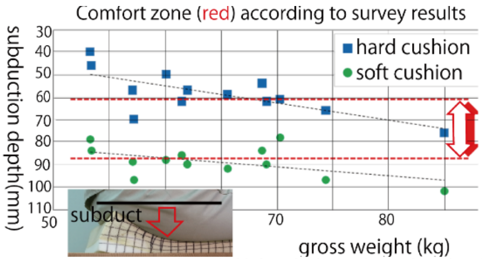
3 devices developed for the experiments

Experiments were conducted on the sensor-link system (Fig.3) and a multichannel D-A convertor, shown in left side of Fig.3. Two kind of pressure sensors were used and mounted on chair as shown in right side of Fig.3. A wide variety of sensors are available at electronic component mail order stores and shops in Akibahara, Tokyo's electronics district. In use, one thing to keep in mind is measurement accuracy and part-to-part quality variation. Togami (2022) publishes actual measured results. The diagram is a slight rework of Noto 2022. Originally, she illustrated how to measure a patient's movement on a bed. Ergo Device is a compact multi-channel AD converter that is wireless with Bluetooth (Low Energy). Analog sensors and digital sensors can be connected with the same I/O connector. The size and weight are 8cm x 6cm x 2.4cm and 114g. It can be attached to many life-related devices. Sliding Analog Sensor (SAS)for comfort rating (left side of Fig3): The SAS was inspired by the user questionnaire pushbuttons in airport toilets. Airport restroom users and surgical operators are in a similar position with respect to the evaluation required. In other words, when both of them leave the place, their interests shift to other things. And forget about the comfort of the place or chair. The responses obtained from SAS are included in the CSV data. Therefore, the freshness of responses is guaranteed.

Results

Result for experiment for household chair and the surgical chair.

We analyze the data to identify the comfort parameters. For a household chair, body weight is selected as the parameter in Fig.4 where we measured the amount of cushion sinking (subduction depth) and the relationship between the amount of displacement and sitting comfort. For a chair used for



a household chair, body weight is selected as the parameter

Fig.4 a household chair, body weight is selected as a comfort parameter

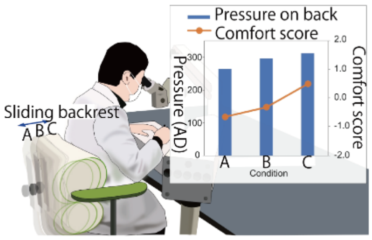


Fig.5 the backrest of the chair slides forth to increase upper body stability : a comfrt parameter (Oyama,H., et.al.,2021).

Fig.6 Simone, a professor avatar and VR space

ophthalmic surgeries, sliding position of chair back was measured and analyzed. Decided as a parameter for control to slide back of the chair. Both of the parameters obtained from the two chair experiments are derived from the individual's body shape and weight. So the comfort they got is personal.

An example of counseling by Simone and professor avatar

The developed system provided each sitter with characteristics of a cushion presumably preferable to the sitter along with advices on health concern in daily life when the cushion was used. In this system, Simone, a concierge in the communication space（Fig.6）, instructs a subject how to compare cushions before choosing the most preferable cushion. Upon completion of a chair equipped with the desirable cushion, Simone would be replaced by a professor avatar appearing in a bid to give advices on possible health concerns likely to be caused when the chair is used. If the subject selects a soft cushion, for instance, the professor avatar would give an advice, based on the experimental results and findings in the past, such that it is apt to cause a posterior tilt of the pelvis, before recommending stand-up actions once in half an hour. As a result, when a surgeon took a seat on this chair to perform a surgery, it became possible for the counseling system to immediately set the backrest at the position most appropriate for the surgeon.

Conclusion – comfort in daily life and work

The sensor link system and multi-channel DA converters used were satisfactory to the experimenters, even taking into account the peculiarities of the experimental site and subjects.

The professor avatar’s explanations and advices closely matched to subjects were most favorably accepted by ordinally people and surgeons who participated in the experiments. The concierge Simone was affectionately accepted by diversified age groups, including when the whole family received her counseling, because she helped people have familiar impression on the relevant systems.

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Static comfort properties of polyurethane foams for mattress under cyclic fatigue and photodegradation

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THE WORK IN CONTEXT

The main objective of this study is to investigate the effect of different accelerated weathering factors on the structure and comfort factors of three commercial flexible PU foams used for mattress fabrication. To this aim, in this work three commercial flexible polyurethane foams used for mattress have been submitted to artificial weathering in a climatic chamber, to investigate its effect on their structure and some functional properties of interest for bedding applications, and to cyclic fatigue loadings in a mattress aging station, to evaluate the alteration in mechanical response and comfort level. Colorimetric analyses demonstrated that during weathering all three foams undergo oxidation of the polyether soft segments, whereas the optical microscopy observations demonstrated that after fatigue cycles a well-visible cell structure disruption occurs. The resulting changes in the structure and molecular mobility of the foams affected their comfort in static conditions, giving a general reduction of the hysteresis loss, surface firmness, and sag factor, more significant for the foams having a slow recovery rate after compression.

KEYWORDS

Polyurethane, Flexible foam, Comfort, Cyclic fatigue, Photodegradation

Introduction

Polyurethane (PU) flexible foams represent one of the most important class of polymers that can properly selected to the desired application (such as mattresses, pillows, automotive seating, etc.), thanks to their high chemical and morphological variability and to a wide range of physical and mechanical properties [1-2]. Nevertheless, the knowledge of comfort performances of these materials on long timescales is still lacking. In this study, with the aim to improve the understanding of the durability of polyurethane foams, three commercial flexible PU foams, used in mattress sector, were firstly tested to determine their original structure, cellular morphology, thermal characteristics, and the compression mechanical properties related to comfort, i.e., the hysteresis loss, the surface firmness and the cushioning quality [3]. Then, the PU foams were submitted to accelerated aging tests in an environmental chamber, by exposure at controlled temperature, humidity, and UV radiation, and to cyclic fatigue loadings in a mattress aging station and tested again, in order to evaluate the effects of the changes on final properties and comfort level.

Method

The study was performed on three commercial flexible PU foams for mattress, commercially named FF60N, VISCOPUR and AP35B (kindly supplied by Rinaldi Group, Italy), having open cell structure and different viscoelastic behavior. The apparent density tests were carried out in accordance with ASTM 3574-03 (test A). Optical microscopy observations were made using a LEICA MZ6 microscope; the images were analyzed with the IMAGEJ software. Compression mechanical tests (SANS CMT 6000 Series testing machine, MTS, China) were performed to determine the properties related to foam comfort levels in static conditions: mechanical hysteresis loss (HL) (ASTM D3574-03 X6), indentation force deflection (IFD) (ASTM D3574-03 B1) and sag factor (SF). Accelerated aging tests were performed on each foam samples by exposing them in the environmental chamber Challenge ACS CH250 (Angelantoni, Italy) at 40°C, 85% R.H. and UV radiation. Colorimetric analyses were carried out with a CR-410 HEAO colorimeter (Konica Minolta Sensing, lnc.). The color changes were evaluated according to the L* (lightness), a* (redness), b* (yellowness) system (ASTM 0-1925, CIE 1976) and by the ΔE* total color change [4]. Cyclic fatigue loadings were carried out on the flexible foams using a mattress aging station (Mod. ST-INV1, DELVA, Italy), submitting the samples up to 300.000 loading-unloading cycles (40°C, flat-horizontal indention, vertical force: 1200 N, frequency: 12 cycles/min).

Results

The three flexible polyurethane foams were preliminarily characterized in terms of density and structure. Optical microscopy observations show that all foams have an open cell structure, with average pore size ranging in the interval 440-570 microns and wide pore distribution for all samples. The density and the original comfort parameters of the three foams are listed in Table 1.

Table 1. Density and comfort parameters of unaged PU foams.

SAMPLE	Density [kg/m^3]	HL [%]	25%IFD [N]	SF
FF60N	47 ± 1.6	50.0	10.4	2.57
VISCOPUR	40 ± 2	46.7	14.0	2.24
AP35B	35 ± 2	27.0	38.8	2.51

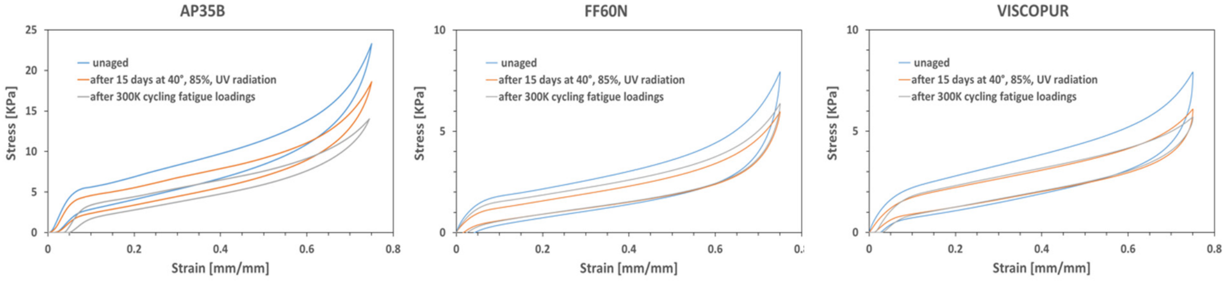

Figure1. Hysteresis loss curves for unaged and aged AP35B elastic sample, FF60N, and VISCOPUR viscoelastic samples.

In order to evaluate the effect of environmental weathering and fatigue cycles on the comfort of the investigated foams, the materials were tested for their durability as specified in the experimental part. Figure 1 shows the effect of different weathering on the stress-strain curves obtained during the hysteresis loss (HL) tests for all the foams.

Both artificial weathering change the mechanical parameters related to comfort factors; the lowering of the loading curve for all the samples, accompanied by the decrease of HL values, is indicative of a softening of the aged foams due to the accelerated aging conditions. In particular, in the elastic sample AP35B, the reduction of the foam ability to distribute body weight is greater after the application of fatigue loadings in the mattress aging station due to the thickness loss. Instead, the combined effect of temperature, moisture, and UV radiation in the environmental chamber causes a more pronounced decrease in mechanical performance in the FF60N and VISCOPUR samples having a less rigid molecular structure.

However, even if in all cases both the weathering factors shift bottom the stress-strain curves reported in Figure 1, the alterations induced in the materials have different natures. As an example, Figure 2 compares the OM of the VISCOPUR foam unaged and aged by both accelerated weathering. As you can see, UV weathering mainly affects the chemical structure of the polymer, as suggested by the yellowing of the material that can be related to oxidation phenomena. In particular, after a weathering time of 6 days the total color difference ΔE* values for the AP358, FF60N and VISCOPUR foams are equal to 1.01, 2.53 and 4.29, respectively. Instead, the fatigue weathering gives a well-visible cell structure disruption, with the formation of very large pores.

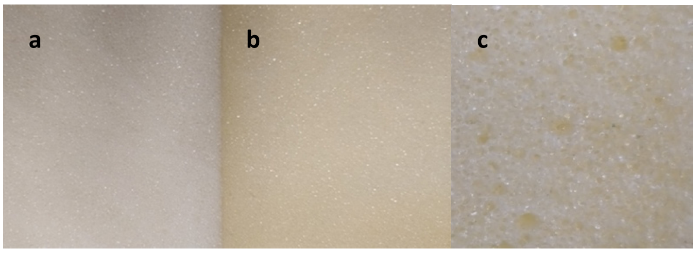

Figure 2. OM images (5 x) of VISCOPUR foam unaged (a), aged by UV (b) and aged by fatigue cycles (c).

Conclusion

In this work three commercial flexible PU foams, used for mattress fabrication, have been tested to investigate the relationships among composition, morphology, and some functional properties of interest for their application in the bedding sector. The performed analyses evidenced that all three foams have open cell morphology and similar cell size and distribution but differ for their chemical structure (length of soft segments, amount and strength of the hydrogen bonds) and thus for their mechanical response. In particular, the AP35B system, which has a more rigid molecular structure, has a lower hysteresis loss, i.e., requires lower energy consumption while moving, but also a firmer surface (higher 25%IFD) and lower resistance to bottoming out (lower SF), compared to the two others, which are better able to distribute the body weight and to reduce the pressure on the body.

After the artificial weathering in the climatic chamber, all the foams undergo oxidation phenomena that cause color changes and alteration of mechanical parameters related to the foam comfort. Moreover, the fatigue weathering gives a well-visible cell structure disruption, with the formation of very large pores. The effects are more significant for the FF60N and VISCOPUR samples having lower crosslinking degrees and slow recovery rates after compression.

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