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A Multi-factorial Approach for the Assessment of Comfort in Clothing – A Footwear Application

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Abstract The perception of comfort is a complex and multi-factorial phenomenon based upon three main components: (i) psychological factors relating to an individual's role, values and social being, (ii) sensorial factors relating to the thermal, tactile and pressure sensations generated between clothing and the skin and (iii) physiological factors which affect body function during activity i.e. mechanical aspects (fit, level of support) and thermal aspects (heat and moisture transfer) (1,2). The evaluation of comfort in clothing has primarily been determined in relation to the physiological component. The exploration and understanding of psychological and sensorial factors of comfort is therefore limited. This paper will consider the methods which can be used to explore all three components of comfort and the insights gained from undertaking a multi-factorial approach. This multi-factorial approach was adopted in relation to a footwear application investigating the importance and role of the sock on comfort within the foot-shoe system. Four socks identical in design/construction but different in fibre composition (94% of either cotton, wool, polyester or coolmax with 3% polyamide and 3% elastane) were used for the assessment. Psychological factors were explored using Best-Worst Scaling to allow for the assessment of attribute importance and consumer preferences. Sensorial factors of comfort for each sock were evaluated by filling in a questionnaire containing 15 sets of opposing adjectives (e.g. thick vs thin, comfortable vs uncomfortable) to allow for semantic profiling. This was performed at rest with socks being applied to the participants feet (passive assessment) and following exercise (dynamic assessment). The evaluation of physiological comfort was achieved through completion of five running trials performed on separate occasions for each sock and without a sock. Foot skin temperature, in-shoe temperature and in-shoe humidity were monitored throughout. Subjective ratings (thermal sensation, wetness perception, stickiness and thermal comfort) for the foot were recorded. Comfort and functionality were identified as important attributes influencing sock purchase. Assessments performed passively allowed for sensitive discrimination of textile properties between sock conditions (i.e. rough/smooth, scratchy/silky). During dynamic assessment however, the ability to discriminate between textile properties reduced. Wearing socks during running reduced discomfort compared to not wearing a sock but did not affect shoe microclimate. Overall, assessment of clothing comfort utilising a multi-factorial approach indicated that: (1) assessment of sock properties change from passive to dynamic assessments, (2) socks influence sensorial comfort within the foot-shoe system but have little physiological impact and (3) running without socks result in greater thermal discomfort compared to running with socks.

Keywords: Comfort, Multi-factorial interactions, Footwear

1 Introduction

The perception of comfort is a complex and multi-factorial phenomenon based upon three main components: (i) psychological factors relating to an individual's role, values and social being, (ii) sensorial factors, relating to the thermal, tactile and pressure sensations generated between clothing and the skin and (iii) physiological factors which affect body function during activity i.e. mechanical aspects (fit, level of support) and thermal aspects (heat and moisture transfer) (1,2).

The evaluation of clothing comfort has primarily been determined in relation to physiological factors. Havenith (3) showed how parameters relevant to heat exchange processes (air and radiant temperature, humidity, wind speed, metabolic production and clothing insulation) impact a worker's thermal stress and highlighted the relevance of clothing design, clothing fit and clothing air permeability. Knowledge of human local sweat patterns (4) have recently been applied to the design of sportswear. Results have shown improvements in thermo-physiological responses and thermal perception for body mapped ensembles compared to traditional ensembles when running in a warm environment (5).

Sensorial factors have also been evaluated, primarily through touch and interaction with textiles, the process of which is referred to as the 'fabric hand'. Although there is lack of consensus regarding the psychophysical techniques to apply, the use of semantic profiling (bipolar rating scale consisting of opposite word pairs i.e. hot – cold, rough – smooth) is now frequently used (6–8). Semantic profiling allows for the identification of specific sensory qualities (hot – cold, rough – smooth etc.) but also the perceived magnitude of those sensations (very hot, slightly rough etc.). Primarily assessed through the 'fabric hand', it is not known how these sensations translate to the sensations experienced when a garment is worn at rest or during activity. Moreover, there are no subjective criteria relating to hand feel (9) and so the specific qualities and magnitude of sensations required for clothing comfort have not been identified.

Despite growing interest, the exploration and understanding of psychological factors of comfort is limited. To identify consumer needs and expectations, researchers have assessed the importance given by consumers to various clothing attributes such as fit, price and comfort etc. (10,11). However, discrimination between attribute importance is not always possible when using rating scales as respondents often rate all attributes as 'important'. Best-Worst scaling commonly used in sensory science to explore consumer perceptions to food products and packaging allows for greater discrimination of attribute importance. Individuals are required to identify the best and worst attributes for combinations of profiles relating to clothing features and characteristics (12,13). Although the method has not been applied within clothing science, identification of consumer expectations is useful for product innovation and marketing.

This paper will consider the methods which can be used to explore all three components of comfort in clothing and the insights gained from undertaking a multi-factorial approach. This multi-factorial approach was adopted in relation to a footwear application investigating the importance and role of the sock on comfort within the foot-shoe system.

2 Method

10 healthy females [age: 23 ± 4 years; height: 169.1 ± 4.6 cm; body mass: 62.7 ± 8.2 kg; foot size: 6.5 ± 0.6 UK] volunteered to participate in this study. Participants were required to visit the laboratory for 6 experimental sessions performed in a climatic chamber maintained at 23°C, 50% RH.

Four socks identical in design/construction (ankle length, single jersey, ribbed cuff) but different in fibre composition (94% of either cotton, wool, polyester or coolmax with 3% polyamide and 3% elastane) were used for the assessment of comfort. Socks were matched for thickness and mass.

During the first experimental session, the assessment of psychological comfort was performed using Best-Worst scaling. 13 key attributes (Table 1) were identified from clothing literature (6,9). Using a balanced, incomplete block design, 13 choice sets were formed with each set containing four attributes (Table 2). Each attribute appeared once with each other and appeared four times across choice sets. All 13 choice sets were presented to respondents in a questionnaire (Fig.1).

Table 1. Attributes consumers considered when purchasing socks for use during running

Attribute no.	*Attribute*
1	Price
2	Colour
3	Fit
4	Length
5	Thickness
6	Material (cotton, wool, polyester)
7	Material weave (plain, knitted, ribbed)
8	Attractiveness
9	Brand name
10	Durability
11	Ease of care
12	Functionality (moisture management, breathability, anti-blister)
13	Comfort

Table 2. Balanced incomplete block design for the assessment of 13 attributes utilising a Best-Worst scaling approach

Choice set	*Attribute number*			
1	1	2	4	10
2	2	3	5	11
3	3	4	6	12
4	4	5	7	13
5	5	6	8	1
6	6	7	9	2
7	7	8	10	3
8	8	9	11	4
9	9	10	12	5
10	10	11	13	6
11	11	12	1	7
12	12	13	2	8
13	13	1	3	9

Considering only these four attributes, which one would be most important and least important when purchasing socks for use during running?

Most important	**Attribute**	**Least important**
☐	Price	☐
☐	Colour	☐
☐	Length	☐
☐	Durability	☐

Fig. 1. An example choice set presented to respondents utilising a Best-Worst scaling approach for the assessment of attributes considered when purchasing socks for use during running.

For the assessment of sensorial comfort, participants were required to evaluate each sock during a passive assessment using a questionnaire. Socks were applied onto the feet and removed by the experimenter with each sock type assessed in turn. Participants were shielded from seeing the socks, performing the evaluations seated behind a black drape. The questionnaire contained 15 sets of opposing adjectives (e.g. thick vs thin, comfortable vs uncomfortable) each arranged on a five-point bipolar scale to allow for semantic profiling.

Experimental sessions 2-6 involved running in each of the experimental socks on separate occasions (dynamic assessment). One trial was performed without a sock. Participants were not allowed to visually inspect the socks and they were not provided with information regarding sock related differences. Participants donned test shoes and rested for 10 minutes before performing 40 minutes of running at a constant speed (7.5 km.hr^{-1}). This was followed by a 15 minute recovery period.

Foot skin temperature (t-type thermocouples) and in-shoe temperature and in-shoe relative humidity (SHT31, Sensirion, Switzerland) was measured at seven sites on the right foot. In-shoe measurements were made by applying sensors to each sock/to the skin for the no sock trial using transpore surgical tape. Data was collected with a specially developed Bluetooth data acquisition system (University of Applied Sciences Kaiserslautern, Zweibrücken, Germany), secured to the participants ankle (14). Ordinal scales were used to assess thermal sensation, wetness perception, stickiness and thermal comfort for the right foot every 5 minutes.

Following each trial, participants were required to evaluate the socks worn by filling in the questionnaire used in the first experimental session for sematic profiling. This allowed for a dynamic assessment of sensorial factors of comfort following exercise.

2.1 Analysis

Best-Worst Scaling: An overall sum of best (B) and worst (W) votes for each attribute was determined by totaling the number of times each attribute was selected as most important and least important. To determine a B-W score for each attribute, the number of times it was least important was subtracted from the number of times it was most important. The average B-W score was calculated (Equation 1) by dividing the totals of B-W scores by the number of responses and the frequency that each attribute appeared in the design of choice sets.

$$Average\ Best - Worst\ score = \frac{Best\ scores - Worst\ scores}{(number\ of\ respondents\ \times attributes\ per\ set)} \quad (1)$$

Semantic profiling: An average score based upon the five-point scale for each set of opposing adjectives was taken forward for graphical representation. To assess differences between sock properties for passive and dynamic assessments a Friedman test was conducted. When significant effects were observed, post hoc analysis was conducted with a Wilcoxon signed rank test.

Physiological responses: The mean foot response for each individual variable (foot skin temperature, in-shoe temperature and in-shoe relative humidity) was calculated by averaging the data recorded from seven foot measurement sites for each participant over time and taken forward for statistical analysis. To investigate whether shoe microclimate was affected by sock fibre type and time a two-way repeated measure analysis of variance (ANOVA) was performed with post hoc multiple comparisons (Bonferroni correction). To investigate subjective perception of shoe microclimate between sock conditions a Friedman test was conducted. When significant effects were observed, post hoc analysis was conducted with a Wilcoxon signed rank test.

3 Results

The most important attributes to consumers when purchasing socks were comfort and functionality (Fig.2).

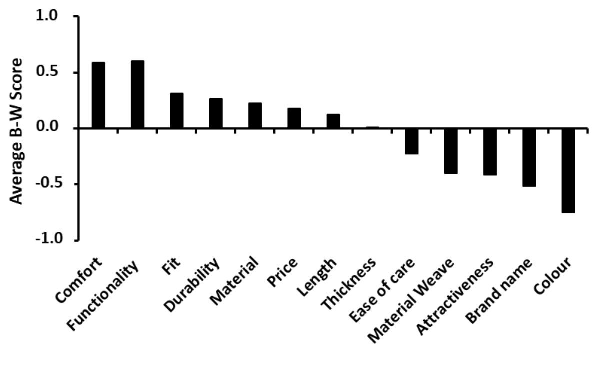

Fig. 2. Average Best-Worst scores for 13 sock attributes

Foot feel assessments performed passively (Fig.3a), showed that the cotton sock was identified as rougher and scratchier compared to the other socks (p <0.05). Participants only identified a difference in fibre composition (natural vs synthetic) between the wool and polyester sock (p=0.01). The wool sock was perceived as being less restrictive compared to cotton (p=0.02) and coolmax (p=0.03) socks. The cotton sock was identified as less comfortable, less pleasant, less satisfactory and less acceptable in comparison to wool, polyester and coolmax socks (p <0.05).

Foot feel assessments performed dynamically after exercise (Fig.3b) indicated no differences in texture related sock properties (rough/smooth, scratchy/silky). Participants identified the wool sock as being natural in composition compared to the cotton (p=0.02), polyester (p=0.05) and coolmax (p=0.01) socks which were perceived as being more synthetic. No differences in toe restriction were identified. All socks were comfortable, pleasant and satisfactory. The wool sock was rated less acceptable for wear during running compared to synthetic socks (p <0.05). For both passive and dynamic assessments, there were no differences in thermal perception based upon sock fibre composition.

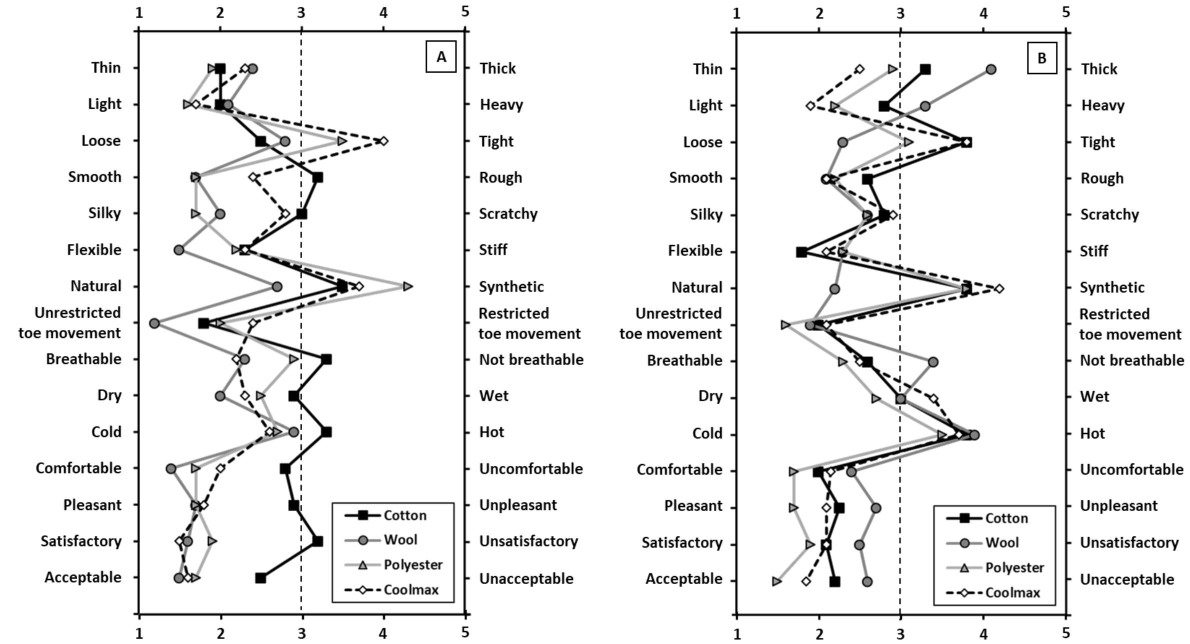

Fig. 3. Semantic profiles for the assessment of four socks (cotton, wool, polyester and coolmax) during (a) passive foot feel assessment and (b) dynamic foot feel assessment following exercise

Assessment of thermal aspects relating to physiological factors of comfort revealed that during exercise there was no main effect of condition or condition*time on mean foot skin temperature, mean in-shoe temperature or mean in-shoe relative humidity.

No differences in thermal sensation, wetness perception or stickiness were observed between sock conditions. Wetness perception and stickiness were higher for the no sock condition during run (p <0.05) which resulted in greater thermal discomfort (p <0.05) in comparison to the sock conditions.

4 Conclusions

The identification of comfort and functionality as attributes which are important to the consumer when purchasing socks for running provide important insights to the process of product design but also for effective marketing, as packaging/labelling can communicate functional and information benefits to the consumer.

Foot feel assessments performed passively allowed for sensitive discrimination of textile properties between sock conditions (i.e. smooth/rough, scratchy/silky). During dynamic assessment however, the ability to discriminate between textile properties reduced. Greater sensitivity during passive assessments were important, driving the perception of (dis)comfort. Cotton socks were perceived as rougher and scratchier and consequently more uncomfortable, unpleasant, unsatisfactory and more unacceptable in comparison to the wool, polyester and coolmax socks.

Running without a sock results in greater thermal discomfort. The type of sock worn however, has no discernible effect on an individual's thermal comfort. Running in socks of different fibre compositions or running without a sock did not affect foot skin temperature or shoe microclimate (in-shoe temperature and in-shoe relative humidity) in the conditions used.

Overall, assessment of clothing comfort utilising a multi-factorial approach indicated that: (1) assessment of sock properties change from passive to dynamic assessments, (2) socks influence sensorial comfort within the foot-shoe system but have little physiological impact and (3) running without socks has little physiological impact but results in greater thermal discomfort compared to running with socks.

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Determining Anthropometric-related Comfort Areas of Automotive Seat Components: Results from a Subjective Comfort Evaluation

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Abstract In the past, there has been a lot of research on different factors influencing the comfort sensation of vehicle seats [1]. The results of several studies showed that the unique anthropometry of each human is a significant variable in seat comfort evaluation [2, 3]. Nevertheless, no study in the literature was founded, that explored anthropometric-related comfort areas of different seat components in more detail. Therefore, the objective of the presented study was to investigate if anthropometric-related comfort areas for different automotive seat components are existing and how they are affecting the comfort evaluation.

Seventy participants (36 males, 34 females) from a broad anthropometric spectrum tested two experimental car seats. On the first seat, the original adjustment tracks of the cushion depth adjustment (50 mm) and cushion tilt adjustment (approx. 5°) were increased by the factor of three. To enable a continuous adjustment of the side bolster angles for the cushion and backrest, special electromechanical adjustors were constructed at the second seat. With the new side bolster adjustments, the angles could be varied in a range of 15° and 20° to 90°. The aim of the seat modifications was an optimal adjustability of the respective seat components for each subject independently of their individual anthropometry. For researching anthropometric-related comfort areas, up to seven predefined discrete levels were tested in order to quantify the turning points from a good to a bad comfort experience. The measured body dimensions were *body height* and *weight, shoulder width, sitting height* and *waist circumference* on the upper and *sitting width, sitting depth* and *thigh circumference* on the lower body.

The results of the presented study showed various correlations between the individually preferred adjustment of the seat components and specific body dimensions. The anthropometric-related comfort areas were investigated by analyzing the subjective assessment of the discrete levels depending on the measured body dimensions. The statistical analysis of the anthropometric effects on the subjective comfort evaluation indicated that each seat component had specific anthropometric-related comfort areas.

In conclusion, with the method used in this experiment it was possible to determine anthropometric-related comfort areas of specific automotive seat components. Accordingly, specific design and adjustment recommendations can be given for future seat concepts considering anthropometric needs of occupants. Further research is necessary to explore how the anthropometry affects the comfort experience on other seat parts as well.

Keywords: Anthropometry, Automotive, Comfort Areas, Seat Components

1 Introduction

Many different factors are affecting the seat comfort experience in a vehicle. Beside the usage or task performed in a car, the seat characteristics are important parameters influencing the passenger´s perceived comfort. The contour of the backrest and seat cushion as well as the foam properties are essential for an optimal fit between the seat and passenger. The third main affecting factor is the human with its unique anthropometric and morphologic characteristics. The fact that humans are different concerning their individual anthropometry poses a significant challenge in the seat development process [4].

Various studies had previously researched how the anthropometry affects subjective and objective comfort parameters. The results generated by Paul et al. (2012) show several correlations between a variety of body dimensions, such as body weight, hip breadth, waist circumferences and pressure parameters. They concluded that more research is needed in order to quantify whether or not these values correlate with a subjective comfort evaluation [5]. The experiment of Kyung and Nussbaum (2013) found significant correlations and weak to moderate effects between different subjective comfort ratings and pressure parameters [6].

Heckler et al. (2018) studied anthropometric effects on subjective comfort sensation on serial production car seats in detail. They compared the effect of eight body dimensions on the comfort evaluation between two different car seats. The results of this investigation showed that there are stronger anthropometric effects on the rather simply and sportively shaped seat in relation to a highly adjustable and comfort-orientated contoured seat. The authors concluded that the unique anthropometry of each human still poses a great challenge, even in current modern seat design. They suggest that a deeper understanding of how the specific body dimensions influence the comfort sensation of different seat components is needed [3].

Based on the literature findings, a knowledge gap had been identified. No study was found that researched anthropometric-related comfort areas of automotive seat components in detail. Subsequently, the target of the experiment described in this paper seeks to fill the discovered gap in research regarding the influence of human anthropometry on the comfort experience of different automotive seat components.

2 Objective

The aim of the presented study was to define anthropometric comfort areas for various seat components. Therefore, two experimental seats had been constructed in order to enable a comfortable adjustment of different seat parts independently of the unique anthropometry of each individual. The analyzed seat components were cushion depth (CDA), cushion tilt angle (CTA), cushion and backrest bolster angle (CBA, BBA). The scope was to investigate the following hypotheses:

- Specific anthropometric-related comfort areas are existing for certain seat components.

For researching the anthropometric comfort areas, a study with a broad anthropometric sample was conducted. The participants evaluated several configurations of the modified adjustment tracks under static testing conditions in a partial body vehicle.

3 Method

3.1 Experimental seats and testing environment

Two manual sport seats of an Audi A6 (C8) were modified to investigate the influence of anthropometric properties on different seat components. On the first seat, the serial adjustment of the cushion depth (CDA = 50 mm) and cushion tilt (CTA = 5 °) was extended up to 150 mm and 15 ° travel distance. For the second seat, new seat adjustment mechanisms were designed to enable a continuous adjustment of the cushion and backrest bolster angle (CBA, BBA). The CBA and BBA tilt angles could be adjusted from 15 ° to 90 ° and from 20 ° to 90 °, respectively (Fig 1.).

Fig. 1. Experimental seats with modified adjustment tracks.

The aim of the modifications was to ensure that every subject found an optimal setting of each mentioned seat component independently of their individual body dimensions. Furthermore, the wide adjustment range of each part was intended to provide the possibility to determine individual comfort areas by defining the thresholds between a positive and a negative comfort sensation.

For a realistic sense of space, the tested seats were mounted in partial body Audi A6 with a fully equipped interior. The static experimental setup was constructed in a workshop hall.

3.2 Measurement tools

Overall, eight body dimension were measured of each subject by using an anthropometer, a statiometer and a scale. Besides *stature* and *body weight,* three body measurements of the lower body (*seat depth, hip breadth* and *thigh circumference*) and upper body (*shoulder breadth (bideltoid), sitting height* and *waist circumference*) were measured.

The comfort questionnaire from the experiment of Heckler et al. 2018 was used for quantifying the subjective comfort perception of each configuration. The questionnaire consisted of 22 items and a five-point ordinal evaluation scale in order to rate different influencing factors like the initial contact with the seat, the functionality, the contour of different seat components and the pressure distribution in eight body areas. The existing questionnaire was modified for the specific setting by adding the items cushion and backrest bolster angle.

The pressure distribution between seat and passenger was analyzed with two pressure mats (XSensor Technology Corporation, LX100:48.48.02). However, the results of the pressure analysis are not presented in this paper.

3.3 Experimental design and participants

The presented study was conducted with a mixed-model design. The independent variables (IV) are the different test conditions and the different body dimension groups. The dependent variables (DV) are the subjective comfort items of the questionnaire. The ordinal data were analyzed with non-parametric tests, such as the Friedman test, Kruskal-Wallis test and the Wilcoxon signed-rank test.

Table 1. Average values of the body dimension groups for eight anthropometric variables.

Anthropometric variable	small (n = 15)	mid (n = 15)	large (n = 15)
Stature	Ø 163.0 cm (SD: 4.3 cm)	Ø 175.6 cm (SD: 1.6 cm)	Ø 188.7 cm (SD: 4.6 cm)
Body weight	Ø 55.6 kg (SD: 3.3 kg)	Ø 73.0 kg (SD: 3.4 kg)	Ø 103.6 kg (SD: 11.7 kg)
Sitting height	Ø 84.2 cm (SD: 6.6 cm)	Ø 92.2 cm (SD: 0.4 cm)	Ø 98.6 cm (SD: 2.1 cm)
Shoulder breadth	Ø 39.6 cm (SD: 1.1 cm)	Ø 44.9 cm (SD: 1.1 cm)	Ø 51.9 cm (SD: 2.6 cm)
Waist circumference	Ø 69.3 cm (SD: 4.1 cm)	Ø 83.2 cm (SD: 2.7 cm)	Ø 109.1 cm (SD: 9.9 cm)
Seat depth	Ø 47.1 cm (SD: 1.3 cm)	Ø 51.3 cm (SD: 0.67cm)	Ø 55.7 cm (SD: 1.9 cm)
Hip breadth	Ø 35.6 cm (SD: 0.7 cm)	Ø 39.3 cm (SD: 0.6 cm)	Ø 42.6 cm (SD: 1.2 cm)
Thigh circumference	Ø 51.7 cm (SD: 1.8 cm)	Ø 57.3 cm (SD: 0.5 cm)	Ø 64.8 cm (SD: 4.8 cm)

Overall, 36 men (Ø 41.4 ± 10.9 years) and 34 women (Ø 32 ± 10.6 years) of a broad anthropometric spectrum participated in this study. For the investigation of the anthropometric comfort areas, the sample was divided in three groups for each measured anthropometric variable separately (Tab. 1).

3.4 Procedure and setup

The test subjects were asked to wear casual clothes for both experiment sessions. At the beginning, eight body dimensions were measured by the experimental staff. Then, the participants were instructed in the overall test procedure by explaining the items of the used questionnaire, the adjustability of the specific seat and the duration of each configuration.

After this procedure, the subjects took a seat in the vehicle and adjusted the seat to their preferred driving position only by using the original adjustment tracks. The participants rated their individual driving position with the whole questionnaire. The second comfort rating was obtained by evaluating the seat component, the pressure distribution in the affected body areas as well as the overall comfort. Starting from the optimal position, the experimenter adjusted the following discrete configuration of the specific seat component as shown in table 2. If the comfort rating reaches a comfort score of 1 (“seat is unacceptable”) for the item overall comfort the session has been aborted. For avoiding order effects, the test procedure was permuted by changing the evaluation order of the four modified seat components.

Table 2. Test conditions for the different seat components.

Test conditions	CDA [mm]	CTA [°]	CBA [°]	BBA [°]
Serial adjustment	0 - 50	15 - 20	63	55
Additional adjustment	0 - 150	15 - 30	15 - 90	20 - 90
1. Configuration	0	15	15	20
2. Configuration	25	17.5	30	34
3. Configuration	50	20	45	48
4. Configuration	75	22.5	60	62
5. Configuration	100	25	75	76
6. Configuration	125	27.5	90	90
7. Configuration	150	30	-	-

The evaluation time of each configuration was at least five minutes. For a standardized data collection, the pressure parameters of each setting were recorded after the first minute. Each experimental seat was tested in a separate meeting in order to avoid long testing sessions.

4 Results and discussion

In order to research anthropometric comfort areas of specific seat components, a variety of statistical tests were executed. The change of the subjective comfort sensation in the different configuration was tested with a Friedman test for each body dimension group separately. For defining anthropometric comfort areas, a mean comparison between the configuration "Additional adjustment" and the other configurations was calculated. Another comparison between the body dimension groups of each configuration was performed to highlight the anthropometric dependency in specific settings. For the multiple comparisons between the different configurations the significance level was adjusted with the Bonferroni method to $\alpha = 0.00625$.

The subjective evaluation of the cushion length for the modified CDA showed different comfort areas in dependence of the body dimension "*Seat depth*" (Fig. 2). For the group *"Seat depth short"* the Bonferroni-adjusted post-hoc analysis showed a significant worse comfort rating of the third configuration (Mdn = 2.0) compared to the configuration "Additional adjustment" (Mdn = 4.0; Wilcoxon test: z = -3.35, p = .001, n = 15). The comparison for group *"Seat depth mid"* revealed a first significant difference at the fourth configuration (Mdn = 2.0) compared to the configuration "Additional adjustment" (Mdn = 4.0; Wilcoxon test: z = -3.16, p = .002, n = 15). The first configuration of the group *"Seat depth long"* that was rated significantly worse was the fifth setting (Mdn = 2.0) in relation to the individual adjusted configuration (Mdn = 4.0; Wilcoxon test: z = -2.99, p = .003, n = 15). The statistical analysis between the three body dimensions of the test condition CDA showed significant differences in configuration three, four and five. The results corroborate the presence of specific anthropometric comfort areas for the CDA in dependence of the body dimension "S*eat depth"*.

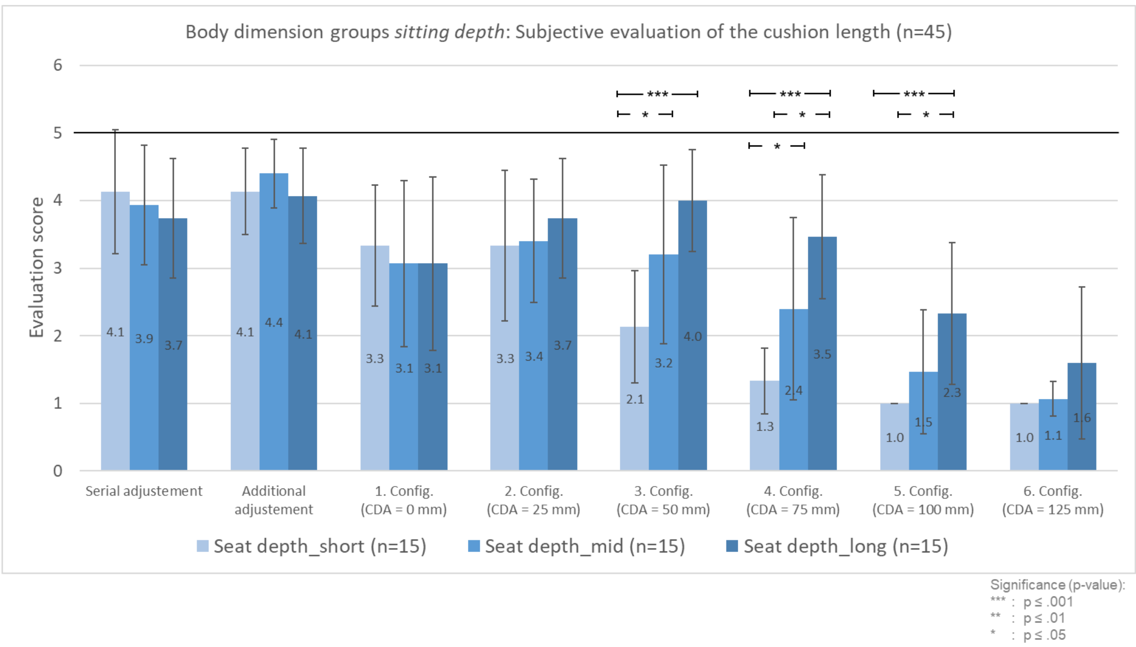

Fig. 2. Subjective evaluation of the CDA for the body dimension groups "*Seat depth"*.

The subjective evaluation of the item cushion bolster angle for the experimental seat with the modified CBA showed a significant improvement with the additional adjustment for two body dimension groups. For the group *"Hip breadth mid"* the configuration "Additional adjustment" (Mdn = 5.0) was rated significantly better compared to the "Serial adjustment" (Mdn = 4.0; Wilcoxon test: z = 2.57, p = .010, n = 15). For the group *"Hip breadth wide"* the configuration "Additional adjustment" (Mdn = 5.0) was rated significantly better compared to the “Serial adjustment” (Mdn = 3.0; Wilcoxon test: z = 3.10, p = .002, n = 15). In the second condition, the comfort rating of the cushion bolster angle differs between the body dimension groups (Fig. 3). The value of group *“Hip breadth thin”* (Mdn = 2.0) was significantly worse compared to the group *“Hip breadth wide”* (Mdn = 3.0; Mann-Whitney U test: U = 39.00, p = .002).

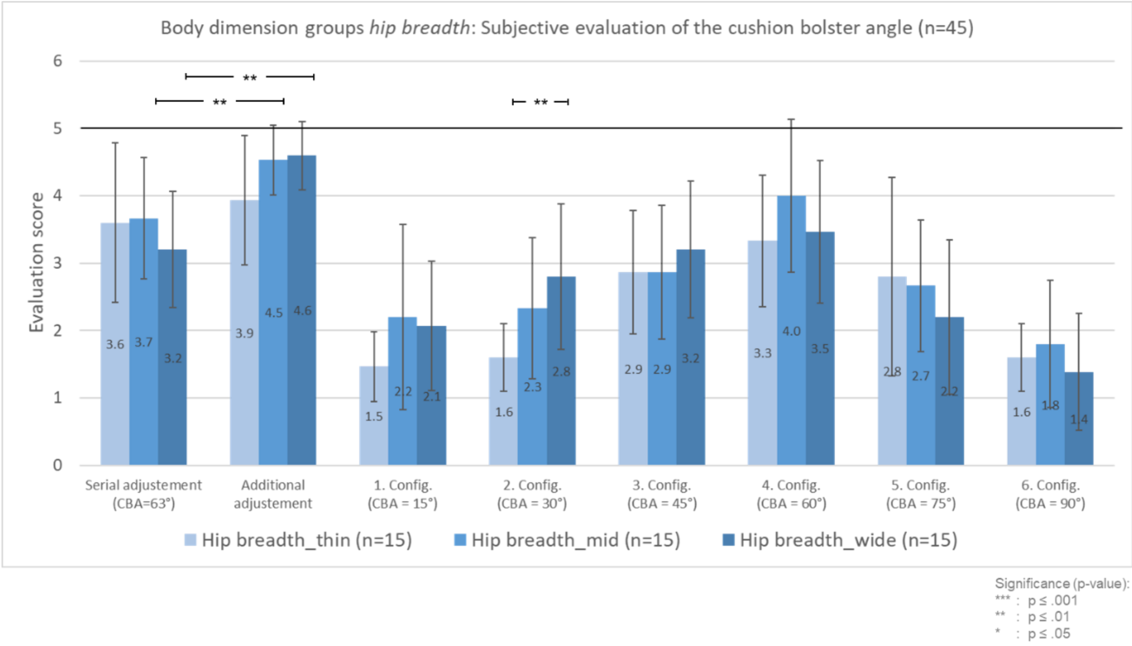

Fig. 3. Subjective evaluation of the CBA for the body dimension groups “*Hip breadth”*.

With the additional BBA adjustment, a significant effect on the evaluated item cushion bolster angle has been detected for all body dimension groups of the *“Waist circumference”* (Fig. 4). For the group *“Waist circumference thin,”* the configuration “Additional adjustment” (Mdn = 4.0) was rated significantly better compared to the “Serial adjustment” (Mdn = 3.0; Wilcoxon test: z = 2.33, p = .020, n = 15). The configuration “Additional adjustment” (Mdn = 4.0) of the group *“Waist circumference mid”* was also evaluated significantly better compared to the “Serial adjustment” (Mdn = 3.0; Wilcoxon test: z = 1.96, p = .050, n = 15). For the group *“Waist circumference wide”* the configuration “Additional adjustment” (Mdn = 5.0) was rated significantly better in contrast with the “Serial adjustment” (Mdn = 4.0; Wilcoxon test: z = 2.76, p = .006, n = 15).

The analysis of the configuration four, five and six showed significant effects between the body dimension groups. For example, in configuration five the group *“Waist circumference wide”* (Mdn= 1.0) rated the backrest bolster angle significantly worse compared to the group *“Waist circumference mid”* (Mdn = 4.0; Wilcoxon test: z = -2.98, p = .003, n = 15).

The results indicate the presence of anthropometric-related comfort areas for the BBA as well. The first three configurations up to a Backrest bolster angle of 48° were rated negatively and thus representing the lower level of the comfort areas for all three groups. The upper threshold of the comfort areas were different and specific for the groups. The upper level of comfort areas for the group with a wide waist circumference was between configuration four and five. The comfort rating of the other two groups only changed at configuration six to a negative rating.

The anthropometric effects on the CTA were not that strong in comparison to the other seat parts. Only small effects were recognized between the body dimension groups and thus the anthropometric-related comfort areas were almost the same for each group.

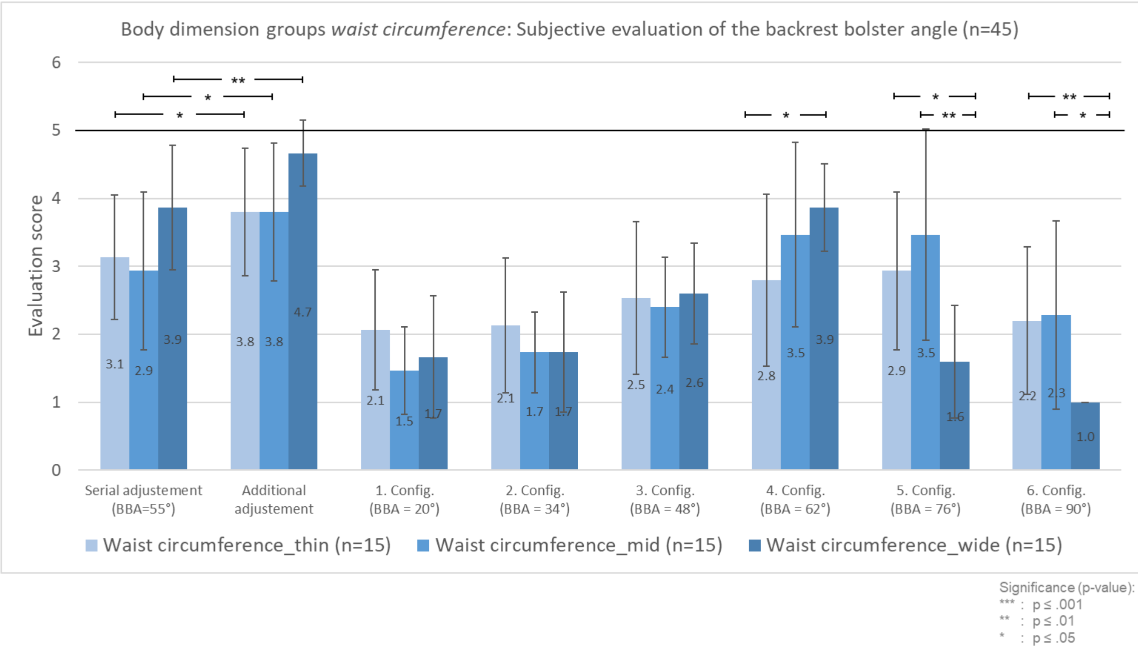

Fig. 4. Subjective evaluation of the BBA for the body dimension groups *"Waist circumference"*.

5 Conclusion

The aim of the present study was to define anthropometric-related comfort areas of different seat components. With the results, the initially formulated hypotheses was verified, by partly strong anthropometric effects on the comfort sensation in different configurations. It was observed that the body dimension *seat depth* has an effect on the individual comfort areas of the cushion depth adjustment. Furthermore, the adjustability of the cushion and backrest bolster angle lead to a significant increase on the subjective evaluation score for the respective seat component, indicating a strong individual preference of these seat components. The comparison between the different configurations for the specific body dimension groups showed that anthropometric-related comfort areas also exist for these two components.

It can be concluded, that the knowledge about anthropometric-related comfort areas is essential for designing the seat geometry in general as well as specifying the adjustability ranges of specific seat components. For example, a cushion depth adjustment of 75 mm in combination with a CTA appears to be sufficient to provide most passengers an optimal thigh support. Another insight of the experiment is the fact that an adjustment range of the cushion bolster angle from around 40° to 75° was needed for receiving a positive evaluation score for the participants. The comfort area of the BBA varies from 48° up to 76°. Any additional adjustability outside of these ranges only had a positive effect for individual participants and can be ascribed to personal preferences.

The fact that anthropometric-related comfort areas exist for the research seat components opens the possibility for preadjusting the seat in relation to the unique anthropometry of each passenger. This can increase the comfort experience of new seat concepts. Another important finding of this experiment is the containment of the adjustment ranges for the particular seat component to increase the comfort values in the subjective assessment by an optimal adaption of the seat.

Further research is needed to investigate if the determined comfort areas are although existing under real traffic conditions and during prolonged driving. To research how different design concepts of seat components can affecting the anthropometric-related comfort areas of different body dimensions seems to be another useful approach.

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Study on Optimizing the Comfort of Long-standing Crowds

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Abstract Because of the flexibility and freedom of legs, standing posture can improve the efficiency of workers, so standing posture is a common working condition, and standing for a long time will lead to workers' physical discomfort and muscle fatigue. Working in this condition for a long time may lead to occupational injury. Because standing for a long time has many negative effects, we should study some methods to solve or reduce the harm to the body. Many studies have shown that floor mats and insoles are effective ways to improve physical comfort and occupational health when standing for a long time. Nelson et al. found that standing on an inclined platform significantly reduced the discomfort of the waist and back of subjects and attributed this phenomenon to the reduction of lumbar protrusion at the end of the lumbar spine and the increase of movement posture. However, up to now, few studies have considered standing platform as an intervention to reduce long standing muscle fatigue. Therefore, this paper takes the long-standing worker as the research object, studies the comfort effects of different tilt angle platforms on the long-standing worker, uses plantar pressure, surface muscle power and skin temperature to analyze and test the physiological changes of the long-standing worker in the experimental process, and uses subjective methods such as visual analogue scale to measure their psychological fatigue, from the material of the tilt platform, soft and hard. The optimum design scheme of inclined platform is discussed by changing the parameters of degree and inclination angle, which provides an effective scheme and theoretical basis for solving the comfort of long-standing crowd.

Keywords: Long Standing; Tilt Angle; Physiological Changes; Psychological Fatigue; Comfort

1 Introduction

Standing work can be a more important work posture because the legs have great flexibility. This work posture allows workers to perform process operations in a simple and efficient manner, thereby making workers more productive. However, when workers are standing for a long time during working hours, they may feel uncomfortable and fatigued, causing occupational injuries for a long time. If a worker spends more than 50% of the total working time of working hours, then it is considered to be standing for a long time [1]. Long-term work is considered to be an important factor in reducing the efficiency of industrial workers, often leading to occupational injuries, reduced productivity, increased treatment and medical costs, and low worker mood. When the worker works for a long time, the back and legs are statically contracted, resulting in weakened function of the calf muscles [2]. This situation can cause discomfort and muscle fatigue to workers, so employers will lose income due to workers' compensation and medical expenses [3]. For example, standing for a long time causes back pain, which can affect the worker's bending posture in the next work, which may adversely affect the productivity of the worker. In addition, injured workers must go to the hospital for treatment, resulting in a large amount of medical expenses.

Standing in the workplace for a long time can cause discomfort and muscle fatigue, especially at the end of work. Discomfort or subjective fatigue can be associated with mental fatigue, which is considered a factor of alertness, concentration of mind, and decline in positivity [4, 5]. Under normal circumstances, subjective evaluation of psychological fatigue caused by prolonged standing is conducted through questionnaire survey [6], Borg scale [7], body part symptom questionnaire [8] or using visual analogue scale [9]. On the other hand, muscle fatigue can be technically identified by observing changes in the amplitude and frequency of the electromyogram (EMG) signal over time [10]. When the amplitude of the signal increases and the power frequency decreases, it indicates that the muscle being evaluated is in a fatigue state [11]. sEMG (surface electromyography) is one of the most well-recognized techniques for evaluating muscle fatigue in many studies [12].

A number of studies provide a strong argument that research on long-standing work is important to workers, industry owners and the entire national economy. Many studies have investigated the effects of floor types on long-term populations, which are thought to be related to standing discomfort. Nelson et al. found that standing on a sloping platform significantly reduced the subject's feeling of lower back discomfort and attributed this phenomenon to a reduction in end lumbar lordosis and an increase in exercise posture [13]. However, to date, few studies have used the use of tilting platforms as an intervention to reduce long-term muscle fatigue, and the specific effects of using tilting platforms to reduce long-term physical discomfort have not been fully explored. Therefore, the main content of this paper is to study the specific impact of inclined platforms from different angles on the long-standing crowds.

2 Experiment

The study completed two main tasks: determining the psychological fatigue experienced by production workers when they were engaged in long-term standing; measuring and analyzing muscle activity in the legs and waist. The following sections provide procedures and methods for applying STEM to determine muscle fatigue, as well as the fatigue time experienced by workers in locations where they need to stand for long periods of time. Eight college students were recruited as subjects, and all subjects were healthy. Each subject participated in data collection for four working days, each working day required to stand on the inclined platform at the same angle for 80 minutes, except 0°, there are 5°, 10°, 15° three different angles of inclined platform, as shown in Figure 1, Figure 2 and Figure 3.

Fig. 1. 5 °inclined platform

Fig. 2. 10°inclined platform

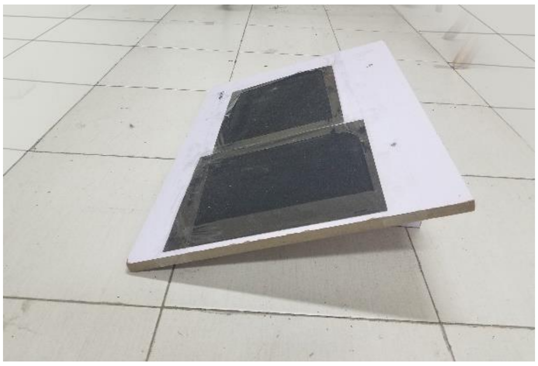

Fig. 3. 15°inclined platform

2.1 Data Collection

All data on the muscle activity of the subject were recorded, stored and analyzed using the sEMG and Mangold-10 wireless Bluetooth multi-channel physiology instrument, as shown in Figure 4. The Mangold-10 Wireless Bluetooth Multi-Channel Physiology System is equipped with electrodes to detect the subject's EMG signal. The electrodes were attached to the subject's skin and the activity of the three muscles during standing work was measured: left erector spinae, left and right gastrocnemius muscles. Figure 5 shows the location of the SEMG electrode used to measure the selected muscle fatigue.

Fig. 4. Mangold-10 wireless Bluetooth multi-channel physiology system made in Germany

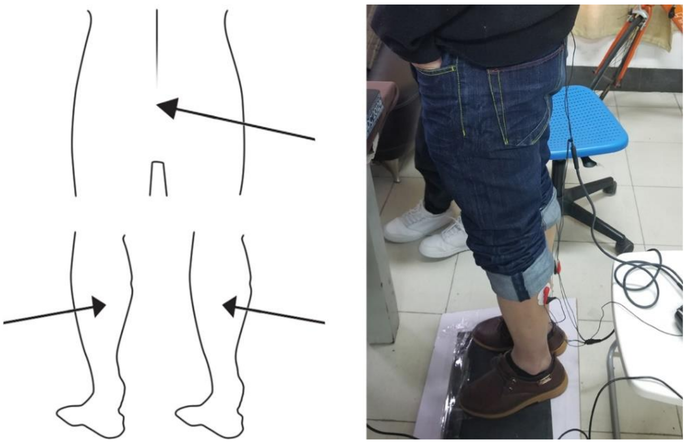

Fig. 5. Surface Electrode Patch Position

In this experiment, the muscle electrical signal data of 80 minutes was continuously measured on the inclined platform of each angle, and the data points of 5 minutes were collected every 20 minutes for analysis, and a total of 5 times were collected. After the collected raw EMG signals were processed, the amplitude-frequency comprehensive analysis method was used to analyze the fatigue changes of the muscles. As shown in Figure 6, the amplitude-frequency analysis method divides the sEMG signal into four quadrants through iEMG and MF spectrum changes to determine the increase or decrease of muscle strength, and the generation and recovery of fatigue.

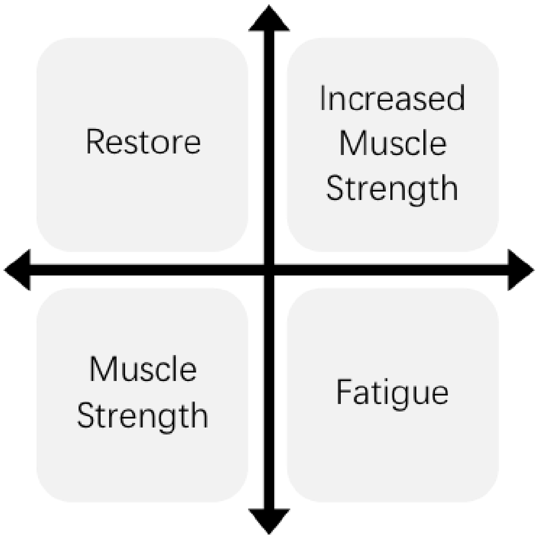

Fig. 6. Schematic Diagram of the Amplitude-Frequency Joint Analysis Method

2.2 Data Processing Results

1）The primordial EMG signals of the gastrocnemius muscles of 8 subjects in the 4 groups of experiments were evaluated, and the iEMG values of the patients' intestinal muscles were obtained, and standardized treatment and significant difference test were performed. The results are shown in Figure 7.

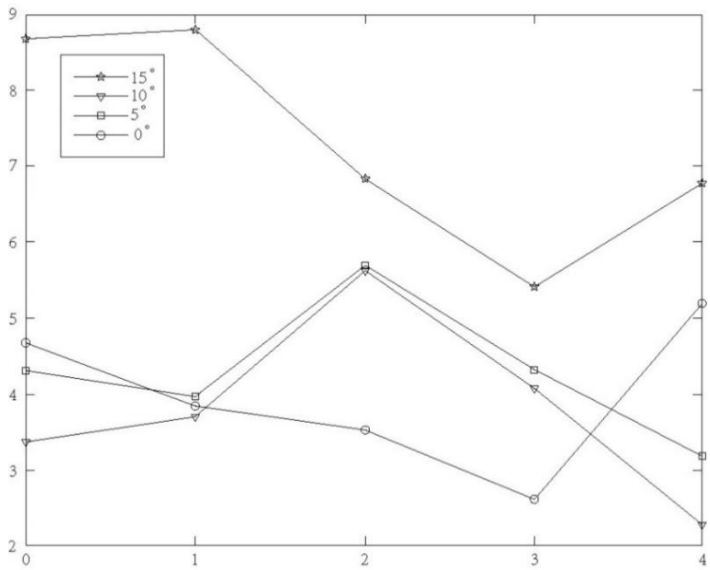

Fig. 7. Changes in the Intestinal Muscle iEMG at Different Angles of the Inclined Platform

Table 1. Significance Analysis of iEMG Signals of the Intestines Muscles at Different Angles

	T1	*T2*	*T3*	*T4*	*T5*
	0°	0°	0°	0°	0°
5°	0.13	0.360	0.025*	0.037*	0.027*
10°	0.715	0.356	0.021*	0.038*	0.042*
15°	0.002*	0.008*	0.013*	0.006*	0.015*

As shown in the above table, there is a significant difference between the data marked with'*', that is, the intestinal muscle iEMG value standing on the 0° platform is 5°, 10°, 15° in the T3, T4, T5 time period. There was a significant difference ($p < 0.05$).

2) Next, the MF values of the intestinal muscles of the subjects were normalized and the significance difference test was performed, and the results are shown in Figure 8 and Table 2.

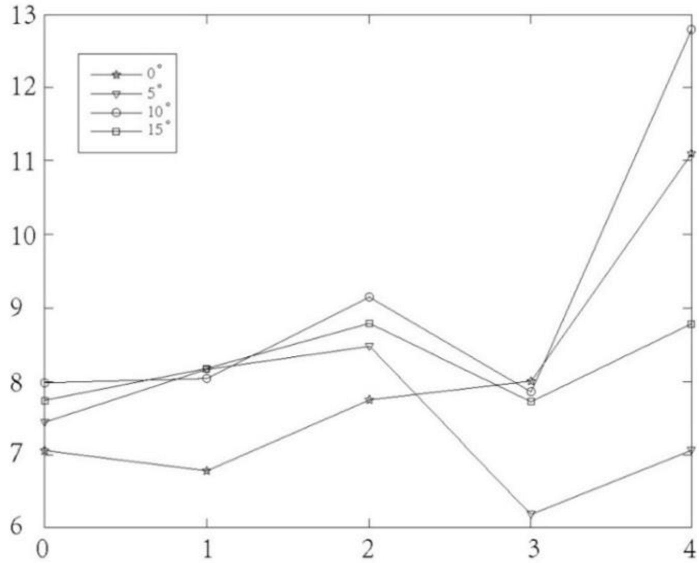

Fig. 8. Changes in MF Values (%) of the Intestines of Inclined Platforms at Different Angles

Table 2. Significance Analysis of Migrating Muscle MF Signal at Inclined Platforms with Different Angles

	T1	*T2*	*T3*	*T4*	*T5*
	0°	0°	0°	0°	0°
5°	0.25	0.80	0.83	0.88	0.023*
10°	0.10	0.52	0.11	0.96	0.046*
15°	0.30	0.37	0.22	0.92	0.041*

As shown in the above table, there is a significant difference between the data marked with '*', that is, the EF value of the gastrocnemius standing on the 0° platform and 5°, 10°, 15° in the T4-T5 time period. Significant difference ($p < 0.05$).

3) Standardized treatment and significant difference test were performed on the iRGG values of the erector spinae of the subjects. The results are shown in Figure 9 and Table 3.

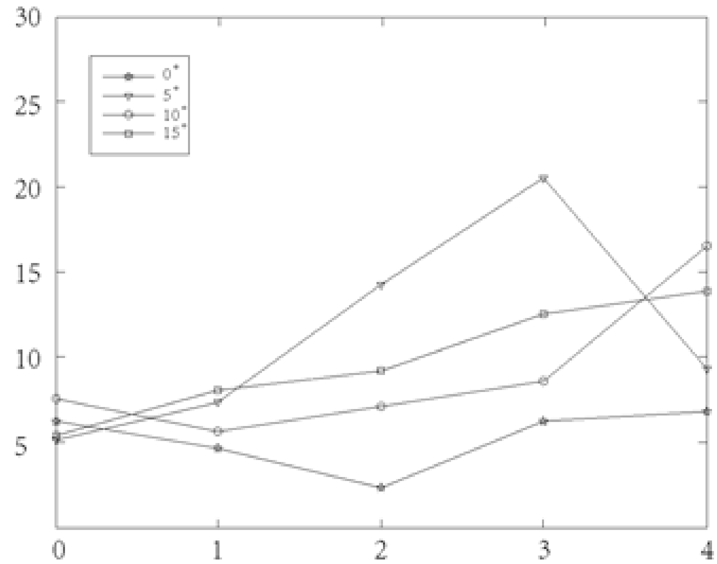

Fig. 9. Changes in iEMG Values of Erector Spinae at Different Angles of Inclined Platform

Table 3. Significance Analysis of iEMG Signals of Erector Spinae at Different Angles

	Sum of Squares	*df*	*Average Squared*	*F*	*Significance*
Between Groups	8.23	3	2.743	1.691	0.192
Within the Group	45.43	28	1.623		
Total	53.663	31			

From the above analysis of variance table, it can be seen that the erector spinae iEMG value signal standing under different inclined platforms has a significant $p=0.192>0.05$, that is, the iEMG signal of the gastrocnemius muscle standing on different inclined platforms is not significant. Sexual differences.

4) Standardized treatment and significant difference test were performed on the vertebral muscle MF values of the subjects. The results are shown in Figure 10 and Table 4.

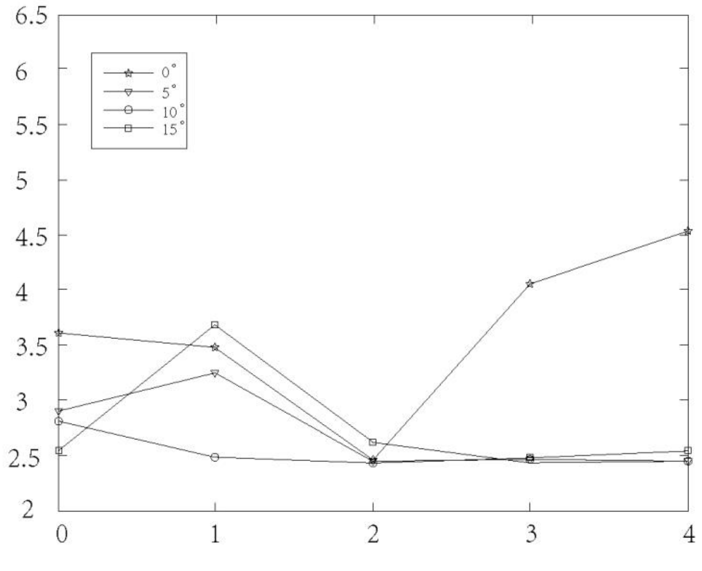

Figure 10. Changes in MF Value (%) of Erector Spinae at Different Angles of Inclined Platform

Table 4. Significance Analysis of MF Signals in Erector Spinae of Inclined Platforms at Different Angles

	Sum of Squares	*df*	*Average Squared*	*F*	*Significance*
Between Groups	3.617	3	1.206	0.285	0.836
Within the Group	118.37	28	4.228		
Total	121.98	31			

From the above analysis of variance table, it can be seen that the MF value of the erector spinae muscles standing under the inclined platform at different angles is p=0.836>0.05, that is, the MF signal of the gastrocnemius muscle standing on different inclined platforms is not significant. Sexual differences.

3 Conclusion

This experiment simulates the long-term standing situation and analyzes the muscle and electric data of the legs and the waist when different people stand at different tilt angles and draws the following conclusions.

When standing on a 15° tilting platform, the leg's self-adjusting ability is worse, and the body fatigue is large, which is not suitable for long standing. Standing on the inclined platform at different angles, the muscle fatigue of the human waist does not change much, that is, standing at different inclination angles has no significant influence on the waist. It can be known from the analysis of the EMG signal data of the leg that when the subject stands for about 40-60 minutes, the objective data of the leg muscles of the body will reach a maximum value, after 40-60 minutes. The leg muscles are slowly in a state of recovery, and the leg muscle self-regulating effect of standing on inclined platforms at different angles is: 10°>5°>0°>15°. When standing between 0-40 minutes, standing on a platform with an inclination angle of 0°, the leg muscle fatigue is relatively small.

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Posture prediction of a human on a chair: model description

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Abstract: One of the aspects that influence the sitting comfort is the distribution of the pressure applied to the skin by the seat surface. In the scientific literature, many studies show experimental activities in order to evaluate the influence of pressure distribution at the seat-human interface on the comfort evaluation. The main limitation in seat design is based on the difficulties to predict the contact pressures distribution without prototypes because of the complex interaction among body muscles, wearing, human's anthropometric characteristics, shape and materials of the seat. Moreover, the same human can assume different postures on the same seat, and different people, seated on the same chair, can assume different postures even if they have the same anthropometric percentile. The aim of this study is to propose a mathematical model evaluating interaction loads between human segments and seat segments. In this model, a human body represented by 8 segments is placed on a 6 segments seat with posture dependent on seat segments and on position of the cocciyx on seat and feet on floor. Human segments can be configured in length and weight and friction between body and seat is considered. A model validation study based on an experimental comparison with contact pressures is also presented.

Keywords: Seating posture, seat, contact pressures.

2 Physiological and Postural Comfort

The word "*comfort*" refers to a state of well-being perceived by an individual during any activity, and involves factors such as temperature, brightness, noise, ventilation, assumed posture, level of anxiety, level of fatigue, or anything that alters human physiology. The Vink-Hallbeck model [1] of comfort perception shows how the factors that act on comfort can be grouped into few large categories that refer to external aspects during the use of the product, to the product, and to the subjectivity of the user.
The perception of the comfort of a chair depends, in a objective manner, on the human assumed posture that depends, in a still objective manner, on how the chair is designed, but also on the subjective way in which the person decides to sit.

Another fundamental factor is the duration of the interaction: it is easy to observe how, regardless of the comfort level of a chair, each of us after a certain period of time changes posture (without changing the chair). For example, there are numerous correlation studies between the micro-movements of the person and the level of perceived discomfort. Macromovements are instead a consequence of the type of human activity on the chair, but also a sign of the need to relax muscles that have guaranteed the posture up to that moment or to lighten the level of pressure localized in the areas of contact that causes a reduction in blood circulation.

The comfort of the seat is a topic of considerable importance in the field of transport, but not only, considering that each of us carries out many activities (working, eating, studying, ...) sitting on a chair or relaxing sitting on armchairs. The design of a seat, whatever it is, must adequately predict the level of comfort perceived by the user.

Currently it is difficult to predict the comfort of a seat except from the experimental point of view, using prototype versions of the product trying to overcome the effects of experimental reliefs on the perception of comfort [2]. There are two main lines of thought: the first believes that the factor to consider, in the search for constructive geometry, is the contact pressure while the second directly measures the assumed posture of the various parts of the body.

In the first case we focus mainly on the back of the thigh and on the buttocks, areas in which most of the load is discharged [3-7]. We try to limit the average pressure as much as possible by increasing the contact surface. For example, the study by Noro et al. [8] starts from the idea that from the posture assumed by those who practice Zen meditation, which is maintained long time, indications can be obtained for the design of a session for a specific application. A seat is created (Figure 1) that reproduces the same contact pressures obtained on meditation cushions that optimize posture by providing support to the lumbar area, taking into account the differences linked to surgical activity.

Fig. 1. Standard surgical chair and zen surgical chair.

In the case of posture analysis, the focus is mainly on the position of the back, legs and head [9-18]. Figure 2 shows how excessive inclinations generate shear stresses on muscles and skin that limit, once again, the passage of blood. The inclination of the back slightly affects the extent of the shear stress, while it greatly influences the geometry assumed by the spine, with minor consequences such as headache, shortness of breath, pain in the neck, wrists, back and vision problems , as well as real diseases: dorsal hypercyphosis, epicondylitis, carpal tunnel, loss of elasticity of the optic nerve, myopia. The most deleterious cases are those with an inclined seat. Some studies published in the journal Experimental physiology in 2015, have shown that 3 hours of seated position (body sitting) without interruptions lead to a reduction in the physiological vasculature in the body by 33% (reduction in the number of vessels that allow the passage of blood) and that this prolonged position is associated with an increase in cardiovascular diseases.

It can therefore be said that assuming a correct posture is essential to avoid the aforementioned back problems and high cutting efforts, but for the purpose of comfort it is also necessary to distribute the loads in the best possible way and find configurations in which the muscles are activated the least possible.

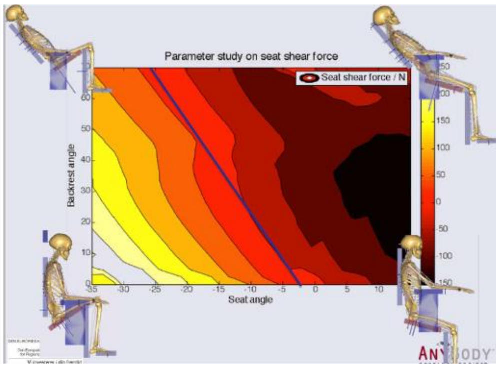

Fig. 2. Shear stress vs. seat angles.

This work presents a predictive mathematical model of postures that can be assumed by a human being seated as a function of the anthropometric measurements and the geometry of the chair, including the calculation of the consequent articular and shear stresses on the skin.

3 A simulation model of the sitting

The model is based on a static analysis, in which body and seat are seen in profile and are considered as set of segments on a two-dimensional plane; human articulation are represented by joints that allow rotations but not translations. For the realization of these simulations was used the program Python.
To simulate in the best way the different assumable posture, human body has been schematized with 8 segments (Figure 1): head and neck, upper trunk, lower trunk, buttock, thigh, leg, sole of the foot, toes.

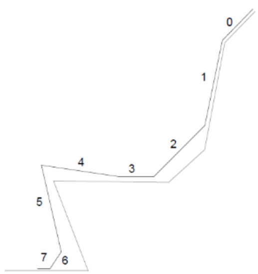

Fig. 3. Schematisation of human body with 8 segments: 0 – head and neck; 1 – upper trunk in contact with the backrest; 2 -trunk part with no contact; 3 – leg part always in contact (buttock); 4 – upper leg (thigh); 5 – lower part.

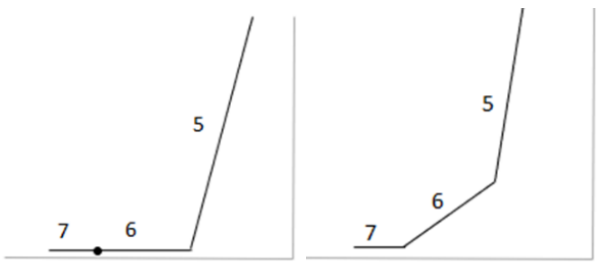

Fig. 4. a) Foot totally in contact; b) Foot in contact but with the sole lifted

This allow to consider also that cases in which, for the the moderate height of the seat, instead of stretching out foot forward the thigh are lifted from the sitting plan: the buttock part, in this case, however remains in contact

and it corresponds to one of the additional parts of this model. It is also possible to vary the foot position that changes depending on whether person is sitting with legs forward, upright or under the seat (Figure 4), so the forepart of the foot is always in contact with the respective support (footrest or floor). His length and his weight are fractions of the total values that pertain to the foot (taken from the percentile Table 1). It has been seen that, generally, toes have length and weight equal to 1/3 of those of the whole foot.
Each segment, for which it's indicated the length, the angle compared to the horizontal and the weight, will be subject to the loads coming from the hinges, to his own weight and to the contact forces with the seat. The inclination of the generic anatomical segment compared to the floor is equal to $\boldsymbol{AngBody_{(i)}}$ and his length has been indicated as $\boldsymbol{LengBodySeg_{(i)}}$.

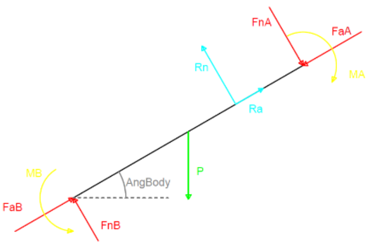

Fig. 5. Loads on a segment

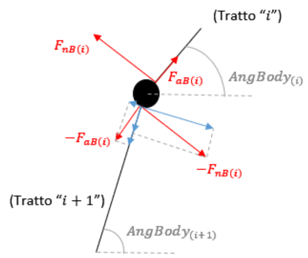

Fig. 6. Loads conversion from segment i to segmenti i+1

The weight $\boldsymbol{P_{(i)}}$ of the various parts of the body acts in the middle of the segments ($LengBodySeg_{(i)}/2$) at a distance from the respective bond $B_{(i)}$ equal to $\boldsymbol{LengCoGSeg_{(i)}}$. It is counterbalanced by external torques $\boldsymbol{M_{A(i)}}$ and $\boldsymbol{M_{B(i)}}$, applied to the constraints from the muscles and by bond's reactions $\boldsymbol{F_{A(i)}}$ ed $\boldsymbol{F_{B(i)}}$, of which we consider the components in axial and normal directions of the segment: $\boldsymbol{F_{aA(i)}}$, $\boldsymbol{F_{aB(i)}}$, $\boldsymbol{F_{nA(i)}}$, $\boldsymbol{F_{nB(i)}}$.

Table 1. Percentile weights and lengths of the various parts of the body [19, 20]

Segment	*Segment mass / Total body mass*	*Segment length / Total body height*
Hand	0.0060	0.108
Forearm	0.0160	0.146
upper arm	0.0280	0.186
forearm and hand	0.0220	0.108
total arm	0.0500	0.259
Foot	0.0145	0.152
lower leg (calf)	0.0465	0.285
upper leg (thigh)	0.1000	0.245
total leg	0.1610	0.530
head and neck	0.0810	0.182
Trunk	0.4970	0.288

The reference system used for the single part is that linked with the one (local system, relative system), with origin in $B_{(i)}$, axis of the abscissas coincident with the segment and axis of the ordinates normal to it. The weight

and the height of the considered person are divided on the various segments based on percentiles of Table 1 to obtain weights $P_{(i)}$ and lengths $LengBodySeg_{(i)}$:
The arm's weight is summed to the one of the upper trunk, that of thighs, legs and feet is counted twice. The trunk's length is divided into the upper and the lower trunk part in proportions 1/3 and 2/3 to make difference between lumbar and thoracic part.
There are different kind of seat, depending on the context in which they are used. They differ in various aspects but those of interest to us are geometry and shape. An automotive seat follow the body's shape from the trunk downwards leaving the legs free; the chaise longue of a psychologist also supports these one, while a generic kitchen chair usually doesn't provide head support.
So we can find a scheme that allows us to characterize every kind of seat; they can be used up to six segments: headrest, backrest, upper part, backrest, lumbar part, sitting plan, legs support, footrest. The inclination compared to the floor and the length of the generic segment of the seat are respectively equal to $\boldsymbol{AngSed}_{(i)}$ and $\boldsymbol{LengSed}_{(i)}$. To each segment for which is expected contact with the body, it's assigned a friction coefficient $\boldsymbol{Mu}_{(i)}$.

Contact between Body and chair

Depending on the size of the body segments and on the seat configuration, for those anatomical segments that eventually rest on the chair, the intersection part between seat segment and body segmenti is considered as the contact surface.
For the segments in contact, the force $\boldsymbol{R}_{(i)}$ is applied in the center of gravity of the contact pressures indicated with the distance $\boldsymbol{l}_{\boldsymbol{R}(i)}$ from the constrain $B_{(i)}$ and decomposable in normal support reaction $\boldsymbol{R}_{\boldsymbol{n}(i)}$ and in the friction force $\boldsymbol{R}_{\boldsymbol{a}(i)}$.
The determination of the seated body posture starts from the hypothesis that the first segment that interacts with the chair is represented by the buttocks and that the rest of the body adapts later. If the posture obtained is not satisfactory, the position is remodulated compared to the seat until the most comfortable posture is reached.
The model calculates the posture starting from the seat coverage percentage $\boldsymbol{K} = PosBacino * LengSed_{(i)}$ (Figure 7) calculated from the side of the knees. Starting from the buttocks position, we calculate (Figure 8) the position of the thoracic part and the extension of the corresponding contact surface compared to the eventual back of the chair. Then we calculate the eventual contact in the lumbar area and the head position compared to the headrest.

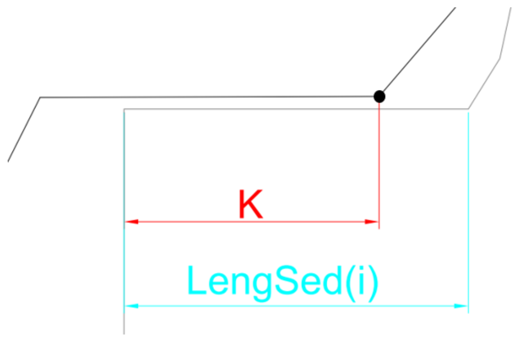

Fig. 7. Back on seat.

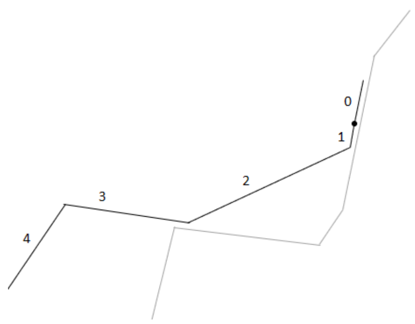

Fig. 8. Human seated at the extreme of the chair.

The second postural parameter imposed is the leg angulation $\boldsymbol{AngKnee}$, both forward and backward compared to the thigh. In this way it is also controlled the feet contact on the floor or on the footrest and the possible contact of the thighs on the seat.
Depending on the upper trunk position or headrest configuration, the head angle and contact head on is calculated. As an example in Figure 9 a) Trunk longer than the back and headrest backwards with an angle greater than 45 °; b) Trunk longer than the back and headrest backward with an angle smaller than 45 °; c) Trunk shorter than the backrest, headrest forward, the contact occurs only with the top of the head.

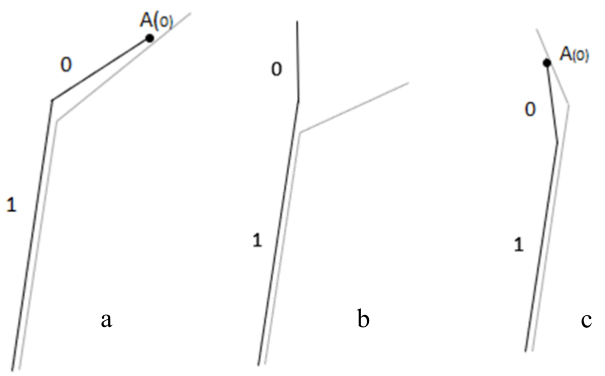

Fig. 9. Samples of head posture

Once the posture is defined and the extensions of the contact surfaces between the body segments and the seat segments are calculated, it is calculated the position $l_{R(i)}$ in which is applied the contact force $R_{(i)}$. In particular, it acts in the middle point of the contact length, defined as part of the seat section on which an anatomical segment or part of it rests.

1) If the contact length is exactly equal to $LengSed_{(i)}$ the part of the seat is occupied for the 100%. This means that the anatomical segment's length it's equal or greater than the one of the respective section of the seat ($LengBodySeg_{(i)} \geq LengSed_{(i)}$), and the contact starts from the constraint $B_{(i)}$ to which reference is made. Then $l_{R(i)} = LengSed_{(i)}/2$
2) If the contact length in less than that of the seat section we can have:
   - Anatomical segment's length smaller than that of the respective seat section ($LengBodySeg_{(i)} < LengSed_{(i)}$) and the contact starts from the hinge $B_{(i)}$. As the latter is the reference point for lengths, the distance from it is null and we have $l_{R(i)} = LengBodySed_{(i)}/2$:
   - Anatomical segment's length smaller than that of the respective seat section ($LengBodySeg_{(i)} < LengSed_{(i)}$) and the contact doesn't start from the hinge $B_{(i)}$; in this case, to the latter relationship, it must be summed the distance between the hinge $B_{(i)}$ and the starting point of contact;
   - Anatomical segment's length equal or greater than that of the respective seat section ($LengBodySeg_{(i)} \geq LengSed_{(i)}$) but the contact takes place at a not null distance from $B_{(i)}$; to the seat section's length it must be subtracted this distance; $R_{(i)}$ is applied at half of that value.

Mathematical analysis

Once the posture and the contact forces position are determinated we can analyse loads and equilibrium conditions considering weights and frictional forces between the foot and the footrest and between the body segments and the seat segments (Figure 10 and 11).
For each segment, all the equilibrium conditions are calculated compared to the local reference system, imposing that in the joints between segment and segment it must result the equality of the resulting forces and torques on the two sections. The segments head and toes have both a free extreme where forces and torques assume null value. The frictional force is $R_{a(i)} = R_{n(i)} * Mu_{(i)}$.

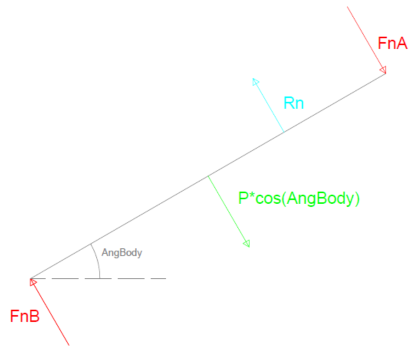

Fig. 10. Normal forces scheme acting on single element

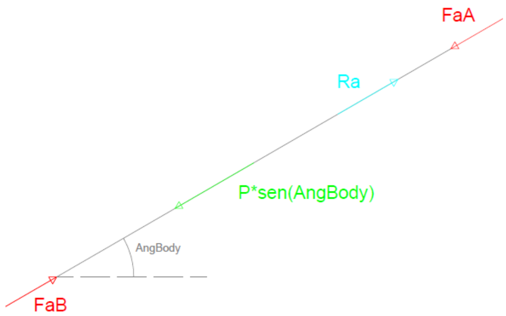

Fig. 11. Axial forces scheme acting on single element

For the purposes comfort, it was considered preponderant to keep the muscular efforts necessary to guarantee the moments present in the joint joints low. From the count of equations and unknowns, it result to be indeterminate 6 values for which it is necessary to make some hypotheses.
In particular, it is possible to choose among 5 options in function of the type of study that we desire to make and of the related scientific literature:

1) impose null torques condition as ideal condition
2) impose as ideal condition the one in which all torques are equal
3) impose known values in place of unknown torques
4) make a study of torque's variability in a wide range
5) impose a constant ratio between thigh contact pressure and pelvis contact pressure

Conclusions

A mathematical model has been developed and tested that determines how the weight of the body is distributed on a chair. This model allow us to study the unconscious logics that determine the choice and maintenance of a posture. An experimentation phase is now possible comparing pressure pad results with model results in order to find any recursion of stress values of the articular joints or in assumed postures, highlighting seating comfort drivers.

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Posture prediction of a human on a chair: model validation

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Abstract One of the aspects that influence the sitting comfort is the distribution of the pressure applied to the skin by the seat surface. In the scientific literature, many studies show experimental activities in order to evaluate the influence of pressure distribution at the seat-human interface on the comfort evaluation. The main limitation in seat design is based on the difficulties to predict the contact pressures distribution without prototypes because of the complex interaction among body muscles, wearing, human's anthropometric characteristics, shape and materials of the seat. Moreover, the same human can assume different postures on the same seat, and different people, seated on the same chair, can assume different postures even if they have the same anthropometric percentile. The aim of this study is to propose a mathematical model evaluating interaction loads between human segments and seat segments. In this model a human body represented by 8 segments is placed on a 6 segments seat with posture dependent on seat segments and on position of the cocciyx on seat and feet on floor. Human segments can be configured in length and weight and friction between body and seat is considered. A model validation study based on an experimental comparison with contact pressures is also presented.

Keywords: Seating posture, seat, contact pressures.

1 Introduction

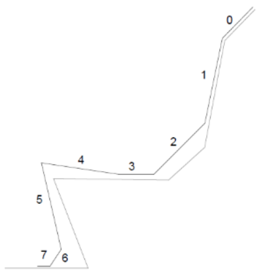
The study of the interaction between chair and posture to predict the comfort level of a seated person is necessary for the correct design of any type of chair. The scientific literature recognizes, from the experimental point of view, the analysis of contact pressures and the analysis of comfortable postures the most significant aspect to be investigated [1-16].

In the paper "Posture prediction of a human on a chair: model prediction" authors presented a mathematical model that has been developed and tested in order to determine how the weight of a human body is distributed on a chair. This model allow the study of the unconscious logics that determine the choice and maintenance of a posture assumed during sitting. It is an open problem because for the same human on the same seat, we observe very different postures An experimentation phase is now possible about this model comparing pressure pad results with model results in order to find any recursion of stress values of the articular joints or in assumed postures, highlighting seating comfort drivers.

Knowing the comfort needs of a seated person means knowing which inclinations the various parts of his body need to assume and in which area he needs to have more support to reach a comfortable seating. This allows designing of any type of seat to accommodate a human in order to optimize it from the point of view of comfort.

2 Model description

The model is based on a static analysis, in which body and seat are seen in profile and are considered as set of segments on a two-dimensional plane; human articulation are represented by joints that allow rotations but not translations. To simulate in the best way the different assumable posture, human body has been schematized with 8 segments (Figure 1): head and neck, upper trunk, lower trunk, buttock, thigh, leg, sole of the foot, toes.



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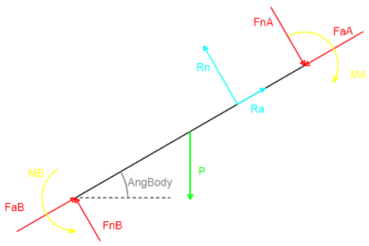


Fig. 2. Loads on a segment

The arm's weight is summed to the one of the upper trunk, that of thighs, legs and feet is counted twice. The trunk's length is divided into the upper and the lower trunk part in proportions 1/3 and 2/3 to make difference between lumbar and thoracic part. There are different kind of seat, depending on the context in which they are used and we used six segments to model it: headrest, backrest, upper part, backrest, lumbar part, sitting plan, legs support, footrest. To each segment for which is expected contact with the body, it's assigned a friction coefficient.

The model calculates the posture starting from the seat coverage percentage $\boldsymbol{K} = PosBacino * LengSed_{(i)}$ (Figure 3) calculated from the side of the knees. Starting from the buttocks position, we calculate (Figure 4) the position of the thoracic part and the extension of the corresponding contact surface compared to the eventual back of the chair. Then we calculate the eventual contact in the lumbar area and the head position compared to the headrest.

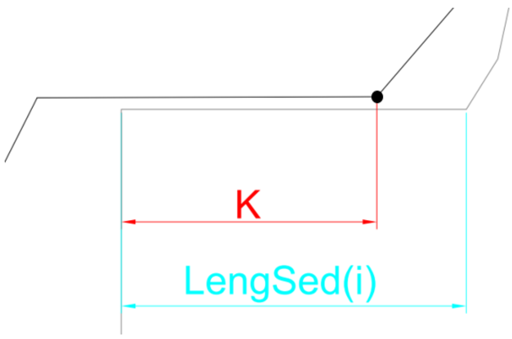
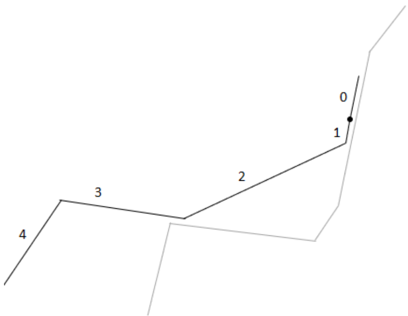


Fig. 3. Back on seat.



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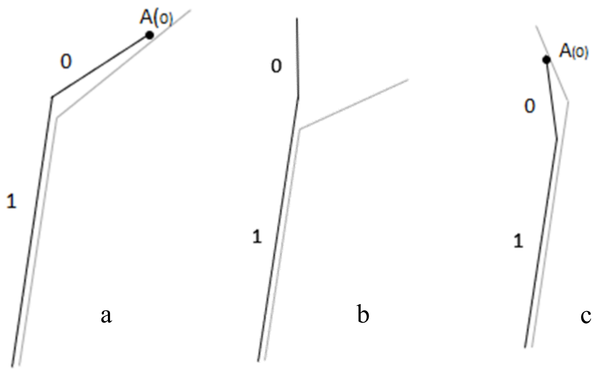

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2) impose as ideal condition the one in which all torques are equal
3) impose known values in place of unknown torques
4) make a study of torque's variability in a wide range
5) impose a constant ratio between thigh contact pressure and pelvis contact pressure

4 Experimental setup and model validation

To evaluate the proposed model, it was made a comparison of the numerical results obtainable by varying the unknown torques in a wide range with those deriving from the pressure measurements obtained during an experimental phase carried out in the laboratory.

The experimental phase implicated the use of the chair shown in Figure 7 on which a measuring mat of the contact pressure was placed.

Fig. 6. Chair used in experimental tests

There isn't headrest, so the head-neck segment is always upright (section 0, $LengSed_0 = 0cm$); the backrest allows the contact only for the part indicated in yellow in the previous imagine (section 1, $LengSed_1 = 26cm$); the blue part is, instead, the one where there is no contact because it's empty (section 2, $LengSed_2 = 12cm$); the sitting plan, indicated in black, corresponds to the section 3 of length $LengSed_3 = 46cm$; the sitting plan is $41cm$ ($= LengSed_4$) far from the ground, and this distance represents the section 4 on which, however, there is no contact; there's no footrest so the section 5, on which the foot lean, correspond to the floor. His length is set as equal to that of the foot ($LengSed_5 = LengBodySeg_5$).
The inclinations of the seat chosen, compared to the floor, are: Segment 0: absent; segment 1: 88 °; segment 2: absent; segment 3: 0 °; segment 4: it is represented by a distance but physically does not provide support; segment 5: 0 °.
The friction coefficients have been set, hypothetically, all equal to 0.3 with the exception of that of the foot, chosen equal to 0.4. The standard time to which the tests refer is equal to 1 second and the acquisitions took place every 0.04 seconds, for a total of 25 pressure states. This result has been compared with the normal reaction explicated by the sitting plan on the said segment, equal to $R_{n(3)}$, calculated by the program.
The tests were carried out on 4 different subjects; the pressures exercised on the sitting plan by each of them were measured for three different knee inclinations: 1) 90 °; 2) legs forward in the most comfortable position; 3) back legs still in the most comfortable inclination. Each subject was photographed and the position of the pelvis compared to the chair and the values of the knee angles were taken from the photo.

5 Results and considerations

In Table 1 there are the ranges of results (minimum and maximum values) of the acquisitions made with the pressure mat, in the 25 fractions of a second, compared to the $R_{n(3)}$ calculated with the six-segments model for the four subjects and for the three knee angles (AngKnee) for right leg, stretched leg and leg under seat :

Table 1: Characteristics of the subjects that have participated to the experimentation.

ID	Weight (kg)	Height (cm)	Ang Knee (deg)	RN measured min (kg)	RN measured max (kg)	RN measured media (kg)
1	71	170	90	31.2	38.5	35.5
			147	50.1	55.3	53
			51	49	53.4	51.5
2	71	162	90	20.8	25.7	23.7
			148	35.2	39	37.1
			45	28.2	33.8	31.2
3	53	165	90	24.5	29.5	26.3
			146	29.2	37.1	32.6
			50	30.2	37.6	34
4	63	170	90	33.4	37.3	34.9
			162	31.6	38.8	35
			44	34.4	38.2	36.9

The mathematical model was applied varying the torques applied to the knees, hips and sacral joint from 0 to 100 kg * cm with step 5, thus analysing 9261 possible combinations. Table 2 shows results for one of simulated subjects.

Table 2: Load conditions of the joints corresponding to the experimental data for the Subject 1.

AngKnee	M_{hip}	M_{leg}	M_{knee}	P_{pelvis}	P_{leg}	P_{foot}	P_{carpet}	Real P_{carpet}	Toll.
51	**35**	**30**	**0**	23.6	24.5	42.5	48.1	51	±3
	40	25	5	23.6	24.5	42.5	48.1		
	…	…	…	…	…	…	…		
	65	0	30	23.6	24.5	42.5	48.1		
90	25	45	0	18.6	18.2	65.1	36.8	35	±3
	30	**40**	**5**	18.6	18.2	65.1	36.8		
	35	**35**	**10**	18.6	18.2	65.1	36.8		
	40	**30**	**15**	18.6	18.2	65.1	36.8		
	45	25	20	18.6	18.2	65.1	36.8		
	…	…	…	…	…	…	…		
	70	0	45	18.6	18.2	65.1	36.8		
147	**40**	**20**	**0**	28.6	25.8	29.9	54.4	52.5	±3
	45	15	5	28.6	25.8	29.9	54.4		
	…	…	…	…	…	…	…		
	60	0	20	28.6	25.8	29.9	54.4		

The resultant of the experimental measurements obtained from the mat is compared with the sum of the normal force acting on the buttocks ($R_{n(3)}$) and of that acting on the thigh ($R_{n(4)}$). In particular, all the combinations of joint moments that result in the load value on the seat corresponding to the measured value with a certain tolerance (± 3 kg corresponding to the load oscillations during the acquisition interval) have been identified. Among these, the combinations for which the component relative to the thighs and that relating to the buttocks are equal (unless of the same tolerance value) have been identified since this condition corresponds to a better pressure distribution which induces greater comfort or less discomfort. Table 1 shows the results about one subject.
The moment applied to the hip (more precisely to the sacral joint) conditions the other two, therefore depending on the activation of the back there will be a consequent activation of the leg muscles. M_{hip} varies on average between 20 and 65; M_{leg} and M_{knee}, instead, between 0 and 40. The extent of these intervals, based on the information collected, proportionally depends on the overall weight of the subject.
Since the sacral and lumbar joints have the same axis of rotation and must both hold the weight of the upper part of the body, we assume that in conditions of comfort they exercise the same level of effort. In this hypothesis the results are further filtered by choosing the solutions for which | Mhip-Mleg | <= 10 (sum of tolerances on both moments).
From the analysis of the data it results that, in the hypotheses carried out and comparing the simulations with the experimental results, we tend to always assume the same values of articular stress, which grow linearly in proportion to the weight, as shown in the Table 3, independently from the position of the legs stretched forward, straight or placed under the pelvis.

Table 3: Load conditions of the joints corresponding to the experimental data for the Subject 1.

Weight	Leg ahed			Vertical leg			Leg behind		
(kg)	Mhip	Mleg	Mknee	Mhip	Mleg	Mknee	Mhip	Mleg	Mknee
53	27.5	22.5	2.5	27.5	22.5	2.5	27.5	22.5	2.5
68	30.0	30.0	5.0	30.0	30.0	5.0	30.0	30.0	5.0
71	38.8	33.8	15.0	35.0	37.5	12.5	36.3	31.3	3.8

Conclusions

A mathematical model has been developed and tested that determines how the weight of the body is distributed on a chair, so as to study the unconscious logics that determine the choice and maintenance of a posture. The experimentation allowed to highlight that there is a remarkable recursion of some stress values of the articular joints of the pelvis, hip and knee. By imposing these values in the calculation model, it is possible to determine, for each chair configuration, which postures will be assumed by a person, and to make a preliminary assessment of the level of comfort obtainable.

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Prediction of Automotive Seating Thermal Discomfort related to Wetness Perception

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Abstract Sweat production during summertime inside vehicle cabins may lead to an accumulation of heat and moisture at the seat-person interface increasing microclimate vapor pressure (p_{mic}) and skin wettedness and consecutively causing local thermal discomfort. Currently applied comfort models focus on the convective and radiative heat transfer disregarding evaporation associated with wetness perception (*WP*). Therefore, this laboratory study aimed at providing a model predicting *WP* by p_{mic} serving as comfort benchmark. One-hundred-and-twelve young adults (56 females, 56 males) wearing summer clothing with estimated insulation of 0.6 clo participated in 2h-sessions under heat stress in a climatic chamber occupying a car seat fastened by a 4-point seat belt to reduce body movements to a minimum. We calculated p_{mic} from the continuously recorded temperature and relative humidity of the seat-clothing microclimate at the cushion and the backrest, respectively. We registered *WP* every 5 min in the first hour and every 10 min in the second hour of exposure applying a 5-point scale, which we dichotomized for classifying a vote as a definite *WP*. Applying logistic regression analysis to these training data, we developed models predicting *WP* by p_{mic} and by additional predictors. Percentage of persons stating *WP* significantly increased with p_{mic} and the root-mean-squared prediction error (*rmse*) was 5.2%. With exposure time as additional predictor, *rmse* decreased to 2.5%. We compared the model predictions to independent test data obtained in similar studies with different types of automobile seats under varied thermal conditions. The model with p_{mic} and time as predictors yielded unbiased *WP* estimates with *rmse* below 10% for climatic conditions similar to the training conditions. For neutral or hotter climates, models disregarding the predictor time or substituting it by local or whole body thermal sensations showed improved performance. The apparent effect of exposure time mediated via thermal sensation agrees with the concept of alliesthesia, indicating that alterations in the general thermal state over time may influence *WP* under heat stress. Neutral conditions or auxiliary cooling, e.g. by seat ventilation, might change the temporal relationship so that simpler models based on microclimate vapor pressure alone or in combination with thermal sensation predictions, e.g. by ISO 14505, become preferable. Overall, the introduced models, when used in connection with sensors, thermal manikin measurements or software simulations providing information on microclimate vapor pressure (p_{mic}), show the potential for delivering unbiased estimates of *WP* related discomfort on automobile seats with acceptable error.

Keywords: Thermal comfort, vehicle seat, heat stress, sweating, model.

1 Introduction

The thermal environment represents one of several aspects related to automobile seating comfort [1, 2, 3]. Sweat production during summertime inside vehicle cabins may lead to an accumulation of heat and moisture at the seat-person interface [4] increasing microclimate vapour pressure (p_{mic}) [5] and skin wettedness (w_{sk}) [6] and consecutively causing local thermal discomfort [7, 8]. Although thermal manikins and models [5] are increasingly used for evaluating seating thermal comfort, the underlying comfort models, e.g. ISO 14505, focus on the convective and radiative, i.e. 'dry' heat transfer [9, 10] disregarding evaporation associated with wetness perception (*WP*) [11].

1.1 Objectives

In a study with moderate sample size (n=43), we had recently shown that p_{mic} has equal capacity in predicting *WP* compared to w_{sk} [12]. Therefore, this study aimed at providing a model predicting *WP* by p_{mic} serving as comfort benchmark in manikin and model simulations based on a larger sample, and at validating the resulting model against independent test data obtained with different types of automotive seats under varied climatic conditions.

2 Methods

2.1 Training data

For model development, we obtained training data (*TRAIN*) from one-hundred-and-twelve young adults (56 females, 56 males) wearing short-sleeved T-shirts and jeans with estimated clothing insulation of 0.6 clo, who participated in the climatic chamber experiments. For 2 hours, they were exposed to air temperature $t_a = 25$ °C, mean radiant temperature $t_r = 60$ °C, ambient vapour pressure $p_a = 1.58$ kPa and air velocity $v_a = 0.5$ m/s occupying a car seat fastened by a 4-point seat belt to reduce body movements to a minimum.

2.2 Procedure and measurements

We calculated p_{mic} from the continuously recorded temperature and relative humidity of the seat-clothing microclimate at the cushion and the backrest, respectively, using a Pt100 sensor combined with a capacitance hygrometer (Vaisala HMP 233). We registered *WP* every 5 min in the first hour and every 10 min in the second hour of exposure applying a 5-point scale (1='dry', 2='slightly moist', 3='moist', 4='wet', 5='very wet'), which we dichotomized applying a cut-off scale value greater than two for classifying a vote as a definite *WP*. Concomitantly to *WP*, we also registered thermal sensation votes for the whole body (*TSV*), as well as for body regions located at the seat-person interface (TSV_{loc}), for which we also registered local skin temperatures (Tsk_{loc}) using thermistors (YSI 427).

2.3 Data analysis and model validation

Applying logistic regression analysis with a generalised estimation equation approach to account for the within-subject correlation of the time-dependent observations [13], we developed models predicting the probability of *WP* by p_{mic} as single predictor and by exposure *time*, *TSV*, TSV_{loc} and Tsk_{loc}, respectively, as additional predictors.

For validation purposes, we compared the model predictions to independent test data obtained in similar studies with different types of automobile seats. One study with conventional seats (*CONV*) comprised 2-h-exposures to a thermo-neutral climate with $t_a = t_r = 25$ °C, $v_a = 0.3$ m/s, (*NEUTRAL*, $n = 108$ experiments), and two heat stress conditions with $t_a = 32$ °C (*HEAT1*) and 37 °C (*HEAT2*), respectively, with $t_r = 50$ °C, $v_a = 0.5$ m/s, $n = 107$ for each condition [14]. Another study investigated the effects of 90-min heat exposures similar to *TRAIN* (with t_r reduced to 40-50 °C) on ventilated seats (*VENT*) with $n = 144$ experiments [15].

Prediction errors were calculated as differences of predicted minus observed percentage probability of *WP* for all models applied to the different datasets and were summarized as averaged prediction error (*bias*) and root-mean-squared error (*rmse*), respectively.

3 Results

For *TRAIN*, percentage of persons stating *WP* significantly increased with p_{mic} and the root-mean-squared prediction error (*rmse*) was 5.2%. As *WP* also increased significantly with exposure time, *rmse* decreased to 2.5% after including time as additional predictor (Table 1). Figure 1 depicts the resulting models for the seat backrest and cushion, respectively. Substituting time by thermal sensation or skin temperature as predictors yielded similar *rmse* between 3.6% and 4.5% (Table 1).

For the validation experiments *CONV*, the model with p_{mic} as sole predictor yielded unbiased *WP* estimates with *rmse* = 10.0%, however, adding time as additional predictor caused overestimation with 3% *bias* and increased *rmse* to 14.7% (Table 1). The latter was due to a 19% overestimation bias in the *NEUTRAL* climate accompanied with 11% underestimation in *HEAT2*, whereas for the p_{mic} only model, this *bias* reduced to 7% and -8%, respectively. Predictive accuracy further improved in models replacing exposure time by either global or local thermal sensation, yielding overall *rmse* of 7.6% and 6.8%, respectively (Table 1). Notably, there was negligible *bias* with small *rmse* for *HEAT1*, the condition closest to *TRAIN* (Table 2).

The model with p_{mic} combined with *time* shown in Figure 1 performed best for the validation experiments *VENT* (Table 1), which had been conducted under thermal conditions similar to *TRAIN*.

Under all conditions in Tables 1 and 2, the usage of local skin temperatures did not improve the predictive accuracy compared to models applying time or thermal sensation as additional predictors.

Table 1. Averaged *WP* prediction error (*bias*) and root-mean squared error (*rmse*) from different models for the training data (*TRAIN*) and for independent test data from experiments with conventional (*CONV*) and ventilated seats (*VENT*), respectively.

	TRAIN		*CONV*		*VENT*	
model	*bias*	*rmse*	*bias*	*rmse*	*bias*	*rmse*
p_{mic}	2.4%	5.2%	-0.3%	10.0%	-5.8%	10.0%
p_{mic} + *time*	1.5%	2.5%	3.0%	14.7%	-1.8%	7.3%
p_{mic} + *TSV*	0.6%	4.0%	-1.5%	7.6%	-6.6%	10.5%
p_{mic} + TSV_{loc}	0.0%	3.6%	1.9%	6.8%	-6.5%	10.4%
p_{mic} + Tsk_{loc}	2.2%	4.5%	2.8%	9.6%	-4.6%	9.3%

Table 2. Averaged *WP* prediction error (*bias*) and root-mean squared error (*rmse*) from different models for the different climatic conditions of the independent validation experiments with conventional seats.

	NEUTRAL		*HEAT1*		*HEAT2*	
model	*bias*	*rmse*	*bias*	*rmse*	*bias*	*rmse*
p_{mic}	6.9%	8.7%	0.5%	9.6%	-8.2%	11.5%
p_{mic} + *time*	18.6%	22.0%	1.0%	5.3%	-10.5%	11.5%
p_{mic} + *TSV*	1.6%	2.2%	0.7%	8.7%	-6.7%	9.7%
p_{mic} + TSV_{loc}	1.7%	2.3%	5.8%	9.1%	-1.8%	7.1%
p_{mic} + Tsk_{loc}	8.7%	10.5%	3.9%	8.5%	-4.2%	9.7%

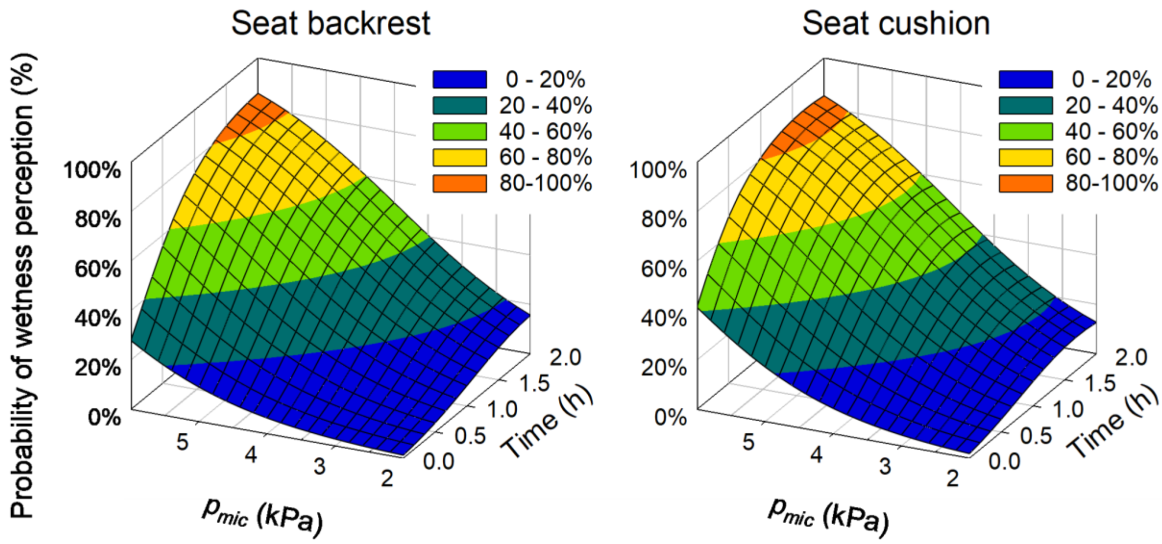

Fig. 1. Models predicting *WP* at the backrest (left) and cushion (right) by p_{mic} and exposure time.

4 Discussion

Though the prediction error was, as expected, higher for the validation data compared to *TRAIN*, our results indicate that the introduced models can deliver unbiased predictions of *WP* related discomfort on car seats with a typical error below 10%.

The apparent effect of exposure time mediated via thermal sensation is in agreement with the concept of alliesthesia [16, 17], indicating that alterations in the general thermal state over time may influence *WP* under heat stress.

Thermal environments closer to neutral conditions or auxiliary cooling, e.g. by seat ventilation, might change the temporal relationship. Thus, simpler models based on microclimate vapour pressure alone or in combination with predicted thermal sensation become preferable, e.g using. ISO 14505-2 [9] or other appropriate algorithms [18, 10]. Local skin temperatures, requiring higher effort in measurement, did not provide any advantage with respect to predictive accuracy in our study.

5 Conclusion

In summary, the introduced models predict the thermal discomfort related to wetness perception on automobile seats and were validated against a large number of controlled experiments under varying climatic conditions with different types of seats. Overall, these models, when used in connection with the information on microclimate vapor pressure (p_{mic}) provided by sensors integrated in the seat, thermal manikin measurements or software simulations, show the potential for delivering unbiased estimates of *WP* related discomfort on automobile seats with acceptable error.

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Comfort and Personal Protective Clothing

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Abstract Harsh thermal conditions directly affect human health, performance and comfort. The interaction between the human body and functional clothing, e.g. personal protective equipment (PPE), can be described by measurements of thermo physiological parameters. For PPE these parameters and performance requirements are given in standards such as DIN EN 469(1) for fire fighters or DIN EN ISO 11611(2) for welding and allied processes. First, PPE should protect the wearer from external influences such as fire, heat, weather and water. Also, it should protect from internal dangers such as overheating which can cause - in the worst case - cardiovascular failure or heat stroke. These important but minimalistic thermophysiological requirements are given in the standards and describe the insensitive sweating. Further it is desirable that PPE is comfortable, too. So, the sensible sweating state of a human body should be characterized more in detail for PPE.

With the Hohenstein Skin Model (sweating guarded hot plate) according to ISO 11092(3) the instationary buffering capacity of liquid sweat (buffering index k_f) can be measured(4). With this measurement a wear condition is comprehended where the wearer is sweating so heavily that there is liquid sweat on his skin. It could be shown that there is a huge difference between state-of-the-art fire fighter PPEs. Some show poor buffering capacities of liquid sweat with an K_f-value of 0.3 – 0.4. On the other hand, there exist fire fighter PPEs with higher (better) buffering capacities of liquid sweat with k_f-values between 0.75 – 0.88. By combining the fire fighter PPE with functional undergarments, the buffering capacity of liquid sweat could be improved.

Further studies deal with the influence of reprocessing and reimpregnation on the sweat management of PPE. By reprocessing of fire fighter suits contaminations of the PPE can be removed and the functional integrity of such PPE may be extended. Therefore, the usage of special laundry processes according to the manufacturer information is necessary. To preserve the water and oil repellent characteristics of the face of the outer shell fabric in long term an impregnation with perfluorocarbon during the last rinsing bath is recommended. It could be shown that such perfluorocarbon impregnations have a negative influence on the thermophysiological wear comfort of PPE.

Keywords: personal protective clothing, clothing physiology, comfort, sweating

1 Introduction

The main task of personal protection equipment (PPE) is the protection from external dangers. In case of fire fighters or welders this is fire, heat or extinguishing water. At the same time heat and moisture produced by the human body should be transferred through the PPE to the ambient and the mobility of the wearer should not be influenced by the PPE. These performance requirements are given in standards such as DIN EN 469(1) for fire fighters or DIN EN ISO 11611(2) for welding and allied processes.

During wearing the PPE gets dirty by different contaminations depending on the operation area and activity. In case of firefighting it could be soot or hazardous substances, at an emergency response blood or at technical aid mud, acid, brine and oil. Those contaminations are sometimes not visible for the human eye on the PPE. But if not removed the function of the PPE could be influenced. Soiled reflective stripes for example impair the visibility of the fire fighter. So, the contaminations should ne removed to obtain the function. One way, the expensive one is the replacement of the PPE. As an alternative the PPE could be reprocessed professional. Until now there is no guideline for reprocessing fire fighter PPE. There are only care instructions given by the PPE or detergent manufacturers. To guarantee the water repellent effect of fire fighter PPE a perfluorocarbon impregnation is recommended after every fifth reprocessing cycle. To activate this hydrophobic finish heat (ironing, tumbler, finisher) is necessary. Such a perfluorocarbon impregnation obtains the water and oil repellent effect of the outer fabric. The question arises if these perfluorocarbon impregnations within the last rinsing bath of reprocessing PPE influences other characteristics such as the clothing physiological parameters.

2 Materials and Methods

Five state of the art fire fighter suits were characterized about clothing physiological parameters in new state and after reprocessing cycles with and without perfluorocarbon impregnation. Table 1 shows the used fire fighter PPE in detail.

Table 1. Fire Fighter Materials.

Sample	*Description*	*Structure*	*Grammage [g/m²]*	*Watervapor-permeability "breathability" R_{et} [m²Pa/W]*
1	Outer fabric: Nomex Moisture barrier: 2-layer laminate with PU-membrane Thermoinsulation: quilted Nomex with AR/CV_{FR}	liner; membrane orientated to outer fabric	660	25.68
2	Outer fabric: Nomex Moisture barrier with thermoinsulation: 2-layer laminate with PTFE-membrane and spacer dot Lining material: AR/CV_{FR}	liner; membrane orientated to outer fabric	495	28.98
3	Outer fabric: AR/PBI/C Moisture barrier with thermoinsulation: 3-layer laminate with PTFE-membrane and spacer dots	liner; membrane orientated to skin	570	17.97
4	Outer fabric: Kermel Moisture barrier: 2-layer laminate with PU-membrane Lining material: AR	liner; membrane orientated to skin	595	21.53
5	Outer fabric: Kermel/Belton Moisture barrier: 2-layer laminate with PES-membrane Thermoinsulation: quilted AR with AR/CV_{FR}	liner; membrane orientated to outer fabric	660	24.65

2.1 Methods

The reprocessing of fire fighter PPE is performed according an industrial laundry process (ISO 15797)(5). The developed washing procedure is named "contaminated with oil" and simulates a worst-case scenario for PPE soiled during a mission. During the process the washer extractor Kannegiesser Favorit Plus is used as well as Almesin as detergent and Mulan as detergent booster. Drying process A is used with an input temperature of 110°C and an exhaust air temperature of 80°C. Through each washing cycle the fire fighter PPE was impregnated with a perfluorocarbon.

For characterisation of the perfluorocarbon impregnation the Sorption speed of a water drop into the fabric (sorption index i_B). This sorption speed can be determined by a video film of a water drop of defined size falling from a burette 5 cm above the sample onto the fabric's inner surface. By crossing a light beam just before touching the fabric's surface the falling water drop triggers a video camera. which takes pictures of the water drop on the fabric's surface. Out of the time-pattern of the contact angle of the water drop the time lapse can be extrapolated, after which the water drop has been completely absorbed by the sample. This time lapse yields the sorption index i_B. Regarding its sensorial comfort a fabric must be judged the better, the smaller i_B. Particularly i_B should be below 270.

The thermoregulatory model of human skin (Skin Model) simulates the dry as well as the sweating human skin. With the Skin Model the specific thermophysiological quantities of textiles as layers, relevant to physiological comfort, can be determined. Under "normal" or "stationary" conditions the moisture flux from the skin appears as water vapor (insensitive sweating). In this stationary case the water vapor resistance R_{et} can be measured according ISO 11092(3). DIN EN 469 requires a water vapor resistance R_{et} (stationary conditions) between 30 and 45 m² Pa/W for Level 1 PPE and $R_{et} \leq 30$ m² Pa/W for Level 2 PPE. Level 1 PPE is not water vapor permeable.

For the clothing physiological properties of textiles not only their stationary thermo-physiological properties are important but also the capacity to buffer sweat pulses which are occurring quite frequently in the practical use of textiles and clothing. Concerning the buffering capacity, it must be distinguished between two mechanisms:

Buffering capacity of water vapor (moisture regulation index F_d): This measurement describes the wear condition where the wearer is already sensibly sweating, but the sweat is still evaporating within the channels of the skin's sweat glands. In the clothes' microclimate an increased water vapor pressure is occurring but still no liquid sweat.

With the buffering capacity of liquid sweat (buffering index K_f) a wear condition is comprehended where the wearer is sweating so heavily that there is liquid sweat on his skin.

Like the stationary wear conditions, also the instationary conditions can be simulated with the Skin Model. A description of the test procedures is given in the Standard-Test Specification BPI 1.2(4, 6).

3 Results and Discussion

Fire fighter PPE was characterized about the thermophysiological comfort in new state and after reprocessing with and without perfluorocarbon impregnation. First the sorption index i_B was determined. According this parameter the sorption characteristics of a textile can be described. During hard exercise like in case of a fire fighter mission the produced sweat should be absorb by the lining and transferred through the material combination to the ambient. If this is not the case heat and moisture accumulate in the clothing. Therefore, the concentration and performance of the fire fighter decreases. Regarding its sensorial comfort a fabric/clothing must be judged the better (hydrophilic), the smaller i_B. Particularly i_B should be below 270.

Figure 1 shows the sorption index of the lining materials of fire fighter PPE in new state (blue), after reprocessing with (red) and without (green) perfluorocarbon impregnation during the last rinsing bad. In new state sample 1, 4 and 5 with AR quilted AR/CV_{FR} as thermoinsulation or aramid fabric as lining have a sorption index of i_B<60. Except sample 3 all materials can be rated as hydrophilic.

After reprocessing with perfluorocarbon impregnation during the last rinsing bath all samples have a sorption index i_B>600 (Fig. 1, red bars). This means all samples are hydrophobic. Without perfluorocarbon impregnation (Fig. 1, green bars) sorption indices i_B<60 are measured. This shows that the hydrophobic effect residues from the perfluorocarbon impregnation. Sample 3 is an exception: in new state the lining shows a high sorption index. During reprocessing without perfluorocarbon impregnation, the sorption index increases. In this case an impregnation of the lining was performed during manufacturing and removed during reprocessing.

By perfluorocarbon impregnation during reprocessing of fire fighter PPE not only the outer fabric gets impregnated, but also the lining. Therefore, the liquid sweat, which occurs during exercise, could not be absorbed by the lining.

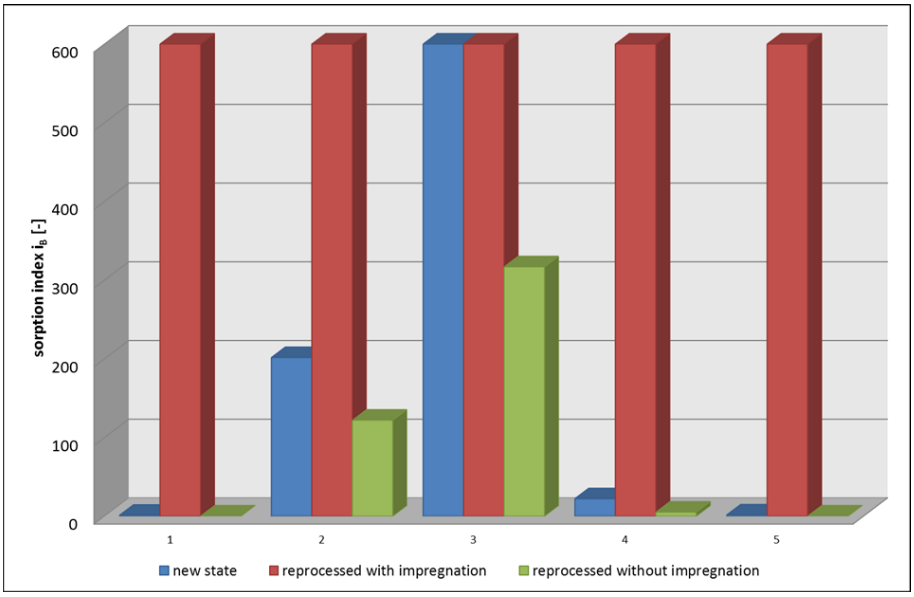

Fig. 1. Sorption index $_{iB}$ of lining material of fire fighter PPE new state (blue), after reprocessing with (red) and without (green) perfluorocarbon impregnation

In Case of fire fighter PPE, the watervaporpermeability R_{et} is an important parameter required in DIN EN 469: it should be between 30 and 45 m² Pa/W for Level 1 PPE and $R_{et} \leq 30$ m² Pa/W for Level 2 PPE. Level 1 PPE is not water vapor permeable. This means that the PPE is only for temporary use. But all tested material combinations (MA1- MA5) showed a water vapor resistance beneath 30 m² Pa/W. Furthermore, it was shown that if the membrane is orientated to the lining or skin the R_{et} is lower than if it is orientated to the outer layer (Table 1).

Further the hydrophobic effect of the perfluorocarbon impregnation on the sweat transport was investigated by measurements with the Skin Model in instationary case. For this purpose, the buffering capacity of liquid sweat K_f of fire fighter PPE in new state (blue), after reprocessing with (red) and without (green) perfluorocarbon impregnation was investigated (Fig. 2). Fabrics with high buffering capacity of liquid sweat K_f (high K_f values) transport the liquid sweat better from the inside to the outside of clothing. In new state as well as reprocessing without perfluorocarbon impregnation the fire fighter PPE has higher K_f values than reprocessing with perfluorocarbon impregnation. In addition, liquid sweat which is produced during high physical strain during fire fighters work cannot be absorbed by the lining material caused by the impregnation. Residual sweat on the skin poses a risk for the fire fighter and may end in circulatory collapse or scalding in case of flash over.

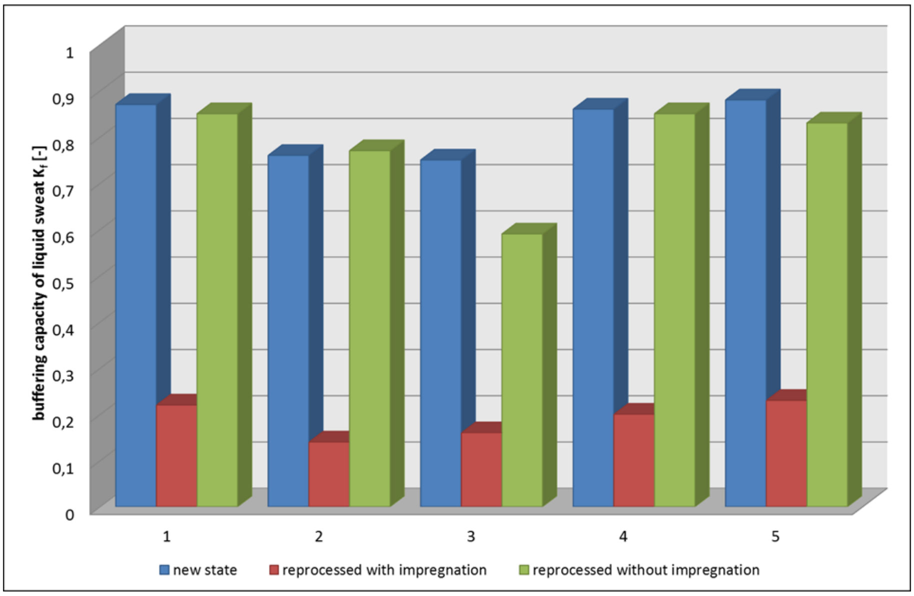

Fig. 2. Buffering capacity of liquid sweat K_f of fire fighter PPE new state (blue), after reprocessing with (red) and without (green) perfluorocarbon impregnation

4 Conclusion

In conclusion it can be stated that reprocessing of fire fighter PPE is important to remove contaminations and to guarantee a long-time function of the PPE. Nowadays there is no standardized reprocessing process for such PPE.

The reprocessing with perfluorocarbon impregnation one hand has a positive effect on oil and water repellent characteristics of the face of outer shell fabric. But on the other hand, there is a negative effect on sweat absorption and sweat transport of fire fighter PPE. By reimpregnation via perfluorocarbon within the last rinsing bath during reprocessing the whole material combination of the fire fighter PPE is getting hydrophobic properties. Therefore, the clothing physiological characteristics including the sweat management deteriorate. The lining material of the PPE is no longer able to absorb from the human skin and transfer it trough the material combination.

An approach to receive the clothing physiological characteristics of fire fighter PPE after reprocessing with reimpregnation is a spray impregnation. In this process the perfluorocarbon impregnation is applied only on the outer fabric. So, the clothing physiological parameters of the inner textile layers are not affected by the impregnation. Further investigation dealing with this topic are ongoing.

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Designing a floor plan using aircraft seat comfort knowledge by aircraft interior experts

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Abstract Recent research indicated that an 18"x30" aircraft seat resulted in nearly the same level of comfort as a 17"x34" seat, however, it took less space in the floor plan. Based on this research outcome, 88 experts in the field of aircraft interior were invited to make a floor plan of a part of a Boeing 777 aircraft. First, experts were informed by the outcomes of the research and then, they were asked to make the floor plan in groups of three. Participants were given the freedom to design an economy and/or first-class interior of the cabin (5.87m wide and 3.7 m long) where besides these two types of seats, an old business-class size seat of 20"x36" was introduced as well for more flexibilities in design. In total 29 floor plans were made and these plans were analysed to compared against the complexity of the operations, the number of passengers on board, the revenue of the airline, and the width of the aisle. Results showed that 14 groups opted for the economy seats, while the rest utilized a hybrid setup where the business class seats was used in the configuration. Among all plans, four groups opted for a combination of 20 18"x30" seats and 24 17"x34" seats, and the aisle width was 0.76 m. This floor plan fits the regulations and has the potential of the highest revenue at €1,108.

Keywords: Aircraft Seat, Pitch, Width, Comfort, Layout

1 Introduction

The airline industry is a competitive market where passengers demand for comfort at a low price. Airlines are adding different comfort features in order to be chosen by customers, but they also need to maintain a certain level of revenues for a sustainable business. Therefore, between of choices of offering maximum comfort to all passengers and making this an upgrade service feature, most airlines opt to the latter option, especially the low-cost carriers (LCCs) as: 1) the fares are low regardless of their service quality; and 2) by adding additional features, LCCs can get a revenue stream of 8-13% from service features [1]. Furthermore, Hunt and Truong [2] also recommended this upgrade feature for full-service carriers (FSCs), as it will affect passenger choice by giving an option to increase comfort for passengers who are willing to pay more.

Additional seat space is one of the highlighted upgrade features that is offered by airlines. Some airlines choose to provide longer seat pitches and wider seats throughout their economy class, while others have a special premium economy class which offers this feature. Lee and Luengo-Prado [3] found that having a larger seat space only for the premium economy is more profitable for the airline. This is because not all customers were willing to pay more for an upgraded legroom, as price was the third selection criteria for most airplane passengers [4]. This premium economy concept was also seen as an additional revenue stream since 4-6% of passengers were willing to upgrade a seat with extra space for €25-30 [1]. This upgraded seat space is a primary factor for passengers to opt for premium economy [5]. Espino, Martín [6] also found that passengers flying for 2.5-3 hours were even willing to pay €38 for this extra seat space. This willingness to upgrade to economy plus class increased for medium-haul flights and was even higher for long-haul flights [5]. Moreover, researchers also identified that the demands for premium economy had grown quickly, causing several airlines expanding the size of this cabin [7].

Anjani, Li [8] found that comfort increases when increasing seat pitch. This study was later compared to increased comfort when extending seat width of 1 inch [9]. Comparison of the results indicated that increasing the width by 1-inch increases comfort more than increasing the pitch by 2 inches, though both require the same additional space in the floor plan. And for reaching the same level of the comfort score of this additional 1-inch in width, 4-inch increase in pitch direction is needed. Meanwhile, passengers were willing to pay an additional €22 for extra seat pitch and €29 for extra seat width, though these additions correlated negatively meaning that they were not willing to pay for both additions simultaneously [10]. Some care should be taking intyerpreting these data as what passengers say they will do might differ from really buying the extra's.

Besides those scientific discoveries, designers of the floor plan should also consider the complexity of the operations, the number of passengers on boards, the revenue of the airline, and aviation regulations (e.g. aisle width). All of these contribute to the complexity of designing the floor plan and selecting the types of seats for the premium economy class. This leads to the research questions of this paper: 1) Which seat layout is more preferred by experts for the economy class in their view? And 2) Which choice is more beneficial?

2 Literature Review

For airlines it is important to differentiate from other airlines also within the cabin [11]. One way of differentiating is adding premium economy or just a good economy class. In the assignment the good economy class is described and in this literature review the focus is on premium economy class. Premium economy class was introduced to prevent business passengers from downgrading too much and giving an option to high income leisure passengers to upgrade [7]. It provides a choice as an answer to most passenger dissatisfaction, which are seat comfort and legroom, luggage/flight disruptions and staff behaviours which occur in both LCCs and FSCs [12].

Adding a premium economy class itself adds the complexity to the operation of the airliner. A differentiation needs to be made not only in the seats but also in other services provided by the airline [7]. Adding two types of economy class options will increase this complexity further as it needs two different types of seats. Even though Boeing introduced open architecture which gives flexibility in the interior with lots of seat combinations, it costed two years of planning before installing and a considerable amount of man-hours were needed as well [13].

Kollmuss and Lane [14] found that in the US markets, the space for a first-class seat is 313% bigger than an economy seat, while a premium economy seats only occupies 29% more space than economy. This extra space could be beneficial as ticket prices of premium economy seats are higher, however, it was also found that the production cost of the seat is also 1.6 times more expensive than an economy class seats [7]. On the other hand, airlines also want to increase the number of seats in a cabin, as airplane manufactures predicted that adding another row in the airplane can reduce 5% of the seat cost per trip [15].

FAA regulates the size of the aisle to be minimum 15 inches for airplanes with more than 20 passengers. Some experts neglected this minimum. Though occupying larger space in the floor plan, a wider aisle may accelerate the (de)boarding process, as wide aisles enable people to pass each other during boarding. Another regulation Sec. 25.817 of the FAA regulates that there is a maximum of 3 seats beside each aisle per row, therefore the layouts with an additional floor is not possible.

3 Materials and Methods

Eighty-eight experts in the field of aircraft interior were asked to make a floor plan of a part of a Boeing 777 aircraft of 5.87m wide and 3.7 m long. 29 groups were made and 1 person left during the workshop. Each group was given a printed scaled aircraft floor plan and 2 types of economy seats to choose from (Figure 1**Error!**

Reference source not found.), and additional business class seat were given as a choice, if they wanted more flexibility. The sizes of two types of economy seats were 17” x 34” and 18” x 30”, respectively, while the business class seats were 20” x 36”. During the session, experts could put contours of the top view of the seat (including legroom) on top of the given floor plan according to different arrangement using their experience and/or creativity. The end results of the workshop were photographed and analysed based on aviation regulations and outcomes of previous studies. At the end of the session a general evaluation was made and experts were asked to give a reasoning for the decision. All floor plans were analysed and compared based on their manufacturing complexity, the potential of the total ticket price, the perceptual choice, the number of seats installed and the width of the aisle.

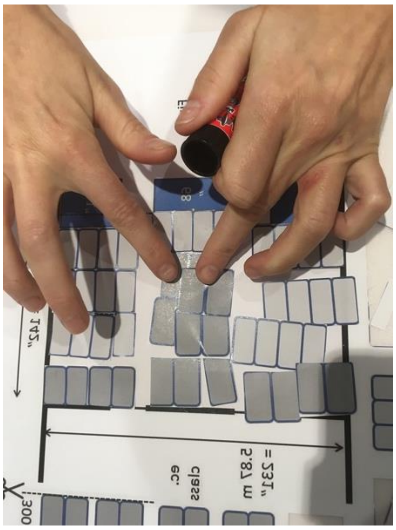

Figure 1 Discussion process

4 Results and Discussions

Twenty-nine floor plans were collected from this workshop (Figure 2).14 groups chose to only use the two types of economy class seats. These photographed floor plans were analysed based on the complexity of the operations, the number of passengers on boards, the revenue of the airline, and it might also bump some rules such as aisle width. Since this aircraft has 2 aisles, the sufficient aisle width would be 30 inches.

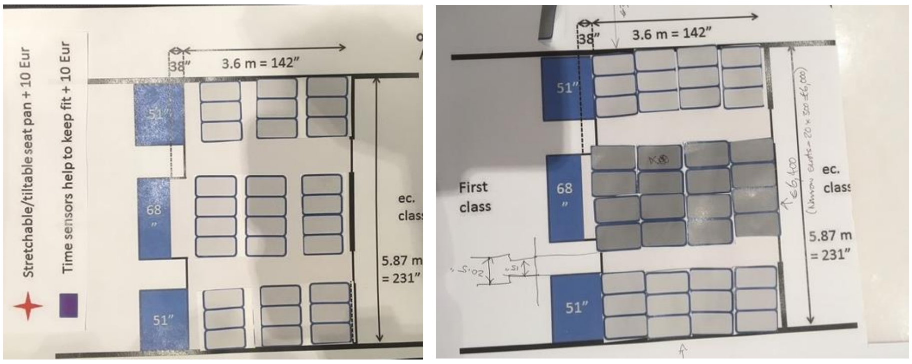

Figure 2 Examples of floor plans in the study

Each group was provided with three different types of seats. Adding different seat types would increase the operation complexity as it would change the process of the maintenance, booking, ticketing, etc. The number of seat types are included to give an overview of the complexity level of the operation.

The size choice of seats placed in the premium economy will affect the revenue of the airliner, as adding more seats can lead to price reduction per seat, but having an upgraded space could attract the passengers to pay more [10, 15]. Calculations of the potential total of additional revenue were made based on the price of Balcombe, Fraser [10]. Each 17”x 34” seats were valued €22 and the 18” x 30” seats were valued €29 additionally. This upgrade could be attractive for economy and premium economy passengers since 68.1% perceived legroom as the source of discomfort, while 50.7% had high discomfort on seat width [16]. The complexity level, the aisle width, the additional value of floor plans and numbers of seats were calculateed as Table 1.

Table 1. Calculation of floor plans

No.	*18”x30”*	*17”x34”*	*Number of seat types*	*Aisle width (m)*	*Additional value*	*Seat Count*
1	0	40	1	0.9	€880	40
2	0	30	1	0.9	€660	30
3	16	24*	2	0.9	€992	40
4	40	0	1	0.6	€1,160	40
5	38**	0	1	0.6	€1,102	38
6	16	24	2	0.78	€992	40
7	22**	24	2	0.78	€1,166	46
8	20	24	2	0.78	€1,108	44
9	0	44	1	0.47	€968	44
10	36	0	1	1.06	€1,044	36
11	20	24	2	0.78	€1,108	44
12	20	24	2	0.78	€1,108	44
13	20	24	2	0.78	€1,108	44
14	28	20	2	0.26	€1,252	48

*) Seats were placed sideways
**) Layout contained a second storey

Table 2. Profit/loss calculation for each floor plan

Photo Number	*Business class*	*Premium Economy*	*Cost (US$)*	*Revenue (US$)*	*Profit/Loss*	*Comply Regulations***
2	0	30	10.770	24.510	13.740	✓
25	21	13	20.753	36.892	16.139	×
16	7	28	15.414	31.633	16.219	✓
10	0	36	12.924	29.412	16.488	✓
24	19	16	20.298	36.841	16.543	✓
18	12	24	17.808	34.620	16.812	✓
27	24	12	22.692	39.828	17.136	✓
5	0	39*	14.001	31.863	17.862	×
28	20*	18	21.782	39.726	17.944	×
17	9	30	17.664	35.769	18.105	×
1	0	40	14.360	32.680	18.320	✓
3	0	40	14.360	32.680	18.320	×
4	0	40	14.360	32.680	18.320	×
6	0	40	14.360	32.680	18.320	✓
22	16	24	20.872	39.624	18.752	×
23	16	24	20.872	39.624	18.752	×
26	24	16	24.128	43.096	18.968	×
20	16	25	21.231	40.441	19.210	✓
21	16	25	21.231	40.441	19.210	✓
15	6	36	17.520	36.918	19.398	×
7	0	44*	15.796	35.948	20.152	×
8	0	44	15.796	35.948	20.152	✓
9	0	44	15.796	35.948	20.152	×
11	0	44	15.796	35.948	20.152	✓
12	0	44	15.796	35.948	20.152	✓
13	0	44	15.796	35.948	20.152	✓
19	12	32	20.680	41.156	20.476	×
14	0	48	17.232	39.216	21.984	×
29	52*	0	39.832	65.052	25.220	×

*) Layout contained a second storey
**) Regulations regarding the aisle width and additional store

In some plans, experts added an additional storey for more seats in the cabin. This did increase the numbers of seats, regulation wise it might not be possible since each aisle only allows three seats on each side of the aisle. One group placed the 17” x 34” seat sideways for fitting more seats in. However, it is not yet known the comfort level of the passenger in this type of seat as the orientation of the seat might also influence the comfort level. Four floor plans had an aisle width shorter than 0.76 m, which does not fit the FAA regulation. The floor plan with the highest additional revenue (€1,108) contains 20 seats of 18” x 30” and 24 seats of 17” 34”. Four groups opted for this combination with 44 seats in total in the given section of the cabin.

Another comparison was made to see the potential revenue gained by combining business and premium economy class seats shown in Table 2. This calculation was based on a Boeing cost model [7]. The real cost per passenger was US$ 766 for business class and US$ 359 for premium economy. While the real revenue per passenger was US$ 1,251 and US$ 817 for business and premium economy, respectively. By comparing the potential revenue from all floor plans, it was found that having a cabin with premium economy is more profitable than just having business class seats or even combining them. Among all floor plans that are complying to the regulations, the variation with 44 premium economy class without business class was found to gain more profit. This might be due to the different space-profit ratio of the business class and premium economy class seats. Therefore, adding business class seat to this cabin section does not add to the profitability. Though, this calculation might change if the load factor of each class is added.

5 Conclusion and Future Works

This study tries to explore the potential of the floor plans of the economy cabin using two types of economy class seats. Aircraft interior experts were asked to make floor plans, which were analysed based on the complexity of the operations, the number of passengers on boards, the revenue of the airline, and its aisle width. 14 groups of experts used only the economy class seats. These floor plans were then photographed and the protentional additional revenues were calculated. The most profitable plan was using 20 seats of 17”x34” and 24 seats of 18”x30”, resulting €1,108 with the highest seat count with 44 seats. Adding the business class seats to the floor plan did not increase the potential profit of the cabin section.

This study explores this seat configuration modelling by aircraft interior experts, where comfort was one of the main goals. Besides listed criteria, researcher also investigated aircraft seating layout by measuring load/unload time of passengers [17-20]. Another study also tries to model an aircraft seat configuration by maximizing customer satisfaction and in-flight safety as well as being profitable for the airliners [21]. They utilized tools such as digital human models, layout optimization, and a profit-maximizing constraint to their model for an optimal floor plan. Further studies are needed to understand the impact of having different types of seat in one cabin, its effect on loading and unloading process and optimizing the floor plan based on those understands.

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A body-shaped lumbar-sacral support for improving car-seat comfort

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Abstract Nowadays the ergonomic study of the driving position is a critical aspect of the design in the automotive field. Indeed, due to the rising needs on the market, car industries are focusing even on internal comfort. The use of the seat could cause some complaints in various regions of our body, especially in the lumbar-sacral one for prolonged postures. Thus, in order to reduce this kind of complaints, a comfort evaluation on a special lumbar support for driver seat has been done. Two prototypes of lumbar/sacral support have been realized: the first one was integrated into the seat and the second one was shaped as a removable pillow (removable support). Fifty participants were asked to rate the perceived comfort in lab tests performed on a seating-buck. Three tests, 5 min each, were performed in three different conditions: standard car seat, car seat with removable support, car seat with integrated support. Both subjective data (by questionnaires) and objective data (pressure at interface between backrest and driver) have been acquired and processed. Correlations between subjective and objective data have been calculated by statistical analysis and showed interesting results about comfort improvement through the adopted solutions.

Keywords: Car seat comfort, Seat design, Lumbar-sacral support, Body shaped pillow

1 Introduction

An automotive trade journal "Wards Auto" [1] estimated that the number of cars in the world surpassed 1 billion in 2010. Thus, the car is an integral part of our everyday routine. Despite of that, there are still some unsolved issues related on driving comfort, especially on car seat that represents an important factor [2,3].

Studies have been carried out to improve comfort by changing the seat pan tilt angle and the friction coefficient of the seat surface [4]; or by studying the pressure at the seat-man interface, where it had been found out there is a strong correlation between the pressure distribution and the lumbar-pelvic area pain [5].

Furthermore, a study indicated the ideal pressure distribution on the seat is the one with the minimum load in the pelvic area [6].

To study the seat's comfort, objective and a subjective method can be used. The subjective results are linked with questionnaires, such as Localized Postural Discomfort, Body Part Discomfort, CP-50 scale and so on, which differ on the scale [7]. The objective data can be gained from pressure-mat, sensors, tools and so on.

As regard as the pressure mat, information related to the seat–man interface contact, such as medium pressure contact, peak pressure, and contact area, could be sufficient for a short/medium time session analysis [8].

Moreover, De Looze [9] demonstrated that the pressure distribution is the objective measure with the most associations with the subjective evaluations.

A lacking of a lumbar support plays an important role on the global discomfort of the seat [3,10], thus a continuous contact in the lower back leads to a considerable reduction of lumbar pain [11] and to an improvement of seat comfort [12].

According to this, two lumbar supports had been realized following the comfort curve of the seat [13]: one integrated with the seat and one as a removable support.

The impact of those supports have on the driver comfort perception had been analysed and compared with the standard seat (without the support).

Since there are not substantial differences between with and without legroom in the analysis results [14], the man-seat contact had been analysed in laboratory.

This work aims to see whether the lumbar supports influence the postural comfort.

2 Materials & Methods

2.1 Realization of integrated lumbar support

Basing on the natural spine curvature while seated [13], a lumbosacral support, whose dimensions are chosen in order to involve a limited contact area with the body (i.e. a height at least equal to 200mm from the seat pan), has been modelled in the virtual environment of Rhinoceros®. The seat of the Fiat Grande Punto MY2013 was chosen as reference seat.

The curve representing the spine-shape was modelled and used for creating a solid that match perfectly the backrest.

Once obtained the virtual model, the physical model of the support was manufactured (hand made) using elastic-plastic with hysteresis foams; two types of foams, with different densities, has been chosen to achieve the desired shape: SIP 30PK and memory foam. The innermost layer was made with SIP 30 PK that has a higher density than the memory foam; memory foam was used as a surface layer for its heat-sensitive property. Indeed, the memory foam gradually deforms with the body heat, keeping this deformation in memory for a few seconds so adsorbing the gaps between the own subject's back shapes and the support itself and distributing the pressure evenly.

Foam layers were assembled by the Aquagum B/194-EC glue, applied with a catalyst by a special external mixing gun.

This foam support was split in two and integrated inside the seat-pan and the backrest of the FIAT seat (see Fig. 1), that was previously emptied for achieving an appropriate space for the pillow.

Fig. 1. Seat with integrated cushion

2.2 Realization of a removable lumbar support

In line with the aim of realizing a universal lumbar support that can be applied to any type of seat, it was decided, subsequently, to realize a removable support (Fig. 2). The dimension of the integrated model had been modified. In particular, in correspondence of the upper area, the thickness has been reduced from the initial value of 40mm to a value of 9 mm, to avoid that the passenger perceives a feeling of discomfort in that area.

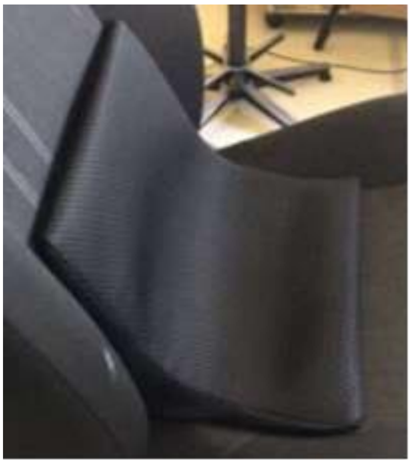

Fig. 2. Real prototype of the mobile cushion

This second support has been realized with the same sponges of the previous one and covered with DOUPLEX / 230 material (having characteristics very close to the seats' one).

2.3 Experiment set-up

The validation of the lumbar-sacral support function was obtained through a series of tests carried out in the laboratory on University of Salerno (UNISA).

Using a seating-buck system, two seats of the Fiat Grande Punto, one standard and one with the integrated support, has been placed opposite position. The seats layout and engagement system on the seating-buck metal frame allowed the longitudinal translation of the seats. The inclination between the back-pan and seat pan had been fixed at 101° for both seats [15]. The driving posture had been simulated by a built-in foot support.

Medilogic® Seat Pressure Measurement System had been used and positioned along the backrest (see Fig. 3) in order to acquire the pressure between the human back and the backrest itself.

Fig. 3. The Medilogic® Seat Pressure Measurement System placed on the seat

2.4 Participants

Fifty volunteer students, 17 females and 33 males, took part to the experiment. The 76% of them used to drive the car every day. Table 1 shows statistics about participants.

Table 1. Statistics of participants

	Range	Mean	SD
Age (years)	29÷19	23.4	2.02
Height (cm)	191÷150	173.04	9.42
Weight (kg)	90÷48.5	71.72	10.89
Body Mass Index	31.57÷17.71	23.92	2.95

2.5 Questionnaires

Questionnaires had been used to collect subjective data. Participants were asked:

- To give information about age, height and weight;
- To rate on a 10-point scale the expected comfort on the testing seat (from 1=”minimum comfort” to 10=”maximum comfort”);
- To rate on a 9-point Likert scale the body part perceived comfort after the test (from -4=”maximum discomfort” to 4=”maximum comfort”). The investigated body parts were: neck, upper back, lower back, buttock, upper tight, lower tight;
- To rate on a 10-point scale the global perceived comfort (from 1=”minimum comfort” to 10=”maximum comfort”);
- To express a comfort sensation choosing between “annoying”, “intrusive”, “cozy”, “unstable”, “no sensation”, “other”.

2.6 Protocol

Prior the experiment, participants signed an informed consent and had been instructed on how to perform the experiment.

The experiment had a total duration of 15 minutes spread over three different tests: test without support (standard seat), test with support, and test with integrated support. Each of these three tests lasted 5 minutes. For each test, the pressure has been measured through the Medilogic® System, connected to the backrest.

At the beginning of each test, once participant sat on the seat, the expected comfort has been asked and the pressure-mat system has been activated.

Then, after each test, participants have been asked to complete the questionnaire about the perceived comfort related to each specific part of the body.

After the experiment, the acquired pressure maps have been processed by Enthought Canopy software [16], a Python open access source, to obtain mean values of coordinates of the center of gravity, total load, coordinates of the involved area, total area of the mat, average pressure, number of sensors involved. Then, those data have been statistically processed by Excel routines.

3. Results & Discussions

3.1 Questionnaires

Outcomes from questionnaire results:

- The integrated lumbar support scored the higher comfort values than the standard seat: 7.18 vs 6.86 at the beginning of the tests, and 7.06 vs 6.48 at the end of the tests (Table 2).
- The removable support was the only one to score about same values of *Initial Comfort* and the final *Global Comfort* (Table 2).

- The integrated lumbar support scored highest comfort values for each body part, except for buttock where the best one was the removable support, and the upper thigh where the best one was the standard seat (Table 3). It was assumed that the removable support was more beneficial on the buttock area, while the integrated one on the lumbar area.

Table 2. Results from questionnaires – Comparison between *Initial Comfort* and *Global Comfort* rated at the end of test, where μ is mean, σ standard deviation. The rating scale was from 1=”*minimum comfort*” to 10=”*maximum comfort*”

		Initial comfort	*Global comfort*
Standard seat	μ	6.86	6.48
	σ	1.16	1.31
With removable support	μ	6.94	6.96
	σ	1.24	1.52
With integrated support	μ	7.18	7.06
	σ	1.44	1.86

Table 3. Results from questionnaires – Mean values (μ) and standard deviations (σ) of body perceived (dis)comfort. The rating scale was from -4=”maximum discomfort” to 4=”maximum comfort”

		Neck	*Upper Back*	*Lower Back*	*Buttock*	*Upper thigh*	*Lower thigh*
Standard seat	μ	1.44	1.98	1.30	2.38	2.36	1.96
	σ	1.53	1.81	2.09	1.47	1.17	1.21
With removable support	μ	1.58	2.14	2.22	2.40	2.10	2.06
	σ	1.53	1.51	1.75	1.31	1.22	1.25
With integrated support	μ	1.66	2.32	2.32	2.30	2.22	2.14
	σ	1.36	1.35	1.74	1.61	1.37	1.34

As far as the questions about the sensations, participant felt cosier with the lumbar supports than the standard seat, in which participant felt mostly no sensation in this area (Fig. 4).

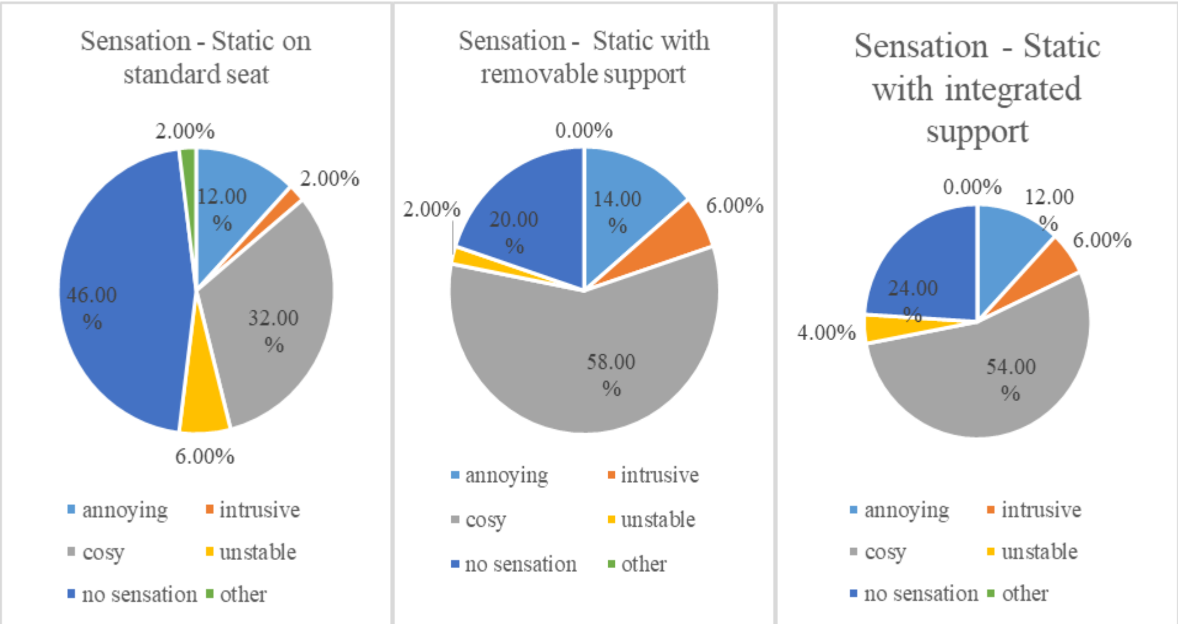

Fig. 4. Results from questionnaires – Participant sensations on lumbar-sacral area.

3.2 Pressure mat

In Table 4, there are the output values of pressure mat, used to gain the pressure distribution that can be linked with the lower-back comfort.

Table 4. Results from pressure-mat, where μ is mean, σ standard deviation

		Max Load [kN]	*Area [cm^2]*	*Mean Pressure [N/mm^2]*	*Max pressure [N/mm^2]*
Standard seat	μ	527	254	20.51	66.97
	σ	202	58	4.24	11.96
With removable support	μ	659	311	20.33	78.77
	σ	374	74	6.78	34.18
With integrated support	μ	472	272	17.08	69.58
	σ	238	78	5.22	23.59

These data show there was a bigger contact area between seat and participants in the two different solutions because they were able to lay their back entirely on the backrest.

3.3 Correlations

Analysis of Pearson correlation coefficients has been done through IBM® SPSS® Statistics. Results are shown in Table 4-5-6. Moreover, there was a negative strong correlation (p=-0.397**) between the lower back and the weight in the case of standard seat.

Table 5. Correlation between *Overall Comfort* and other parameters for each case

		Initial Comfort	***Neck***	***Upper Back***	***Lower Back***	***Buttock***	***Upper Thigh***	***Lower Thigh***
Overall comfort	*Standard seat*	0.808**	0.513**	0.510**	0.541**	0.506**	0.390*	0.282*
	With removable support	0.724**	0.405**	0.498**	0.797**	/	/	0.301*
	With integrated support	0.791**	0.387**	0.653**	0.713**	0.651**	0.555**	0.628**

Table 6. Correlation between *Mean Pressure* and other parameters for each case

		Gender	***Height***	***Weight***	***Area***	***Max Pressure***	***Total Load***
Mean pressure	*Standard seat*	0.478**	0.547**	0.369**	0.485**	0.516**	0.852**
	With removable support	/	/	/	0.656**	0.652**	0.931**
	With integrated support	/	/	/	0.368**	0.757**	0.847**

Table 7. Correlation between *Max Pressure* and other parameters for each case

		Initial Comfort	***Buttock***	***Overall Comfort***	***Area***	***Total Load***
Max pressure	*Standard seat*	/	/	/	0.545**	0.600**
	With removable support	/	/	/	0.389**	0.564**
	With integrated support	-0.372**	-0.382**	-0.519**	/	0.523**

4. Conclusions

To reduce lumbar pain, relating to a standard seat, a lumbar support had been realized. In order to verify its performance, two solutions had been tested: a seat with removable support and a seat with integrated support. Both the solutions seem actually advantageous compared to the standard seat. In particular, the integrated support increased the comfort on the lumbar zone while the removable one on the buttock area. These perceptions could be valid for a large number of people because the interviewed population that appreciated the two different new solutions belonged to a percentile bigger than the fiftieth one. Subjective data had been gathered through questionnaires, while the objective ones through the Medilogic® pressure-mat: the correlations between the comfort perception and the pressure distribution at interface gave the possibility to obtain important results. For utilizing simple instruments, this methodology can be easily replicated. Furthermore, the performed analysis is multiphysics and psychological together because the objective postural data, physical data of pressure, subjective data from the questionnaires had been acquired in different temporal moments then to use everything for a targeted planning.

Analyzing the results, it was figured out that in the standard seat the comfort decreased over time more quickly than the solutions with the lumbar support, as confirmed in literature [17]. Indeed, there was a bigger contact area between seat and participants in the two different solutions respect the standard one because they were able to lay their back entirely on the backrest. In addition, participants felt cozier on the seat with a lumbar support than the standard seat.

Moreover, some limitations of this experiment have to be acknowledged. Firstly, the seat angle had been fixed and the seat had been placed in a fixed position. Some research with different angles and regulations could be done. Secondly, there was a lack of freedom of movement during the test because the aim was to focus on the perceptions of the lumbar-sacral zone. Thus, more experiments leaving the participants free to move themselves needs to be performed, in order to be closer to reality. Finally, this work did not consider the temperature at the interface, thus more experiment could be carried on to understand the influence of the temperature in the long run contact.

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Smart Heating Panels to Increase Thermal Comfort and Efficiency

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Abstract The increasing electrification poses new challenges with respect to thermal comfort in vehicle passenger cabins. As waste heat in BEVs (battery electric vehicles) is mostly available on lower temperature levels, e.g. below 40 °C, it cannot effectively be used for heating. While conventional air heating with electric heaters is technically possible, it causes significant reductions in the electric driving range. Two contradicting objectives are to be achieved: Fast heat up to provide thermal comfort as well as high energy efficiency in order to maximize the driving range under all conditions.
This apparent area of conflict can be eased by the usage of low temperature radiation reducing the energy intensive heat up of the cabin air. In order to provide high energy efficiency, the emitted radiation should mostly be directed towards relevant body regions of the passengers, resulting in the necessity to redesign the passenger cabin. In this paper, a novel approach to redesign and optimize the dashboard as well as a resulting radiation heating system are presented. For the purpose of reducing computational effort of such an optimization, the complex three-dimensional geometry is sliced into simplified two-dimensional regions which are considered individually. The resulting heating system has been manufactured and integrated into the passenger cabin of a class A vehicle. Objective thermal comfort measurements as well as subjective comfort ratings have been conducted in order to validate the simulative approach and the resulting energy savings of approx. 30 %.

Keywords: Thermal Management, Thermal Comfort, Simulation, Comfort Measurement

1 Introduction

Currently, a trend for increasing electrification of the drivetrain, up to fully battery electric vehicles (BEVs), can be observed both in vehicle development as well as in customer demand. This trend is based on a variety of reasons. On the one hand, legislation, such as CO2 regulations, force OEMs to reduce fleet emissions to a level that can hardly be reached by conventional combustion engines alone. On the other hand, customer demand for electrified vehicles increases as well, due to ecological and economical aspects. In [1], different drivetrain concepts and their primary energy requirements have been compared for Germany. According to [1], the primary energy requirement for any other drivetrain concept would be at least 1.8 higher compared to battery electric vehicles. Additionally, the total cost of ownership for the customer can also be reduced due to the higher efficiency of the drivetrain and lower cost of electric energy, even if the initial invest for a BEV is higher, as shown in [2, 3].

Due to the lower energy density of current Li-Ion batteries compared to conventional fuels however, the vehicle range is limited and subject to significant variations, especially due to heating purposes in winter [4].

Therefore, a heating system reducing the impact on the overall the energy demand and simultaneous increasing thermal comfort is desirable.

One possibility to solve this conflict of objectives is the usage of radiative heating systems, e.g. presented in [5, 6]. Therefore, in this paper a novel approach to design such a heating system as well as experimental results on a prototypic implementation. Measurements show approx. 35% lower energy demand to reach thermal comfort for a class A vehicle.

2 Fundamentals

In conventional combustion engine vehicles, the waste heat of the combustion engine is used to heat the passenger cabin and thus heating has no impact on the energy demand [7]. While this waste heat can easily be used to heat up air, convection heating also is prone to losses by leakage or fresh air mode [8]. These losses are especially harmful in BEVs, where energy for cabin heating is provided by the traction battery and could otherwise be used for locomotion. Thus, conductive and radiative heating offer higher efficiencies as these technologies are not prone to the same losses as convective heating.

The overall energy balance for a vehicle cabin respecting convective, conductive and radiative heat flows can thus be stated as shown in equation (1), also including the metabolism M of the passengers.

$$\frac{dU}{dt} = \sum \dot{Q}_{convection} + \sum \dot{Q}_{conduction} + \sum \dot{Q}_{radiation} + M \quad (1)$$

Analogous to the passenger cabin, the occupants themselves as a thermodynamic system are exposed to convective, conductive and radiative heat transfer as given in equation (1). Therefore, in order to achieve the same thermal state in quasi-steady-state conditions with lower air temperatures, the conductive and the convective share are to be increased. The convective heat transfer is subject to the airflow, e.g. the air velocity, and the temperature differences between the passengers' surfaces (skin, clothes) and the surrounding air as shown in equation (2).

$$\dot{q}''_{convection} = \alpha \cdot (T_{air} - T_{surface}) \quad (2)$$

The usage of additional radiative heating elements has shown the possibility to significantly decrease the cabin temperature, e.g. by 3 K as shown in [9], or the velocity of the air and thus the mass flow, both resulting in a lower convective heat flux, cf. equation (2). In [6], subjective and objective studies have shown a reduction of approx. 30 % compared to the conventional electric heater.

A textile heating system is used for the study in [6] in order to improve the acoustic absorbance in the passenger cabin. While such a system can be easily applied to existing textile surfaces in the passenger cabin, a large portion of the passenger cabin has to be used to achieve the desired effect. Additionally, the conversion of an existing interior design to include surface heating elements is possible, but offers potential for improvement as shown below.

Therefore, in this paper, the authors will present a design fundamental for radiative surface heaters as well as a results from a prototypic implementation of a system based on these principals.

3 Design of Radiative Heating Panels

In order to ensure additional functionalities, e.g. window defogging or good air quality, are available, the radiative system will be used in combination with a conventional convective heating system. Due to lower thermal inertia, also the dynamic heat up process is improved.

The radiative heat flow of a gray body in general is given in equation (3), with σ as the Stefan-Boltzmann constant, the thermal emissivity ε, the area of the radiating surface A and its temperature Tsurface.

$$\dot{Q}_{radiation} = \sigma \cdot \varepsilon \cdot A \cdot T^4_{surface} \quad (3)$$

Considering two surfaces A and B, the amount of heat that is transmitted via radiation from surface A to surface B can be calculated with the corresponding view factor between these surfaces as shown in equation (4).

$$\dot{Q}_{AB} = F_{AB} \cdot \dot{Q}_A \quad (4)$$

With regard to equations (3) and (4), the net heat transfer from surface can thus be increased in several ways: Increase in emissivity, surface area (design and package restrictions), temperature (safety for touchable surfaces) and increase of the view factor for surface A to B.

An increase in emissivity can be achieved by choice of material and production process, although most plastic materials already show high emissivity, thus only offering minor potential of improvement. The surface area can be increased, but has to fulfill safety (visibility) and package constrictions and will be part of the design process. While an increase in temperature shows high potential (cf. equation (3)), it is restricted to safety reasons, e.g. based on [10]. Especially the view factor is important to consider as it describes the portion of heat that is emitted towards the target surface as shown in Figure 1 and thus increasing the efficiency.

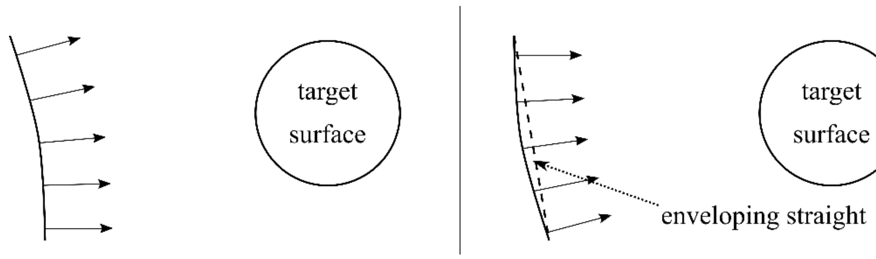

Fig. 1. Representation of convex and concave emitting surfaces.

As can be seen in Figure 1, concave surfaces offer the possibility to increase the view factor. Additionally, the view factor for the original surface (black line) and the enveloping straight result in the same view factor towards the target surface. This relation reduces the number of iterations in search for an efficient panel orientation and position, as only enveloping straights have to be considered. For the design process, a set of parameters describing the possible heating panel positions and orientations as well as feasible target surfaces have to be identified. While the former is mainly based on available surfaces and functional integration, the latter is based on a thermal comfort model with local resolution, [11]. In order to achieve a high impact via the radiative heating panels and allow for a reduction of the air temperature, target surfaces are defined on body parts sensitive for warm sensation. The areas for this study are based on the thermal comfort model in [11] and are listed in Table 1.

Table 1. Body parts selected as target surfaces.

selected body segments
head
neck
chest
upper arms
forearms
lower legs
feet

In order to reduce the degrees of freedom and parameters for a three-dimensional design, a series of principal design studies is conducted in two-dimensional planes. Figure 2 shows an example of such a design plane as a slice from a three-dimensional interior model. Panel enveloping straights, which can be manipulated in position, size and orientation, are depicted in red, a target surface for the head and shoulder region is depicted as well.

STAR-CCM+ and Optimate are used to investigate the potential heating panel designs and calculate the resulting view factors. In a finale step, the best results from the two-dimensional considerations are combined to a three-dimensional design, which can then be further detailed, e.g. as a concave surface to increase the emitting area. This design process has been used in the OPTEMUS project, results of which will be presented in the following.

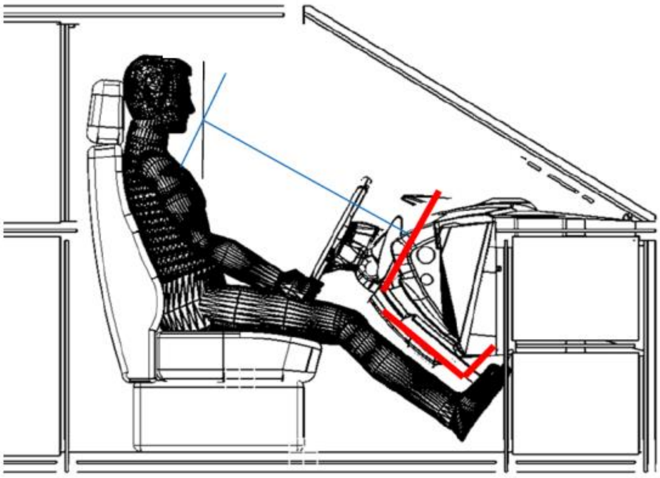

Fig. 2. Two-dimensional design space with panel enveloping straights (red) and target surface.

4 Radiative Heating Panels in OPTEMUS

The OPTEMUS (Optimised energy management and use) aims at increasing the electric range for a class A vehicle, amongst others by the use of electrical surface heating panels. Figure 2 shows the base areas, which have been considered for heating panel integration, and relevant areas for head impact. Especially the dashboard area on the passenger side is relevant for head impact investigations as shown in [12].

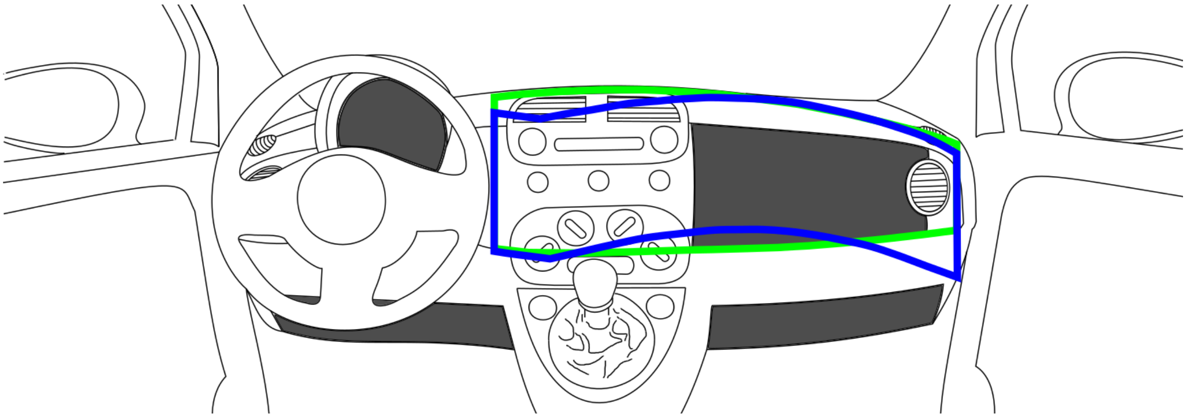

Fig. 3. Base areas for the OPTEMUS project (dark grey) and areas relevant for head impact (green: FVMSS-201, blue: ECE-R21) in a Fiat 500.

The process as described in chapter 3 has been used in order to design a radiative heating system for a Fiat 500, which simultaneously increases efficiency while heating the cabin and reduces the amount of time needed to reach acceptable thermal comfort based on the Predicted Mean Vote (PMV = 0). This newly designed radiative heating system has been implemented in a Fiat 500 alongside the convective heating system ("combined system") and compared to a conventional convective heating system ("conventional system"), both in objective as well as subjective testing. The goal of these measurements is to replicate the measured comfort of the conventional system with the combined system, while measuring the energy demand for the heating system.

Table 2 shows the boundary conditions for these measurements. Objective comfort measurements have been used to achieve a similar behavior of the combined system compared to the conventional system. Additional information regarding the measurement setup is given in [12].

Table 2. Boundary conditions for comparison between conventional and combined heating system.

parameter	*conventional*	*combined*
ambient temperature	-10 °C	
power level surface heating (0 to 5)	0	5
blower level (0 to 5)	4	3
position air flap	100 % ambient air	
air distribution		

The measured comfort is depicted in Figure 4 (thick graphs). Since the PMV scale is limited to the range of -3 to 3, the measured comfort only increases after approx. 15 minutes, with a 3 minute benefit for the combined system. Afterwards, the combined system also shows a steeper comfort slope, increasing the temporal advantage of the combined system compared to the conventional system.

Subjective ratings are conducted for this setup as well. The offset to the measurements is noticeable, especially as the ratings start higher than the scales lower limit. This is to be explained by the expectance of worsening conditions and the tendency to avoid extreme ratings. The graphs are thus shifted compared to the measured thermal comfort. Additionally, as the PMV is by definition limited to quasi-stationary and uniform conditions, but widely used in the automotive industry (cf. [8]), thus damping the comfort measurements responses compared to the subjective ratings.

Nevertheless, the subjective ratings show a clear advantage of the combined system at approx. 5 to 10 minutes, as the radiative heat transfer with its lower thermal inertia already significantly heats the passengers and increases the comfort ratings by one unit, from “cool” to “slightly cool”.

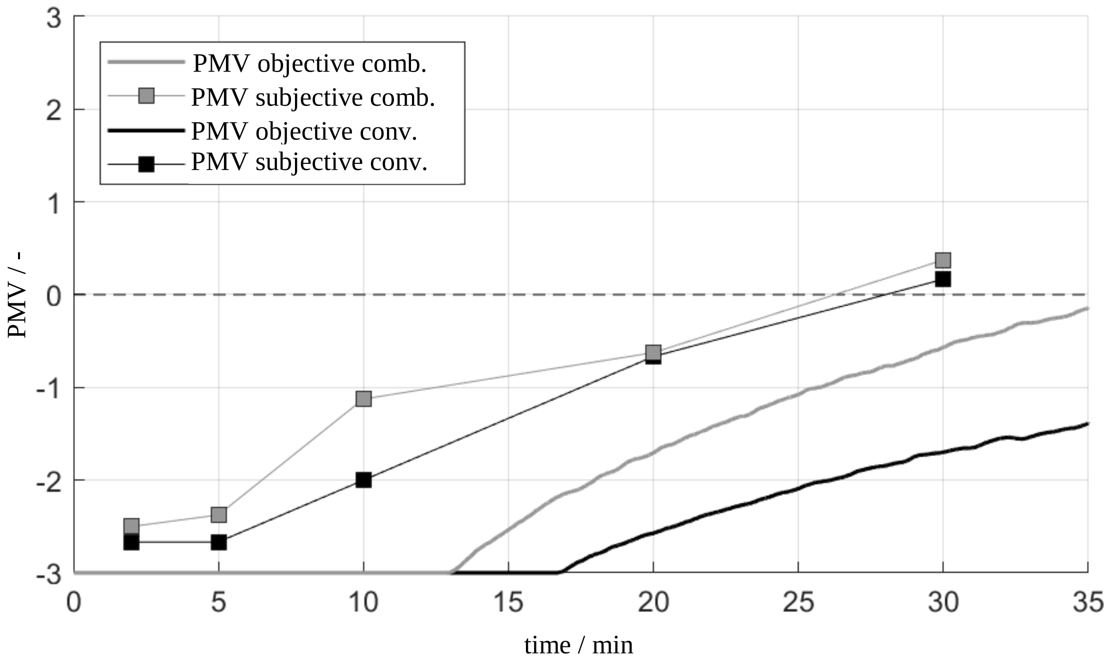

Fig. 4. Subjective ratings and objective measurements for the combined system (grey) and the convective system (black).

Additionally, the combined system shows an increased energy efficiency and performance (cf. Table 3), showing the reduced energy demand at increased comfort.

Table 3. Energy demand and time to comfort.

parameter	*conventional*	*combined*	*reduction*
energy demand to reach comfort (PMV = 0)	~ 6.3 kWh	~ 4.2 kWh	~ 33 %
time to reach comfort (PMV = 0)	~ 54 min	~44 min	~ 18.5 %

5 Conclusion

In this paper, a design process for a supplementary radiative heating system and results from measurement for such a combined convective and radiative system. The design process is based on the radiative heat transfer fundamentals and is thus applicable to a variety of applications. Additionally, by the reduction to two-dimensional considerations, the number of considered designs can be increased significantly, allowing the integration of the heating surfaces into the design of the vehicle cabin at a later stage.

Such a heating system has been designed for a class A vehicle at ika, showing promising results both in objective measurements as well as subjective ratings. Both subjective and objective comfort assessments show a faster response for the combination of radiative and convective systems with a significant reduction of the energy demand to reach comfort (approx. 33 %), resulting in an increased electrical range of the vehicle.

Acknowledgments The research work reported here was made possible by the post graduate program "Integrated Energy Supply Modules for Roadbound E-Mobility" by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – GRK 1856 and the Horizon 2020 project "OPTEMUS".

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Towards an adjustable aircraft seat pan creating comfort for small and tall persons

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Abstract When designing a comfortable aircraft seat a large variety of occupants must be considered. Also, variation of posture is seen as an important factor for creating comfort, and the question is how to translate that in a seat design. Past studies show that, for a comfortable position in an SUV and sedan seat, most of the pressure (50-60% of the total body weight) should be under the posterior one third of the contact area between seat and human, along with 20% in the middle and 10% in the anterior part. Other studies show that a large contact area between human and seat is preferable. It is not simple to design a seat facilitating variation of posture, creating an ideal pressure distribution and large contact area for a large variation in human sizes. For instance, having short lower legs increases the pressure in the front of the seat and having short or long upper legs might reduce the contact area. To overcome these problems in this project an aircraft seat pan was developed that was able to adjust both the height of the front of the seat pan and the length of the seat pan. The question was if this is technically feasible without adding too much weight. Therefore, a project was started to develop and design a mechanism that could be implemented into an aircraft seat. In this paper the background for the development of this seat is described and an evaluation was done technically to see if further technical improvements are needed and some people used the seat to have a first impression on the users' opinion. The first impressions are promising, but a lot has to be done also on the usability of the controls and further development is suggested.

Keywords: Aircraft seat, comfort, adjustable, technical feasibility

1 Introduction

There are many requirements for aircraft seats (Vink & Brauer, 2011). The seats should be lightweight, comfortable, reliable, maintenance costs should be low and seats should facilitate as many passengers as possible. Additionally, to increase revenue maximising the amount of seats in an airplane is a requirement as well. Airlines can in principle increase their profit margin by reducing maintenance costs. However, according to Brauer (2004), at a typical airline a 14% reduction in maintenance costs will result in only a 1 percentage point improvement in the airline's profit margin, while a passenger revenue increase of only 1% has the same result. To increase passenger revenue, we need to understand the flight selection behaviour of passengers. According to Brauer (2004) most passengers first select the most convenient route and departure time at the best price. In those cases in which the passenger is indifferent between equally convenient flights at a similar price, other aspects break the tie. These other aspects include comfort, service, the airline's reputation for on-time performance, and marketing programs such as frequent flyer programmes. For short distances on-time performance is more important and for long haul flights the comfort and service aspects play the most important roles. Under the foregoing flight selection paradigm, individual passengers never make a choice to pay more for more comfort. However, Vink et al. (2012) show that comfort has a high correlation with ‘fly again with the same airline’.

There are many complaints on leg room on the internet (Bouwens, 2018) in the current economy class seats, but also in the seats of 2011 (Vink et al., 2012). However, on average the seats of 2011 score better in comfort than the seats of airplanes 10-20 years ago (Vink et al., 2012). One of the challenges in designing an aircraft seat is that a large variation of people uses the seats. Molenbroek et al. (2017) showed that in measuring the anthropometrics relevant for seating of 346 persons that there is a large variation in buttock-popliteal depths (length of upper leg sitting between knee cavity and back of the buttock). The p5 female buttock-popliteal depth in 2014 was 449 mm while the p95 male had a depth of 558 mm. This was not significantly different from the recordings in 1986, which means that changes in time in these values probably go slow. So, ideally, the seat pan length should vary between 449 and 558 mm. The popliteal height sitting in the study of Molenbroek et al. (2017) varies between 406 and 544 mm for p5 female band p95 male in 2014 respectively, which could mean that about 14 cm difference in seatpan height is needed. However, in this case less dispersion is needed as longer persons can sit on a lower seat by stretching their legs. Also, 3d scans of subjects in an aircraft seat made by Hiemstra-van Mastrigt (2015) show a large variation in the form of the area touching the seat pan, especially in the area close to the knees (see fig. 1).

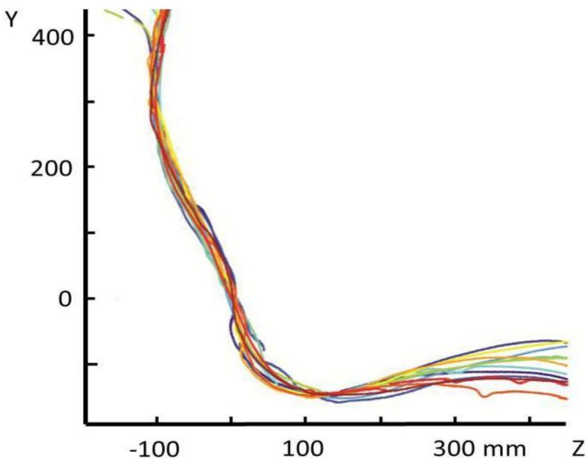

Fig.1. A cross-section of the contact area between seat and human in which the different 3d-scans are rotated and translated to create as much overap as possible between the different subjects (Hiemstra-van Mastrigt, 2015).

Supporting the area close to the knees is complex. First of all, there is the difference in sizes recorded by anthropometrics and 3d-scans. Secondly, there is the characteristic of the human body that influences the design of a seat close to the knee area. Vink & Lips (2016) studied the sensitivity of the back and buttocks with a view to choosing the best foam softness for different parts of the seat, and to define areas where a more flexible shell is needed. To this end, a special seat was made by Vink & Lips (2016) with 32 holes and a device with a round surface recording force was placed in the holes and pushed until the occupant stated that they were no longer comfortable. Sensitivity readings for 23 subjects were recorded (8 females and 15 males; 19-54 years old). Results from this sensitivity study are summarised in figure 2. Results indicated that the area of the human body in contact with the front of the seat pan is more sensitive – a conclusion that corresponds with the findings of Zenk et al. (2012), Mergl et al. (2005) and Hartung (2006), who state that the pressure in this area should be around 6% of the total pressure on the seat. Both increases and reductions in pressure result in more discomfort. Zenk et al. (2012) arrived at the ideal pressure distribution map for a BMW 7-series based on years of research with TU Munich and BMW (e.g. Hartung, 2006). A short-term test involving 84 subjects showed lower discomfort ratings in the ‘ideal distribution’. In a long-term test, eight participants drove three hours in their own preferred position and in a position derived from to the ideal pressure distribution. Results showed that the latter position produced significantly lower discomfort values. Results of a recent study by

Kilincsoy (2019) show that the ideal pressure distributions of both sedan and SUV passenger seats are close to these values. Companies designing seats can use these values to validate their seat designs. Both studies indicate that areas more posterior in the seat have greater pressure. The area around the tuberositas ischiadicus can bear up to 50-65% of the load and the load at the front of the seat should be around 6% of the total load.

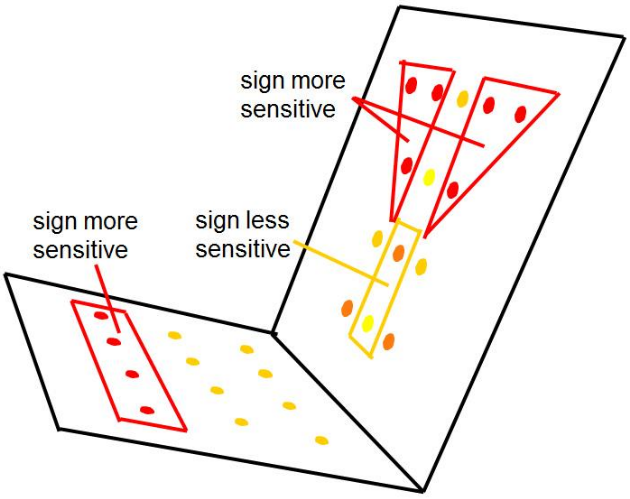

Fig.2. Areas with significantly different sensitivities (Vink & Lips, 2017).

An additional requirement for seats is that variation of posture should be stimulated. growing number of scientists in the field of musculoskeletal injuries are of the opinion that it is more important to vary posture (and avoid the static postures) than to design seating for the ideal posture (e.g. Lueder, 2004). It is not always easy to stimulate variations in posture. In office seats, variation is enabled via variations in tasks and having a movable seat pan and backrest (e.g. Ellegast et al. 2012). For many vehicles, however, this is not possible. Posture variation might be less important for short travel distances, but for larger distances it is certainly important in order to prevent discomfort and deep vein thrombosis. Hu et al. (2003) state that every two hours sitting time increases the risk of obesity by 5% and the risk of diabetes by 7% in female workers. The catchphrase du jour that ‘sitting is the new smoking’ is perhaps overstating it. However, there is a weight of literature showing that there are health risks attached to sitting in restricted postures. While alternating sitting with other activities is better for our health, small changes in the seat can also have positive effects.

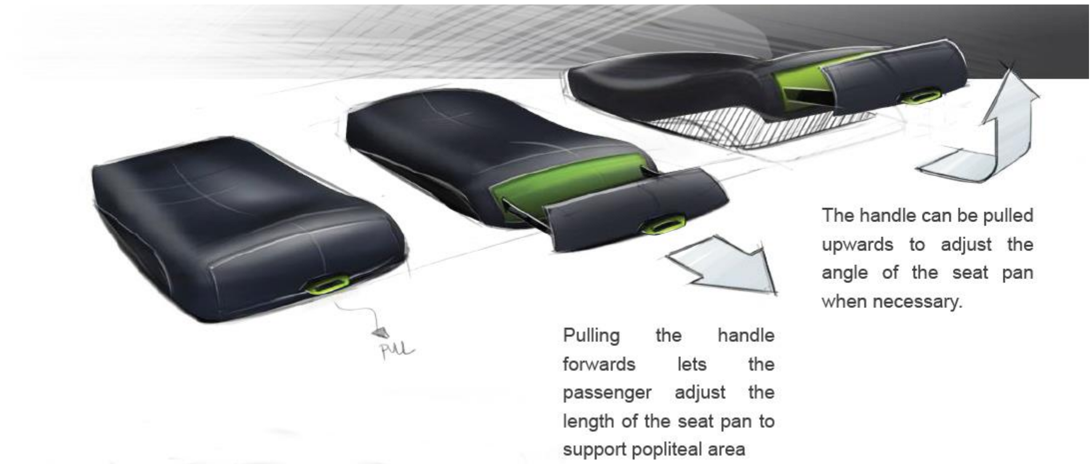

Fig.3. Rough design and working principle of the adjustable seat pan.

2 The design

So, it is not simple to design a seat facilitating variation of posture, creating an ideal pressure distribution and a large contact area for a large variation in human sizes. For instance, having short lower legs increases the pressure in the front of the seat and having short or long upper legs might reduce the contact area. To overcome these problems in this project an aircraft seat pan was developed that was able to adjust both the height of the front of the seat pan and the length of the seat pan. The question was if this is technically feasible without adding too much weight. Therefore, a project was started to develop and design a seat pan. After various brainstorms, idea sketches a decision was made on the design (see fig. 3). However, the technical feasibility and detailed design still had to be done. Detailed design was made of the frame, the frame adjustment system, the control mechanism, the locking mechanism, the bullnose and seating content (e.g. foam). A light weight and stiff carbon fibre composite seat frame forms the base of the seat, which is mounted from its rear end to the backrest mount. The seat pan can also articulate in combination with a suitable backrest adjustment mechanism if the seat structure allows for this function. A suspension fabric stretched over the frame forms the sitting plane. Therefore no additional weight is needed for components such as springs and attachment clips. A part of the mechanism is shown in figure 4 and 5.

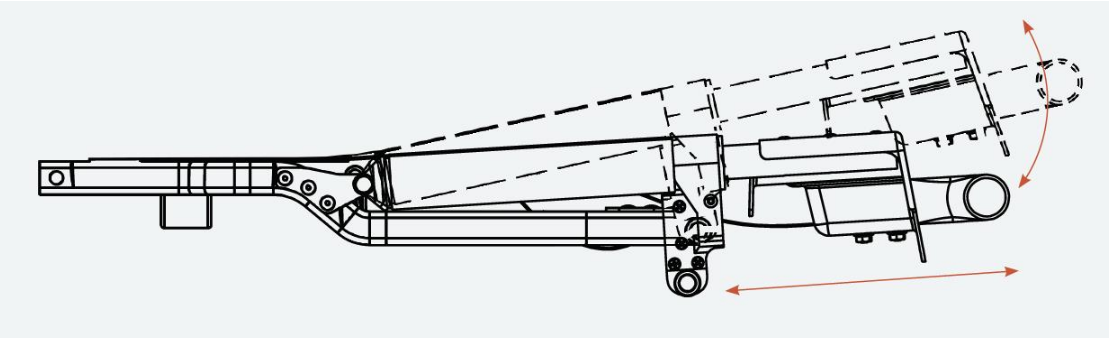

Fig.4. Elements of the structure of the adjustable seat pan.

Fig.5. The basic structure of the seat pan developed in this project.

Fig.6. One of the two protypes that can operate the way the envisioned product should work and tested at the AIX trade fair.

3 Evaluation

Two working prototypes were made (see fig. 6) and presented at the AIX in Hamburg. Visitors at the EXPO were asked to take a seat and adjust the seat pan in length and height and impressions from the visitors were noted. Additionally, the technical side is evaluated as well and a list of further ti study technical aspects was made. Apart from the aircraft seat certification, several tests still have to be done, like the strengthof the various parts, the maintainability and how many cycles it will hold. Also, due to the short time frame of the project (6 months), design developments of several parts with the longest lead time had to be frozen in order to start production. For example, the most important part included the carbon fibre seat pan frame to which other parts had to be attached. This part took a long time to develop, but also took quite some time to produce as it was produced in the Aeroworks facility in Thailand. So when other parts or subassemblies were already manufactured and assembled, the overall assembly process had to wait until the main seat frame arrived from Thailand. Other parts, such as the telescopic mechanisms were purchased and tested. However, by the time all the parts had arrived, several design flaws had been detected and it was be too late to re-order or re-manufacture the parts that caused functional problems. Nevertheless, the system worked and people were able to sit on it and the system looks promising despite the technical work that still has to be done.

During the testing of the seat at the AIX in Hamburg, several design concerns were confirmed by participants of the test. For example, having a handle in the middle of the seat may not work well for women who happen to wear a long dress or skirt. Many participants had trouble understanding how the raising and lowering mechanism functioned. As pulling the handle would disengage the locking mechanism, the user would have to tense their body to lift up their legs prior to raising the nose of the seat pan. In observing participants trying to figure out how the seat worked unnatural behaviour was seen according to the observers. Participants for instance overstrained the handle mechanism which resulted in several components of the prototype to fall apart. It was easy to fix, but in indicates that the adjustment and handle mechanism is far from optimal. Feedback provided by every participant with various body dimensions showed that individual adjustment per body type and the ability of supporting the popliteal area proves to be a highly pleasant and was experienced as comfortable. Everyone (appr 20 participants) who had the chance to sit in the seat believed it to be a valuable addition to current economy class seats. Other feedback gained from industry experts revealed that simple icons or use cues that would clarify how the handle should work would result in less confusion.

4 Conclusion

Variation in anthropometry and sensitivity of the human legs and buttock ask for a special aircraft seat design. In this project an attempt was made to design a mechanism making many people fit in a seat in a comfortable way and making variation of the posture possible. After half a year of working, a promising direction for a solution was made. End users see and feel the benefits. However, in the technology improvements have to made and also the control needs further improvement.

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The Visual Categorization of Production Automotive Seats on Descriptors of Comfort by End Users

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Abstract The seat is the largest significant point of interaction with any vehicle (1), which plays an important role in the overall impression and appeal of that particular vehicle (2) . The concept of automotive seat comfort is regarded a highly subjective and multi-faceted phenomenon where comfort assessment is generally held with different tools and scales with increasing effort to quantify the feelings and impressions associated with the whole experience. Erol (3) conducted a study to identify and analyze how the end users constructed the "holistic automotive seat comfort experience" which indicated that certain descriptors and category labels reflected certain visual and physical attributes as design cues forming the basis and the rationale for the descriptors utilized. In this respect, the main aim of this study was to explore the effects of the appearance of automotive seats, based on the hypothesis that visual design differentiations are affective in creating comfort expectations. This in return was expected to lead to a taxonomy of features and provide an understanding of the effects of attributes on comfort perception. The pre-determined descriptors of assessment for automotive seats were identified from the visual impression descriptors and also literature as *Sporty*, *Luxurious* and *Comfortable* (2, 4, 5). The particular inter-relationships between the descriptors were also of interest. A spectrum of 38 automotive seat designs were utilized from a manufacturer's (OEM) website. A sample of 24 people (equal gender split, mean age = 35.5, SD=11.4) took part in the study where an image-based card sorting app (6) was utilized. The resulting data was analyzed with hierarchical clustering analysis (HCA) and non-parametric tests. The results indicated that the perceived sportiness, comfort and luxury were significant descriptor items in visually differentiating seats with certain design attributes. A striking finding was that for *Sporty* perception, both in HCA and graph plots based on the mean value ratings, two major clusters formed where the design stimuli displayed a "discontinuity" for the seats having integrated triangular headrests forming angular shapes. On the other hand *Comfortable* perception was more readily associated with separate headrest design and rounded seat back/cushion shapes.

Keywords: Automotive, Seat, Comfort Experience, Visual impression, Attribute mapping

1 Introduction

Automotive seat comfort is a key topic for all car manufacturers when designing upcoming models. Providing optimal comfort attributes if not superior ones that support both the psychological and physiological comfort experience as a whole is the utmost goal of the new seat designs. The comfort literature adopted approaches to quantify the comfort perception and expanded on various models describing the underlying factors and mechanisms that exists for seating comfort (7, 8). A recent model by Vink and Hallbeck (9) specifically defines and denotes different underlying mechanisms leading to outcomes of discomfort or comfort or both in relation to various conducted studies in literature. Van Veen & Vink (10) extended this comfort model for additional tactile and sensory experiences as a pre-condition that influence comfort expectations of the user regarding the automotive seats. It was deduced that physical interaction with a different product will influence the evaluation of an automotive seat in terms of the sensation of tactility properties. However as the study was conducted with draped seats, the visual properties and how it affected the expectations were not investigated. Erol (3) conducted a study to identify and analyze how the "holistic automotive seat comfort experience" was constructed retrospectively by the consumers. The results revealed three major dimensions: *Visual Impression & Aesthetical Appearance Design, Safety & Design Functionality and Feelings & Well-being*. In relation to the product design literature, these dimensions were consistent with think-feel type of products where Creusen argued that "think" and "feel" dimensions regarding the information processing of products were independent of each other (11). The "think dimension" relied on functional properties and "feel dimension" on emotions and self-expression attributes. Focusing on the aesthetical appearance design, the descriptors and the categorizations reflected certain physical features of automotive car seat as design cues and the product appearance roles (6) formed the basis of the rationale for the descriptors. Moreover, luxury, plush, sleek, elegant, sporty and other various descriptors (attributes) were found to play a vital role in the holistic perception of perceived comfort in automotive seats which were classified under the visual impressions dimension.

Pinkelman (5) hypothesized a consumer utility model of "comfort characteristics for automotive seats", where he argued that comfort/discomfort, sporty and luxurious were the three key variables to characterize any car seat for "comfort characteristics". The hypothetical assumptions relied on J.D. Power and Associates APEAL survey data where the study falls short of verifying the proposed variables with empirical data. Kamp (10) utilized the assessment items were comfortable, protected, relaxed, sporty and luxurious for three automotive seats adopted from a prior study by Zenk et al. (1) in order to assess the significance of relationships of seats' physical features(e.g. width, steepness of side wings, contour etc.). It was reported that the seat designs were significantly differentiated on luxurious and sporty feelings where the variable comfortable was not found to be significant. This led to the conclusion that only sporty and luxurious seat have specific design characteristics that are recognizable by the participants (10). One major limitation of the study was that the relationships between the significant variables and how it affected comfort were not investigated whereby the seats were also not subjected to visual assessment regarding the variables. However, the findings can be partially supported by the fact that in the Erol (3) study "Luxurious" and "Sporty" variables were also observed where they were mostly used by male participants for describing the visual attributes of comfort of automotive seats. In order to investigate and to identify the visual features (the tangible elements) that prompt these experiences, a number (or a family) of production seat designs are necessary with incremental variances in the designs (12) . Moreover the selection of the particular variables (or dimensions) that the products evaluated are crucial for extracting the value of the particular attributes.

Therefore there aim of this study is twofold;

1) To explore the effects of the appearance of automotive seats on expected comfort based on the hypothesis that design differentiations lead to a taxonomy of perceptual attributes assessed. This in return is expected to provide an understanding which attributes are affective in creating comfort expectations. The pre-determined variables of assessment for automotive seats were identified from literature and from the visual impression descriptors as *Sporty*, *Luxurious* and *Comfortable* (2, 4, 5).

2) To enhance the understanding if the proposed comfort characteristics variables of "automotive seats" are truly determinants in relation to the visual design of the seats. Moreover the particular relationships between the three proposed variables are of interest.

2 Methods

An extensive family of automotive seat pictures have been adopted from the AUDI AG (13) website for every model on offer, with approval of AUDI AG Medienzentrale. The rationale behind the selection was the amount of variance in seat shapes within the family of seats for every car segment of the AUDI range provided a good source for the relative assessment in scope of this study, from SUV to passenger car seats i.e. A1, A3, A4, A5, A6, A7, A8, Q3, Q5, Q7, TT, R8. For each of the car segments AUDI offers a “normal” (alternatively referred to as standard) seat, a “comfort” seat and a “sport” seat type, where for certain sports car segments “shell” seats (or alternatively bucket seats) are also offered. These seat renderings are available as 3D renderings of the designs in monochrome colors (see figure 1). For this study the 38 monochrome car seat pictures for sorting was utilized from the manufacturers site (See appendix figure A.2.), which were all commercially available real physical seats on the market at the time.

Figure 1. Four of the 38 AUDI seat designs for performance cars, “Sport” to “Shell/Bucket seat” types offered on the AUDI AG website in 2016.

The 38 seat design utilized in this study had consistent features and functional parts throughout the sample of production automotive seats (i.e. trenches, tie-down lines, seat inserts, seat back and seat cushion side bolsters) and were in accordance with the generic automotive seat designs as depicted in SAE Standard J2732 2008 “Motor Vehicle Seat Dimensions Standard” (14) (see appendix figure A.1.).

2.1 Methods: Participants, Data Collection Tools and Procedure

A sample of 24 people (equal gender split, mean age = 35,5, min=20, max=59, SD=11.4) partook in the study and were all university students and staff. Participants had at least 3 years driving experience. The participants were asked to utilize an image-based card sorting app “qCard Sorting” (6) , where they distributed and rated the set of seat images in to 9 groups e.g. least sporty: = 1 to most sporty: =9. The first sort allows the distribution in to 3 major groups then it is followed by a sort in to 9-groups where methodology was inspired by divide-and-conquer sorting algorithm (see figure 2) (15) .The seat designs were displayed in identical dimensions on the iPad app.

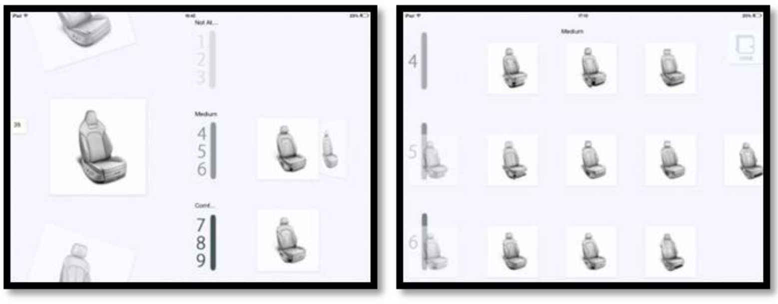

Figure 2. Typical subsequent scroll screenshots of the iPad app for sorting phase (on the left) final phase after sorting and fine tuning between categories (on the right).

Each of the three variables is entered on the semantic scale each time on the iPad app for every sorting task in a randomized manner. This was a within-subject design where all the participants were instructed to sort the images for all the variables in to the categories acting as scales from 1-9 and be mindful that it is also a rating sort (see figure 2 above). The application finally allowed the participants to see the rating at the end of each sort by scrolling on the whole range where it enables a final review and fine tune on sorting results. The participants on purpose were not informed of the particular brand and real life size of the seats. There was no limitation on sorting time. Following the sorting task, a post-trial interview was conducted to obtain participants qualitative comments regarding the seat designs and the sorting task.

3 Analysis and Results

The data has been analyzed with standard non-parametric tests and Hierarchical Clustering Analysis (HCA) which forms clusters of seats with respect to the rating scales used in the study (16). The HCA used "average linkage" algorithm which tends to produce clusters based on measured characteristics with rather low within-cluster variance (17).The resulting "dendogram" produces a tree of hierarchy, where the shorter linkage distance (the lines in terms of distance displayed) from the origin indicate the similarity of the objects. Following the clustering, the mean rating values for each individual seat design on the descriptors e.g. *Sporty* vs *Luxurious,* was utilized to display the design differentiation effect of the 38 seats utilized based on attributes (16).

3.1 Analysis for individual car seat designs

The mean values with regards to the three variables provide an insight of the effect of the particular attributes and their effects on the perception for each seat design. In this study, the seat image sizes were kept constant, in order to provide a cross examination of all the seat designs used.
The *Sporty* rating mean values by the participants' displayed the lowest standard deviations, which indicate that the 24 participant's perceptions were more homogenous on this variable. The distribution of the C*omfortable* and *Luxurious* variables displayed a larger spread with higher SD in the ratings indicating that there were higher variances in the categorization process.

The bucket/shell type seats had the highest *Sporty* mean ratings where the *R8 Shell seat* had the highest rating (mean=8.46, SD=1.67). The *A3 Normal (alternatively referred to as standard) seat* had the lowest rating (mean=2.17, SD=1.5) (see figure 3).

Figure 3. *R8 shell seat* (on the left hand side) had the highest *Sporty* mean rating. The *A3 Normal seat* was the lowest mean rating (in the middle) and closely followed by the *A8 Normal seat* (the right hand side)

The overall rating for seats for the *Comfortable* sort having the highest comfort mean rating was *A4 Sport seat* had the highest ratings (mean=6.54, SD=2.14). The *Q5 Normal seat* had the lowest ratings (mean= 3.13, SD=1.8) (see figure 4).

Figure 4. *A4 Sport seat* had the highest *Comfortable* mean rating (on the left hand side). The *Q5 Normal seat* has the lowest mean rating (on the right hand side)

For the overall mean ratings in the *Luxurious* dimension, having the highest luxurious mean rating was *A8 Sport seat* (mean=6.50, SD=2.4) where The *Q5 Normal seat* was the lowest (mean=2.96, SD=2.2)(see figure 5).

Figure 5. *A8 Sport seat* has the highest *Luxurious* mean rating (on the left hand side). The *Q5 Normal seat* has the lowest *Luxurious* mean rating (on the right hand side)

Non parametric tests were used for the statistical analysis. Friedman (two way) tests were significant across the 38 seat designs on all the three variables. For *Sporty* ($\chi 2$=630.6, N=24, df =37, p< .001), the pairwise comparisons yielded significant differences. The 14 sport category seats were found significantly sportier than *A8 Normal seat* and *Q5 Comfort seat*. Moreover the *A7 S Sport seat, A8 Sport seat, A1 Sport seat, TT Sport seat, R8 Sport seat, A3 Sport seat* were also found significantly more *Sporty* than *Q5 Normal seat*; see appendix for each design (p< .05,Bonferroni correction applied). For *Comfortable* ($\chi 2$=131.9, N=24, df =37, p< .001) pairwise comparison tests yielded that *A7 Comfort seat, A8 Sport seat, A6 Comfort seat, A5 S Comfort seat, A5 Sport seat and A4 Sport seat* were significantly found more *Comfortable* than *Q5 Comfort seat and Q5 Normal seat* (p< .05,Bonferroni correction applied). For *Luxurious* ($\chi 2$=155.5, N=24, df =37, p< .001) *Q5 Normal and A6 Normal seat* were found significantly less *Luxurious* than 6 type of seats; *A5 S Sport seat, A5 S Comfort seat A6 S Sport seat, A7 S Sport seat, TT S Sport seat, A8 Sport seat, A3 S Sport seat*; see appendix for each design (p< .05, Bonferroni correction applied).

3.2 Hierarchical Cluster Analysis (HCA)

The aim of HCA is to link more and more objects together and *amalgamate* larger clusters of increasingly dissimilar elements. The dendogram tree structures generated by the HCA procedure in figure 6, display the particular grouping of the seat designs. At the cut off distance of 10, the distinct two separate groups in *Sporty* can be observed. Amongst the three variables, *Sporty* variable can be attributed as the most coherent within subjects in terms of the distance generated. The categorization effects are concurrent within the participants with respect to the mean values and SD values of the sportiness ratings (see figure 6). The particular group of seats which from the upper cluster group 1(**box 1**) of *Sporty* including the shell seat type have the highest sportiness mean rating of *R8 Shell seat* (mean=8.46, SD=1.67) where the lowest is of the *TT Sport* seat with a mean value of 6.87 (SD=1.42). These formed typically the sport seats typology of design characteristics.

Cluster group 1 for the lowest *Sporty* perception encompasses the *A8 Sport seat* (mean= 5.13, SD=2.07) which has the only separate headrest in the 14 sport seats within the group. The bottom larger cluster **box 2** for the *Sporty* dendogram, the box includes the *A3 Normal seat* (see figure 3) as the lowest for sportiness with a mean value of 2.17 (SD=1.5), and has the highest scoring member as the *A5/S5 Comfort seat* (mean=4.20, SD=1.82) displayed in figure 4.

Kendall's W known as Kendall's coefficient of concordance is a non-parametric statistic and can be used for assessing agreement among raters'. Kendall's W ranges from 0 (no agreement) to 1 (complete agreement). The agreement among raters' for *Sporty* displayed a good level of agreement (Kendall's W = 0.71 ,p<.0001; SPSS 25).

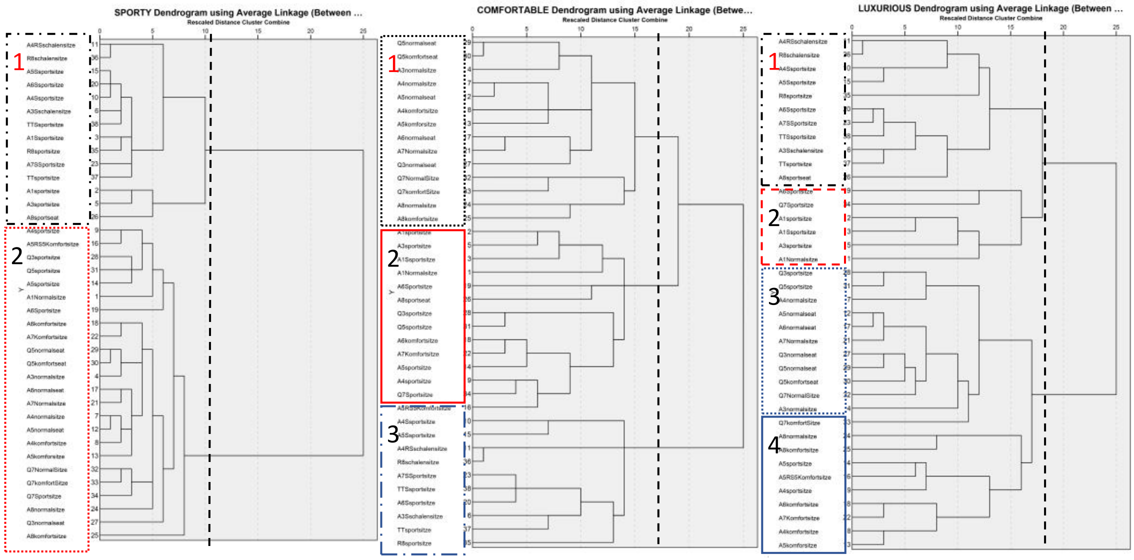

Figure 6. HCA dendogram for the variable *Sporty* (left), *Comfortable* (middle) *and Luxurious* (right) with average linkage

In terms of the *Comfortable* variable, there were three distinct clusters at a cut off distance of 16. The first two clusters that displayed rounded back rest shapes displayed higher similarity (as of branch distance) where the third cluster (**box 3)** displaying integrated headrest mostly had increasing levels of dissimilarity. The third group belong to the manufacturers' sporty characteristics marketing segment and encompasses the *R8 Shell-bucket seat* and *A4/S4 Shell-bucket seat*. Specifically this group holds the same characteristics form the sporty sorting exercise which have integrated headrests and appear to have prominent shoulder supports. The first cluster (**box 1**) shows characteristics of the manufacturer's "normal"(standard) seats which have majorly a single rounded piece backrest where the segmentation of the back rest cushion is limited, and there are lesser partitions on the cushion surfaces and trenches. In comparison, the following cluster (**box 2**) having higher average comfort ratings for the designs, more prominent features of side supporting bolsters on the seat back and more partitioned shoulder supports which also belong to the manufacturers, "comfort" seats and "sport seat" category. In accordance with the larger distances observed in the *Comfortable* dendogram, the agreement among raters' for *Comfortable* displayed a poor level of agreement (Kendall's W = 0.149, p<.0001; SPSS 25). The statistics for the *Comfortable* dimension suggest that most of the seat comfort perceptions can be within 2 or more rating categories (for each seat as the SD values in the vicinity of 2 for each rating). This also confirms that the comfort perception has more variance within the participants in contrast to *"Sporty"* dimension and is very much subjective.

Luxurious displayed four clusters as displayed in figure 6 at a cut off value of 16. The first seat cluster (**box 1**) has particularly dominant features of integrated headrests and shoulder supports where the quilt patterns on certain seats have formed a finer second cluster. Specifically this cluster has the highest mean rating values. The bottom cluster (**box 4**) also has higher mean rating values where similar seat back insert patterns can be observed with more pronounced rounded back bolster shapes. The agreement among raters' for *Luxurious* again displayed a poor level of agreement (Kendall's W = 0.175, p<.0001; SPSS 25).

3.3 Plot graphs mapping visual attributes and linear regression

In order to analyze further the relationships amongst the three dimensions proposed, the results were plotted against each on a *Comfortable* vs *Sporty* regarding the mean rating values, explicitly plotting the seats on a coordinate basis. The plot maps plotted in excel with the mean values for each of the 38 seats in the categorization task has yielded certain tendencies and clusters of seat in terms of the proposed 2 axes and evidently explaining the relationships.

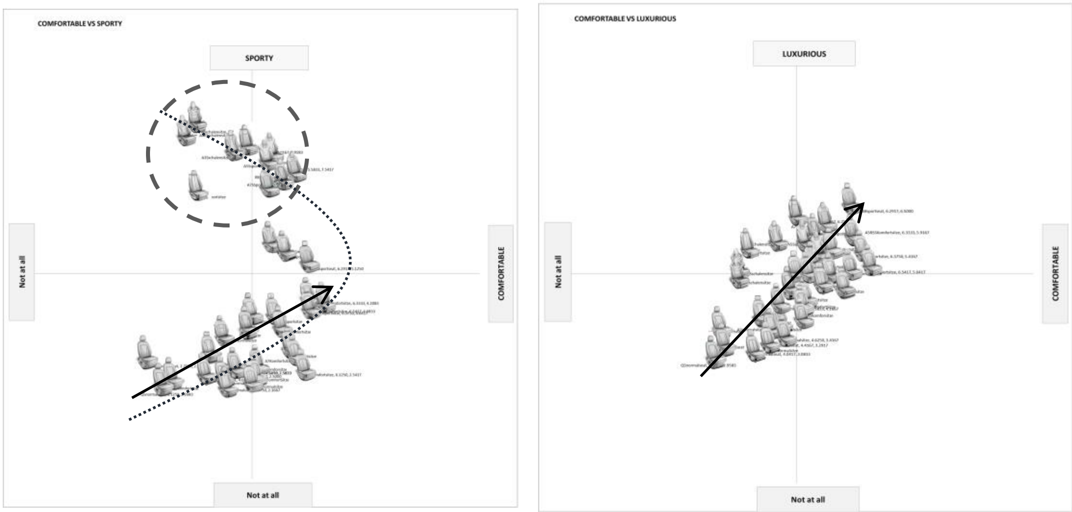

Figure 7. The plot graph of 38 seats on a *Comfortable* vs *Sporty* perception on the left (Mean value plot) and *Comfortable* vs *Luxurious* on the right.

The plot graph of *Comfortable* versus *Sporty* perception displays a clear indication of the clustering of integrated headrest feature on the seat designs in terms of *Sporty* perception (see figure 7). As displayed in figure 7, the 10 seats that were of particular distance in the HCA analysis, can be observed to form a separate cluster denoted in a circle in the plot graph from the remaining 28 seats. A closer inspection of the features reveal all the seats belong to the "Sport" category features of integrated headrest with prominent bolsters and shoulder support. Hence in relation to the graph plots, a quadratic relationship can be argued between the *Comfortable* and S*porty* mean values similar to the inverted U depicting an ideal point for expected comfort being increased with increasing sportiness. The graph plot of *Comfortable* versus *Luxurious* perception displays an indication of a linear relationship for the set of seat designs utilized (see figure 7).

The plot graph results display that the *A4 Sport seat* with bolstered seat back and separate headrest was found to perform better than all of the seats in terms of *Comfortable* (*Comfortable:* mean=6.54, SD= 2.14, *Luxurious* mean= 5.04, SD=2.3). In terms of luxury the *A8 Sport seat* was found more *Luxurious* (*Comfortable* mean=6.3, SD=2.1, *Luxurious* mean= 6.5, SD= 2.4).

Using *Comfortable* ratings obtained from the sorting exercise as dependent variable, a linear regression was carried out using *Sporty* and *Luxurious* ratings were used as predictor variables. Entering all data, a significant model emerged ($F_{(2,909)}$ =74.045, $p<.000$; Adjusted R square=.138). Both of the predictor variables significantly predicted the *Comfortable* ratings where, the *Sporty* $\beta = -.065$ ($p<.05$) had a negative relationship with *Comfortable* and the *Luxurious* ratings $\beta = .390$ ($p<.0001$) had a positive relationship, explaining 13.8% of the variation on comfort ratings.

3.4 Qualitative assessment; comments by participants on car seat designs in relation to descriptors

The participants were asked to comment on what they were taking into account when assessing the seat images on the particular semantic scale prompted. The sample of participants commented on the 38 seat pictures while scrolling through them and indicating the particular references that they identified in assessing and categorizing. The most mentioned *Sporty* seat characteristics were of “shape of the backrest”, ”Integrated Head Rest”, “Triangle”, “cut outs” on the back and the prominent side supports and side bolsters. Two female participants also indicated that there was a “streamlined” look of the seat suggestive of the car design that it belonged to specifically a sports car. “Bucket Seats” or “Racing Seats” were referred to as the exemplar seat type for this variable by 6/24 participants. Approximately all of the participants indicated that the *Sporty* categorization process was much easier to assess, compared to *Comfortable* and *Luxurious* variables. The extremity of the shapes of the side supports and the prominence was indicated to be perceivable and the narrow taller looking back design was suggestive of sportiness characteristic. However these particular characteristic features such as “hugging”, “snug” seats were indicated and interpreted by the participants as being less comfortable in use. Another concern was that sporty seats were not convenient and had too much of a seat angle at the back and an inclination on the seat pan. Also the “firm” and “hard” look of the seat cushions were mentioned.
In terms of *Comfortable* assessment of the seats, the comments were generalizable in two themes; the level of padding and segmentation of the surfaces that was perceivable by the participant and lesser angularity in comparison to sport seats which the comfortable seats were deemed more curved or had more rounded bolster elements. On top of these appearance attributes, the attribute of being “adjustable” was directly mentioned 6/24 participants, whether this is limited to adjustability of the headrest or the whole seat to conform to the positional requirements. At least 4/24 participants mentioned that sporty and comfort would not be compatible as sporty meant stiffer and flatter look (feel) whereas comfort was more associated with plush puffy and padded seats. Five participants expressed explicitly that strong *Sporty* features such as very prominent side bolsters and wings were a hindrance to “comfort”. In terms of the criteria and characteristics for “luxury” and “luxurious seat”, a major comment was that without the material and the color application, 8 /24 participants deemed it very “tricky” or “difficult” to assess the seats. Most of the participants indicated that upholstery material was the key for luxury characteristic, where certain patterns (i.e. quilted upholstery pattern) lead the participants to believe or assume the seat had “leather” as upholstery material. The width of seats was also associated with luxury perception, where a bigger, larger padding on the seat was referred to as more luxurious. Electric adjustment buttons were also mentioned by 6/24 participants as a luxury element that lead those to believe the seats were luxurious and expensive.

4 Discussion

The first aim of this study was to explore the perceptual attributes regarding the pre-determined variables of automotive seats and second exploring the particular relationships between the three proposed variables identified in literature (2, 4, 5). The foundation of these variables relied on “voice of customer” surveys which weighed seat styling above all other characteristics when judging the appeal of the automotive seating system. However it had a limited approach in determining seat characteristics and the effects of the seat styling and visual design elements. Pinkelman (2) used the J.D. Power and Associates APEAL self-reported survey data, argued that the customer experiences the seat comfort as a function of “Discomfort”, the “Luxury” and “Sportiness” feeling of a particular seat. Trying to define a hypothetical equation of “comfort character” utility of an automotive seat he further proposed the difference between expected and experience of comfort (dE) depended on the variables of “Luxury” (L), “Sportiness” (S) and “Discomfort” (D), where they were weighed. One proposed equation for comfort utility of a seat was:

$$Cu = dE(L^x S^y/(D^z) \quad (1)$$

However the proposal of this comfort utility model relied heavily on assumptions of a previous study and secondary data. In this study with first hand empirical data on what can be deemed customers' expectations of comfort, the findings suggested that "Sportiness" of a car seat is a recognized characteristic by the consumers, however utilized more as a categorical variable. In line with Erol et al (18) study, this categorization process as an "appearance role of product" lead to a high differentiation between the car seat designs. One of the key findings; the integrated headrest and prominent side bolsters were the most commented feature in the seat pictures which does put an emphasis on characteristics such as "lateral holding" ability of the seat as previously found in literature (4). However the effect of the headrest/head restraint was not foreseen by any of the prior research in literature. In this regard, the assessment of sportiness of a seat design was found to be "easier" by the participants which was also reflected by the Kendall's coefficient of concordance with high agreement. It can be argued that particular referral to integrated headrest, the emphasis on the "triangular" shape, is an indication of the saliency of the design element and relatively objective feature of the sport seat designs. Moreover it was observed that the extreme cases of *Sporty* created an attitude amongst the participants that they have referred to as "gaming" seats using allo-referential semantic cues, and were deemed hampering comfort. Focusing on the mean value ratings of the seats and the HCA clusters, a segregation or "discontinuity" amongst the designs of the seats in terms of sportiness was observed in relation to the headrest design. These effects of the categorization are in stark contrast of utilization of continuous variables in seat comfort characteristic equations proposed by Pinkelman (5). One important hypothesis is that an inverted-u-hypothesis (19); quadratic relationship between the variable *Sporty* and *Comfortable* might be possible. The optimal point for sporty features being constructive for comfort when exceeded hampers the expectancy; leading to an inflection point. Future studies could aim to address the hypothesis with increased data points where a structural equation model could aid in determination of the nature of the variables in further detail.

For attributes that led to this categorization behavior; in terms of *Sporty*, the *A8 Normal seat* and *Q5 Comfort seat* design were found significantly different than the 14 sport category seat designs. The most important difference between the designs can be pointed as the sport seats displayed angular shapes and more pronounced segments (trenches) especially in the shoulder support area (see appendix). Again for *Comfortable*, the *A5 S Comfort seat*, *A5 Sport seat* and *A4 Sport seat* displayed more segments on the back rest and also had pronounced shoulder support areas in comparison to the *Q5 Comfort seat* and *Q5 Normal seat* (see appendix). This feature discrimination in conjunction with the graph plots for comfort perception depicts that the increase in prominence of the side bolsters linearly increases with increasing *Sporty* and *Comfortable* perception. The third separate group is formed of integrated head restraint/rest element and reported triangular features.

For *Luxurious*, *A8 Sport seat* was significantly rated higher than *Q5 Normal* and *A6 Normal seat* designs (see appendix). The intricate quilt pattern and pronounced shoulder areas proved to be perceived more luxurious. For *Comfortable* vs *Luxurious* plot, the graphs show that certain seat features incrementally increased the perception of both comfort and luxury, where a continuous nature is achievable. Focusing on the HCA *Comfortable* dendogram, the first group seat designs display single piece backrest cushion whereas the second group displays increased segmentation on the backrest cushions which increases both comfort and luxury expectancy. Furthermore, the amount of "padded" or "cushioned" areas on the seats were commented as references (design cues) leading to an increased understanding of a more comfortable seat. From the participants comments it was deduced that the *Luxurious* content encompassed the quilt patterns and craftsmanship details which implies a degree of complexity of the design.

A very important insight was that monochrome pictures were harder for the participants judge the seat designs on the variable of *Luxurious*; a number of participants reported that the inability to know the tactility, color and the material of the upholstery was particularly hindering the impressions, and 6/24 participants deemed it "tricky" to evaluate. In this aspect the participants relied on the particular details of stitching (trenches) and the quilt patterns that were suggestive of craftsmanship therefore luxury content. Also the subjective "width" and the "larger" dimensions of a seat forming a "spacious" look were referred to as luxury traits, where in fact all images were presented in consistently same dimensions on the iPad. This can be attributed to the visual effect of tapering single piece seat back cushion designs (e.g. *A4 Normal seat* etc.) and how narrow it was visually perceived. These results were also consistent with the previous study of Kamp (4) and Coelho & Dahlman (20); where participants associated width and softer materials with luxurious car seats.

The results of the linear regression on *Comfortable* confirmed that the *Luxurious* perception had a positive linear relationship also that was observed on the plot with mean ratings; hence they were also verbally associated by 6 participants. Strikingly, the *Sporty* had a negative significant relationship with *Comfortable*. Corroborating the mean value plot graph results, this can be interpreted that there is a cut-off value for achieving maximum comfort perception with increasing *Sporty* design attributes where it can be suggested that further incremental increase of these attributes reverses the relationship.

5 Conclusion

The findings have significant implication for the appearance design of automotive seats, where the consumers rely on specific design cues that elicit an expectation towards the seat comfort experience. In this study seats with angular shapes and integrated headrest deemed in "sport" category generated expectations of lesser comfort and more function, whereas visually more padded and pattern bearing designs were apprised as affording more comfort. Moreover, perceived (expected) comfort had a negative linear relationship with increasing sportiness (utilitarian-functional) and positive one with the perceived luxury. It has been demonstrated that "product appearance roles" as previously hypothesized (18) does indeed guide the end users to develop expectations regarding comfort; specifically strong "sporty" features such as integrated headrest were deemed being function oriented and a categorical variable. It can be further concluded that for automotive seat design evaluation *Sporty*, *Comfortable* and *Luxurious* variables can be utilized to evaluate car seat appearance, given that salient design differentiation cues are present in the sample of seat designs selected e.g. prominent shoulder support area vs tapered seat back design. In scope of these findings, it can be proposed that the "holistic" evaluation processes relied on the overall impressions which lead to categorization of the seats where the "piecewise" evaluation processes associated with comfort and luxury dwelled on the partial visual attributes e.g. the prominence of bolsters and various patterns (11, 21, 22). Future studies on various comfort descriptors/variables can be conducted to enhance the understanding and provide the insight on various visual seat design attributes and their relationship with overall comfort perception.

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7 Appendix

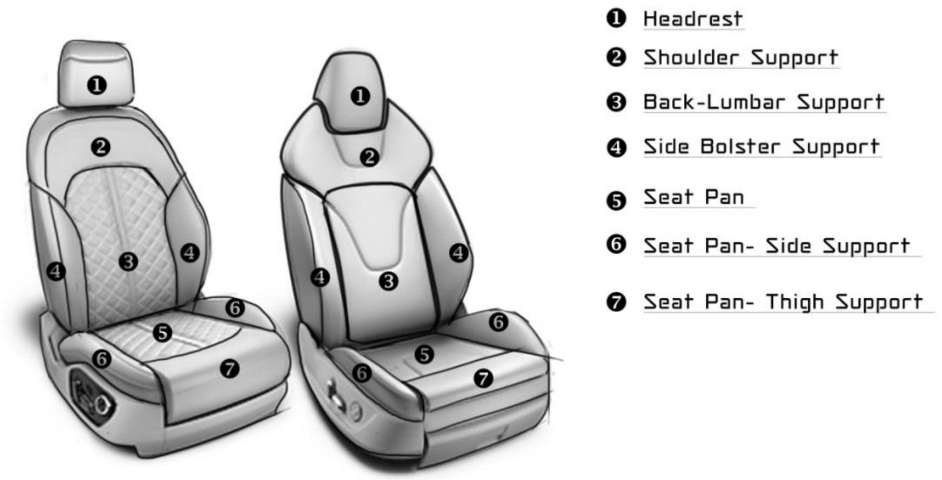

Figure A.8. Seat attributes in generic seat design for Production Automotive car seats on the left an *A8 Segment Sport seat* and on the right *A5 Segment Sport seat*

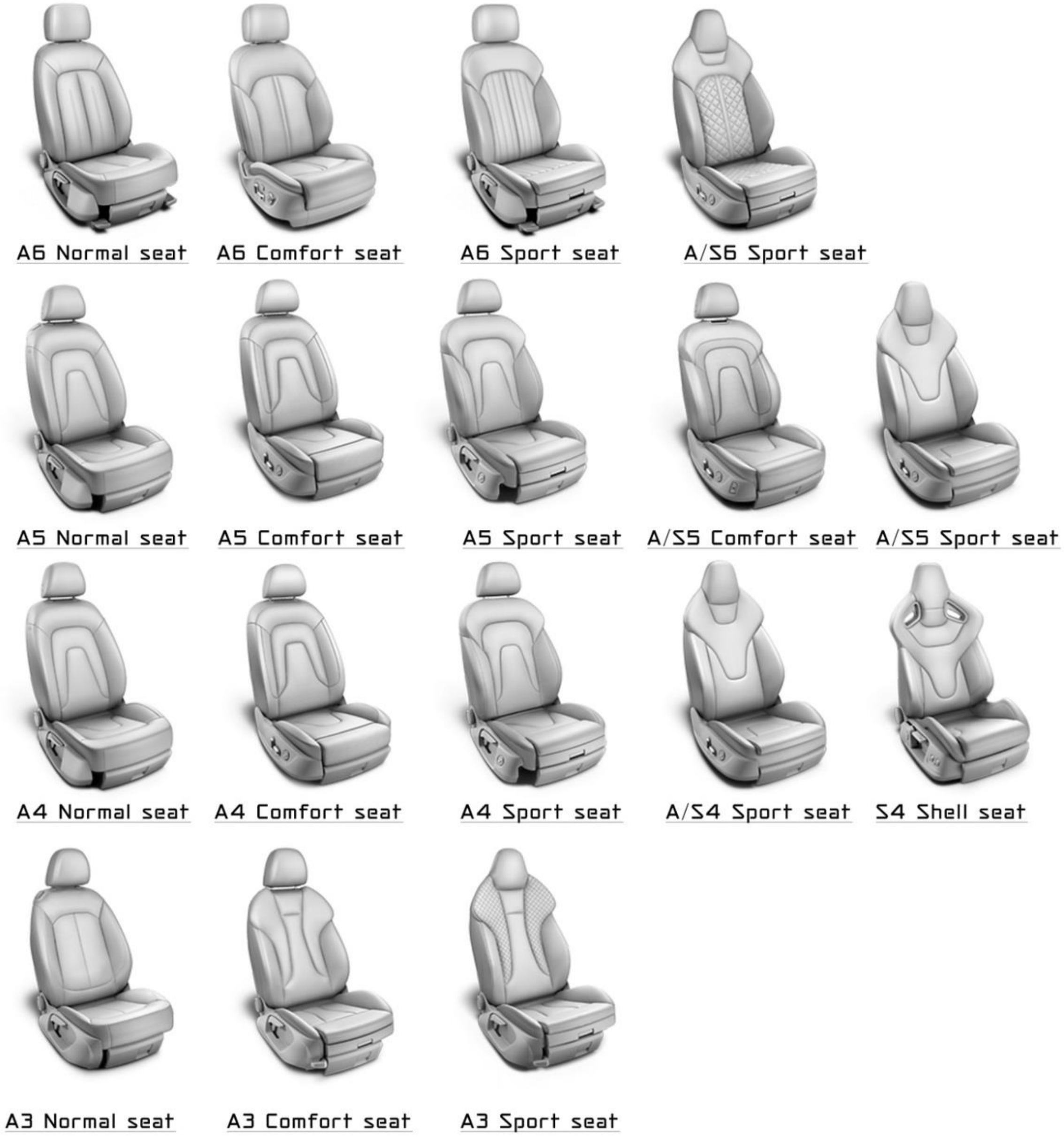

Figure A.2. The 38 AUDI AG (model year 2016) seat designs for each passenger car segment adopted in this study. The designs vary from "Normal" (alternatively referred to as standard) to "Sport" and "Shell/Bucket seat" types offered on the AUDI AG website.

Figure A.2 (continued). The designs vary from “Normal” (Standard) to “Sport” and “Shell/Bucket seat” types offered on the AUDI AG website.

Figure A.2 (continued). The designs vary from "Normal" (Standard) to "Sport" and "Shell/Bucket seat" types offered on the AUDI AG website.

School combo-desk comfort assessment: a method for weighting postural factors that affect the overall perceived comfort while performing different activities

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Abstract In recent years, a growing interest in ergonomics and comfort perception in secondary schools and universities can be detected, with the aim of going beyond the UNI-EN regulations and understanding how practically improve students' perceived comfort during lessons. The aim of this study was to analyse the discomfort perceived by students while sitting on combo-desk during lessons. A statistical sample of 20 healthy students performed a combination of three different tasks in two sessions - listening, reading on a tablet and writing - in a mixed sequence. Subjective perceptions were investigated through questionnaires, in which the expected comfort and the overall one were rated on a 10-point comfort scale and the perceived comfort on a 5-point Likert scale. Subject's postures were acquired non-invasively using cameras; Kinovea® software was used to detect postural angles directly on pictures; the acquired angles were used for the virtual-postural analysis, using a DHM (Digital Human Modelling) software; CaMAN® software was used to obtain an objective measure of the postural comfort. Once correlations between subjective and objective data were calculated, the results of the analysis were used to define the influence of each body part comfort on the overall perceived comfort and to quantify the weight of each factor influencing the overall perception. Finally, some guidelines to modify the combo-desk design, in order to increase the level of perceived comfort, were developed.

Keywords: Perceived (dis)comfort, School seat, Combo-desk, School activities.

1 Introduction

Ergonomics studies the interface between people and activities they perform, the products they use and the environments in which they work, travel or play; as stated by Mokdad and Al-Ansari [1], the use of ergonomic principles allows developing guidelines for improving and redesign old/new products. The interdisciplinary nature of ergonomics makes it markedly applicable to various fields that involve human performances. Education is one field where ergonomics can give a significant contribution, but the application of ergonomics to education receive only limited attention. Educational ergonomics is that branch of ergonomics/human factors concerned with the interaction of educational performance and educational design [2].
Much research on physical comfort and discomfort in the workplace were conducted; most papers discuss on relationships among environmental factors such as temperature, humidity, applied forces and so on that can affect perceived levels of comfort/discomfort [3]. Several papers follow the assumption that a relationship exists between self-reported discomfort and musculoskeletal injuries since these injuries affect perceived comfort [4,5]; however, theories relating comfort to products and product design characteristics are still rather underdeveloped.

In this work, the authors want to investigate the problems related to the adoption of a common combo-desk used by university students.
The classroom is a learning environment in which the furniture is an important physical element that is expected to facilitate learning by providing a comfortable and stress-free environment. Poor sitting posture in the classroom is one of the main negative effects of bad furniture design on students [6].
Since students spend a considerable part of the day at school, sitting on a chair [7,8], school furniture should match students' requirements. However, studying in fixed-type furniture may induce constrained postures [9,10]. Since people differ in size and postural preferences, workstations with adjustable seats are preferred as they have a significant positive effect on muscle tension and sitting posture, promoting health, comfort and concentration [11,12].
Commonly schools and universities prefer fixed-type chairs than adjustable chairs due to the higher price and maintenance costs of adjustable chairs [13]. Side-mounted desktop chairs are often used in university classrooms. However, their correct design is neglected, and Thariq's study [12] showed that side-mounted chairs in their learning environment do not meet postural and comfort requirements of university students. About that, Naddeo et al. [14–16] identified that a custom seat influenced positively the comfort perceived from students.
It is generally accepted that continuous static muscle activity results in discomfort [17]. Regarding the number of movements, Graf et al. [18] suggested that natural movements are desirable and necessary as long as they are within an acceptable range; another study [19] stressed the importance of variation between severable stable and healthy body postures. Several studies on seating, in general, describe a relation between seating time, discomfort and body movement. Telfer et al. [20] found that subjective discomfort and movement increases over time. Vergara and Page [21] stated that macro-movements are a good indicator of discomfort, Fujimaki and Noro [22] also found discomfort to increase over time but argued that macro-movements occur in order to decrease discomfort in a repeating pattern during prolonged sitting. Callaghan and McGill [23] suggested that humans redistribute their muscular loads according to their comfort level using posture adjustment. Finally, Fasulo et al. [24] suggested that the number of movements was a good indicator of perceived lower-body (dis)comfort, particularly, it was demonstrated that an increase in discomfort causes an increase in the number of movements.
Certain medical studies showed that each joint has its own natural Rest Posture (RP) [25,26], wherein the muscles are completely relaxed or at minimum strain level: when this occurs, the geometrical configuration corresponds to the natural position of the resting arms, legs, neck, etc. This position appears to minimize musculoskeletal disease and optimize comfort perception [3].
One area in which comfort studies can be applied is public offices and public furniture like those used in schools. Our study evaluates the level of comfort perceived by students while using university furniture (combo-desks). A study published in 2014 [25], involved a classroom of 126 Portuguese students and demonstrated that their university classrooms were not well-designed for the students.
In this paper, critical issues shown by the combo-desk are analysed using the quantitative method for comfort evaluation, the software CaMAN® was used [16,27] to make a quantitative evaluation of postural comfort, and the modifications of the combo-desk to increase the level of comfort perceived by the users are suggested.

2 Materials and methods

2.1 Purpose

The aim of this study was to investigate the discomfort perceived by participants during class-hours. The participants were observed during thirty minutes of lesson while sitting on a combo-desk. Each student performed a combination of three different tasks (listening, reading on a tablet and writing) and at the end of each task the perceived comfort, related to the upper limbs, was investigated by a questionnaire.

2.2 Participants

Twenty healthy volunteer MD students (8 females and 12 males), took part to the experiment. All participants signed the Informed Consent about the nature of the test, in accordance with ethical standards of the University of Salerno. Demographic data of participants are gathered in Table 1.

Table 1. Demographic data of the participants.

	Age (years)	Mass (Kg)	Height (m)
Mean	*25,6*	*67,9*	*1,7*
Std. Deviation	*2,1*	*11,7*	*0,1*
Minimum	*23*	*50*	*1,55*
Maximum	*31*	*86*	*1,9*

2.3 Testing Devices

The equipment used in this study for data acquisition and set-up was composed by: a common combo-desk, a photographic acquisition system and a comfort questionnaire.
The combo- desk was a side-mounted desktop chair (**Fig. 1.** Combo-desk.Fig. **1**). It was characterized by a rigid seat-pan, a rigid seat-back, a right armrest and a side desk.

Fig. 1. Combo-desk.

In the adopted configuration, the photographic acquisition system was equipped with five commercial cameras. This allowed to acquire photos from five points of view: front, behind, left side, right side, and above.
To acquire the subjective perceived comfort, a body comfort questionnaire was used in which students had to rate:
- the expected comfort before starting the experiment on a 10-point scale.
- the perceived comfort for each part of the upper body, left and right, (Fig. **2**), at the end of each task on a 5-point scale from 1 (Not comfortable) to 5 (Extremely comfortable);
- the overall perceived comfort, at the end of each task on a 10-point scale.

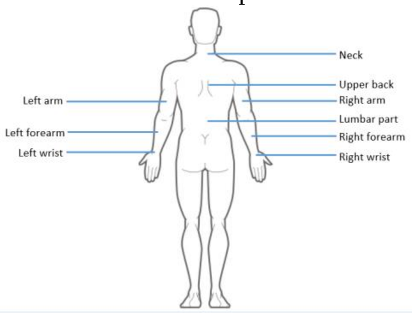

Fig. 2. Comfort questionnaire.

2.4 Simulation Software

CATIA® V5R16 was used for the virtual-modelling of the combo-desk. DELMIA® Digital Human Modelling (DHM) software was used for modelling a 'dummy' based on the real participants' anthropometric measurements [28–33] Kinovea® software rel. 0.8.7 was used for the angular detection of users' joints (while performing the required activities). Few small modifications were carried out to guarantee the accuracy of the manikin's postures, according to the photogrammetric acquisition previously verified in [34] and [35]. Comfort evaluations were performed using CaMAN® [5,16,27,36,37] – a MatLab application developed by Cappetti and Naddeo, which takes the angles describing operator posture as input, and gives an index of postural comfort (CI) with a value range of 0-10 as output.

2.5 Procedure

Testing was conducted in a class of the Faculty of Engineering at the University of Salerno. Participants were asked to sit on a combo-desk and to perform three main tasks: writing, listening and reading on a tablet. The overall duration of each test was 30 minutes, divided in two sessions of 15 minutes. In each session, each task was performed in 4 minutes, with a 1-minute pause between tasks to fill questionnaire. Photos, from all views, were taken simultaneously just before the end of each task, making sure to have the same participant's posture in all views. During the tasks, students were able to move freely.
Photos were processed by the software Kinovea® to gather postural angles of human joints.
Postural angles were then used into Delmia® to simulate each posture (Fig. **3**). In this step, some assumptions were made to ensure the correspondence between the angles evaluated by the two different software (Kinovea® and Delmia®). Delmia® was used to evaluate angles that were not available through the photographic acquisition, such as the arm medial rotation, the forearm pronation/supination and the hand flexion/extension, as well as the radio-ulnar deviation;
The upper limb angles were processed by CaMAN® to obtain comfort indexes of, shoulders, neck, hand and elbow.

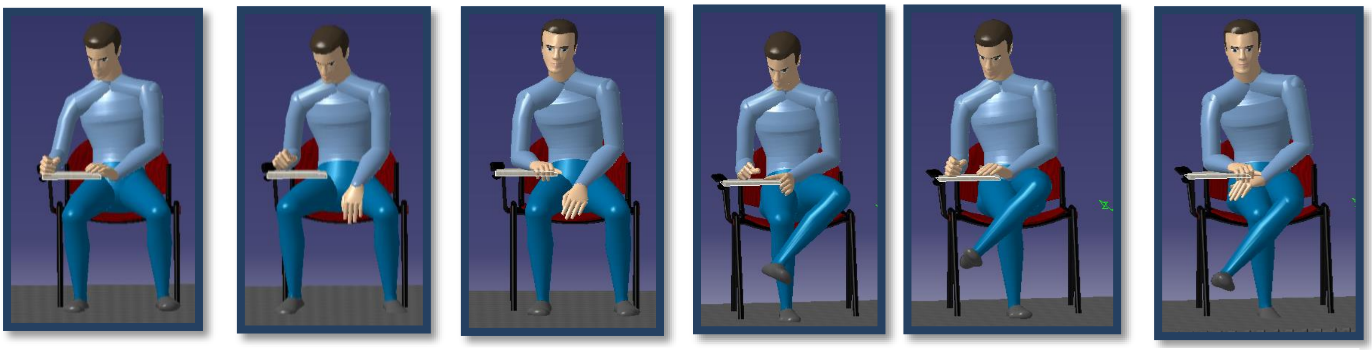

Fig. 3. (a) Writing 1; (b) Reading 1; (c) Listening 1; (d) Writing 2; (e) Reading 2; (f) Listening 2.

2.6 Data Analysis

Data were gathered to evaluate the impact of the objective/subjective comfort scores of each part of the body on the overall perceived comfort. The analyses were conducted for each task performed during the two sessions of the test. The statistical analysis software SPSS® rel.13 was used to perform these analyses. Spearman correlation coefficients were calculated to determine the strength of the relationships among the acquired variables.
Table 2 shows the most significant correlations between the subjective overall comfort and the subjective comfort scores for the body-parts during the reading and writing tasks. A strong correlation emerged between the overall comfort and the subjective comfort scores of the neck, upper back, lumbar part, right arm, right forearm and right wrist, perceived in the two sessions of reading and writing tasks. Meanwhile, the subjective comfort scores of the left arm, left forearm and left wrist were not correlated with the overall perceived comfort.

Table 2. Correlation between the overall comfort and the subjective comfort scores about reading and writing tasks.

Subjective Comfort	Neck	Upper back	Lumbar part	Right arm	Right forearm	Right wrist	Left arm	Left forearm	Left wrist
Writing1 (W1)	**	**	*	**	**	**			
Writing2 (W2)	**	**	*	**	**	*			
Reading1 (R1)	*	**	*	**	**	*			
Reading2 (R2)	*	*	*	**	*	*			

*** The correlation is significant at level 0.01 (2-queues)*
** The correlation is significant at level 0.05 (2-queues)*

In Table 3 are reported the significant correlations between the subjective overall perceived comfort and the subjective comfort perception for the body-parts, during the listening session. The table shows a strong correlation between the overall perceived comfort and the subjective comfort scores of the right arm, right forearm, right wrist and upper back. Even in this case, the subjective comfort scores of the upper left limb were not related to the overall perceived comfort. Unlike other tasks, there is a lack of correlation between the overall perceived comfort and the subjective comfort scores of the neck and the lumbar part.

Table 3. Correlation between the overall comfort and the subjective comfort scores about listening.

Subjective Comfort	Neck	Upper back	Lumbar part	Right arm	Right forearm	Right wrist	Left arm	Left forearm	Left wrist
Listening1 (L1)		*		**	*	*			
Listening2 (L2)		*		**	**	**			

*** The correlation is significant at level 0.01 (2-queues)*
** The correlation is significant at level 0.05 (2-queues)*

The correlation analysis, between the overall perceived comfort and the objective comfort scores of body-parts, showed no correlations. The reason is that the CaMAN® software calculates comfort scores assuming that the weight of the upper limbs is not supported, while in the analyzed tasks the sample rested the right elbow on combo-desk and the left one on leg, crossed arms on the stomach or on the legs. So, the objective comfort scores are not reliable for this comfort analysis.

2.7 New global comfort indexes

To understand the influence of perceived comfort of the different parts of the body on overall comfort, a new global comfort index for each task was created.
These new global comfort indexes were calculated as weighted averages, considering, for each of them, only the body parts where the correlations were found: neck, upper back, lumbar part, arm and forearm for the reading and writing tasks (see Table 2); upper back, arm and forearm for the listening task (see Table 3).
These indexes were calculated excluding the objective comfort scores.

The new global comfort indexes for the writing task (subscript W), performed two times, are defined by the following formulas (1) (2):

$$\text{Global Comfort Index (Writing 1)} = a_1{*}A_{W1}+a_2{*}N_{W1}+a_3{*}B_{W1}+a_4{*}L_{W1} \quad (1)$$

$$\text{Global Comfort Index (Writing 2)} = a_1{*}A_{W2}+a_2{*}N_{W2}+a_3{*}B_{W2}+a_4{*}L_{W2} \quad (2)$$

The new global comfort indexes for the reading task (subscript R), performed two times, are defined by the following formulas (3) (4):

$$\text{Global Comfort Index (Reading 1)} = b_1{*}A_{R1}+b_2{*}N_{R1}+b_3{*}B_{R1}+b_4{*}L_{R1} \quad (3)$$

$$\text{Global Comfort Index (Reading 2)} = b_1{*}A_{R2}+b_2{*}N_{R2}+b_3{*}B_{R2}+b_4{*}L_{R2} \quad (4)$$

The new global comfort indexes for the listening task (subscript L), performed two times, are defined by the following formulas (5) (6):

$$\text{Global Comfort Index (Listening 1)} = c_1{*}A_{L1}+c_3{*}B_{L1} \quad (5)$$

$$\text{Global Comfort Index (Listening 2)} = c_1{*}A_{L2}+c_3{*}B_{L2} \quad (6)$$

In which:

A is the subjective comfort score of the upper right limb, given as arithmetic mean of the subjective comfort index of arm, forearm and wrist;
N is the subjective comfort score of the neck;
B is the subjective comfort score of the upper back;
L is the subjective comfort score of the lumbar part.

The weights must be determined considering that:

- the sum of the weights must be equal to 1;
- the individual weights must be strictly included in the range [0,1];

2.8 Optimization Problems

To determine the weights of the new global comfort indexes, three optimization problems were settled.
The aim, in this phase, was to maximize the sum of:

- The correlation between the overall comfort perceived and the new global comfort index relative to the same task performed in the first session.
- The correlation between the overall comfort perceived and the new global comfort index relative to the same task performed in the second session.

O.F. max (correlation (overall_comfort_i; $\text{new\_global\_comfort\_index}_i)_{1st\_session}$+ correlation ($\text{overall\_comfort}_i$; $\text{new\_global\_comfort\_index}_i)_{2nd\_session}$)
where i= reading, writing or listening tasks
Constraints:
$0<\text{weight}_i<1$ for i=1,2,3,4 (for reading and writing tasks); for i=1,3 (for listening tasks)
$\sum \text{weight}_i=1$ for i=1,2,3,4 (for reading and writing tasks); for i=1,3 (for listening tasks)

The weights of the three global comfort indexes were calculated using the Excel Solver (Table 4). The values of the objective function, and the correlations between the overall comfort perceived and the new global comfort index relative to the same task performed in the first and second session were reported in

Table *5* and
Table ***6***.

Table 4. Weights (Excel Solver).

WEIGHTS (EXCEL SOLVER)	LISTENING	READING	WRITING
	0.6715486	0.510145	0.46046757
		0.000000	0.09779941
	0.3284389	0.421435	0.12740034
		0.068420	0.31418044
Sum	1	1	1

Table 5. Correlations (Excel Solver).

CORRELATIONS (EXCEL SOLVER)	LISTENING	READING	WRITING
First session	0.73220626	0.822757	0.86209561
Second session	0.7706147	0.686990	0.73451648

Table 6. Objective Function (Excel Solver).

O.F. (EXCEL SOLVER)	LISTENING	READING	WRITING
	1.50282093	1.50974757	1.59661209

As a further check of the excellence of the results, a Macro was created in Excel to generate 10000 random weight values subject to the already-discussed constraints. If this research reveals a value of the objective function greater than the one found by the Excel Solver, it means that the weights associated to that O.F. are stored, in decreasing order, in a suitable table. Doing this macro for each task, the search never showed a value of O.F. higher than the one of the Excel Solver, which therefore has identified the optimum global point.
In addition, another Excel Macro was created to write, in decreasing order, all the results of its exploration for 10000 random values of the weights in a suitable table. The maximum value found by the Random Method is, however, closer to the one of the Excel Solver (Table 7, Table 8 and Table 9).

Table 7. Weights (Random Method).

WEIGHTS (RANDOM METHOD)	LISTENING	READING	WRITING
	0.67154423	0.513530623	0.461724661
		0	0.11
	0.32845577	0.41	0.11
		0.076469377	0.318275339
SUM	1	1	1

Table 8. Correlations (Random Method).

CORRELATIONS (RANDOM METHOD)	LISTENING	READING	WRITING
FIRST SESSION	0.732207534	0.822222405	0.8636268
SECOND SESSION	0.770613428	0.687399898	0.732818948

Table 9. Objective Function (Random Method).

O.F. (RANDOM METHOD)	LISTENING	READING	WRITING
	1.502820962	1.509622303	1.596445747

3 Results & discussions

The new global comfort indexes were used to evaluate the comfort perception and to compare the single tasks, in order to determinate in which tasks students perceived less comfort. In the Table 10 results obtained are shown:

Table 10. New global comfort for each task.

TASK	1° SESSION	2° SESSION
LISTENING	6,24909335	5,42
WRITING	5,359639179	4,556962546
READING	5,145628357	4,54339886

It is clear that in both sessions, the worst comfort index is related to reading, even though the value is very similar to writing. This result is mainly due to the position taken by students during these work activities that force the student-body to be located too far from the reading and writing surface.

In addition, there is a worsening of comfort indexes between the first and the second session, caused by student tiredness, that was accentuated during the test. This results is in accordance with the results of Vink et al. [38] in which the influence of effects over time on comfort and discomfort were studied

Instead, listening has the best value. This result was expected because: during the listening task the subjects were less constrained. They could place themselves in the most comfortable way to carry out the task. Definitely, analysis was reasonably satisfactory and consistent:

- In both sessions, listening is the better task and reading is the worst one
- Listening in the first session is the most comfortable activity
- Reading in the second session is the most uncomfortable activity

It is evident that, during learning activities, the student-body was always located too far from the working surface, and while taking notes or reading something, there were negative effects on his/her back, neck and arms. In order to solve this problem, it was necessary to make changes to the folding chair desk. The proposed changes consisted of a system that allows the student to set the distance between chair and writing surface and, in addition, to tit it during reading, for example. In this way, the physical characteristics of the users would be considered, so to set the system according to own needs. In this new configuration, we expect better results in terms of global comfort indexes.

4 Conclusions

In this work, the authors investigated the problems related to the adoption of a common combo-desk used by university students during a combination of three different tasks (writing, listening and reading).

The method used in this work was based on photo/video recording and photogrammetry, image processing using Kinovea® software, coupled with the use of DHM commercial software (CATIA® for modelling, DELMIA® for simulation) and comfort rating software developed by the authors for the evaluation of non-subjective comfort (CaMAN®) .

Via a correlation analysis, through the Spearman index, it was possible to understand the influence of subjective comfort (questionnaires) and non-subjective one (CaMAN®) of the different parts of the body on overall comfort. From the results obtained, a new global comfort index for each task was developed. Three optimization problems were set in Excel to estimate the best weights for each one.

In the work was showed a method for the definition of the comfort indexes. All the acquisition methods used are very cheap and easy to use. The precision of the acquisition method, as well as the fact that by not using complicated, expensive acquisition methods we were still able to reach a very good level of numerical/experimental are important results revealed by this paper. The method can be easily reproduced for other applications.

It is widely demonstrated that fixed-type furniture may induce constrained postures and these have a significant negative effect on comfort [9–12]: that was confirmed through the results of this work, based on a real application. During the tasks in which the subjects were obliged to utilize the desk (reading and writing) the subjective comfort was the lowest one. Instead, when they had to carry out the task in which they had not utilized the desk (listening) the subjective comfort was the highest one.

The comparison between global comfort indexes, firstly, was useful to understand the most uncomfortable task in both the sessions. The test procedure, additionally, allowed us to study the influence of effects over time on comfort. The second session showed that the comfort was reduced for all the tasks. Sitting still for extended periods of time can lead to physical discomfort.

Obtained results can be a useful support during the problem solving and directly suggest, to designers, easy solution to re-design the combo-desk. The proposed solution takes into account the characteristics of the tasks that the subjects have to carry out during the lessons and the subject's anthropometrics characteristics.

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A comfort evaluation tool for sitting postures: the case of Library chairs

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Abstract According to ergonomic researches regarding a good sitting posture, the chair, the desk and the objects on the desk, have to be aligned in a certain way to ensure to users a natural curve of the back in order to prevent musculoskeletal disorders. A brief observation among the main Scientific Technology Library inside the University campus showed that students used to complain about neck and lumbar pain, especially after a study day. Thus, a sitting posture comfort analysis had been performed on chairs inside the library. A long-time sitting posture during the daily study activity had been simulated with fifteen volunteer students performing 1-hour tests (divided into four tasks of 15 minutes each). Subjective perceptions had been gathered through questionnaires rating on a 5-point Likert scale both the expected comfort at the beginning of the experiment, and the Localized Postural Comfort at the end of each task. Moreover, just before the end of each task, postural angles had been detected by photographic acquisition and processed by Kinovea®; in addition, CAMan® software had been used to calculate the (dis)comfort indexes by detected postural angles. Finally, subjective and objective data had been statistically processed and compared. Results showed the lumbar area as the most suffering area (lower perceived comfort) while perceived (dis)comfort was independent on participants and tasks, but dependent on the time.

Keywords: comfort, office seat, university students, library, postural comfort

1 Introduction

Students spend the majority of their time studying, thus sitting on a chair. The importance of the environment cannot be underestimated due to the fact that negative feelings can affect the learning, especially for a long time sitting [1,2]. Indeed, uncomfortable and awkward body postures can decrease a student's interest in learning, even during the most stimulating and interesting lessons [3]. Considering the position of chair and desk, in literature there have been several studies regarding the correct sitting posture and the awareness of a good sitting posture [4–7]. Furthermore, it exists even an equation to quantify the comfort in function of measurements and distances between chairs, student and desk [8].

Any seat design is influenced by the context. Some studies, moreover, gave guidelines to design a comfortable seat, taking into account the natural curve of backbone, the body sensitivity [9–12], the performed activities and anthropometric measurements of the target group [13–17]. Different target groups have different body sizes and this implies differences in seat width, backrest length, seat pan length, armrest

height, that should be designed to fit at least the 99% of the population [10]. However, the body's optimal position in terms of comfort requires every joint and eye position to be close to the neutral position, where the perception of comfort is high [18–21].
'Postural comfort' is commonly defined as the absence of discomfort, or a state where the need to change position is not present [22,23]. The comfort zone, defined as the area of the most comfortable motions/postures for a given task, does not predicate an absolute measure of well-being. Users within their comfort zone are unlikely to change into other postures.
The evaluation of postural comfort can be achieved through subjective or objective data. Subjective data are related with questionnaires, such as Localized Postural (Dis)comfort (LPD), Body Part (Dis)comfort (BPD) and so on [24–26], while the objective one can be obtained with tools such as pressure mate, sensors and so forth [27,28]. One of these tools is the software CAMan® [21,29–31] realized by University of Salerno: the software considers the human joints and the comfort curves over angles associated with them. Thus, for a given angle of a human joint, the software gives the associated comfort index (on an 11-point scale where 10 is the maximum comfort).
Despite this background, some applications on the daily life do not follow the ergonomists' tips, as in the case of this study.
The Science and Technology Library (S&T Library), designed by the architect Nicola Pagliara [32], is collocated inside the campus of the University of Salerno (UNISA) and is actually used as a place to study [33].
With a brief analysis among students inside the S&T Library, it came out there had been several complaints about neck and lumbar pain after a study day. Regarding this, one hypothesis was the students used to assume wrong sitting posture on those chairs.
Since the students tended to change posture frequently, a sitting postural comfort analysis had been done [35–37].

2 Materials & Method

2.1 Experiment setup

The experiment had been setup on the last floor of the S&T Library when there was less affluence of students, by permission of the library staff.

On each floor, there are 36 desks with corresponding chairs, grouped six by six, where three are aligned and the other three are opposed to them. For the experiment, three consecutive desks had been occupied to have a clear space.

Three Nikon D3300 cameras had been used and fixed on tripods among the desks: one had been placed on the left and one on the right to obtain the lateral views; and the last one behind the chair, at an adequate distance, to obtain the rear view. In addition, one phone-camera had been fixed on selfie-stick support to take photos from the top view.

To simulate a study day, two main tasks of the studying had been performed: writing and reading. Thus, books, pens, papers had been provided. To consider the time effect, each experiment lasted 1 hour, where the two tasks had been performed for 15 minutes each one, switching them at the end of the 15 minutes. Between the tasks, a pause of 1 minute had been given in order to fill the questionnaire. Photos had been taken from all cameras simultaneously at the end of each task to capture body posture and obtain then postures over time.

2.2 Experimental sample

Fifteen students of University of Salerno, 8 males and 7 females with the age between 23 and 31, took part to the experiment. Table 1 shows demographic data of participants. All students enjoyed good health. These anthropometric data had been gathered measuring directly the participants' body with a meter, and recorded in an Excel file.

Table 1. Demographics of participants

	Male (n=8)			*Female (n=7)*		
	Mean	*SD*	*Range*	*Mean*	*SD*	*Range*
Height (cm)	*178.5*	*6.2*	*168 – 185*	*162.7*	*5.7*	*154 – 169*
Weight (kg)	*72.5*	*10.2*	*57 – 90*	*57.1*	*4.8*	*50 – 63*

2.3 The chair

To obtain a complete overview, dimensions of the chair had been compared with human body measurements.

The dimensions of the chair are showed in Figure 1. The high of armrest is about 61 cm from the ground, while the lower part of the desk is 60 cm high from the ground: it means the chair cannot be positioned under the desk. Moreover, there is a gap between the backrest and the seat-pan about 14 cm (66,1cm – 52,4 cm); it means students have to move backward their back in order to lay on the backrest.

Fig. 1. Pictures of the chair in three views. Measurements of the chair are reported.

From DINED [38], choosing the international population, values regarding the sitting height, the hip breadth, popliteal height, buttock-knee depth and elbow-grip length had been gathered, as shown in Figure 2:

Measures sitting (mm)	**International, female**		**International, male**		**International, mixed**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
17) Sitting height	800	40	935	40	868	78
14) Popliteal height	365	29	460	27	413	55
33) Buttock-knee depth	505	33	615	33	560	64
25) Hip breadth	305	27	395	27	350	52
31) Elbow-grip length	305	21	375	21	340	41

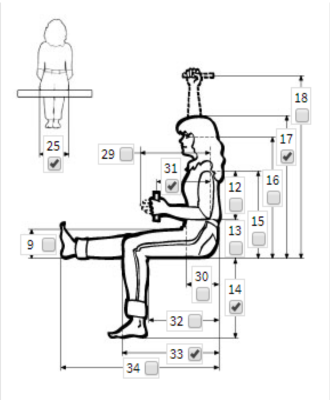

Fig. 2. Anthropometric measurements from DINED. The numbers refer on the picture placed on the right. Measurements refers on 50-percentile of the population, for both genders.

Comparing the measurements, it had been figured out:

- Popliteal height is not suitable for 50% of female population;
- Buttock-knee depth is not suitable for 50% of female population;
- The hip breadth for both population is smaller than the seat pan length.

2.4 Questionnaires

Questionnaires of Localized Postural Comfort have been used to collect subjective data regarding the postural comfort of participants.
Prior the experiment, participants were asked to rate on a 5-point Likert scale (from 1=No comfort to 5=High comfort) the expectation of perceived comfort once sitting on the chair, that is, how the chair seemed comfortable at the first sight [39].
At the end of each task participants were asked to rate on a 5-point Likert-scale [24]:

- The perceived comfort on the following body parts: neck, left shoulder, right shoulder, left arm, right arm, left forearm, right forearm, left wrist, right wrist, thoracic zone, lumbar zone;
- The global comfort.

2.5 Experiment protocol

Prior the experiment, participants has been asked to sign an informed consent and instructed about the experiment.
Then participants sat on the chair, positioning it closer to the desk and assuming a correct sitting posture, that is, forearms on desk, raised back, 90 ° legs, and feet leaning against the ground.
Tasks have been performed in sequence, alternating between writing and reading, both among the tasks and the sequential participants (Table 2). Each one lasted 15 minutes, which a stopwatch that told the time, and with a pause about 1 min between the tasks to fill the questionnaire; photos have been taken just before the end of the task.
Survey data have been analyzed calculating weighted averages and the comfort trend over time starting from the expectation.

Table 2. Protocol regarding time

	Task 1	**Task 2**	**Task 3**	**Task 4**
Participant A	Reading	Writing	Reading	Writing
Participant B	Writing	Reading	Writing	Reading
	15 min	*15 min*	*15 min*	*15 min*

1 min *1 min* *1 min*

2.5 Postural angles and the simulation

A total of 240 photos (15 participants x 4 tasks x 4 views) have been analyzed with Kinovea® to gather postural angles, trying to be as accurate as possible, aware of any human errors, both in visual perception and in the program operation.
Analysis has been made of the following upper limbs movements: head rotation, head bending, head flexion, shoulder rotation, shoulder bending, shoulder flexion, trunk rotation, trunk bending and trunk flexion. Body rotation has been analyzed in the transverse plane, body flexion in the frontal plane and body bending in the sagittal plane. Considering the aforementioned correct sitting posture as a reference posture, the gathered angles have been defined as the deviations from the reference posture.
A virtual environment of S&T Library have been realized in Delmia® (Figure 3), representing one floor with fifteen students. French mannequins, that represent the European standard, have been used to simulate participants' movements through the gathered postural angles. Anthropometric data, movements and tasks have been respected.
Through the simulation, it was possible to see the temporal changes for each student, going from a correct posture to the last one gathered.

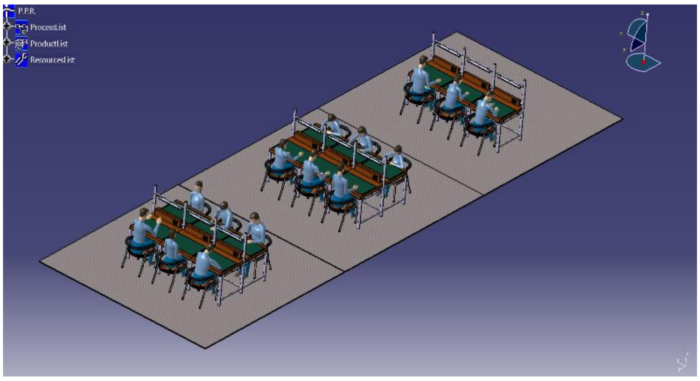

Fig. 3. Virtual representation of S&T Library on Delmia.

2.5 CAMan: objective comfort indexes

To obtain objective comfort indexes from the collected angles, the CAMan® software [21] has been used.

The CAMan® software is based on experimental studies conducted by A. Naddeo et al. to give a comfort index according to postural angles assumed, especially the angles of the human joint. As far as upper limbs, it considers:

- neck: frontal flexion, rotation and lateral flexion
- shoulder: frontal flexion, abduction/adduction
- elbow: flexion/extension, pronation/supination
- wrist: flexion/extension, radio/ulnar deviation

For each joint, curves of postural comfort over angles are used. Comfort indexes are rating on an 11-point scale where 0=”no comfort” and 10=”maximum comfort”.

These comfort indexes consider the limbs moving freely in the space, without any kind of support.
Since students used to lay their wrist, forearms and elbow on the desk for the whole of time, only neck and shoulder comfort indexes have been evaluated.

3 Results

As regards the trend of global comfort over time, results are shown in Figure 4. The values represent the average of expected comfort and global comfort for each task. There was a decay over time, starting from a higher comfort expectation to the lower perceived comfort in “Task 4”.

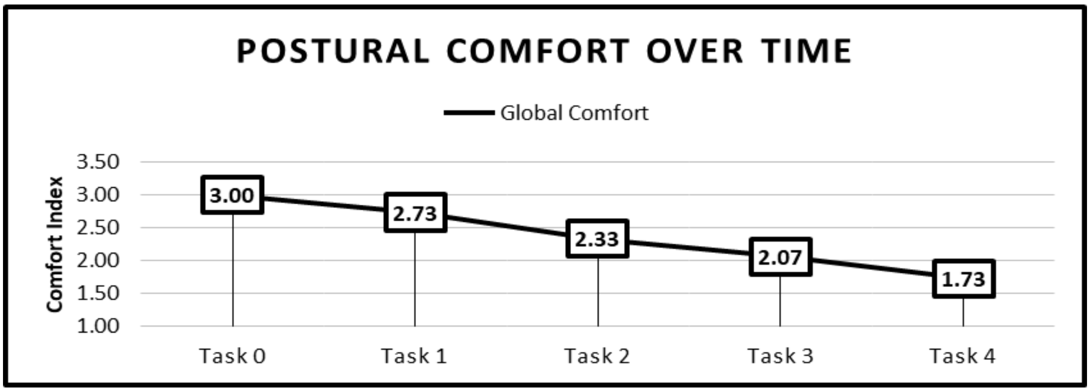

Fig. 4. Evolution of the average global comfort over time (Task 0 represents the expected comfort, while the other tasks the evaluation given by participants). Values are the average mean on a scale from 1=”no comfort” to 5=”maximum comfort”.

Analyzing the questionnaire results, Figure 5 shows the values of average mean of postural comfort for each body part. Comfort indexes in "Task 4" scored lower values than the ones in "Task 1": this confirms the comfort decay over time. Furthermore, the lumbar zone scored the lowest values of comfort, followed by the neck, torso and shoulders, while the arms, forearms and wrist scored the highest values.

Wilcoxon test have been performed to compare each task and results were significant at $p<0.05$, especially between "Task 1" and "Task 4". It means there are significant differences between the first task and the last task.

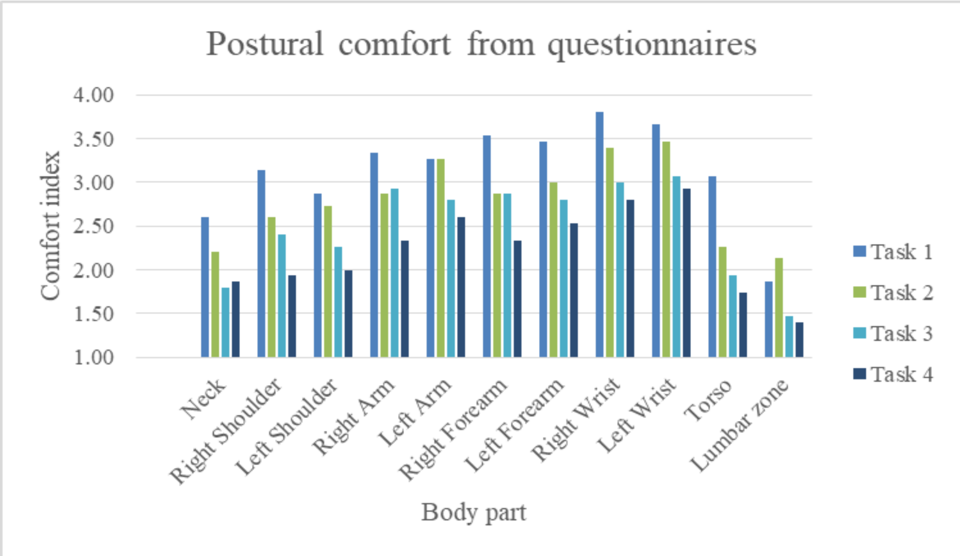

Fig. 5. Mean values from questionnaires for each body part (1=no comfort; 5=maximum comfort)

3.1 Correlations

Correlations between subjective comfort indexes from questionnaires and objective comfort indexes from CAMan have been calculated with IBM® SPSS® Statistics version 24, taking into account even the dependence on type of activity, it means to evaluate whether the comfort depends or not on the initial activity.

Thus, correlations have been calculated between the following comfort indexes:

- body parts from Questionnaires & body parts by CAMan®
- body parts from Questionnaires & Global Comfort from Questionnaires
- body parts by CAMan® & Global Comfort from Questionnaire

It has been found that height, weight and gender did not affect the Global Comfort. There have not been correlations between the first task and the last task: this is coherent with the decrease of the Global Comfort over time. Each single task affected only the next one.

Outcomes from results:

- strong correlations between body part questionnaire & body part CAMan (mean $p\sim0.8$)
- strong correlations between body part questionnaire & Global Comfort Questionnaire (mean $p\sim0.7$)
- strong correlations between body part CAMan & Global Comfort Questionnaire (mean $p\sim0.6$)

Doing the same analysis by grouping the participants that began with the same task, only few correlations had been found out, therefore the postural comfort depends only on the time evolution.

4 Discussion

Due to students' disorders and complaints, a postural comfort analysis had been done, following the existent methods in literature [35,40,41].

A brief evaluation showed the chair was not suitable for students (Figure 1 & Figure 2); it means there were already prerogatives to force students moving on the chairs to find a comfortable posture.

As a matter of fact, considering the correct sitting posture, it means sitting up straight, leaning arms on the desk, keeping feet on the floor, the chair seems too large to fit an international population (Figure 2) with medium anthropometric measurements [34]. Indeed, even if the chair is completely close to the desk, due to the height of armrests, the backrest is too far away from the edge of the desk (Figure 1). Thus, the students, in order to assume a good posture, are frequently forced to change the posture going from the one near to the desk to the one distant from the desk and the back leaned on the backrest. During the tests, all participants accused pain in the lumbar region, because to sit properly they were unable to lean their back on the backrest and to unload the weight of the head and the back.

Furthermore, as far as the people with the height approximatively lower than 1.60 m, they have some problems with the chair because their knees lean on the seat-pan when their back is leaned on the backrest, thus they are not able to bend the knees and to put their feet on the ground.

The postural comfort trend over time, starting from the correct sitting posture, had been simulated through the two main tasks of the study (writing and reading). To keep the importance of time effect, tasks had been performed in succession without a long pause. Results showed a decay over time; it means the chair was not comfortable as expected at the beginning, scoring the lowest value of global comfort in the last task.

There had not great differences between expectation and the values of global comfort because some students had already some experience with the chair and this could have influenced the answers about the expectation.

Postural angles had been gathered by Kinovea® using pictures taken during the experiment.

The virtual simulation had been done in Delmia® to see the postures assumed by students over time: starting from the correct sitting posture, they used to assume a slouched one at the end of the experiment.

It is recommended to make modifications to the virtual environment and test the renovation to improve students' postural comfort, by assuming the correct sitting posture.

Objective indexes of postural comfort had been collected by CAMan®, where for each human joint angle a comfort index had been obtained.

There are some limitations of CAMan® software to be acknowledged. Firstly, the software considered the participant itself positioned in the space without any kind of support: comfort perception is different in the presence of support. Indeed, if someone bends the upper limbs in the space, without any support, the feeling of comfort is very low; instead, with a presence of a support to unload the weight, the comfort perception is higher. Since during the tests, participants laid their forearms on the desk, the comfort perception on this posture was higher than the same posture without the desk. This has been even confirmed by questionnaire results (Figure 5). Thus, objective comfort indexes of elbow and wrist had been excluded.

Secondly, when the experiment had been performed, the CAMan® version did not consider the lower limbs. Thus, it was not possible to compare the subjective results of the lumbar zone with the objective indexes of lower limbs from CAMan®. Thus, it is recommended to repeat the experiment implementing the evaluation of lower limbs.

Using CAMan® allowed comparing subjective comfort indexes with the objective ones, given more validity to the experiment and its results.

The chair could be improved by increasing the area of backrest using, for example, a pillow in the lumbar region. Otherwise, it could be better to amend the chairs by reducing the width in order to reduce the gap between the seat pan and the backrest.

5 Conclusion

After a brief investigation among students inside the S&T Library, it had been found out a general physical complaint. Thus, a postural analysis had been performed following a systematic method. A typical study-day had been represented through two tasks: writing and reading. During the experiments, photos had been taken from four different views to detect postural angles by Kinovea®. Those postural angles had been used both to realize a simulation inside the virtual environment of Delmia®; and to obtain objective postural indexes by CAMan®.

In summary, this paper argued that:

- The comfort perception decreased over time;
- The lumbar region scored the lowest value of comfort, thus, this region influences all postural performance, as confirmed by literature studies;
- Software CAMan® had been used as a tool to obtain objective data of postural comfort;
- There had been correlations between subjective and objective comfort indexes;

The main goal was to demonstrate through the postural comfort analysis that the chair was few comfortable, so it is necessary to do some modifications, like an extension of the back-support area or a reduction of the seat-pan width. These renovations can be simulated with Delmia® through a careful analysis, in order to detect quickly the areas to be improved, then to realize a prototype already optimized.

Furthermore, in this work, a method for the definition of comfort indexes has been shown. All the acquisition methods used are very cheap and easy to use. The precision of the acquisition method, as well as the fact that by not using complicated, expensive acquisition methods, gave us the possibility to reach a very good numerical/experimental level obtaining important results revealed by this paper. The method can be easily reproduced for other applications.

Acknowledgments The research work reported here was made possible by students' help that kindly took part to experiment.

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A Holistic Comfort Model for Virtual Cabin Designs

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Abstract Holistic comfort models are becoming increasingly important for the design and virtual evaluation of advanced automotive cabin and occupant experiences. Whereas for manual driving the main driver tasks have been relatively fixed, with the advent of automated driving the possible occupant activities dramatically increase which should influence the experience of comfort. The question is how trade-offs between comfort, efficiency, and costs can be balanced to create optimal cabin designs: How much do entertaining or time-saving activities like watching movies or reading reports influence the overall experience of comfort? Compared to this, how important is physiological comfort toward the overall experience of comfort? Such questions are investigated in the European research project DOMUS that is addressing the challenge of increasing the range of electric vehicles by 25% in different ambient conditions while maintaining or improving the experience of comfort of driver and passengers.
As part of this project we are postulating a holistic comfort model that is based on existing comfort models and extend them to include the experience of satisfaction as a main second factor beside physiological comfort. We then report the results of the first study to investigate the connection between the vehicle occupants' activities and their experiences of acoustic comfort.
Participants performed a motoric tracking task at three levels of difficulty while hearing the sound recordings of either one of two electric vehicles. The results indicate that at increased activity levels participants also reported greater acoustic discomfort for bother types of vehicle sounds. The results are consistent with the postulated holistic comfort model and we discuss the implications and planned next steps to test and expand the model.

Keywords: Holistic comfort model, auditory comfort, mobile tracking task, virtual development, automotive comfort.

1 Introduction

Increasing virtualization of vehicle design and development pushes design and development processes from physical prototypes to digital environments. Physical prototypes are expensive and take a long time to build whereas novel markets require faster and more flexible design processes. Especially the prospect of automated driving functionality opens a new chapter of designing vehicles that go even further beyond mere physiological comfort considerations. In such vehicles, there exist considerably more trade-offs between design variations to achieve an acceptable balance of passenger experience, functionality, technical efficiency, feasibility, appearance, and costs. These trade-offs can be addressed using virtual design processes to quickly evaluate the large number of permutations of possible designs. However, such processes require appropriate digital models of human behavior and perception. While this push for virtualization can be observed in automotive developments they are also applicable to other domains where environments are being designed for humans such as in aviation, building, and city architecture. Therefore, models of human comfort are now being adopted for virtual developments. Specifically, single-dimensional comfort such as seating, acoustic, or thermal environments are starting to be combined into multi-dimensional, holistic human comfort experience models.

The connection between comfort and vehicle cabin designs is being investigated in the European Horizon 2020 DOMUS project (https://www.domus-project.eu/) that investigates cabin design interventions to increase the range of electric vehicles while at the same time support acceptable human comfort. In this project, different design strategies are virtually evaluated for their potential to increase driving range while at the same time achieving acceptable comfort experiences. Comfort and efficiency thereby represent competing objectives that need to be investigated at the same time to identify acceptable trade-offs. This requires the use of holistic comfort models.

In this paper we propose a model of holistic comfort that is based on existing multi-dimensional comfort models and adapt it for the purpose of automotive cabin designs. We then report a first experimental study to investigate the impact of workload on acoustic comfort. We discuss the findings in the light of the holistic comfort models and propose a concrete additional study to confirm and expand the model further.

1.1 Toward Holistic Comfort Models

Comfort expectations for automotive vehicle cabins go beyond mere physiological comfort as indicated by the inclusion of many non-driving related features such as entertainment and information systems and aesthetic styling characteristics. Especially as driving gets automated these trends are expected to accelerate as vehicles become increasingly places to work, communicate, and relax. Even in today's modern vehicles, designers speak about empathetic assistants[1] who sense human emotions and appropriately adjust to provide optimal occupant experiences. This leads toward a wider understanding of comfort that goes beyond physiological comfort: sitting in a comfortable chair at perfect room temperature for extended time may not result in the experience of overall comfort if the experiencers activities are not taken into account. Therefore, it seems that in order to understand the comfort experiences of modern drivers and passengers comfort models would need to incorporate the human experience to a greater extent. Whereas physiological comfort is mainly influenced by the interaction of the body with the environment, a positive experience of holistic comfort, we think, needs to take into account the experience of satisfaction in the vehicle environment. Human satisfaction experiences have been investigated in many areas, but especially in product design (e.g. [1], [2]) and work places where factors of satisfaction include autonomy, control, tasks and task identification (e.g. [3]).

According to the comfort theories of [4] comfort is influenced by the interaction between the human, the activity, the product, and the environment which results in body sensations that are modified by comfort expectations, resulting in feelings of comfort, discomfort, or no feelings.

[5] expanded this model toward mattress comfort and measured the impact of expectation on comfort judgements. We are expanding this model further by including psychological moderator processes for two different types of comfort aspects: physiological comfort perception and the experience of satisfaction, see Figure 1. Each of the main components is briefly discussed next.

[1] https://readwrite.com/2018/01/18/empathic-ai-next-generation-vehicles-will-understand-emotions/

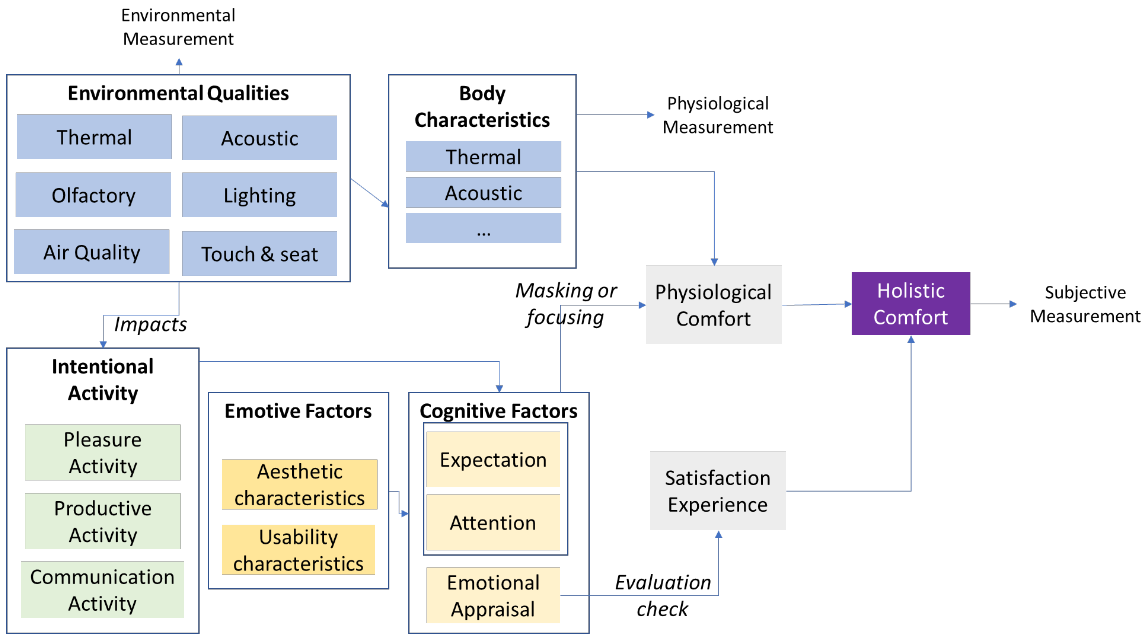

Fig. 1. Holistic Comfort Model

Environmental qualities describe the aspects of the environment with which the human body interacts as basis of a physiological comfort assessment. In the Vink-Hallbeck model [4] these qualities are ordered around person, product characteristics, and usage/task as well as the working environment, but in the end what is sensed by the human body are thermal, acoustic, olfactory, lighting, haptic and seating, and air-quality characteristics.

The specific body characteristics interact with the environmental characteristics so that physiological sensations are formed as indicated in Vink-Hallbeck's model [4]. Clothing for example influences thermal sensations and the shape of the body impacts the seating comfort experience. Both, body characteristics as well as the interaction between environmental qualities and body characteristics can be measured using physiological measurements.

The experience of physiological comfort is moderated by cognitive factors effectively masking or emphasizing the physiological perceptions. This moderation effect of cognitive processes on perception is for example in the focus of the investigation of chronic pain [6]. Also, [7] investigated the comfort of passengers while sitting for a prolonged period of time (e.g. in-flight entertainment) and environmental conditions have been shown to impact passenger comfort. This may be explainable by the fact that attentional resources are pulled from the physiological experience toward other areas or activities which may allow to endure comfort over prolonged amounts of time. Comfort expectations may further attenuate the physiological comfort thresholds: people report experiencing the comfort of a mattress to be higher when it is introduced as a high-quality product versus a low-quality product [5].

Intentional activities represent the activities that the vehicle occupant is engaged in and form the basis for the cognitive appraisal processes of satisfaction or dissatisfaction. Aspects of satisfaction in the work context are listed for example by [3] and include autonomy (see e.g. [8]), level of control, skill variety, task significance, and identity as well as feedback. User satisfaction models have been postulated in the design community (e.g. [2] and [1]). Altogether, these factors are different from physiological factors requiring an emotional appraisal process rather than for physiological comfort. Whereas the perception and evaluation of physiological comfort is based on expectations and the availability of attention to filter, suppress, or emphasize the physiological perceptions, emotional appraisal processes should be involved in the decision concerning the experience of satisfaction or dissatisfaction (see e.g. [9]). The activity itself becomes part of the comfort experience. The environment may more or less support the conduct of these activities. Furthermore, emotive product characteristics such as aesthetic and usability may further strengthen the experience of satisfaction.

1.2 Research Questions

The proposed holistic comfort model has several predictions that can be empirically investigated. The first prediction is that cognitive factors influence the perception of physiological comfort. Specifically, if the physiological characteristics of a given environment do not support the performance of an intended task, the physiological comfort should be perceived to be lower. We investigated this by changing the difficulty of a motor task that requires eye-hand coordination and measured the impact on acoustic discomfort. The motor task however did not require cognitive auditory processing. Performing the task at a higher difficulty level should lead to lower acoustic comfort in the presence of a constant noise that is loud enough (see e.g. [10] for a widened interpretation of the Yerkes-Dodson law). Therefore, we expect that the higher the noise level the higher the perceived discomfort.

In the following, we report a first pilot study that we conducted to investigate this prediction of our model. While the study was originally intended to test the study materials and general feasibility of this concept, we found the results to be significant, both statistically and theoretically. Therefore, we present these results next.

2 Method

The pilot study investigated the influence of three levels of workload on the participants' perception of acoustic discomfort. Eleven participants, 8 of them male and 3 female participated, their mean age was 38 years. After participants completed a sociodemographic questionnaire they indicated their individual noise sensitivity on a noise sensitivity questionnaire [11]. The scale contains 21 items to assess noise sensitivity on a 6-point scale. The items asked the participants to indicate their attitudes toward noise and their emotional reactions to a variety of environmental sounds encountered in everyday life. Then participants were asked to perform a motoric task at either one of three difficulty levels while hearing either one of two electric vehicle sounds through a headset, see following subsections. The participants completed altogether 6 trials (three motoric task difficulties x 2 sounds in a complete within-subject design). The order of the trials was randomized to account for order effects. After each trial, participants indicated their experienced workload using the NASA TLX [12]. Participants were also asked to indicate their acoustic discomfort (annoyance or "Störung" in german) using the Magnitude Estimation Technique (MET, [13], [14]). After the 6 trials, participants rated the sounds using 23 descriptors that were derived from literature, see [15], see Table 1, on a 9-item scale.

Table 1. Adjectives for Psycho-acoustic Evaluation

Loud	Strong	Sharp	Rough
Discrete	Beautiful	Muted	Attractive
Crackling	Comfortable	Whistling	Relaxed
Special	Faultless	Clear	Frightening
Harsh	Sturdy	Stable	Shaking
Monotonous	Growling	Rushing	

2.1 Sounds

To assess the impact of sound quality, the sounds of two different electric vehicles were recorded. The sounds for vehicle A were recorded in a Tesla Model S whereas vehicle B sounds were recorded in a Citroen C-Zero, see Figure 2. Throughout the experiment, participants were not informed about the source of the vehicle sounds. Recordings were made using a bi-aural microphone positioned at ear-height of the passenger seat using an artificial head. During the recording the vehicles were driven at a constant 100km/h. The measured sound pressure levels were 64 dBA for vehicle A and 70 dBA for the vehicle B. These levels were reproduced during the experiment where participants listened to the sounds on a Sennheiser HD25-1 headset.

Fig. 2. Electric Vehicles A and B for which sounds were recorded

2.2 Tasks

The workload inducing task was a critical tracking task [16] as implemented by the mobile tracking task application [17]. Participants were asked to keep a circle in the cross-haired center of a handheld tablet that moved as the tablet was tilted, see. Figure 3. The parameter settings were set as indicated in at x, y, and z, resulting in increasing difficulty in keeping the circle in the center.

Table 2. Used MTT Parameter Settings

Parameter	*Easy*	*Medium*	*Difficult*
Sensitivity	5	20	30
Instability	0	15	25

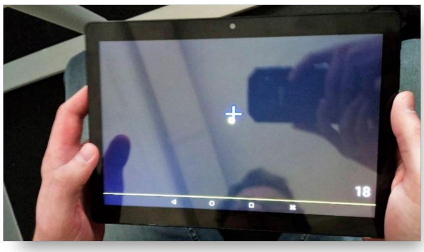

Fig. 3. Mobile Tracking Task

3 Results

As expected, did the participants self-reported workload levels differ between the three task difficulty levels, see Table 3. The ratings were averaged across NASA TLX scales (scale 5, effort, was reverse coded) and transformed onto a scale from 0 to 10, 10 indicating maximal subjective workload. The task difficulty effect was statistically highly significant as indicated by a repeated measures ANOVA (F $df=2,20 = 24.98$, $p < 0.001$ after Greenhouse-Geisser (GG) adjustment due to slight violation of the sphericity assumption). These results serve as confirmation that our experimental tasks indeed led to differences in perceived workload.

Table 3. Mean subjective workload ratings (NASA TLX) per condition

Measure	*Easy*	*Medium*	*Difficult*
Mean	3.49	4.35	4.56
Std	0.61	0.74	0.50

Participants indicated their perceived acoustic discomfort by the drawn length of a line as well as by stating a number. These two types of measurements were, as expected, highly correlated with each other ($r(90)$ =

0.95, $p < 0.001$) so after standardizing and normalizing them, the two types of measurements were averaged and used as an overall indicator for perceived acoustic discomfort. A repeated measures ANOVA with the two within-factors vehicle type and workload level revealed two significant main effects of vehicle type ($F_{df=2,20} = 17.93$, $p < 0.01$) and workload level ($F_{df=2,20} = 5.5$, $p < 0.05$) after GG adjustment as indicated above. The interaction between the two factors was not statistically significant. The sounds of vehicle A were found to be less uncomfortable than the sounds of vehicle B. As result, perceived acoustic discomfort was different between the two vehicle sounds and also differed dependent on workload levels: in the higher workload conditions, acoustic discomfort was also perceived to be greater for both vehicle sounds, see Table 4 and Figure 4. We had hypothesized that the interaction of the two factors would also be significant such that the increase in discomfort should be steeper with the less comfortable noise type. However, this could not be confirmed.

Table 4. Mean Acoustic Discomfort MET ratings (Standard deviations in parentheses)

Measure	*Easy*	*Medium*	*Difficult*
Workload	3.49 (0.61)	4.35 (0.74)	4.56 (0.5)
Discomfort (Tesla)	0.16 (0.21)	0.32 (0.23)	0.45 (0.39)
Discomfort (Citroen)	0.47 (0.35)	0.71 (0.25)	0.77 (0.23)

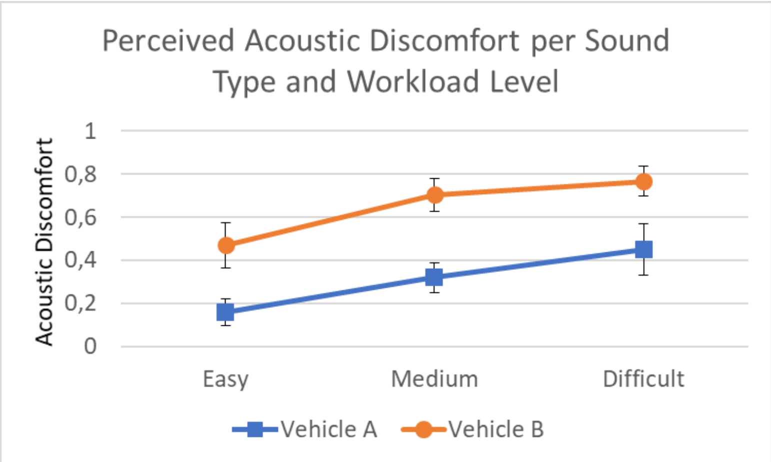

Fig. 4. Mean and standard errors of acoustic discomfort measurements

Participants found that the sounds differed on some of the 23 acoustic aspects on which they had assessed the sounds. Statistically significant using a t-test were found for the following characteristics: Sound B was found to be louder, stronger, sharper, and rougher than sound A. Sound A instead was found to be more discrete, more beautiful, and more muted. These ratings confirmed that the participants were actually able to perceive differences in the sound qualities.

4 Discussion and Conclusions

In this paper we presented a holistic comfort model and reported the results of a first pilot study to evaluate connections between experienced workload and acoustic discomfort. It was found that acoustic discomfort was influenced not only by the sound quality but also by the experienced workload level. Acoustic discomfort was found to be greater at higher workload levels for both types of sound. We had hypothesized this in the model as the physiological environment interacts with the tasks that need to be performed. While this is consistent with the presented holistic comfort model, we also had expected an interaction between sound type and workload level such that the less comfortable sound would cause an even steeper increase in discomfort than the more comfortable sound. This was not found to be the case.

The current study only investigated the link between experienced workload and acoustic discomfort, but not holistic comfort for which we need a more immersive environment. Therefore, in our next study we ask participants to drive a vehicle in a driving simulator and give them different tasks while exposing them to a more realistic acoustic environment compared to the one assessed in this study. We expect that the different task types will trigger different impact on the holistic and acoustic comfort perceptions and therefore allow to differentiate between the explanations given in this study. We will soon report the results of this study.

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Future Cabin for the Asian Market - FUCAM

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Abstract

The paper gives an overview on the main results of the European – Japanese Innovation Project FUCAM, a “Horizon 2020” **collaborative project**, started 1/02/2016, running **36** Months.

Project partners Europe: Airbus, Aalto University, Bertrandt, Cranfield University, EASN, Mormedi, Stelia; Japan: Jamco)

The main objective of the FUCAM (Future Cabin for the Asian Market) project is to develop a conceptual cabin design for the aircraft of the future (after 2025) tailored to the Asian market, and different from the worldwide standard cabin of today. The FUCAM project analysed the operator and user requirements of airlines and passengers in the Asian markets of Japan, China and South-East Asia. In parallel, FUCAM established a panorama of innovative cabin technologies emerging in Europe and Japan. Based on these inputs, a cabin scenario was composed providing innovative concepts for high density seat layouts and dedicated seat solutions on the main deck, combined with extra offers on the lower deck.

To meet cultural specificities of Asian travellers in terms of comfort and also to meet operator requirements in terms of seat density, specially designed business class seats were developed. Derived from Japanese living room chairs, which have a lower relax seat position and use less space than regular business class seats, the design allow for a better use of valuable cabin floor space and thus positively influence affordability of business class travelling. For economy class, a versatile, compact and light-weight seat bench concept was designed that can be used by single passengers, families or provide comfort to people of stature. This element will positively influence affordability as well. Both solutions can use the standard interfaces, so there is no need of any modifications regarding aircraft integration.

The main deck solutions are complemented with very modular passenger offers on the lower deck, the ‘Air-lounge’ concept. The concept comprises a fixed installation on lower deck, with seating possibilities, separate gender lavatories and possibly vending machines. The fixed installation can be combined with additional con-

tainer based modules to increase the passenger capacity of the lounge area and provide catering and experience features for retail, relax, work or gaming.

Various scenarios for using the lower deck space have been developed. The retail module for instance, aims to facilitate on-board brand engagement and shopping. Going beyond current offers of in-flight beverage and drink purchases, it offers the opportunity to connect with the brand through an immersive experience, as well as browse and pre-order from a vast selection of goods and services (e.g., clothing, shoes, taxi, car rentals, hotels or other accommodation, baggage service, spa treatments), to be delivered at the destination airport, hotel, or elsewhere during one's further trip. The 'Airlounge' passenger experience can become a real game changer for airlines in terms of revenue and diversification especially for the fast and growing Asian market

The FUCAM project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690674.

Keywords: Cabin Concept, Asian markets, aircraft seat, aircraft systems, connectivity

1 Introduction

The Asia Pacific region is the fastest growing air transport market in terms of aircraft deliveries and seat capacity growth. It will be the biggest driver of air travel demand by 2036, supplying more than half of the 7.8 billion travellers expected to fly in the next 20 years according to the International Air Transport Association [1].

To develop the cabin concepts addressing these markets, a multi-method approach was used to uncover and analyse market trends and user requirements from the airlines' and passengers' perspectives along with cultural factors in Japan and China. The concepts developed for future aircraft (after 2025) differ from the worldwide standard cabin of today and are tailored to the needs of the Asian market.

Further input for the design development was a systematic scouting and analysis of relevant novel and emerging technologies originating from a variety of industries.

Iterative rounds of out-of-the box concept ideation and reflection on the identified drivers were done.

The FUCAM concepts provide innovative seating layouts and dedicated seat solutions on main deck in combination with extra offers on the lower deck. The lower deck facilities use the existing cargo space in a modular way and provide a fixed installation with lowered floor (full standing height), where restrooms and an interior concept called 'Airlounge' is installed. Additional standard container based 'experience modules' can be installed and easily exchanged to adapt the lower deck experience.

2 The FUCAM cabin

FUCAM involved several comprehensive studies and surveys for acquiring the passengers' requirements and profiles and a further in-depth study on air transport trends, key airports, overview on airlines, challenges in the development of the air transport market, and key routes.
A series of user involvement activities accompanied by desktop research to identify trends, cultural factors and preferences relevant for cabin design have been complemented so as to enhance the user and market understanding. Furthermore, a comprehensive database of relevant latest, emerging and soon-to-emerge technologies for potential application within FUCAM cabin concepts, counting 353 items, has been compiled.

A down-selection of technologies that are most beneficial in scope of the FUCAM project has been performed in accordance with the needs of modern Asian customers as identified by partners, and the preferences of project stakeholders as identified using internal and external expertise.
The basis for the approach to assess the identified technology against the proposed FUCAM cabin concepts has been established following a comprehensive review of existing Technology Assessment methods, having identified around 40 Technology Assessment specific criteria.

Developing the integration approach for the future cabin concepts included the assessment of the concepts in terms of general feasibility, the elicitation of the requirements to achieve this feasibility, as well as the development of concepts for installation, customization and systems integration.

Finally, the functional verification and validation of the developed concepts regarding the functional requirements was also performed.

2.1 Selected passenger & operator insights

Below you will find some example of passenger and operator insights driving the development of the concepts

Passenger in Japan:

- Emphasis on comfort; seats, technology, pleasant environment achieved with personal items. Maintaining a good feeling and atmosphere
- High awareness of quality, the feeling of quality from small details and going the extra mile
- Not disturbing others; Japanese concept of *Meiwaku* has a strong effect in behavior
- Personalization and customization are important, and a way of expressing oneself
- Curiosity and openness to new experiences and information paired with planning and preparation
- Collectivity, traveling as shared experience

Passenger in China

- Growing number of people who are new to air travel, strong and clear indications needed to support activities and preferred behavior
- Experiences are important, there is a willingness to pay for them
- Not afraid to express their thoughts and feedback explicitly and publicly
- Bringing a large amount of bags, food and other personal items on board
- Ability to create a feeling of personal space within limited physical space and separation from others

Operator/Airline

- Important passenger groups: millennials, non-Japanese travelers in Japan (internal market decreasing), elderly people, business travel (even if decreasing) and leisure travel

- Customizing one's travel experience one potential source for ancillary revenue
- Trends affecting air travel: inclusive design (elderly passengers), more holidays (more leisure travel), customizing services and cabin experience (technology and data)
- Potential for differentiation and better brand visibility considered as important elements in future cabin design, with consideration on ease of maintenance and general cost-savings in operations
- Quick modification of the seating ratio (business + economy), as well as seasonal change of interior atmosphere favored

2.2 Cabin Concepts

The concepts include seating solutions for Business Class and Economy Class on main deck complemented by lower deck facilities using the existing cargo space. The lower deck consists of a fixed installation with lowered floor, where restrooms and an 'Airlounge' is installed and a flexible installation where standard cargo container based 'experience modules' can be installed and easily exchanged.

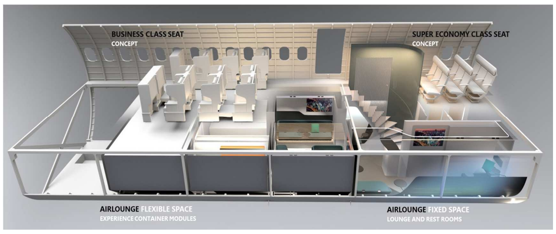
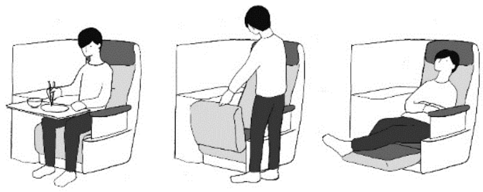


Fig. 1. Concepts overview



- **Business Seat Concept main deck**

For the Business class area on main deck, seats derived from Japanese living room chairs were designed. These seats have a very low relax seat position with a large meal and cocktail table that enables simultaneous multiple activities with a sense of quality and privacy. Passenger can work, eat, relax or take a nap thanks to the interchangeable hard and soft seat cushions.

Fig. 2. Business Seat Concept

The seat is optimized for short-mid haul flights and can be fitted to wide and narrow body aircraft without modifications. In terms of aircraft integration, this element does not require any specific engineering efforts. The usual seat interfaces will be unchanged and provided

Passenger benefit

- A comfortable "nest" with a sense of quality and privacy
- Multi-usability for activities such as work, eat, relax nap
- Relaxing seat reclining positions
- Large meal table and cocktail table surface enables simultaneous multiple activities
- Interchangeable hard and soft seat cushions

Operator benefit

- Optimized for short-mid haul flights
- High density layouts - Enough space to stretch legs without compromising seat density
- Fitted to seat tracks
- Wide and narrow body aircrafts
- Simple in structure which can be made low cost
- Services at flexible timing to not disturb passengers at un-wanting times
- Easy operation

- **Super Economy Seat Concept main deck**

For the Economy Class area on main deck, a versatile compact and light-weight bench style seat was developed. The seat can be used by single passengers, families or provide comfort to people of stature. A variable design allows that the seat may be occupied by three adult persons or two persons of size or even a family with two small children.
This concept provides increased seat pitch with measures to prevent decreasing the level of comfort.

Fig. 3. Super Economy Seat Concept

Accordingly, the seat design allows easy brand customization or pay per use services offered by the airline (for example in seat gaming). Besides the additional revenues this will also help airlines to raise their brand perception by entering into powerful partnerships with iconic brands.

The super economy seat also makes the most of in-seat stowage space and facilitates BYOD (Bring your own device) which is a growing trend with passengers while also saving money for the airlines.

Particularly de-regulated aviation markets ask for more diversity of travel class offers. Enabling affordable travel experiences for emerging markets.

'Airlounge' – Lower Deck "The third place experience"

The 'Airlounge' Concept comprises a fixed installation on lower deck with lavatories, seating possibilities and possibly vending machines. The installation includes a staircase to access the lower deck on a lateral position. The stairs are designed and located in a way that the required space is minimized on main and lower deck. The space below the stairs is used for seating and or vending machines as well.
The fixed installation provides full standing height and is designed to build a convenient experience for relax and as transition space to the lavatories. The lavatories are designed as separate gender lavatories, improving the comfort and designed for Asian preferences. The fixed installation can be combined with additional variable and easily to exchangeable container modules to increase the passenger capacity of the Airlounge and provide additional offers for the passengers. Concepts including the interior design and business scenarios are defined for catering and experience features for retail, relax, work, and gaming

The **'**Airlounge' could be offered to business and/ or economy class passengers that will be located around the stairs for easy access.

Fig. 3. Airlounge Concept

The advantages are:

Passenger benefits

- ✓ Enhanced flight experience
- ✓ Facilitate multiple activities; relax, eat, socialize
- ✓ Gender separated and comfortable lavatories
- ✓ Lowered floor to provide full standing height
- ✓ Builds the comfortable transition space to access experience modules

Operator benefit

- ✓ Especially on medium range routes in Asia where the cargo capacity is not fully needed, the concept allows the Airline to enhance the customer experience and generate extra revenues
- ✓ Can be offered to economy class passengers that will be located around the stairs for easy access – defining an economy+ class where passengers pay a higher ticket price. Alternatively the access to this space can be charged extra/time for all passengers.
- ✓ Extra offer for business class passengers
- ✓ No loss on seat count (lower deck lavatories compensate space

- **Immersive Retail Experience Modules**

The Retail Module is offered to facilitate on-board brand engagement and shopping.
Going beyond current offers of in-flight beverage and drink purchases, it offers the opportunity to connect with the brand through an immersive experience as well as browse and pre-order from a vast selection of

goods and services (clothing, shoes, taxi, car rentals, hotels or other accommodation, baggage service, spa treatments), to be delivered at the destination airport, hotel, or elsewhere during one's further trip.

Retail Module facilitates added benefits from co-branding between the airline and a particular goods supplier, to offer the passenger access to the exclusive content that directly or indirectly promotes the sale of these goods, allowing for an increase of ancillary revenues

Fig. 4. Immersive Experience Retail Module

The advantages are:

Passenger benefit

- ✓ Facilitates on-board brand engagement and shopping beyond current offers of in-flight beverage and drink purchases
- ✓ New entertainment; with more activities and leisure options during flight
- ✓ Convenience of on board sales; time saving for leisure and business trips
- ✓ Access to exclusive & personalized products; only available on flights.
- ✓ New experiences on plane; from the discovery of a new space to new retail concepts.

Operator benefit

- ✓ Retail Module facilitates added benefits coming from co-branding between the airline and a particular goods supplier, to offer the passenger access to exclusive content that directly or indirectly promotes the sale of these goods and allows creating direct revenues from a larger amount of ancillary revenues.
- ✓ Opportunities for strategic partnerships; for brand equity and operational synergies.
- ✓ Diversification of services, away from a commodity provider to integrated service provider
- ✓ All modules use standard container. Flaps are integrated for easy maintenance/cleaning or refill outside the aircraft
- ✓ Simple installation, min extra weight, min cost, quick module exchange

- ✓ All modules use standard container, easy maintenance/cleaning or refill outside the aircraft

3 Conclusion

The shown concepts were developed for a future aircraft cabin for the Asian market, providing means for passenger seating and extra spaces on lower deck that can help to improve the comfort in the future.
Even by having high density seating layouts, mandatory for an economical efficient operation of an aircraft, the FUCAM concepts are developed to maximize the comfort for the passengers, taking into account economical, technical and regulatory requirements and constraints of aircraft operations.

The Passenger experience can become a real game changer for airlines in terms of revenue and diversification especially for the fast growing Asian market.

Fig. 4. FUCAM mock up

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Re-inventing the Journey Experience – A Multifaceted Framework To Comfort in Autonomous Vehicles

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Abstract Future vehicles provide scope to completely re-invent the journey experience. Technological advances have enabled fast progression of driving automation which has the potential to deliver efficient, accessible, sustainable and clean transport systems. Level 4 autonomous vehicles provide an exciting opportunity for drivers and passengers to engage in many activities unrelated to the driving task (e.g. reading, work communication/social networking on mobile technologies, relaxing, watching films etc.) leading to benefits in terms of comfort, pleasure and productivity. There has already been a lot of work looking at the active safety systems autonomous vehicles will need to use as well as the accompanying Human Machine Interface (HMI). For example, studies that look at the time it takes to hand over control from the vehicle to the occupant, and from the occupant to the vehicle. However, little is known regarding the nature of the secondary activities that drivers will want to undertake, and how this will impact occupant comfort, the vehicle architecture, its features and functional safety systems. To understand the ergonomic and engineering impact, first we must capture and fully understand user needs and their preferences in terms of the type of activities that could be undertaken in-vehicle.

Re-inventing the journey experience is a research program addressing the lack of research around the user experience of autonomous vehicles. The main aims of the program are to: (1) understand potential for improving the travelling experience; (2) understand what the ergonomic, legislative, safety and comfort constraints are in order to identify design constraints; (3) understand how design innovations can support new occupant requirements. This paper presents a multifaceted framework which aims to guide researchers and industry professionals to more pragmatic vehicle concepts.

Keywords: vehicle design, autonomy, user experience, comfort

1 Introduction

The automotive industry is approaching a revolutionary shift towards both electrified powertrains and autonomy. These two major developments are expected to improve road safety, reduce traffic congestion and increase occupant productivity as well as many other benefits [1]. Electrified powertrains will create a smoother ride as the engine will produce less vibration and noise, presumably leading to greater levels of comfort. Autonomy will allow the occupants to detach themselves from the driving task and spend that time relaxing, being productive and socializing.

It has been argued that comfort and discomfort are not opposites and can exist simultaneously. 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” [2]. Traditionally, passenger comfort has encompassed air quality, sound and noise, temperature and vibrations [3]. However, with the new paradigm shift toward electrified and autonomous vehicles, there are some new factors to consider. Elbanhawi (2015) argues that these are naturality, disturbances, apparent safety and motion sickness [4]. There is a lot of evidence to suggest that an autonomous vehicle can decrease the level of discomfort of a journey. Drivers will be able to re-adjust their posture when they are not required to drive which will reduce the levels of discomfort [5]. Another potential benefit is an autonomous vehicle could reduce anxiety for nervous drivers or allow the driver to rest and detach from the driving task. There could however be some negative implications for an electrified and autonomous future. Autonomous vehicles could be bullied [6], the occupants could feel range anxiety [7] and a badly designed interface could lead to confusion and disuse [8].

The idea that you could be more productive or do another activity when in an autonomous vehicle is one area of research that is still being explored by research institutions, manufacturers, suppliers and universities. This is often referred to as NDRTs, or Non-Driving Related Tasks and it is believed to be one of the key benefits of using an autonomous vehicle. Previous studies that have been investigating NDRTs have used a variety of methods to determine what the occupant will be doing including surveys, interviews and observations. Some studies have the luxury of using a driving simulator [9] whereas others use road legal vehicles and conduct research within the context [10]. There are however some limitations with how some of the experiments were run. In a longitudinal study by Large et al [5], they wanted to understand the range of activities and items that would be used in highly automated vehicles. The study took place in a medium-fidelity, fixed based driving simulator (Audi TT). It identified some NDRTs as well as the items that participants are likely to use in an autonomous vehicle as well as changes to their physical posture. However, the study did not deal with the risks of future legislation and crash safety, for example the placement of items in relation to airbags. This extra factor could have changed how some participants reacted to the test conditions. Other studies have looked at the broader topic of autonomous vehicle user experience where they have faced similar challenges in addressing future safety and legislative concerns. Another often overlooked consideration when designing an interior of an autonomous vehicle is motion sickness. A large and growing body of literature has investigated the effect an autonomous vehicle will have on an occupant’s physical wellbeing and each of them have generated various design recommendations.

The trend of an aspirational, and often unrealistic vision of an autonomous vehicle has most likely stemmed from OEMs (Original Equipment Manufacturers). OEMs have been producing future vehicle concepts that aim to draw customers into the brands vision. One more recent example of this is the Mercedes F015 [11]. The Mercedes shows the front seats facing the rear seats to create a more social and productive space (example shown in figure 1). This is also shown in the Panasonic concept shown at CES 2017 [12] where they have deploying tables with built in displays. Although the primary purpose of these concepts were to build brand awareness and perception, they have potentially had the unintended effect of misleading researchers to believe that such concepts could be designed safely and within regulation.

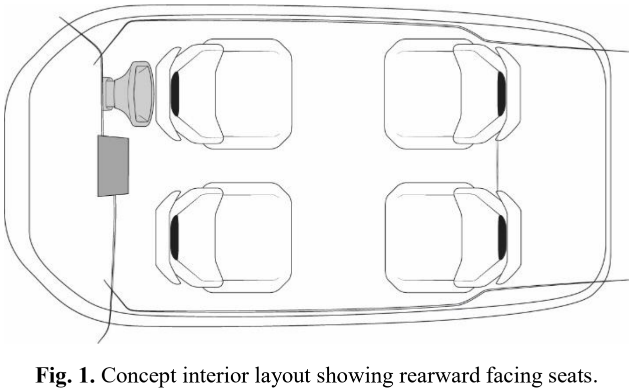

Fig. 1. Concept interior layout showing rearward facing seats.

It is still being debated as to when vehicles will be able to drive fully autonomously, and where there will be no need for a steering wheel [13]. This has been defined by SAE as a ‘level 5’ autonomous vehicle [14]. There will need to be a gradual progression from a ‘level 4’ vehicle to a ‘level 5’ as the latter will require all roads that the vehicle will drive on to be mapped and would require the vehicle to be much more advanced. It is likely that vehicles will be ‘level 4’ for a much longer time, where there is still a need for the driver to take over control for more difficult roads.

This paper will review the published research conducted in the areas of occupant physical wellbeing, including crash safety legislation and motion sickness, and handover of control and create a list of design recommendations for future research to use. This will be restricted to highly automated vehicles that are not yet at full self-driving capability (SAE level 4).

2 Mental Well-being

When a vehicle becomes fully autonomous, or highly autonomous, the occupant will become mentally and physically detached from the task of driving. This could give an opportunity to the occupant to improve mental and physical health. For nervous drivers, it could reduce the stress and anxiety of a journey and for commuters it can give the opportunity to relax after a day at work. There are however some potential added stresses that autonomy can introduce. Especially for early autonomous vehicles, the need to be aware of your surroundings and the responsibility to perform a safe handover of control are both new challenges that come with the technology.

With the freedom of time inside an autonomous car, there is a risk that the driver can become overloaded with non-driving related tasks (NDRTs) and become distracted, reducing the situational awareness. Several studies have investigated the effects NDRTs have on situational awareness and handover of control (HoC) times [15][16][17] and have shown that there is a negative effect on situational awareness when a NDRT is introduced. This is also shown in earlier studies by Giesler & Muller [18], and Lorenz et al., [19] who identified that visual distraction is one of the most important factors related to a safe HoC. As well as over-stimulation, there is also a risk to being under-stimulated [20]. If the driver becomes tired, and falls asleep, the time to regain situation awareness will increase, and this will potentially increase the time required to regain situational awareness over NDRTs [21].

There has been a large and growing body of research that is aiming to identify the handover of control requirements for autonomous vehicles. This work will ultimately result in a recommended handover of control time for manufacturers to use and standardize. This will be for both a safe HoC for transitioning into autonomy as well as into lower autonomy levels, or full manual driving. Kim & Yang (2017) argue that the minimum HoC time will vary depending on the event, for example, roadworks or a car pulling out of a junction [22].

One important, and often overlooked aspect of handover of control is the time it takes to securely stow the items used during NDRTs. Not only will this add to an increase in time to situational awareness and control of the vehicle, it could also have a negative effect on physical well-being in a crash situation. It could be argued that the added pressure of stowing items in a HoC situation will increase the level of discomfort an occupant will feel. Therefore, it is recommended to make the stowing of items a priority in autonomous vehicle ergonomic and user experience studies for both industry and academia.

3 Physical Well-being

Physical wellbeing is arguably the most important factor when considering the perception of comfort in an autonomous vehicle. It is likely that the safety regulations will not change considerably when there are large numbers of highly automated vehicles on the road. Due to this, designers and engineers will be constrained by such regulations which will have an impact on occupant comfort. Below are factors to consider when designing a comfortable autonomous vehicle.

3.1 Motion Sickness

As vehicles progress to become autonomous and electrified, the occupants will have the time to engage in NDRTs. This could potentially lead them to be visually and mentally distracted as well as being outside of the nominal seating position, for example, the use of a display is essential, to watch a movie or to do some work. Kuiper et al (2018) investigated the positioning of vehicle displays, and if it influenced motion sickness. They found that a high-mounted display is preferable to a low-mounted display and this significantly reduced motion sickness [23].

Car-sickness is a form of motion sickness that two-thirds of people will have suffered from at some point in their life [24] and reducing the likelihood of motion sickness will reduce the levels of discomfort an occupant will face. Future research studies should consider the effect their concepts will have on such a fundamental part of physical wellbeing in a vehicle.

Social scenarios are often depicted in vehicle concepts and studies by researchers. They often come to the conclusion that seats should face each other such that the front seats rotate 180° [25]. This however has been found to increase the likelihood of motion sickness in city driving [26]. Sleeping, or relaxing in an autonomous vehicle could have a positive effect on motion sickness as being in the supine position (and sleeping) has been shown to reduce motion sickness [27].

3.2 Seat belts

Seat belts are a fundamental part of the vehicles passive safety system. It is currently required for all new cars to be fitted with seat belts, and they have been proven to reduce the risk of serious and fatal injury by between 40% and 65% [28]. It is unlikely that regulators will decide to de-regulate the use of seat belts, and so should be assumed to be a part of future vehicles.

There is a potential added complication however when NDRTs are introduced. Most seat belts are anchored to the B pillar. This is because it is a structural support for side impact regulations and is strong enough to also anchor an occupant through the seat belt. With the option to disengage from driving, occupants may want to recline the seat, move rearward and create more space in front of them, or partially rotate to be more social and increase the levels of comfort. By being outside of the nominal seating position, and with the seat belt anchored to the B pillar there is an increased risk of serious injury in an accident. This is shown in a study by Dissanaike et al (2008) where they evaluated the accidents of drivers who reclined the seat [29]. Therefore, it is recommended that researchers make assumptions that the seat belt anchor point can be built into the seat itself.

3.3 Seat rotation

Current passive safety systems are not designed for the occupant to be moving outside of the nominal seating position. This includes fore/aft adjustment as well as seat rotation. Full rotation, as shown above, can increase the likelihood of motion sickness [26] and so should be ruled out. There is also an increased complication with designing the safety system. There could be two separate systems for the two seating positions. However, this will not cover the situation of a crash during rotation, and such seats will need to be set either forward facing or rearward facing before the journey, which could limit the usability of the vehicle (e.g. crossing geofenced locations).

Small rotations could be accommodated (shown in figure 2), and a safety system designed for this. There is no evidence that a small rotation of up to 10° will increase motion sickness or risk the occupant's health in a crash and so this would be one way to increase the sociability of the vehicle cockpit. Therefore, it is recommended that researchers limit seat rotation in future autonomy studies.

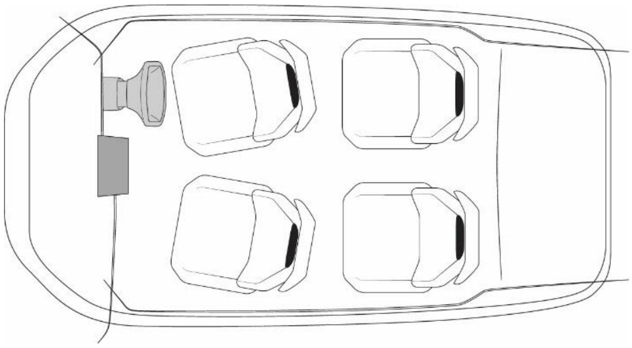

Fig. 2. Vehicle concept showing inward rotated seats.

3.4 Airbags

Airbags are a key element of the safety system, however they are not required in Europe [30]. Front seat passenger airbags can help to reduce the risk of fatal injury by 68% when combined with seat belt use [31]. Airbags, however, are also designed to work in set parameters, usually based on a 50^{th} percentile male in the nominal seat position. This creates a risk for those who are on the extremes like a 5^{th} percentile female, where an airbag can cause injury [30]. There will also be a similar risk in autonomy, when drivers may choose to move outside of the nominal position to relax, sleep or undertake NDRTs.

NDRTs will also introduce more items being brought to the vehicle to occupy the passengers. Previous studies have highlighted how people use these items for example resting their phone on the steering wheel [5]. This can turn into a projectile when the airbag in the steering wheel deploys, leading to serious injury. Modern safety systems are likely to remain as OEMs transition to autonomy, and the fundamental passive safety systems like airbags and seat belts will remain. It is recommended that researchers consider the impact of airbags when designing studies and sharing results, as it could have a major effect on user experience and comfort.

3.5 Item stowage

Securely stowing items in the cockpit, although not legislated, is usually self-regulated internally. Door pockets, cup holders and gloveboxes are all designed to retain the objects in a crash. It is known that loose items can cause serious harm in even low speed accidents [32]. With increase in autonomy, and NDRTs there will be an increase in items brought to the vehicle to be used. This risk can be mitigated, however. There could be dedicated shoe stowage for sleeping and relaxing, as well as easy to access pockets for stowing heavy items in a handover scenario.

There could also be ways to reduce the need to use loose items in the car. For example, if the vehicle interior is designed intuitively, and with these needs in mind the occupant will not need to use a device to watch a movie as the vehicle can provide for that need more safely. This could be achieved by having a suitable display in front of the driver and passengers. If the vehicle can meet the needs of the user more effectively than a device, the occupant will be more inclined to use the built-in system.

4 Factor Hierarchy

The factors already discussed (seat positioning, airbag location, motion sickness, handover of control etc) are not equally important and some factors are more important than others. For example, it could be argued that airbag constraints are more important than the effect of mental loading. Although all factors influence the comfort and journey experience, prioritization is needed when considering the interior design concept. A proposal hierarchy is illustrated in figure 3.

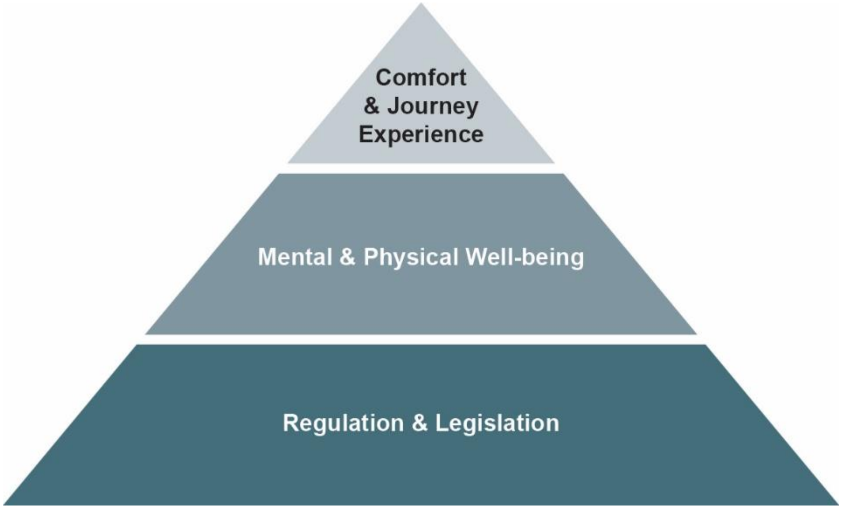

Fig. 3. Factor hierarchy triangle.

5 Design Recommendations

There are a series of evidence-based recommendations that can be made that relate to occupant safety, well-being and handover of control. All of these have an impact on either reducing discomfort or increasing comfort and so should be considered for future studies.

1) Display location should be positioned high up to allow the occupants peripheral vision to be on the outside world. This can be done by increasing the DLO (Day Light Opening) or raising the position of the display. The field of view should be roughly 15° for the display. This is to reduce the likelihood of motion sickness.

2) Seats should be limited to minimal rotation to reduce the likelihood of serious injury and motion sickness. Up to 10° rotation has shown no significant increase in motion sickness [26]

3) It should be assumed that seat belts are built into the seat to allow a greater level of movement. Although this could increase potentially discomfort and could impede on a NDRT; the seat belt is a vital safety component for autonomous vehicles.

4) Stowage of items used during NDRTs should be a priority of both researchers and industry to help increase time to situational awareness and increase mental well-being during HoC scenarios.

5) Use of items during NDRTs should not be placed between the occupant and the instrument panel (or airbag location) as this could lead to serious injury in the event of a crash. Instead consider how the vehicle can provide these needs.

6) Researchers and industry should consider the effect of situational awareness as a key factor when determining the ergonomics and user experience of the vehicle concept. A reduction in situational awareness increases the likelihood of an accident during handover of control.

Finally, it is important that the relationship each factor has on each component should be considered. Figure 4 shows the complex relationships that exist when designing interior concepts, particularly with regards to seat position, handover of control and situational awareness.

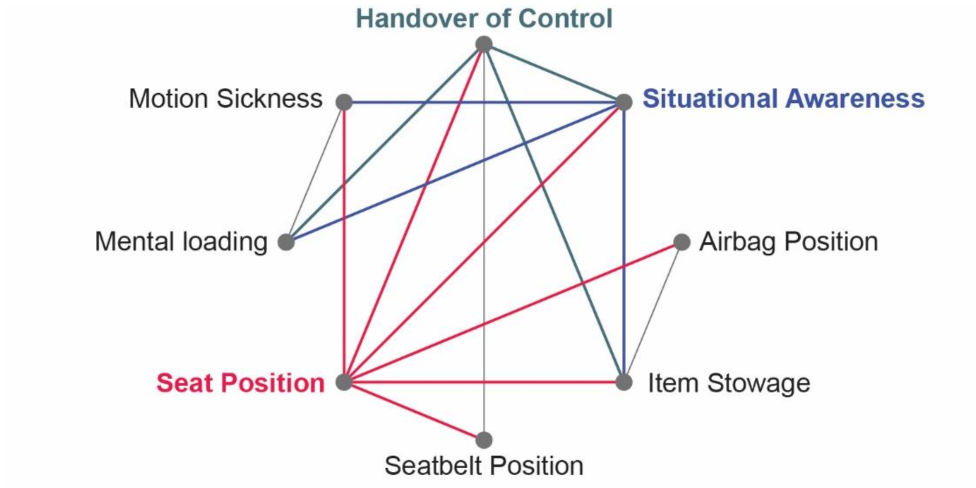

Fig. 4. Diagram showing the relationship between each design factor.

6 Conclusion

Autonomous vehicles have the potential to provide increased levels of comfort, through the ability to adjust seating position more frequently and become mentally and physically disengaged from the driving task. This paper presents a series of design recommendations for future studies to consider when investigating NDRTs. Physical wellbeing, passive safety and handover of control have been identified as important considerations that all researchers should consider but other topics including trust, ease of use and privacy. Future work will investigate the nuanced and complex needs of users to fully understand the holistic human factors requirements.

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Driver seat comfort for level 3-4 autonomous vehicles

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Abstract Autonomous vehicles can classified on a scale from 0 to 5, where level 0 corresponds to vehicles that have no automation to level 5 where the vehicle is fully autonomous and it is not possible for the human occupant to take control. At level 2, the driver needs to retain attention as they are in control of at least some systems. Level 3-4 vehicles are capable of full control but the human occupant might be required to, or desire to, intervene in some circumstances. This means that there could be extended periods of time where the driver is relaxed, but other periods of time when they need to drive. The seat must therefore be designed to be comfortable in at least two different types of use case. This driving simulator study compares the comfort experienced in a seat from a production hybrid vehicle whilst being used in a manual driving mode and in autonomous mode for a range of postures. It highlights how discomfort is worse for cases where the posture is non-optimal for the task. It also investigates the design of head and neckrests to mitigate neck discomfort, and shows that a well-designed neckrest is beneficial for drivers in autonomous mode.

This study was supported by Bridgestone Corporation Japan.

Keywords: Autonomous vehicles, seating, simulator study, backrest, comfort.

1 Introduction

For the past century car seats have been developed primarily for drivers but with little emphasis on passengers or occupants in the rear seats. The classical driving posture involved the driver interacting with pedals and a steering wheel, and with the eyes continually looking at the road ahead or scanning mirrors, controls and displays. Seating postures are well defined and several standards have been produced such as SAE J287 [1] that gives guidance on driver hand control reach.

Technical innovation means that some level of automated control is becoming a standard feature in road cars. This could be a simple as anti-lock brakes, that are now mandated, or intelligent speed assistance, that will be a requirement in Europe from 2022. Autonomous vehicles are classified using six levels of autonomy as defined by SAE [2] (Table 1). From Level 3 autonomy and above the human ‘driver’ may move attention from the driving task. As appropriate for the technology and context, potentially the driver could release the steering wheel, desire to undertake another task (e.g. working, watching entertainment, sleeping), and sit in a different posture (Figure 1). Therefore the requirements for packaging the driver will be very different. Paddan et al. [3] showed that a reclined backrest at 157.5 degrees (i.e. almost reclined was the most comfortable when exposed to vertical whole-body vibration.

At Level 3 autonomy, the vehicle could request human intervention. Therefore the driver might be required to drive in a posture that is optimal for relaxing in the car, but not optimal for driving. At Level 2, drivers will be required to keep close attention on the road ahead forcing a posture that is able to maintain visual vigilance but is still relaxed.

Table 1. Levels of Autonomy as defined by the Society of Automotive Engineers [2].

Level	*Description*
Level 0 No automation:	No direct vehicle control, but warning systems may be present (e.g. parking sensors).
Level 1 Driver assistance:	Automated speed (cruise) control, lateral (lane keeping) control, and parking assistance.
Level 2 Partial automation:	System can take full control of vehicle (e.g. Tesla autopilot), but human supervisor is necessary to re-take control at any time.
Level 3 Conditional automation:	The driver can move their attention from the driving task in well-controlled environments (e.g. highways), but is needed to manually drive the car in complex scenarios. The car can take decisions on whether to overtake and can request a rapid return to human control.
Level 4 High automation:	The car can drive itself in almost all circumstances. Human control may be needed if systems fail (e.g. in poor weather) but the car can safely proceed if the driver is unable to take control. Human control may be possible at the human's request.
Level 5 Full automation:	There is no possibility for the human operator to physically drive the car. The human occupant is effectively a passenger.

Fig. 1. Manual driving assumes hand, feet and head position in a standard posture. In autonomous mode, these assumptions may no longer hold.

This paper reports two studies. The first considered the effect of autonomous and manual driving on comfort in two postures that could be used at Level 3-4 autonomy; the second considered the effect of providing a neckrest.

2 Methods

A driving rig was developed for the study. The rig took overall dimensions from a production saloon car (Toyota Prius) and was custom built from aluminium extruded parts. Steering and seat position were adjustable such that they could be configured for any car model. A seat from a Toyota Prius was used in the driving rig. The visual display comprised four computer monitors each with a width of 630mm. One was placed directly in front of the driver and one placed at an angle of 55° on either side of the front screen providing a nominally continuous field of view of 166° interrupted by the two bezels. The vertical field of view from the primary screens was 21°. The driver sat at approximately 600mm from the central screen, but this was affected by seat fore-aft adjustment. The fourth screen was positioned below the central screen and displayed the instrument panel from the vehicle.

Two sets of driving scenarios were programmed. Set 1 (‘manual driving’) comprised a journey in Great Britain that lasted 30 minutes and was guided using a software ‘satnav’ built into the simulation platform. Drivers needed to manually drive the simulation in this set. Set 2 (‘autonomous mode’) comprised a similar journey to that in Set 1 but the simulation ran in an autonomous mode such that the driver did not need to engage with the steering wheel or pedals in order for the journey to be completed.

Three different seating setups were used in the simulation. In the ‘upright’ position the seat backrest was set to 105° representing a standard driving posture. In the ‘reclined’ posture the seat backrest was set to 127° representing an extreme reclined driving posture, but similar to that used by passengers when relaxing, or in some racing cars and some military vehicles (Figure 2). In the ‘reclined neckrest’ posture drivers were provided with a neckrest designed to support the neck and head, optimised using FEA and piloted. The neckrest (Figure 3) was only used in conjunction with the reclined posture.

Fig. 2. Lab setup showing manual and autonomous modes in the two driving positions.

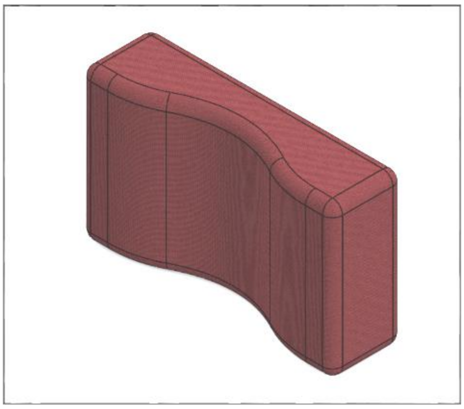


Fig. 3. CAD model of neckrest used in the reclined driving positions in Study 2.

2.1 Study 1 – Backrest angle and driving mode

In Study 1, 7 male and 7 female participants were recruited from the staff and student population of Nottingham Trent University. Each participant visited the laboratory three times. The first visit to the laboratory was a familiarization and preparation session where participants were given instruction, training and information about the study. Participants were given an opportunity to learn how to drive the simulator and ask questions. During the other two visits participants completed four driving scenarios (two per lab visit), presented in a balanced random order. Between each scenario participants left the simulator and completed a 10 minute walk, which has previously been shown to be sufficient to give discomfort recovery [4].

The four driving scenarios comprised:

1. Autonomous mode in the upright posture
2. Autonomous mode in the reclined posture
3. Manual driving in the upright posture
4. Manual driving in the reclined posture

Participants were required to report their discomfort using the two-stage discomfort assessment protocol as previously used by Sammonds et al. [5]. Stage 1 of the protocol comprises a body part discomfort questionnaire where participants were asked to rate their discomfort on a 6 point scale adapted from ISO2631-1 [6]. Seven body regions were considered: lower back, upper back, neck, ankle, sitting bones, buttock area and edge of seat contact. Perceived workload was measured using NASA-TLX [7].

2.1 Study 2 – Effectiveness of neckrest at mitigating discomfort

Study 2 also used 7 male and 7 female participants, but they were different individuals than used in Study 1. The protocol was similar to Study 1 except that five driving scenarios were used:

1. Manual driving in the upright posture
2. Manual driving in the reclined posture
3. Manual driving in the reclined posture with neckrest
4. Autonomous mode in the reclined posture
5. Autonomous mode in the reclined posture with neckrest

3 Results

There were no significant differences between discomfort scores for males and females for any of the conditions in either study. Therefore data were combined for further analysis.

2.1 Study 1 – Backrest angle and driving mode

As expected discomfort increased with time for all conditions studied in Study 1 (Fig 4). In the autonomous mode only small differences were observed between the discomfort ratings in the upright and reclined postures. However, in the manual mode, discomfort was significantly greater for the reclined posture. These discomfort scores were elevated from a mean score in the 'moderate' discomfort range to 'high' discomfort for the manual, reclined.

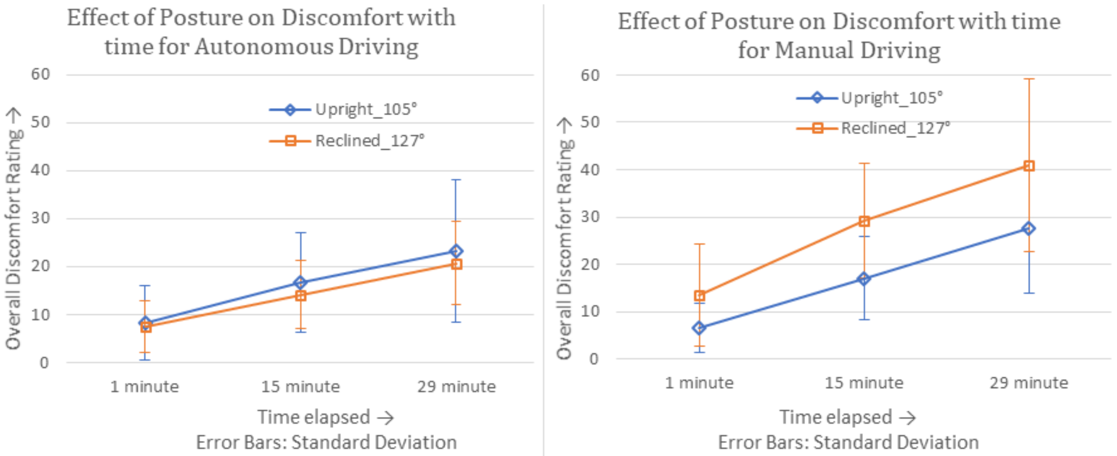


Fig. 4. Mean overall discomfort ratings for Study 1.

Individual body part discomfort scores were low for areas in contact with the seat pan cushion (Fig 5). Scores were highest in the neck region for the manual driving mode in the reclined posture. Increased discomfort was also apparent in the upper back. Verbatim comments also confirmed that the highest levels of discomfort occurred in the neck and upper back and this was attributed to the effort of holding the head in a position allowing for the driver to see the road ahead. Therefore, it was hypothesized that provision of a neckrest optimized for a reclined posture would mitigate the neck pain and improve the overall discomfort scores.

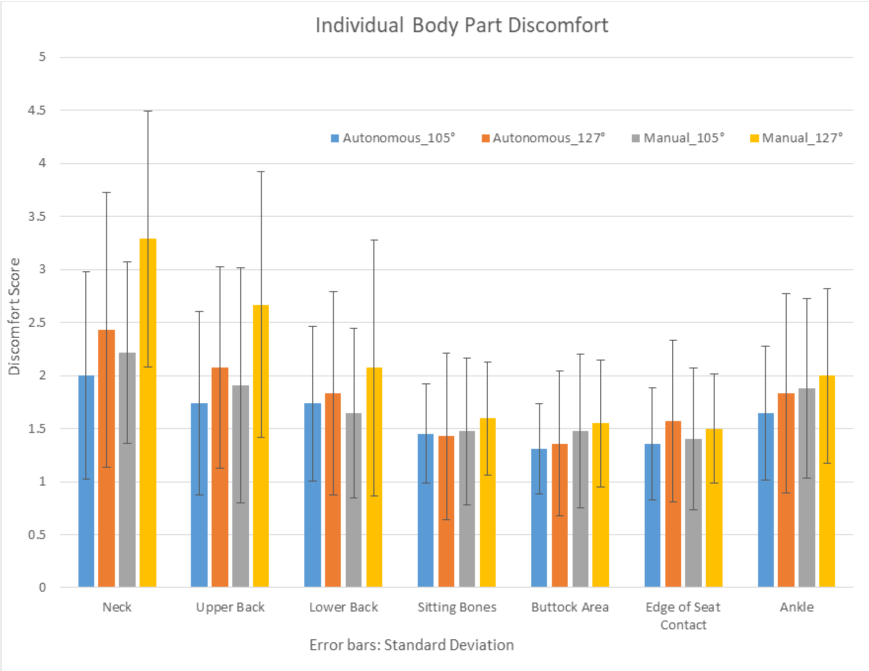


Fig. 5. Individual body part discomfort for Study 1 measured at 29 minutes.

2.1 Study 2 – Effectiveness of neckrest at mitigating discomfort

In Study 2 the overall discomfort scores were not as great as those observed in Study 1. For those conditions that repeated those from Study 1, similar trends were observed with manual reclined being the most uncomfortable posture, and showing significantly more discomfort (Fig 6). In the reclined postures, when the neckrest was used, there was significant improvement in the discomfort scores for both manual and autonomous modes (Fig 7). Individual body part discomfort scores showed that there was no adverse effect on neck discomfort when in the reclined posture when a neckrest was used.

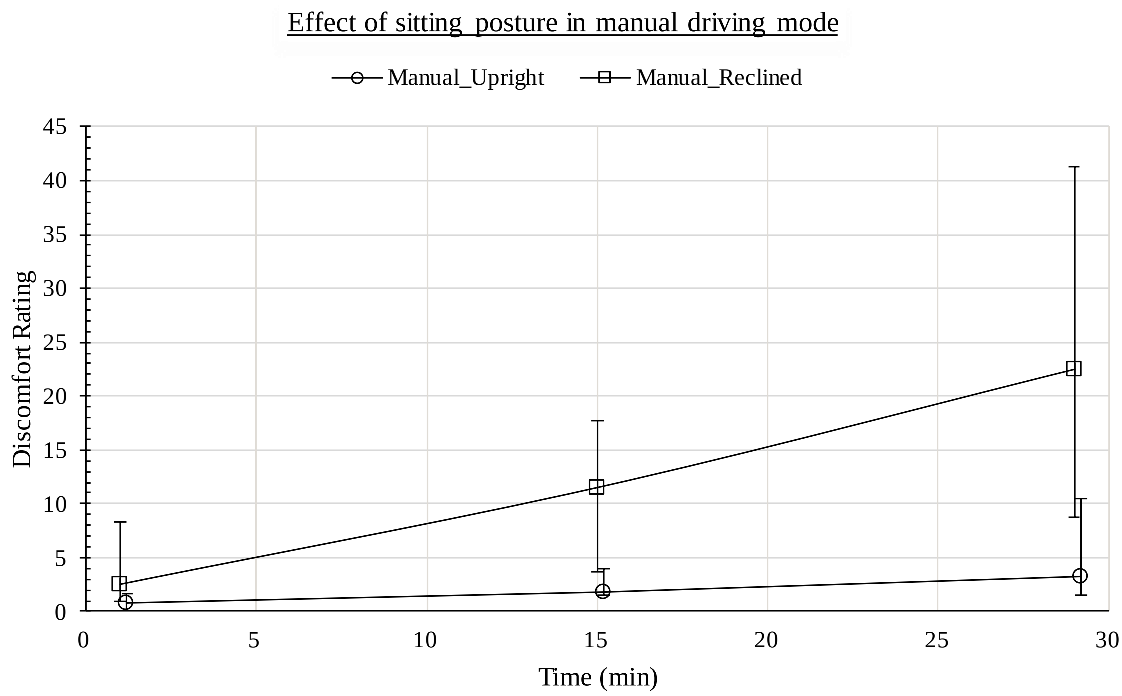
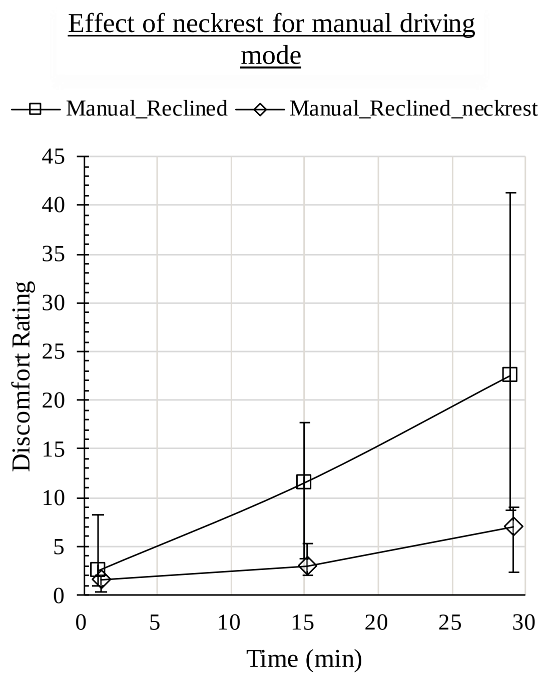


Fig. 6. Overall discomfort measured for manual driving with no intervention in Study 2.



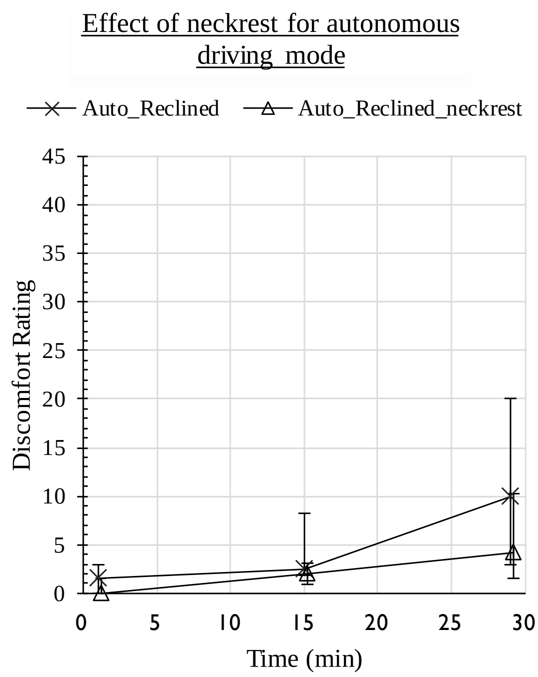


Fig. 7. Overall discomfort measured for manual and autonomous driving with and without neckrest in Study 2.

4 Discussion

The studies in this paper show that reclined postures can induce neck discomfort in both manual and autonomous modes. This might appear to contradict the results of Paddan et al. [3], but the previously published work used a flat seat, and importantly, this seat included a padded headrest. The studies reported here demonstrate how a neckrest can be used to support the head to ensure that the experience of the user is optimized. The neckrest used in this study was a first iteration after initial design using anthropometry and finite element analysis to inform the contouring. Additional improvements are likely to be possible with further optimization of the seat design, the neckrest position and the backrest angle.

Acknowledgments The research work reported here was made possible by the support of Bridgestone Corporation, Japan.

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A Preliminary Investigation of the Association Between Motion Sickness Response and Task Performance and Engagement

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Abstract Vehicle automation will provide the opportunity for occupants who were formerly full-time drivers to become passengers for some or all of their journey. Freed of the constraints of the driving task, passengers will have a much larger behavioral repertoire, including extensive use of handheld devices. Passengers often experience motion sickness, particularly when performing visual tasks such as reading or using a handheld device. However, little quantitative data is available on association between motion sickness response and task engagement in passenger vehicles.

In recent and ongoing studies, UMTRI has developed a vehicle-based methodology to evaluate motion sickness susceptibly in passenger vehicles. This work has been motivated by the opportunities in the design of highly automated vehicles to manage motion sickness through changes in vehicle dynamics and interior configuration, as well as other countermeasures. The in-vehicle methodology includes simultaneous measurements of vehicle motion and the passenger's psychophysical, kinematic and physiological response during typical on-road driving conditions.

This paper describes a preliminary investigation to quantify the relationship between passenger motion sickness and non-driving related task performance and engagement during an on-road vehicle exposure. Data were gathered from 22 participants who self-reported a range of the motion susceptibility levels prior to testing across urban and highway routes. The current protocol is part of a larger research effort to gather passenger response data from road vehicles to inform the design of automated vehicles.

Keywords: Motion Sickness; Passenger Activities; Task Engagement; Automated Vehicles

1 Introduction

Automated vehicles will provide the opportunity for occupants who were formerly full-time drivers to become passengers for some or all of their journey. These occupants will have a much larger behavioral repertoire when freed of the constraints of the driving task. Passengers often experience motion sickness, particularly when performing visual tasks such as reading. For example, Jones et al. (2019) found that motion sickness ratings increased with *task* vs. *no-task* during in-vehicle testing on a closed test track facility. Specifically, participants with higher levels of self-reported motion sickness susceptibility produced higher motion sickness ratings during a 20-minute drive. Isu et al. (2014) also demonstrated differences in passenger's subjective rating response between a no-task condition, visual-search task completed using a handheld book, and movie watching from an in-vehicle display mounted in the front row head restraint. Motion sickness severity was highest for the visual-search task, followed by video watching, compared to the no-task condition.

Most studies that have considered task performance and engagement in road vehicle passenger motion sickness response are focused on variations of in-vehicle displays. Variations have included screens that compensate for vehicle pitch motion and relative motion or displays that provide a visual reference with respect to observing a moving image and control of the image on the display augmented (Kato and Kitazaki 2006; Kato and Kitazaki 2008). Kuiper et al. (2018) also evaluated the impact of the positioning of in-vehicle displays on motion sickness. Visual search tasks were performed on display placed directly in front of the passenger at eye height (high) and at the height of the glove compartment (low). The high display position reduced motion sickness response compared with the low display position.

To date, no studies have quantified the effect of on-road motion sickness response on task performance and engagement. The objective of this investigation is to quantify the relationship between passenger motion sickness and non-driving related task performance and engagement during an on-road vehicle exposure.

2.1 Data-Set

This analysis uses data from a vehicle-based platform designed to study motion sickness in passenger vehicles (Jones et al. 2018). Participants completed in-vehicle testing on local urban roads and highways near the University of Michigan.

2.2 Participants

Data were gathered from twenty-two adults (11 women and 11 men) completed all aspects of the within-subject design. Participant age range was 18 to 33 years with a mean of 24 years. Participant body mass index (BMI) range was 19 to 30 kg/m2 with a mean of 23 kg/m2. Participant stature range was 1516 mm to 1933 mm. Prior to data collection, the participants self-reported motion sickness range using categorical descriptors Never, Rarely, Sometimes, and Frequently. Figure 1 shows the distribution of participants by gender and self-reported motion sickness susceptibly. A University of Michigan Institutional Review Board approved this research protocol.

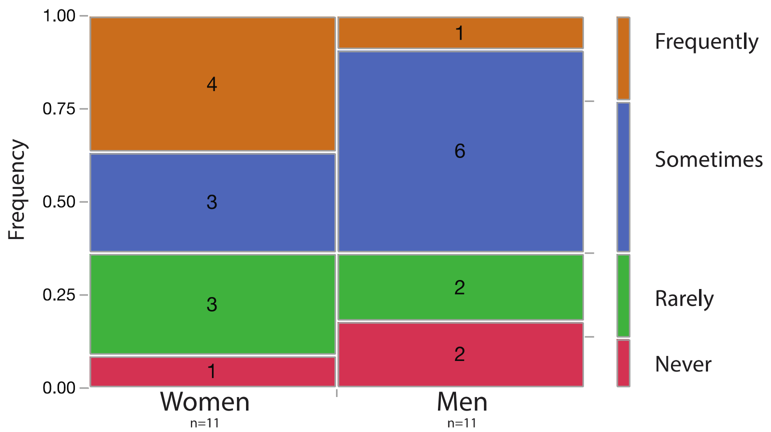

Fig. 1. Mosaic plot of the number of participants who self-report at each frequency level of motion sickness susceptibly stratified by gender.

2.3 Vehicle and Test Conditions

A 4-door, automatic transmission, 6-cylinder, 2007 Honda Accord was used as the test vehicle. The passenger seat was set at its lowest, most rearward position with the seat back angle set to 23 degrees (J826).

On-Road Routes

Testing was conducted on two on-road routes and with and without a task. The urban route was a continuous route on urban and residential roads consisting of a range of vehicle maneuvers (e.g. left and right turns, braking, lane changes and roundabouts). The highway route was designed to evaluate the effect longitudinal acceleration control and higher vehicle speed (~105-112 kph) under conditions of minimal lateral acceleration. Time required to complete each of these on-road routes was approximately 55 minutes.

Task

Two levels of an ecologically relevant task were performed during the in-vehicle scripted route/continuous drive. The no-task condition involved normative passenger behavior and unrestricted gaze. For the task condition a reading task was administered on a handheld mini-iPad tablet. Figure 2 shows a participant seated in the test vehicle for both no-task and task test conditions.

i) ii)

Fig. 2. Participant seated in the test vehicle illustrating two levels of task test condition: i) *no-task*, ii) *task*.

The task was developed based on observed passenger behavior in current vehicles and anticipated behavior in future AVs. Participants were instructed to navigate the pages and attempt to answer a range of questions that involved reading comprehension, visual search, text entry, and pattern recognition, such as local area restaurant reviews, articles about local University sports teams, and maps of the local area (Figure 3). There was no limit to the maximum number of questions that could be answered.

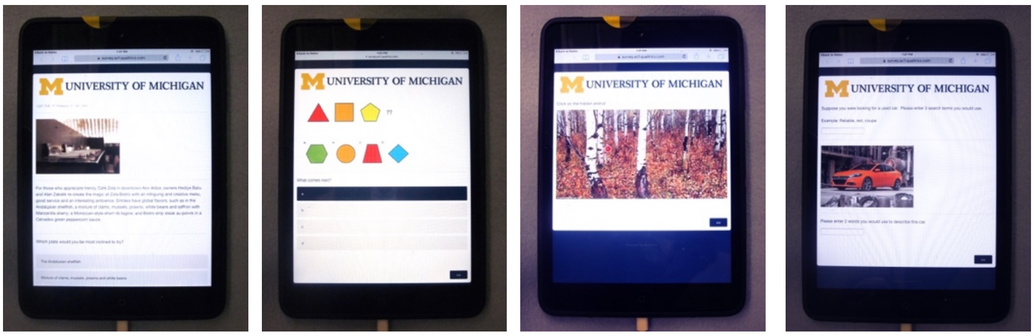

Fig. 3. Example of pages from the iPad task including restaurant reviews, logic puzzles, finding hidden objects and typing words.

A mixed between-within subject design was used. Within gender, participants of similar motion sickness susceptibility were randomly assigned to the two on-road routes. This yielded two participant groups with a similar number of women and men who are approximately equivalent in the distribution of motion sickness susceptibility. Participants completed the task and no-task trials on different days in random sequence.

2.4 In-Vehicle Protocol

During the in-vehicle protocol, a study team driver drove the test vehicle around the scripted route while a second investigator recorded the participant's ratings and sensations associated with motion sickness throughout the drive. Participants rated their motion sickness on a scale from 0 to 10, with 10 the most severe, indicating "Need to stop the vehicle." Motion sickness was quantified by probing the participant for a rating every minute or as they experienced a change in rating and by instructing participants to self-report any sensation they experienced. Each test condition concluded after the route was completed, or when a participant rated their motion sickness as "10" or "Need to stop the vehicle", or when the participant requested to stop the trial, whichever came first.

2.5 Data Analysis

Nonparametric statistics were used to analyze the data given that the data were integer and censored. The maximum motion sickness rating reached during the on-road scripted route was compared across test conditions using signed-rank tests. The 25th percentiles of the distribution of maximum motion sickness ratings for the urban and highway routes were computed and used to classify participants into LOW and HIGH motion sickness response.

Participants controlled the timing of how long each question was displayed for. They also had the choice of whether or not to answer a question. If a participant elected to not provide a response and advance to the next question, they would be asked to confirm their choice to continue without answering. The task would immediately advance on to the next question, after a participant provided an answer and/or non-response. Participant responses to task questions were compared to the answer rubric and classified as: 1) accurate, 2) incorrect, or 3) non-response. Descriptive statistics were computed.

3 Results

3.1 Maximum Motion Sickness Rating

Maximum motion sickness rating was extracted as a scalar representation of each participant's subjective response. Note that maximal ratings did not necessarily correspond with the final rating reported. Across the aggregated data set (i.e. four conditions for a total of 44 individual trials), 25% of the participants did not develop any sensations during the in-vehicle test conditions (i.e. participants reported a rating of 0 or "No Symptoms" throughout), while 5% indicated an illness rating of 10 or "Need to stop the vehicle". Two trials of the urban, *task* test condition ended prior to the intended conclusion of the route due to participant motion sickness.

Figure 4 shows the cumulative distributions of the maximum motion sickness ratings for across all test conditions. The median maximal ratings for the no-task conditions were 2 and 3 for the highway and urban routes, respectively. Task conditions were observed to have higher maximal ratings across the routes. The median maximal ratings were found to be 4 and 7 for the highway and urban, task conditions, respectively. Distribution of maximal ratings between the conditions was evaluated using non-parametric signed rank tests. Population mean ranks of the in-vehicle conditions were found to differ significantly ($\lambda 2 = 10.24$; $p = 0.0166$). Nonparametric comparisons between urban, no-task and task trials ($p = 0.0219$), highway, no-task and urban, task trials ($p = 0.0058$), and highway, task and urban, task trials ($p = 0.0496$) were significant. Further analysis using the Wilcoxon signed-rank test determined that the within-participant difference between the no-task and task conditions was significant for the urban route ($p = 0.0006$), but not for the highway route ($p = 0.0526$).

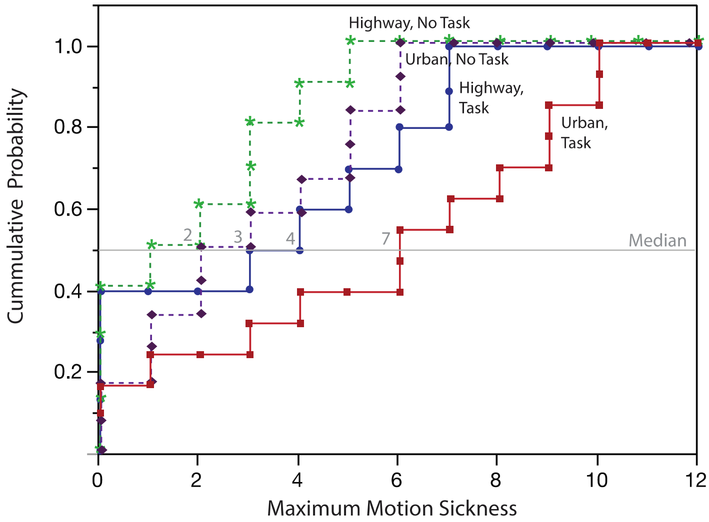

Fig. 4. Cumulative probability distribution of the maximum motion sickness rating across the **urban** and **highway** routes, *no-task* and *task* test conditions.

3.2 Task Performance

Figure 5 illustrates the distribution of task performance during the routes, stratified by two levels of motion sickness response. The number of accurate task responses were observed to decrease with motion sickness response. During the on-road scripted route, the average percentage of accurate task responses was 79% for participants with LOW motion sickness response and 58% for participants with HIGH motion sickness response. The total number of no-responses was also associated with motion sickness response. No-response items were observed approximately two times more frequently for participants with HIGH motion sickness response than for those with LOW motion sickness response (31% versus 12%). The percentage of incorrect task responses was not affected by motion sickness, at 9% for LOW and 11% for HIGH motion sickness responses respectively.

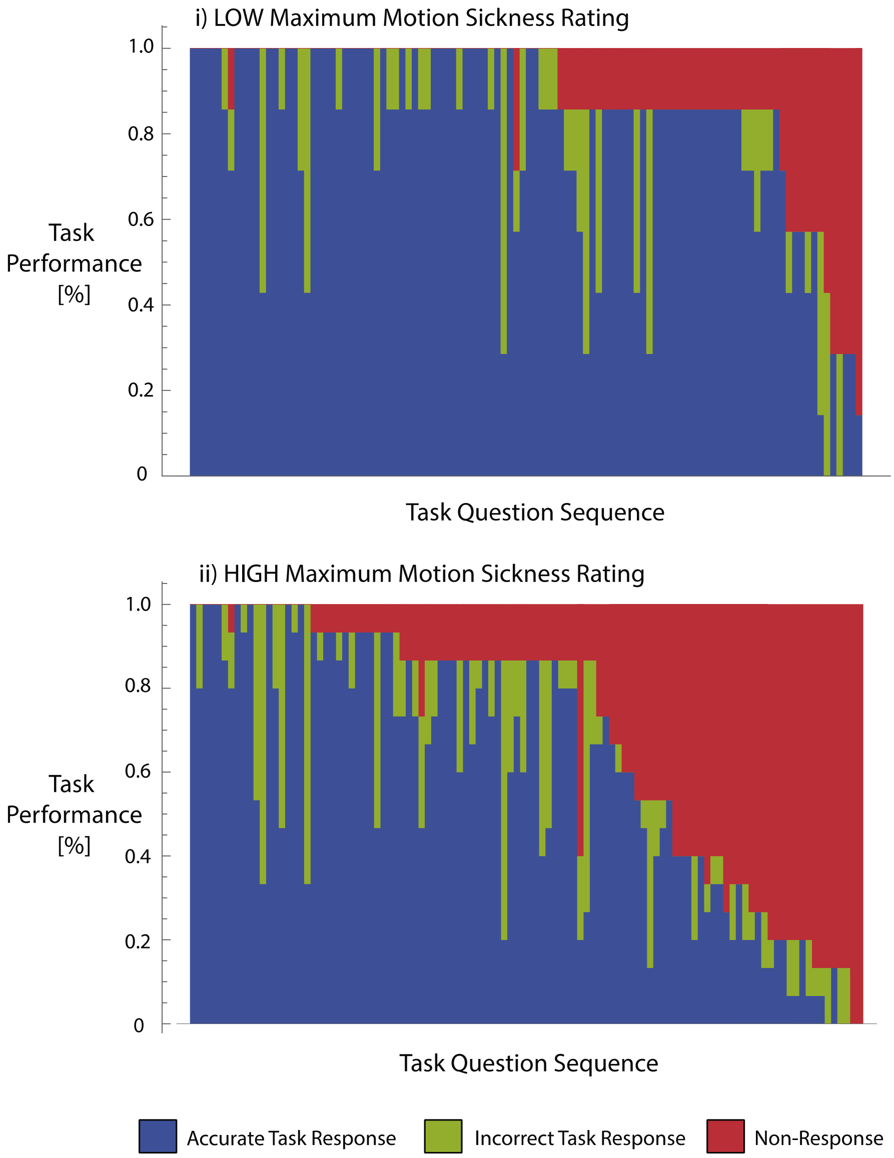

Fig. 5. Distribution of task performance across the levels of passenger motion sickness susceptibility, collapsed across the on-road scripted routes.

4 Discussion

This study is the first to quantify non-driving related task performance and engagement associated with motion sickness response during passenger vehicle operations on-road. The data extends previous research that show motion sickness ratings increase more rapidly when participants are completing visual tasks. Across the dataset, measures of task accuracy and engagement show performance decrements with increasing levels of motion sickness. The data also showed strong differences across individuals, with passengers who experienced a higher level of motion sickness as more likely to have a higher percentage of non-responses.

Future data collection and analyses will investigate the association between the additional performance measures, evaluate differences in task performance between the urban and highway routes, examine changes in task performance with respect to timing progression of motion sickness ratings and sensations, and the comparison of task performance and head kinematic measures. These data will inform the development of a model of etiology of motion sickness consistent with participants' response in road vehicles and enable the design and evaluation of mitigation strategies.

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Objectifying Ride Comfort in Autonomous Driving

An extended Model of the ISO-2631 Standard to Objectify the Ride Comfort of an Inattentive Occupant

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Abstract In order to objectify driving comfort in autonomous driving, an extended model of the existing ISO-2631 standard has been developed, analyzed and tested in the presented work. Therefore the conventional measuring points are extended by the head. For the objectification of the driving comfort a further differentiation for the k-factors is suggested in the weighting. Subsequently the calculated effective values are assigned to a 6-step scale. A first review of the presented method is carried out in a driving simulator experiment with 50 persons. The subjects drove through 5 sections with different vertical dynamic road excitations in an inattentive state and rated the driving comfort on a 7-step Likert scale. Simultaneously a body measurement technology is used to record the movements of the occupants using initial sensors. The evaluation of the results shows that the extended model reproduces the occupant comfort ratings evaluated as ordinal data more accurately than the existing ISO-2631 standard.

Keywords: Ride comfort, Whole Body Vibrations, Objectification, ISO-2631, Autonomous Driving.

1 Introduction

With the progressive advancement of autonomous driving systems, the occupant is becoming the focus of research and development. The different level of attention and the possibility for new activities of the occupant while driving, influence the requirements on the interior concept and vehicle configurations [7, 15]. An important part is the improvement of the ride comfort and the driving dynamics of the vehicle [9]. According to Bubb's comfort pyramid, comfort is referred to as the interaction of smell, light, vibration, noise, climate and aesthetics [1]. This is strongly influenced by the driving dynamics, with its subsections of longitudinal, lateral and vertical dynamics. These directions play a key role in the occupant movement's as well as the acoustics occurring in a vehicle [16]. It can be assumed that through the ongoing improvements in creating comprehensive and consistent environmental models as well as the computation of the trajectory of an autonomous vehicle, longitudinal and lateral excitation can be significantly reduced.

Especially in one of the first possible applications of autonomous vehicles: a long car journey on the highways with a constant speed and less lane changes. At the same time, vertical dynamics and vibration comfort, as well as their objectification in autonomous driving, become more important. For this reason, it is fundamental to concentrate on the vibration comfort during autonomous driving.

1.1 Motivation and Goals

Previous studies and investigations have shown that the head movements of an inattentive occupant, in this case distracted by a secondary activity, increase significantly compared to an attentive driver with the same road excitation [3, 6]. In addition, it could be shown that the best results can be achieved by objectifying ride comfort according to the ISO-2631 standard in comparison to other methods [6]. Combining both statements, it becomes necessary to consider the head as measurement point for objectifying ride comfort. In the past, the objectification of comfort by head movements has been rejected due to a lack of significance [13]. This could change on the basis of these results and in the scope of autonomous driving. The aim of this work is therefore to achieve improved values in the objectification of ride comfort in an autonomous driving scenario by extending the ISO standard by the measuring point head.

1.1 Structure of the Paper

This paper is divided into five sections. The first gives a introduction of the backgrounds and summarizes the motivation and goal of the paper. Section two analyses the current state of research in the objectification of ride comfort in passenger cars with respect to autonomous driving. Section three describes the methodology for the body measurement system, the modified model and the conducted study. In section four, the results are presented and analyzed, followed by a conclusion and outlook of the presented work in section five.

2 State of the Art

Comfort is a strongly subjective feeling, which varies essential between people and is characterized by personal inclinations. Herzberg [10] has defined comfort as the absence of discomfort with the result that only discomfort exists and comfort represents only the absence of discomfort. The reduction of discomfort, however, does not necessarily lead to a positive influence on comfort, which also includes aesthetic aspects and depends on well-being and relaxation [18]. There is no clear separation or scale for comfort perception. That makes it difficult to record the sensation of comfort. Many studies and surveys have been performed to measure comfort. Usually, the data are measured with ordinal or interval scales. Ordinal scales, also called rank scales, arrange the values in an order of standing. For this, a statement cannot be made about the absolute distances between the results (given answers). In the comfort rating, this means that the ratings have different distances within a scale. If, for example, a 7-step scale from 0 to 6 is used, the distance between an evaluation between 1 and 2 in a subject is different in a ratio (distance) than from the 4 to the 5 scale. A particularly common ordinal scale is therefore the Likert scale [8]. For interval scaled data, statements can be made about the absolute distances between the values, but without a meaningful zero point. An example of this is temperature [4]. The distance between 10 and 20 degrees is the same as the distance between 30 and 40 degrees. However, it should be noted that 40 degrees is not twice as warm as 20 degrees. Even though the Likert scale for evaluating comfort actually collects ordinal data, these are often treated incorrectly as interval-scaled data. In regard on whole-body vibrations, one of the most popular methods for objectifying comfort is the ISO-2631 standard. It describes methods for evaluating periodic, stochastic and transient whole-body vibrations in relation to health and comfort in a frequency range between 0.5 – 80 Hz. For the evaluation of the vibration comfort, only acceleration values at certain points and directions of introduction are required. Accelerations are measured at the seat rail, seat cushion, backrest and feet. In addition, the angular accelerations around the three axes are included in the evaluation at some measurement points. A frequency-dependent evaluation function is defined at each point of introduction and direction in order to map the human perception of the vibrations. Figure 1 illustrates the sequence of a comfort evaluation from the measurement as input to the classification and categorization as output.

The most important parameter for the evaluation of vibration comfort is the overall vibration total value. This parameter can be calculated from the quadratic mean value of the weighted vibration intensity of the individual measuring points (point vibration total value) [11]. As already the overall vibration total value, the point vibration total value, can be determined from the quadratic mean value of the individual directions multiplied by a weighting factor k. For the determination of the discomfort sensitivity for multiaxial excitations, the factor k weights the influence of the oscillation at the respective measuring points to varying degrees.

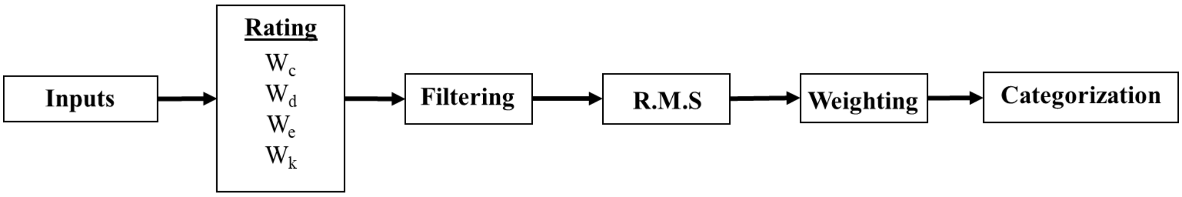

Fig. 1. Sequence of a comfort evaluation from the measurement to the categorization according to the ISO-2631 standard.

Though, as described above, the weighted root-mean-square (RMS) is the most commonly used basic method. The ISO contains a rating table for the discomfort rating. The overall vibration total value intensity changes according to the basic method can be compared with a scale to assign the assumed subjective evaluation of the occupants. Therefore the subjectively felt vibration comfort caused by the mechanical vibrations is set in connection with the vibration strength. The ISO scale indicates that there are overlaps between the individual areas [10]. This makes it more of an orientation than a strictly defined illustration of the subjective comfort value. The difficulty is caused by translating subjective sensations into objective measured values.

3 Method

The first part of this section describes the body measurement system. It illustrates, what is used to record and evaluate the movements of the inattentive occupants and the vehicle while driving and as well the basis of the ongoing research work. In a second part, an extension of the existing ISO-2631 standard is proposed, which includes further measuring points on the occupant's body. The aim is to increase the accuracy of the objectification of ride comfort in an autonomous journey. In the last part, a study is conducted in the driving simulator in order to collect body movement data on the occupant and his comfort impression.

3.1 The Body Measurement System

The body measurement system (BMS) allows the recording of occupant movements while driving in real traffic as well as driving in simulator. It can be used on an attentive driver as well as on an occupant who is distracted by e.g. a secondary task. A detailed description of the system can be found in Burkhard [2]. Comparable systems have been developed independently by DeShaw and Rahmatalla [5, 14]. As shown in Figure 2, a sensor is attached to the head of the subject with a safety cap. Further sensors are with a strap on the subject's chest and with a seat cushion on the seat pad. Another sensor is attached to the seat rail.

At the person's head and on the vehicle body capacitive six degree of freedom sensors Dytran© 7556A1 are used. These combine a triaxial capacitive accelerometer with a gyroscope. The detected frequencies are in the range of 0 to 800 Hz for the accelerations and 0 and 150 Hz for the angular accelerations.

On the chest triaxial a capacitive acceleration sensor PCB Piezotronics® 3713E 1125G is used. However, this sensor will not be

Fig. 2. Occupant in the driving simulator with sensors on head, chest, seat cushion and seat rail.

considered further in the following evaluation. To measure the seat pad as necessary for the ISO-2631 standard, a compliant seat cushion according to ISO-10326-1 [12] is used with a PCB Piezotronics® 356 A16 sensor. The sampling rate of the measurement unit is set to its maximum of 1000 Hz. Recorded data from the sensors can be evaluated in the initial local coordinate system. This does not allow conclusions about the actual relative acceleration to the vehicle. To make the data of head and vehicle comparable, it must be transformed into a standardized global coordinate system. For this purpose, a complete data set of all subjects is created. Subsequently the data set is automatically transformed into a uniform coordinate system, synchronized and cut according to individual measuring sections. The triaxial sensors cannot be transformed due to the missing rotation rate and are only cut and synchronized. The direction of view during driving is not determined.

3.2 Design of an Extended Model

In order to be able to assess driving comfort even when driving autonomously and thus with an inattentive occupant, an extended model of the ISO-2631 standard was developed. In addition to the conventional measurement data, this model includes an assessment of the head movement. The following Figure 3 shows the sequence of an evaluation from the measurement as input to the categorization. In order to prove the fundamental effectiveness of the model, the input variables in this paper were limited to the seat cushion and the head of an occupant. In the following, these were also limited for evaluation according to the existing ISO standard. A preliminary investigation has shown that the measurement of the vehicle body does not improve the evaluation according to both methods. This can be explained by the fact that the body movement of all subjects is identical due to the simulator used, but results in different ratings.

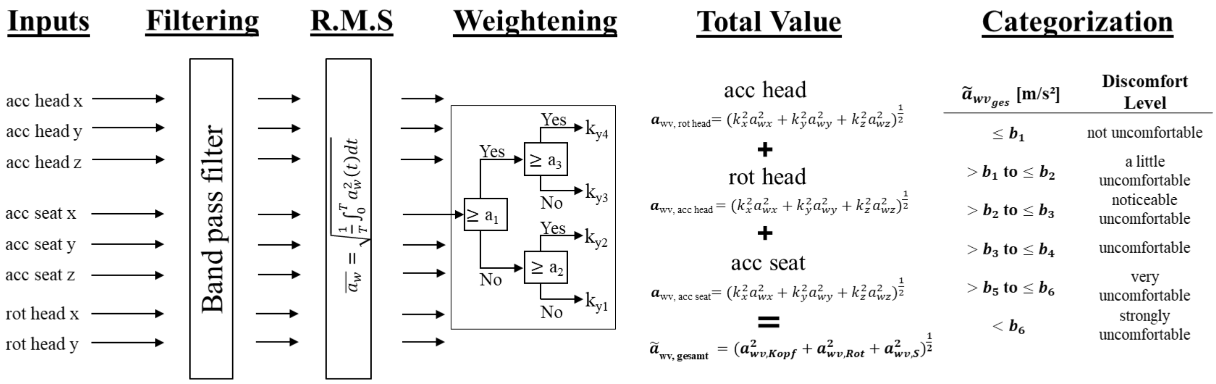

Fig. 3. Sequence of an extended comfort evaluation model that includes the head movements.

The input variables pass in accordance with the ISO-2631 standard through a first band pass filtering and are combined to a total value (RMS) depending on their direction of movement. The factors are classified and weighted depending on their intensity. The appropriate k-factors are selected accordingly. This means that higher movements can also be weighted more strongly. A total value is calculated and assigned to an extended, 6-step scale. For this first experiment, the a-, k- and b-values were determined empirically. In the future, the values can be calculated by mathematical methods for a higher number of subjects. In the outlook section, this is briefly discussed. The different empirical values used for this experiment are described in Table 1 below.

Table 1. RMS values averaged over all 50 subjects at seat rail and head.

a-value			k-factor				b-value				
a_1	a_2 *in m/s²*	a_3	k_1	k_2	k_3	k_4	b_1	b_2	b_3 *in m/s²*	b_4	b_5
1	0.75	2	0.75	1	1	1.25	1.25	2.25	3	3.75	4.25

3.3 Objectification in a Driving Simulator Study

In order to generate real data for the development of an extended model of the ISO standard and to be able to evaluate it, the study is conducted in a driving simulator. Real road measurements with a BMW 750 Li (G12) were performed on five straight sections at 70 km/h. The vehicle movements were recorded with a high-precision gyro platform (GeneSys Elektronik ADMA-G-PRO+). Section 1 has damaged pavement layers with many provisional repairs that lead to strong heave, pitch and roll motion. Section 2 is an undulating road that results in low-frequency heave and pitch motion of the vehicle body. Section 3 has damaged surface layers at the roadside that result in roll motion with subsequent head toss movements. Section 4 is a recently asphalted road with minimal excitation. The last section 5 is quite similar to section one. The data is transferred to a dynamic driving simulator of the BMW Group. This consists of a half vehicle mockup on a hexapod, which is coincidently moved by a tripod in the plane. It can oscillate on a frequency range from 0 to 30 Hz in all directions. The mockup moves in front of a static screen in which the corresponding driving environment is visually shown. The visual environment was modeled according the real roads. Acoustically, the rides over each section was recorded and played back in the driving simulator. The optics, acoustics and excitations were subsequently synchronized and offline motion cued in the simulator. All sections can be permuted in their sequence accordingly. The synchronicity and authenticity were confirmed accordingly by experts from the driving testing.

In the context of the study as within-subject-design, 79 subjects participated over a period of three weeks. An error analysis resulted in a total of 50 valid data sets. Every subject experienced each excitation for 30 sec and subsequently rated their comfort sensation. In order to create a distraction for the participants, they were instructed to complete a survey about personal details on a 12.3 inches tablet. The task and the measurements were monitored by the investigator sitting in the control room. In order to collect objective data, measurements were performed on the inattentive occupants using the body measurement system. To determine the subjectively experienced discomfort of an excitation, a 7-step unipolar Likert scale with verbal marks from zero to six was used. Anchorpoints for the grading scale were “0 - no disturbance” to “6 - very strong disturbance”. All subjects were employees of the BMW Group with no deeper experience in autonomous driving or ride comfort. Table 2 shows statistical data of the sample composition. To be complete, further hypothesis and variants were investigated in the study. Due to the study design, the parts can be viewed separately.

Table 2. Sample composition of the study – 50 subjects, 20% female.

	Age *in years*	**Height** *in cm*
Mean	35	180
Std	12.90	9.51
Min	19	153
Max	60	198

4 Results and Discussion

A comparison of the measurements on the seat rail, seat cushion and head in Table 3 shows the differences in the accelerations of an inattentive occupant. The RMS accelerations and rotation rates on the head are significantly higher on all sections than on the seat rail in a paired comparison. The average acceleration at the head is 0.57 m/s^2 higher than the acceleration at the seat rail. On the other hand, the accelerations on the seat rail and seat cushions are in the same range. A clearer picture emerges when looking at the rotation rates. The average acceleration at the head is 13.42 °/s above that at the seat rail in a paired comparison. Unfortunately, it is not possible to make a statement regarding the seat cushion and seat rail. The limited size of the sensor does not allow the integration of a gyroscope. It can be estimated that only minor differences would exist. It can be assumed that the high head movement results from the limited perception of the drive. Thus, the occupants do not have the capability to perceive and assess any excitation in advance. They can only react to the excitations in a compensatory way and must also rely on their sense of balance. Zikovitz and Harris came to a similar result in their research about the perception of longitudinal and lateral dynamics [17].

Table 3. RMS values averaged over all 50 subjects at seat rail and head.

RMS	Seat rail						Seat cushion			Head					
	a_x	a_y	a_z	ω_x	ω_y	ω_z	a_x	a_y	a_z	a_x	a_y	a_z	ω_x	ω_y	ω_z
	in m/s²			*in °/s*			*in m/s²*			*in m/s²*			*in °/s*		
Section 1	0.21	0.71	0.68	2.61	2.50	0.30	0.30	0.61	0.69	1.18	1.46	1.05	22.54	15.71	17.94
Section 2	0.19	0.38	0.58	1.60	2.83	0.20	0.27	0.34	0.58	1.13	0.96	0.89	15.44	13.25	15.53
Section 3	0.18	0.50	0.62	2.20	2.40	0.20	0.26	0.45	0.61	1.07	1.25	0.93	20.58	15.38	15.74
Section 4	0.07	0.23	0.23	1.10	0.80	0.10	0.10	0.21	0.23	0.51	0.61	0.44	9.11	8.96	7.50
Section 5	0.13	0.52	0.42	2.10	1.30	0.20	0.19	0.45	0.43	0.84	1.17	0.69	18.69	12.99	12.41

An evaluation of the subjective data allows a comparison with the newly developed extended model and with the current ISO-2631 standard. The subject's ratings shown in Figure 4 and the objective values were processed as ordinal data in box plots. The rating of the sections corresponds thereby to the expectations of the selected excitations (cf. Chapter 3.3). The damaged pavement layers on section 1 are rated the worst, the recently asphalted road of section 4 are rated best. It is interesting that the recently asphalted section 4 is still rated as disturbing.

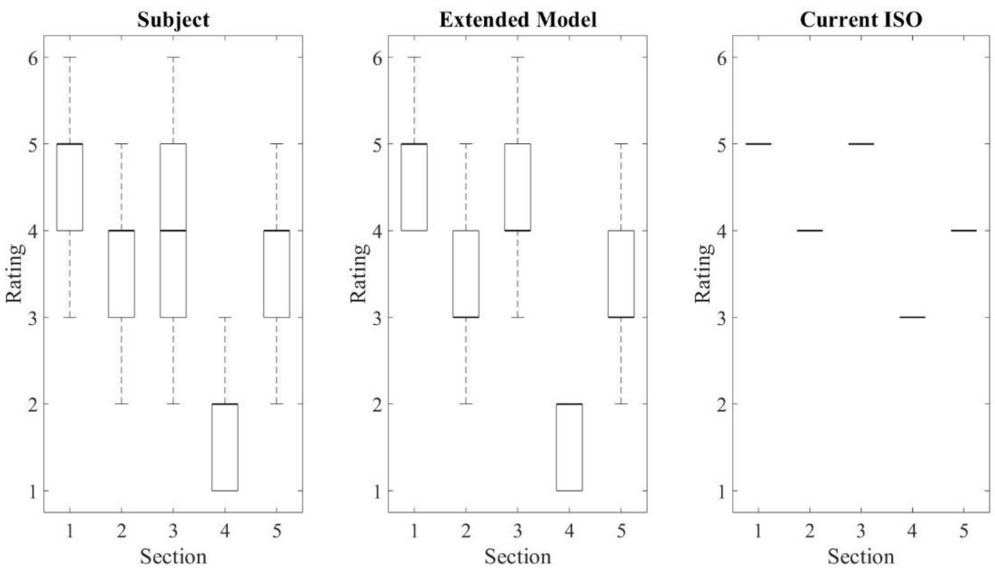

Fig. 4. Boxplot of the evaluation of the subjects, the calculation with the extended model and the current ISO.

If the objectification is compared according to an extended model with the current ISO, the extension allows, in addition to the actual comfort value as median, also to calculate the upper and lower maximum values as well as quartiles. In addition, it is noticeable that the evaluation of the extended model is slightly better than that of the current ISO. A representation of the corresponding numerical value is summarized in the appendix in Table A. In order to compare the objectification methods, a sign test is made between the subject's rating and the objectification methods. For this purpose, an observation is performed across all sections. The results in the form of significance and z-score are described in Table 4.

Table 4. Comparison of the objectification procedures to the real ratings with a sign test.

	Section 1		Section 2		Section 3		Section 4		Section 5	
	ExtMdl vs Subject	*CurISO vs Subject*	*ExtMdl vs Subject*	*CurISO vs Subject*	*ExtMdl vs Subject*	*CurMdl vs Subject*	*ExtMdl vs Subject*	*CurISO vs Subject*	*ExtMdl vs Subject*	*CurISO vs Subject*
Significance	0.42	0.03	0.28	0.09	0.11	0.00	0.82	0.00	0.49	0.08
z-score		-2.16	-1.08	-1.70		-3.95		-6.33	-0.70	-1.74

The results underline that by the current ISO three out of five indicate a significant difference between the subjective impression and objective measurement (Table 4, grey). In comparison the new method has no significant effect. It can be assumed, that the extended model display the subjective data better. As well the extended model gives the trend, that there is no difference between objective and subjective measurements.

5 Conclusion and Outlook

The results of the experiment show that the inclusion of the occupant's head as measurement point can lead to an improvement in the objectification of driving comfort. Even if this was not considered in the past due to only a small influence on the objectification result, it becomes more pertinent in an autonomous vehicle. The reduced degree of attention of the occupants about the route of the drive leads to significantly higher accelerations at the head of the occupants. This makes the head a respectable measured quantity. The evaluations show that the inclusion of the head creates better results in a distracted state than the conventionally used ISO-2631 standard. It must be taken critically into account that the experimental group is a supposedly small sample of 50 persons on five sections. Furthermore, the evaluation of driving comfort, also in the driving simulator, is very subjective, not all external variables can be recorded and also the comfort cannot be measured directly. Therefore, external and environmental factors, as well as the biometrics of the subjects, expectations and experience can influence the results. Last but not least, the seat rail cannot be included as a measured variable due to the always identical body movement of the driving simulator. This leads to a possible influence on the evaluation. In order to account for these shortcomings, data sets from further experiments will be used. This allows the number of subjects to be increased to over 200 on different sections and excitations. Likewise, data from field experiments will be used in the future to allow a measured variable to be studied on the seat rail. In order to improve the accuracy of the extended model, the empirically determined variables a, k and b will be replaced by mathematical calculations. This is possible through increasing the number of test persons. Methods such as k-means clustering are used to calculate the a- and b-values. To determine the k factors, optimizers such as the brute force approach are applied. This should make it possible to objectify the driving comfort of occupants in an autonomous vehicle.

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Contributions First author Georg Burkhard was initiator of the study and involved in the idea and development of the extension of the ISO standard with a body based objectification approach. Second author Tobias Berger created the expansion of the ISO together with the first author conducted the evaluation within the scope of his thesis work. Third author Erik Enders was involved in the planning and analysis of the study as well as the development of the body measurement system. Dieter Schramm made essential contributions to the conception of the research project and revised the paper critically for important intellectual content. Dieter Schramm gave final approval of the version to be published and agree to all aspects of the work. As guarantor, he takes responsibility for the overall integrity of the paper.

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Appendices

Table A. Comparison of medians and frequencies.

		Section 1			**Section 2**			**Section 3**			**Section 4**			**Section 5**		
		Sub	*Ext*	*Cur*	*Sub*	*Ext*	*Cur*	*Sub*	*Ext*	*Cur*	*Sub*	*Ext*	*Cur*	*Sub*	*Ext*	*Cur*
	Median	5	5	5	4	3	4	4	4	5	2	2	3	4	3	4
	Sum	43	43	43	50	50	50	41	41	41	46	46	46	47	47	47
Frequency Rating	**0**															
	1										20	19		8		
	2				6	2		3			22	27		14	3	
	3	6			13	27		9	6		4		46	14	22	47
	4	13	17		22	16	50	15	16					11	21	
	5	17	17	43	9	5		10	18	41				7	1	
	6	7	9					4	1							

PROJECT PURE - THE FREEDOM TO MOVE Automotive Interior Equipment of the Future 2035

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Abstract In 2018, GRAMMER launched the "PURE" project in order to research and address major megatrends such as autonomous driving, connectivity and digitalization. Working together with an internationally renowned automotive design studio in this project, Strategic Product Planning at GRAMMER is developing the products of the future respecting current and future use cases. Out of these, the "PURE" project mainly concentrates on the core aspects of comfort, ergonomics and safety. Factors such as new spatial awareness through the freedom to move, the avoidance of motion sickness, the modularity of interior components, sustainable materials, new functions and the mobile workplace are being explored in detail to prepare for the interior of the future in 2035. The findings from these investigations, coupled with existing knowledge, are being combined in the "PURE" project to create a unique user experience for people 'on the move'. What is certain is that the interior of the future will be vastly different. The market and also OEM customers will be placing high demands on vehicle industry regarding interior functionality, mechatronics and sustainable materials. GRAMMER wants to be fully prepared to address the requirements of future interiors. The findings from the PURE project are applicable across all GRAMMER divisions, as new developments in autonomous driving are not confined to the automotive sector, but increasingly appearing in commercial vehicles as well.

Keywords Freedom to move, avoidance of motion sickness, new spatial awareness, PURE, perceived quality

1 Introduction: Future mobility will change the way we think *Car*

It is without no doubt that today, although we see an ever growing amount of people mover concepts being presented by the transportation value chain (mainly based on new component system architecture), we observe the start of a new dawn regarding drissenger*[1] comfort as part of a total mobility ecosystem. *The way we think car* will change into the freedom to move and the perceived quality of comfort when *not* driving. The ingredients, however, that make up this new recipe of comfort need to come all together in a holistic comfort experience that makes a real difference. For this, the project called "PURE" was initiated at Grammer AG. GRAMMER is developing a concept for catering to future mobility together with an internationally renowned automotive design studio, mainly concentrating on the core aspects of comfort, ergonomics and safety. In the end, this may take the

[1] Driver/passenger

form of a physical show car, similar to the “Vision in Design” VIP program developed by the Technical University of Delft or the BMW Group’s “Fix-Stern” program. Its target is to design a compelling mix of comfort features that will lift the mobile community to a next level. Referring to perceived quality and the definition of comfort below, several factors will be combined: the freedom to move in the seating area, visual spatial awareness of the interior lay-out with the help of ambient lighting and last but not least proprioception control and advanced acclimatization for avoidance of motion sickness

1.1 Perceived Quality

The product development process of the “PURE” project follows the usual GRAMMER AG development process, which has defined “perceived quality” as its guiding theme. This refers to the fact that products are developed and optimized on the foundation of understanding their users and the range of use cases, from which design requirements are deducted. The definition of perceived quality is “a positive user interaction with the product in all relevant use cases”. A diversification of the activities in vehicles is expected for drissengers in manual and autonomous driving modes. These current and future use cases have formed the basis for the “PURE” concept.

Fig. 1 Guiding Theme Perceived Quality

For achieving perceived quality, the areas design, ergonomics and usability contribute and cooperate. The Design department creates and refines product design concerning styling, visual comfort, and design for use. Ergonomics handles perceived quality methods development and the complete scope of comfort related testing. Application comfort refers to the configuration of the product to the specific use case(s), for which usability delivers the applicable user information. Targets of the product development process concerning perceived quality are to provide a positive product interaction in all details, user comfort and to minimize drissenger stress and strain by good product design.

1.2 Comfort Definition

When humans interact with a product, they perceive it through sensory information by several channels simultaneously. Experiencing comfort in this interaction is the result of internal human computing of this sensory input into a holistic impression in a fluid process over interaction time. Comfort will be experienced only if all aspects of the product are able to achieve a good level. Human beings compute this holistic interaction rating with little conscious effort, and generally with low awareness for its components. However, if one aspect comes to the attention of the user and becomes prevalent within the overall impression, it will dominate the comfort rating. This can occur in either direction: The negative occurrence has been named "limiting comfort factor", entailing that the holistic comfort experience cannot be better than its weakest aspect. The positive occurrence can be referred to as the "wow-factor" of a product, exceeding the expectation of the user. Thus, experiencing comfort encompasses all human senses and can be defined as "an overall positive user interaction experience with a product".(1) The "PURE" project respects the holistic interaction by working on optimizing visual, haptic and postural comfort to achieve an overall positive user experience in the context of automated driving.

2 PURE Expectations

Designing the visual, haptic and postural aspects of interacting involves thinking about visual details and coherence, haptic experience for the different elements and the orientation of users in space when entering "PURE" car interior of the future.

2.1 Spatial awareness

First of all we have to place the human into the right spot in the interior (mostly built up as a rectangular cubical space). Figure 2 shows a four-seat set-up and figure 3 shows a two-seat set-up along the interior diagonal.[2]

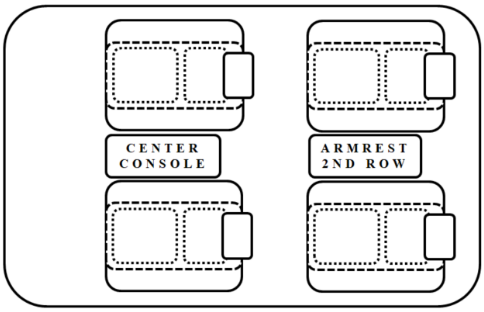

Fig. 2 Normal cockpit lay-out autonomous driving

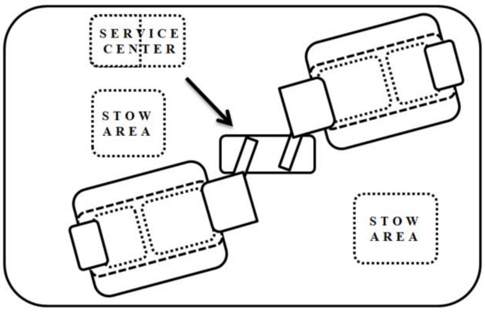

Fig. 3 PURE patent pending cockpit lay-out autonomous driving

To ensure total spatial awareness it is of highest importance to place people in the corner space envelope to support their cognitive ability for best grasping the interior physical appearance. In comparison to Fig 2, where front row passengers only perceive the interior partly because of forward viewing[8], and second row passengers only have a limited view on the interior because of front seats blocking their view, in Fig 3 a passenger has the cognitive ability to visually comprehend the interior space set out by its geometrical boundaries and the open space in the middle. Spatial perception today is defined as the ability to perceive spatial relationships in respect to the orientation of one's body despite distracting information [3]. This is in itself the basic condition to fulfil spatial enjoyment and to counteract motion sickness.

The colour scheme of the interior was designed to give an impression of safety and lead the view to key elements by working with light and dark colour-coordinated tones. Haptic properties support the functionality of the elements, soft for body supportive zones, sleek for panelling, and sturdy for storage.

2.2 Freedom to move

In order to ensure healthy dynamic sitting posture modelling[(4)] in car seating for all PURE use case scenarios *at all times,* GRAMMER AG has looked at its off-road product portfolio and will re-use the concept of turnable-moveable seat backrests, active multiaxial suspensions and seat pivot modules. Converging these seat components into an unified mechatronic system architecture will enable the freedom to move-rotate upper body torso whilst remaining in close contact with the backrest cushion, even buckled up in an ABTS[2] configuration. Together with a central seat pivot point the drissenger is able to turn the seat and the backrest to ensure a comfortable turning scenario. It also allows for more freedom to move your body even when a suspended seat is in zero gravity position. The seating sytem (seat +active suspension) will no longer be a fixed piece of interior furniture, but will evolve towards a dynamic skeleton-like extended body support. One geometrical condition: the roof line has to be high enough to enable seat positions for all use case scenarios.

2.3 Motion sickness and how to reduce it

The symptoms of motion sickness appear when the central nervous system receives conflicting messages from the sensory systems: the inner ear, eyes, skin pressure receptors and the muscle and joint sensory receptors report conflicting information. Roughly one-third of the population is highly susceptible to motion sickness, and most of the rest may get motion sickness under extreme conditions. Travelling in cities with tight curve radii in automated conditions and fixating something other than the street counts as an extreme condition. Studies also indicate that women are more likely to be affected than men [(5)]. There is some evidence that people with Asian ancestry may suffer motion sickness more frequently compared with people of European ancestry [(6)]. Last but not least low frequency (<0,4 Hz) high amplitude vibrations cause more motion sickness than frequencies > 1 Hz [(7)]. This last argument was the one of the motives to start the PURE project.

[2] “All belts to seats“

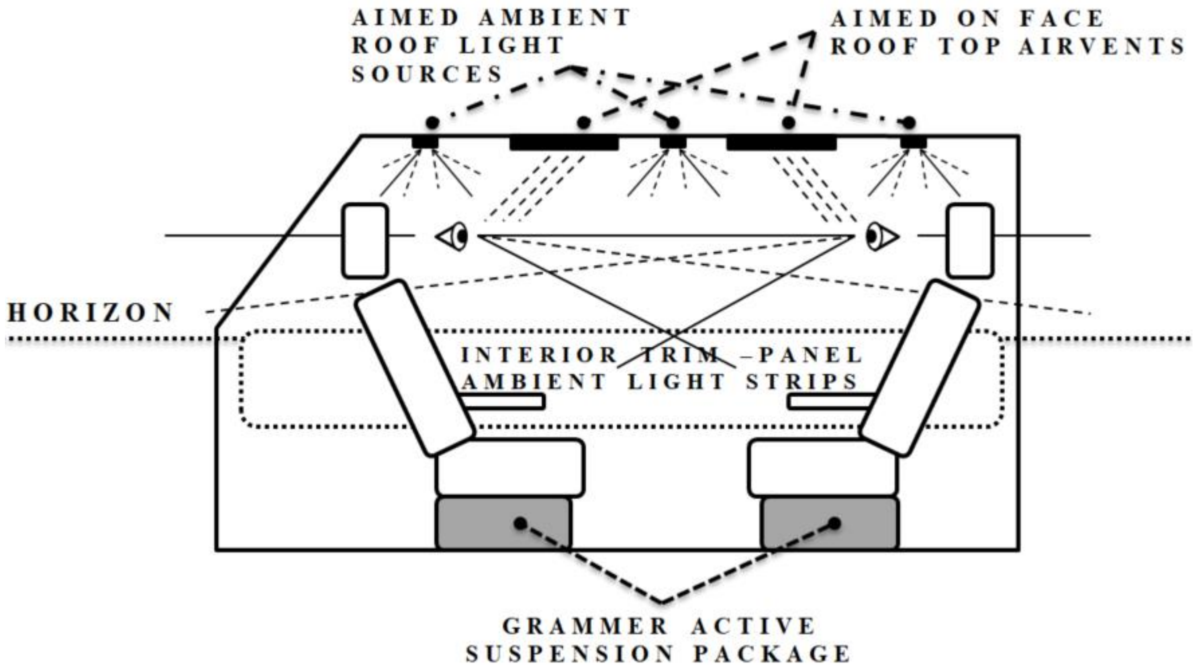

Fig. 4 PURE patent pending cockpit lay-out for reducing motion sickness

Reduction of motion sickness, whilst driving, should address the following topics:

- Reduced head dynamics through seats with active suspension
  With multiaxial active suspension under the seat pan most high frequency vibrations are cut off and very low frequencies with high amplitude are dampened. Lateral G-forces (when changing lanes-driving off the highway) are counteracted with horizontal suspension actuators serving to keep the passenger head as still as possible whilst the sagittal body plane might tilt some degrees. Also people not suffering from motion sickness will benefit from active seating due to the fact that their bodies are isolated from the vehicle movement. Even in zero gravity seat positioning, active suspension will reduce further head dynamics

- Individual Vibration threshold control of the active suspension module
  Every individual experiences vibration spikes from the surrounding environment in a different way. By enabling control over the threshold of 'incoming' vibration we achieve two goals: one is an effective configuration that suits the passenger proprioception level best and the second is that subjective control over environmental parameters affecting their own body comfort has a positive effect and improves there mental state.

- Active individual acclimatization
  Increased air flow on the face of the passenger can help to reduce motion sickness

- Ambient lighting
  The goal is twofold: coloured light strips should indicate change of motion (de-acceleration) and coloured aimed ambient lighting should positively influence drissengers' mental state[9].

The unique combination of spatial awareness, individual vibration control of the active suspension, active suspended seating to minimize head dynamics, increased air ventilation, coloured led light strips pre-indicating movement and aimed ambient lighting working on your mood make up the complete counter action to reduce motion sickness in such a way that automated travelling can be experienced without nausea.

3 **PURE Learnings**

From the range of research at Grammer AG concerning comfort, ergonomics and safety, aspects of visual and haptic comfort as well as spinal health and load reduction for drissengers, and comprehensive understanding of the human product system interaction were applied in the “PURE” project. Its target is to bring together the findings from commercial vehicle applications and the current expectations in automotive contexts to generate a future-proof concept ensuring perceived quality, comfort and the freedom to move in automated driving contexts.

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Comfort and Discomfort in a Chair Using the Smartphone

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Abstract This paper presents the results of an experiment studying the effect of arm support on smart phone use. A chair with a special arm support for smart phone use was developed and tested by 24 participants. The participants were asked by a questionnaire for their comfort and discomfort perception after using the chair with and without armrest for 15 minutes. The effects on posture and productivity were tested. Productivity was tested by counting the number of typed characters and spelling mistakes. There was a non-significant trend that the word count of users in the smart phone chair without arm rest was higher than with arm rest and the spelling mistakes of users in the chair without armrests were lower than in the seat with arm rests ($p< 0.05$). Comfort and Discomfort were evaluated using a questionnaire. The discomfort and comfort differed for the total body, neck, upper back, lower back, lower arm, wrist and leg , but not significantly. Only the upper arm in the condition with arm support showed a higher discomfort and a lower comfort ($p< 0.05$). The posture of the participants was analysed using Kinovea software for the body angles and were processed further using a RULA assessment. The results show that the potential ergonomic risk when people used the smart phone in the chair without arm support is lower than when they used the chair with arm rest ($p< 0.05$). In conclusion, the arm rest increased discomfort of the upper arm of participants, probably because it limits the freedom of movement or because the arm rest is not height adjustable.

Keywords: smartphone, productivity, body posture, chair, texting, comfort

1 Introduction

A survey among 1,500 office workers in the UK and Australia found that nearly half of today's employees use a smartphone or mobile in the work place (abc.net.au, Dec 2012). Much effort is devoted to optimizing the systems and mechanisms of smart phones to increase productivity (e.g. Jewell, 2011; Lee and Lee, 2011). Some milliseconds of improvement seem very important. However, the relationship between smart phone productivity and body posture is seldom mentioned, while the effects could be larger than milliseconds. The users of smart phones are often not aware of their body posture and the question is whether they have tacit knowledge on the body postures that improve smart phone productivity, which is the theme of this study. Body posture research concentrates mostly on the relationship with musculoskeletal complaints or emotions. For instance, a literature review by Gallegher (2005) comes to the conclusion that workers who adopt unusual or restricted postures are at higher risk of musculoskeletal complaints and often exhibit reduced strength and lifting capacity. Regarding emotions Riskind and Gotay (1982) found for instance that the more slumped-over body posture may have led to infer greater helplessness. However, research on the relationship between body posture and productivity is scarce. A search in “science direct” on the terms ‘body posture’ AND ‘productivity’ in title, keywords or abstract showed 8 papers between 1996 and December 2013. Four of these consider human productivity. One of these four papers showed a significant difference in productivity between two assembly work station lay-outs (Lim and Hoffmann 1997). The layout influenced body posture and productivity was increased through more economical use of hand movements. In computer work the number of studies on body posture and productivity is also limited. Some studies, which do not primarily focus on productivity, also measured performance effects. For instance, Moffet et al. (2002) showed that the number of typed characters was significantly higher using a screen positioned closer to the eyes. Sommerich et al. (2002) found differences in productivity between using a notebook computer stand-alone and along with inexpensive peripheral input devices. Participants were more productive with the mouse than with the pointing stick. However, effects on productivity of other postural changes were not found. The changes in parts of the human body in space were small, but significantly different. In a pilot study Commissaris et al. (2008) showed that various office work postures influenced productivity. For instance, an asymmetric posture with the back bent sideward reduced productivity for a VDU task.

So, there are indications that large body posture changes can influence productivity, and it is interesting to know if this is true for the now much used smart phone. Perhaps the smart phone or chair should be designed in such a way that a more productive posture can be taken. Therefore, the first research question for this study is *“Does body posture while using a smartphone influence productivity, comfort and discomfort?”*

To test the assumed effect of large body posture changes on productivity an experiment was performed. In this research productivity is defined as typing performance. First pilot tests were performed to improve the test set-up and the questionnaires. For instance, letters in the pilot texts shown on a paper were too small to read and type size in the smart phone was made larger in the real test as we did not want to measure readability. Pilot tests were also done in developing an armrest chair (se fig. 1) to design the ideal smartphone chair to support the arms in an adequate way.

Fig.1. *Various stages in the development of the armrest chair, supporting working with a handheld device. Left: one of the first drawings, middle: the first test version, right: the final prototype used in this experiment.*

2 Methods

The two research questions “Does body posture while using a smartphone influence productivity?” and “Does body posture while using a smartphone influence comfort and discomfort?” were answered by means of an experiment. The research team were provided materials and method to answer the question.

2.1 Participants

Thirteen men and 11 women of various nationalities (European, American and Asian) participated in the study. Their average age was 25.2 years (20 to 40 years) and the average length was 1.74 m, varying from 1.58 to 1.89 m.

2.2 Measurements and protocol

A pilot test was set up to simulation the planned experiments. One participant participated and followed the planned protocol, that was set up by the research team (see table 1)

Table 1 : the protocol of the smartphone seat experiment.

Introduction and Observation for 10 minutes	Start typing text scenario 1 for 15 minutes, send an email	Rest (change posture) for 5 minutes	Start typing text scenario2 for 15 minutes, send an email	Answer comfort and discomfort questionnaire

After the pilot test, the participant provided comments, on the basis of which the questionnaire was improved. A body map picture was added to stimulate a more effective communication and an explanation of the difference between comfort and discomfort was added. These improvements were implemented for the next participants.

When each participant arrived, the first ten minutes were spent explaining the research protocol and the participant completed an informed consent. The participants were invited to observe the previous participant while this previous person was sitting in the chair and typing.

The 24 participants were asked to type as fast as possible a text on their own smartphone during fifteen minutes in each chair. The chair was presented in two different conditions: with and without armrest. The texts were different in each condition, but had the same type of words. To prevent order effects the sequence of seat use was systematically changed. The participants had to read the texts they were asked to type from a screen in front of them at the appropriate eye height. Video recordings were made to see if the participants used the same typing method in all chair conditions (e.g. using both thumbs in typing, using right finger etc.). The participant typed this text on their own smart phone (the smart phone they are used to) and had to send the typed text to an email of the researcher. 12 participants started in the chair with armrests and other started typing in the chair without armrests. Finally, the participants were asked to rate the perceived comfort and discomfort for each condition on a 7-point Likert scale (1 represents the lowest comfort and discomfort, 7 represents the highest comfort and discomfort) after typing. See Fig 2 sitting in a chair with and without armrest.

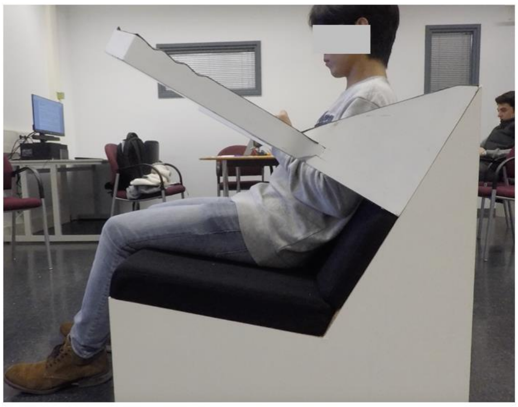

Fig.2. *A chair with and without armrest.*

2.3 Questionnaire

In order to evaluate comfort and discomfort, participants were asked to indicate with a cross on a map of the human body in which region they experienced comfort and discomfort. The sum of the total body, neck, upper back, lower back, upper arm, lower arm, wrist and leg comfort and discomfort was calculated as well as the total of comfort and discomfort regions and compared between the two chair conditions. All participants were encouraged to write a text under the topic “additional comments”. If more than 10% of the participants had similar comments in the open questions these were reported.

2.4 Posture recording

The posture of participants, when they used a smartphone while typing in the chair with and without armrest, was analysed by scoring the angles by using the Kinovea software and then evaluated on ergonomic risk by RULA. The participants used the same posture of the upper limb in the left and right side.

2.5 Analysis

A Wilcoxon test for within participant comparison was used to compare the 2 chair conditions ($p<0.05$). Comfort, discomfort, and productivity were compared with Wilcoxon test as these are usually not normally distributed. The postures were observed and recorded between the two chair conditions and the angle of upper to lower body analysed using the Kinovea program and Rapid Upper Limb Assessment (RULA) to estimate the ergonomic risk when using the smartphone in the two different seat conditions.

3 Results

The results of this study are reported in three parts: productivity, posture and comfort and discomfort with 24 participants.

3.1 Smartphone productivity in two different chairs with and without armrest.

The productivity averaged for each condition over the 24 participants (age varying from 20 to 40 years; length varying from 1580 to 1890 mm; all of higher education), expressed as words counted, was lower when participants used the smartphone chair in the condition supported by the armrest than without armrest. However, the diference was not significant, p-value 0.18406 . There were significantly more mistakes, spaces, and wrong letters when participants used the smartphone chair with armrest than without armrest, (p-value 0.00001).

Table 2. Word count, mistakes, spaces and wrong letters

Type of chair	*Word count*			*Mistakes, Spaces and wrong letters*		
	Minimum	*Average*	*Maximum*	*Minimum*	*Average*	*Maximum*
Chair with arm rest	172	313	416	6	20	52
Chair without arm rest	156	304	418	5	14	31
Significance level	0.18406 ; not significant.			0.00001 ;significant		

3.2 The results of Postures

The results from RULA showed that when the participants used the smartphone with arm support the risk was higher than when they used the smartphone in the chair without armrest at a significant level, p-value 0.00001.

Table 3. The average RULA score separated by part of body.

Posture	*Upper arm*	*Lower arm*	*Wrist*	*Wrist Twist*	*Neck*	*Trunk*	*Leg*	*RULA Score*
Smartphone chair with armrest	5	2	2	1	2	1	2	5
Smartphone chair without armrest	1	2	2	1	2	1	2	4
Significant Level	0.00001 ; Significant	Not Significant	Not Significant	Not Significant	Not Significant	Not Significant	Not Significant	0.00001 ; Significant

The RULA score is separated by 15 items. Column A shows the arm and wrist analysis, column B the neck, trunk, and leg. The results of the RULA score are the same on the left and right side of the body. None of the body parts were significantly different. The only difference at a significant level was in the upper arm: the score was higher in the chair condition with armrest than in the chair condition without armrest.

3.3 The results of comfort and discomfort

The participants evaluated their comfort and discomfort after sitting in the chair with and without armrest and typing the text for fifteen minutes in each chair. On the one hand, the total body, neck, upper back, lower back, lower arm, wrist, and leg comfort and discomfort between the with and without armrest were not significantly different (P-value 0.05). On the other hand, upper arm comfort when using the chair with armrest was lower than without armrest. Moreover, participants' discomfort when using the smartphone on the chair with armrest was greater than when using the smartphone without arm support.

Table 4. The minimum, average and maximum level of comfort and discomfort

Part of body	*Comfort*						*Significant level*	*Discomfort*						*Significant level*
	Min(1)		*Average*		*Max(7)*			*Min(1)*		*Average*		*Max(7)*		
	+ arm rest	*- arm rest*	*+arm rest*	*- arm rest*	*+ arm rest*	*- arm rest*		*+ arm rest*	*- arm rest*	*+ arm rest*	*- arm rest*	*+ arm rest*	*- arm rest*	
Total body	1	2	3.75	4.00	7	7	0.43251	1	1	3.67	3.75	7	6	0.48006
Neck	1	1	3.75	3.46	6	7	0.40517	1	1	3.67	4.54	7	7	0.7493
Upper back	1	2	4.42	4.29	7	6	0.49202	1	1	3.25	3.63	6	6	0.28774
Lower back	2	2	4.63	4.29	7	7	0.30153	1	1	2.92	3.17	7	6	0.2451
Upper arm	1	2	3.33	4.21	6	7	0.02275*	1	1	3.79	3.71	7	6	0.04947*
Lower arm	1	2	3.83	3.75	6	7	0.44828	1	1	3.71	4.04	7	6	0.35569
Wrist	1	2	3.83	4.17	6	7	0.15625	1	1	3.25	3.54	7	6	0.38974
Leg	3	3	4.96	4.96	6	5	0.5	1	1	2.63	2.58	5	6	-**

* The part of body that show significant difference.

** The data in this part were the same level, not compared by the Wilcoxon test.

The comfort differed significantly between the two chair conditions for some parts of the body such as upper arm. For other body parts the results did not significantly differ between 2 chairs, but the participants reported low comfort and high discomfort. For example, in the chair condition with armrest, comfort at the neck, lower arm, and wrist was higher than other part of body, with the average level at 3.75, 3.83 and 3.83 respectively. Moreover, the level of discomfort in the chair condition with an armrest at the neck, lower arm, and wrist was 3.67, 3.71 and 3.25 respectively. The results when using the smartphone in the chair without armrest showed the comfort level of the neck and lower arm were lower than that of other parts of the body. The results showed values of 3.46 and 3.75 respectively. The level of discomfort was higher than for other part of body, with a level of 4.54 and 4.04. That indicated the smartphone chair needs to be redesigned to improve comfort and reduce discomfort at the neck, upper arm, lower arm and wrist.

4 Discussions

Answering the research question, “Does body posture while using a smartphone influence productivity?”, the results illustrated that productivity of word count is different between the participants using the smartphone in the chair condition with and without armrest, but not at a significant level for all recordings. The errors such as mistakes, spaces and wrong letters were significantly fewer when the participants used the smartphone without armrest than with armrest. This is aligned with the study of Liao and Drury (2000) who found that postural discomfort might have an effect on typing performance. The error rate did not increase progressively with the work duration. The error rate increase with Borg scale ratings, but there was a not significant work interval effect. However, they mention that the test time was for 2 hours. Pan et al. (1994) reported that 2 hours may not appear to be a long work duration. In addition, they tested with 6 participants and a large sample size was recommended in the further study.

In a pilot study Commissaris et a (2008) showed that various office work postures influenced productivity. For instance, an asymmetric posture with the back bent sideward reduced productivity for a VDU task.

Regarding the second research question, “Does body posture while using a smartphone influence comfort and discomfort?” The study showed that there is no significant difference between most of the body parts regarding the comfort level. The total body, neck, upper back, lower back, lower arms, wrist, and legs were not significantly different between the chair conditions with and without armrest while using a smartphone. Only for the upper arms, there was a clear significant lower comfort score in the condition with armrest. Also, the discomfort while using the smartphone on a chair with armrest was significantly higher than without armrest. According to the results of RULA, there is no difference between the left and right side of the upper body. The posture during smartphone use in the chair without armrest has a significantly lower risk than with armrest according to the RULA evaluation method. Notably, the upper arms showed a significant difference, because of the height at which the armrest was installed without adjustability at 55cm height from seat level. While the results of comfort and discomfort between two chair conditions provided a significant difference only in the upper arm, other body part were not significantly different. Still, the results showed low comfort and high discomfort scores, for example, in the neck, lower arm, and wrist. Also, Van Veen et al. (2014) reported about neck, arms, and hand comfort and discomfort in a comparison between using the table in a chair with and without armrest. The results of their Wilcoxon Signed Ranks test showed that comfort of the neck region increases significantly while sitting in a chair with armrest, but arms and hands were not significantly different. Moreover, discomfort decreases significantly for the neck, but arms and hands were not significantly different. They were able to adjust the height level of arm support to fit the participant’s anthropometry. This might have been a crucial element. Albin and Mcloone. (2014) reported that the tilt angle of a tablet increases, the neck flexion decreases significantly. Therefore, perhaps in a future design the arms should be made height adjustable to prevent that the shoulders will be lifted and still improve the position of the neck. Another option is that the arm rest limits the freedom of movement and forces the participants in an unnatural posture. Moreover, the comfort score of the arm are in alignment with the RULA scores showing that the chair needs to be improved.

5 Conclusions

In this study, no significant difference in the productivity of word count was found between a chair supporting the arms in using a smart phone and a chair without armrest. However, errors such as mistakes, spaces and wrong letters occurred significantly more frequently when using a smartphone with arm support than without arm support.

This study also found a significant difference in posture from the ergonomics risk assessment level using RULA. The ergonomic risk level was lower without than with the armrest. No significant difference was found in total body, neck, upper back, lower back, lower arm, wrist and leg comfort and discomfort. In the condition without arm support, only upper arm comfort increased while discomfort decreased, both significantly. Further research should focus on the design of the armrest and on productivity, posture, comfort, and discomfort when using the smartphone for a long time. It is advised to study height adjustable armrests.

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Model Construction and Analysis of Comfortbility for High-Speed Rail Chair Surface

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Abstract The seat comfort of high-speed rail has a greater impact on the overall comfort of high-speed rail. However, the existing high-speed rail seat cushion surface has poor fit with human buttocks and thighs. In sitting for a long time, the front end of the cushion shape will affect leg muscle comfort and other issues seriously affect passengers' travel experience. In this paper, the comfort between seat cushion and human body contact surface of high-speed train is studied by combining subjective and objective methods. The main research contents are as follows: (1) In order to explore the influence of sitting posture on comfort of high-speed railway chair surface, the study of rectified sitting posture and relaxed sitting posture is carried out. (2) Analyzing the factors affecting the comfort of passenger seats in the human-seat-environment system, and on this basis, starting from the Ergonomics of seats, processing the important parameters data related to the static comfort of seats, trying to get the best sitting posture of the subjects. (3) According to the existing seat parameters (the best cushion indentation hardness, cushion thickness, cushion material hardness, etc.) and the characteristics of cushion surface morphological variables, we try to design various surface morphological models of high-speed rail seat cushion. (4) To divide the contact area between chairs and people on the cushion, get the unit pressure data at the pressure points of different cushion areas based on ACTILUS pressure sensor system, and use the method of body pressure distribution to calculate and analyze the Seat Pressure Distribution index (SPD%) of the body pressure distribution characteristics on different cushions, so as to find the best surface shape of the cushion. (5) The subjective method mainly adopts the Seven-level comfort evaluation scale, focusing on the comfort score of key parts of the human body. The research is of great significance to improve the comfort quality of high-speed trains and enrich the ergonomics theory of high-speed trains in China.

Keywords: high speed rail seat, body pressure distribution, seat cushion body contact surface, cushion surface shape.

1 Introduction

Nowadays, the backrest of domestic high-speed rail seats is adjustable within a limited range, and the angle of the seat cushion is generally fixed. During the operation of high-speed rail, the design of the seat is directly related to the passenger's riding experience. For example, a good seat design can ease the passenger's nervousness from noisy environment, and a well-designed seat can make the passenger get the maximum rest. Resting and stretching, designing seat cushions that are in line with human physiological characteristics can effectively reduce passengers' risk of sitting sores and other skeletal diseases.

Comfort is one of the sensory mechanisms of human beings. Comfort is a person's response to the whole environmental system when he touches objects. Hterzberg points out that comfort and discomfort are two opposite situations. They are different sensory systems. The correct explanation of human comfort is that there is no uncomfortable feeling. The influence factors of comfort degree of high-speed train mainly include physical factors, human physiological factors and human psychological factors. Nowadays, there are three main research methods on seat comfort of high-speed train: subjective comfort, objective comfort and the combination of the two. In the research of subjective comfort, the comfort performance of each part of high-speed rail seats is validated by establishing comfort model and comfort measurement scale, such as GCR [1], BPD (40), Dannion R. Smith questionnaire and CEC (21). Mainly through surface electromyography, body pressure distribution, vertebral load and other physical means, according to seat-related parameters data analysis, test seat comfort situation; some scholars research is the combination of the two, explore various subjective and objective factors related to seat comfort, such as Yang Zhongliang [3] found only objective. The results of the study are rigorous in evaluating the comfort of high-speed rail seats. Subjective testing and evaluation are indispensable to the comfort test of sitting posture. The research on comfort degree of high-speed rail seats includes static comfort degree and dynamic comfort degree. Static comfort is mostly related to the seat's own characteristics, such as size ratio, material selection, reasonable structure and so on. Zhao Ling [2] and other methods of body pressure distribution were used to compare the running state and static state of the car body. It was found that there was no significant difference in the body pressure distribution between the two methods. Therefore, it is of great reference significance to carry out the experiment of body pressure distribution in the experimental environment for the study of static comfort. Dynamic comfort is mostly related to the body structure and running environment of the high-speed railway in its own running state, such as the vibration frequency or the air pressure of the carriage when the high-speed railway is running. Drummond et al. pointed out that in sitting posture, the ischial tubercle shoulders part of the body weight, up to 18%. In the buttock region, the reasonable pressure distribution should be the maximum pressure at the ischial tubercle, and then gradually decreases to all sides.

Denis Zacharkow [4] found in his research that hip is one of the important factors that influence each other in the key parts of human body which are related to seat comfort. Human body pressure distribution can not only test the body pressure distribution of the corresponding parts, but also find the theoretical relationship between hip and seat comfort through rigorous data analysis, which provides a basis for the study of seat comfort. Based on the theoretical and scientific basis, more relevant comfort evaluation indicators are explored.In the research of seat comfort, pressure distribution can establish multi-parameter evaluation model based on body pressure distribution criterion, optimize seat shape, soft and hard degree and other parameters, and then effectively guide seat structure design, reasonable layout of man-machine and improve ride comfort. The study of pressure distribution plays an obvious guiding role in the study of ride comfort of trains in short-term or long-term operation.

2 Method

2.1 Participant

The object of this study is passengers on high-speed trains. The number of passengers is huge. Given the limitations of time and conditions, it is impossible to carry out experiments on all the subjects. Therefore, before doing the sample survey experiment, we should first determine the reliable sample size that can effectively infer the overall. Because the research object of this paper is very extensive, the acquisition of reliable sample size needs three essential conditions: first, reliable sample size needs to cover a wide range of human body size required by the experimental object; second, these broad human body size should conform to normal distribution; third, the size of sample size should be effective, reflecting the general situation.

In this study, a simple random sample size calculation method [5] was used to obtain the minimum sample size of 96. The sample size conforms to the normal distribution, and the height and weight are between the 5th percentile and the 95th percentile. In this research, 96 samples will be used for subjective evaluation of comfort of high-speed rail chair. In the measurement of body pressure distribution, due to the limitation of experimental time and conditions, two subjects of large, medium and small stature will be selected from 96 samples, each male and female.

2.2 Materials

In view of the comprehensive consideration of the size, accuracy and ductility of the pressure sensor, the cushion pressure sensor test system of TACTILUS model is adopted in this experiment. It can display the pressure value of each sensor unit in real time, as well as the two-dimensional and three-dimensional graphics display. It can display the minimum and maximum graphics in basic colors such as blue, green, yellow and red. At the same time, it can record and store the whole measurement process. The recorded files can be imported into the corresponding software to reproduce the state of the whole recording process. For the output data documents, the system can also support the conversion of mechanical units such as PSI, RAW, mmh, Kpa and so on, accurate to the decimal point 4-digit value.

TACTILUS cushion pressure sensing system is simple and convenient to use. It can record and obtain experimental data and graphics in real time only by placing the sensor cushion on the test seat, connecting an external processor at the corner of the cushion, connecting the computer at one end of the processor and opening TACTILUS software on the computer.

2.3 Procedure

2.3.1 Subjective evaluation measurement

In order to more accurately understand the influence of comfort degree of key parts on comfort degree of high-speed railway chair, the key parts were selected as buttocks, ischial tubercles, thighs, thighs, roots, knees, legs, feet and ankles; the comfort evaluation scale was Seven-level scale, and the comfort level was 1 to 7 points. The experimental scoring steps are as follows:

(1) Before the experiment, the participants were explained the location and range of the body parts in the scale, and the degree and significance of each score of the Seven-level score.

(2) After adjusting the experimental seat, the subjects sat on the cushions of S1, S2 and S3 for 5 minutes in an rectified sitting position, and compared with the lower limb position map, as shown in Figure 4-3, the comfort degree of the human body was scored on each cushion.

(3) After adjusting the experimental seat, the subjects were seated on the cushions of S1, S2 and S3 in a natural relaxation position for 5 minutes, and compared with the lower limb position map, as shown in Figure 4-3, the comfort degree of the human body was scored on each cushion.

(4) Which level should the subjects choose to draw "√" in the corresponding blanks.

2.3.2 Objective body pressure distribution measurement

To measure the pressure distribution of the high-speed rail chair in simulated experimental environment, the force calibration range is carried out on TACTILUS software before the measurement. The pressure unit is PSI. As shown in Figure 4-4, the test temperature is required to be 23 (+%) 2 and the relative humidity is 60 (+) 4%. The test subjects are required to wear shirts: 100% pure cotton, underclothes: 50% polyester and 50% pure cotton, jackets: 55% polyester and 55% pure cotton. 45% wool; the seat before the test is placed in the experimental environment for 24 hours; the subjects rest for 1 hour in the experimental environment before the test, and then test when they feel most comfortable. For the convenience of recording data, the seat cushion in the following article is called as follows:

The protruding cushions on both sides in the rectified sitting posture are C-S1.

The front protruding cushion in the rectified sitting position is C-S2.

The flat protruding cushion under the rectified sitting position is C-S1.

The protruding cushions on both sides under relaxed sitting posture are R-S1.

The front protruding cushion under relaxed sitting posture is R-S2.

The flat cushion in relaxed sitting position is R-S3.

3 Results

Through the subjects'comfort scores of different parts of the human body made by two sitting postures for three different curved cushions (because they are two sitting postures, the C-S1 in the following article represents the situation of the cushion S1 in the rectified sitting posture, and so on C-S2, C-S3, R-S1 represents the situation of the cushion S1 in the natural relaxation sitting posture, and so on, R-S2, R-S3) we get:

(1) In the rectified sitting posture, the average score of comfort of all parts of the human body is listed, and the standard deviation SD is in parentheses.

Table.1. A List of Means of Comfort Scores for Human Parts in Sitting Posture.

Cushion	Hips	Ischial Tubercle	thigh	Root of thigh	Knee joint	A lower leg	Ankle	Feet	Overall comfort
S1	4.64（0.90）	4.50（0.89）	4.54（0.96）	4.52（1.05）	4.50（0.96）	4.28（0.95）	4.30（0.97）	4.25（1.02）	4.41（0.89）
S2	5.00（1.03）	5.02（0.98）	4.25（0,96）	4.36（0.92）	4.68（0.98）	4.63（0.95）	4.59（0.94）	4.68（1.02）	4.65（0.95）
S3	5.04（1.03）	4.98（0.97）	4.75（1.01）	4.65（0,92）	4.50（0.95）	4.43（0.99）	4.52（0.96）	4.36（0.94）	4.67（0.85）

(2) Under the natural relaxation sitting posture, the average score of comfort of all parts of the human body is listed, and the standard SD is in parentheses.

Table.2. A list of average comfort scores for different parts of the human body in natural relaxation sitting posture.

Cushion	Hips	Ischial tubercle	thigh	Root of thigh	Knee joint	A lower leg	Ankle	Feet	Overall comfort
S1	4.47（0.95）	4.40（0.86）	4.64（0.93）	4.58（1.01）	4.47（0.97）	4.35（0.98）	4.26（0.87）	4.23（1.03）	4.42（0.94）
S2	4.46（0.95）	4.35（0.89）	4.32（0.94）	4.26（0.98）	4.43（0.97）	4.53（1.03）	4.35（0.97）	4.30（0.99）	4.37（0.92）
S3	4.53（0.92）	4.40（0.98）	4.57（0.89）	4.62（0.96）	4.35（0.85）	4.55（0.98）	4.43（0.91）	4.31（0.97）	4.47（0.87）

The data were collated and analyzed. The results showed that the two-dimensional pressure distribution icon of the subjects was shown in Table 5-3, and the body pressure data of the cushions in two sitting positions were shown in Table 5-4.

Pre-experiment: In order to explore which sitting posture has better comfort experience for high-speed railway passengers under the two situations of rectified sitting posture and natural relaxation sitting posture, the two-dimensional pressure distribution maps of three cushions S1, S2, S 3, maximum pressure Pm, average pressure Pv and contact surface of a participant (a 23-year-old woman with a height of 160cm and a weight of 45kg) were analyzed first in the two situations of rectified sitting posture and natural relaxation sitting posture. Product A, mass center C data, to compare the impact of two sitting postures on the same subject.

The sampling time of TACTILUS is 5 minutes and the sampling frequency is 5 frames per second. The subjects have 1500 frames of pressure distribution experimental data on each cushion. The data is derived in the form of TXT file. Before the test data is applied to the experimental analysis, it should be pretreated first to reduce the human control error in data collection. In addition, TACTILUS sensor system can intuitively output the maximum pressure Pm, average pressure Pv, contact area A, mass center C and two-dimensional pressure distribution of the cushion.

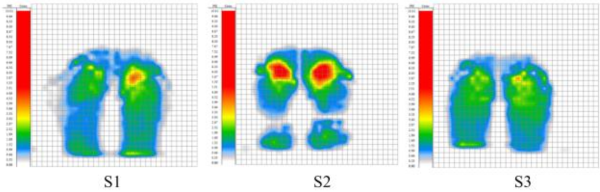

Fig.1. Two-Dimensional Pressure Distribution in Rectified Sitting Posture

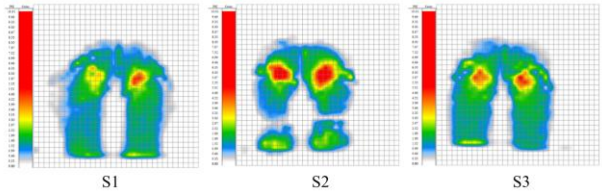

Fig.2. Two-Dimensional Pressure Distribution in Relaxation Sitting Posture

4 Discussion

The highest overall comfort score was S3 flat cushion, followed by S2 and S1. For S1 lateral convex cushion, the comfort of lower limbs is relatively average, and the comfort of lower limbs is more balanced; the comfort of S2 front protruding cushion buttock area is higher than that of leg part, which indicates that the front protruding cushion is beneficial to relieve the pressure of buttock area; the comfort of S3 flat cushion buttock and thigh area is better than that of S2 front protruding cushion buttock area. The effect is the best. The comfort degree of calf and knee joint is worse than that of the former two. Flat cushion can not effectively disperse the pressure of various parts of human body and improve the comprehensiveness of comfort degree compared with S1 cushion. The highest overall comfort score was S3 flat cushion, followed by S1 and S2. In relaxed sitting position, the comfort of thigh area is better than that of buttocks, calves and feet for S1 lateral convex cushions; the overall comfort of S2 front protruding cushions is more balanced than the other two, of which the comfort score of calf area is the highest; the comfort score of S3 flat cushion thigh area is the highest, and the pressure of flat cushion is lower than the other two for thighs, but the comfort score of S2 front protruding cushions is the highest. It's about knee comfort, which is worse than the other two.

In the case of rectified sitting posture, the contact area between the subjects and the cushion is smaller than that of the relaxed sitting posture, and the same is true for the cushion of each shape. It is found that the center of gravity of the relaxed sitting posture will move downward, resulting in the increase of the contact area with the cushion. With the change of the sitting posture and the cushion surface, the center of gravity of the cushion of the shape of the cushion under each sitting posture also occurs. The displacement indicates that both the sitting position and the cushion surface will affect the weight of the subjects on the cushion. According to the Pm and Pv break-line maps of the cushions in Fig. 5-4, it can be found that the average pressure Pv of the cushions in these six different states has no obvious change, and the average pressure of the cushions in the break-line maps is close to the straight line. The average pressure of the C-S1 cushions is the smallest, and the single factor analysis state is more comfortable than other cushions. The maximum pressure of the R-S2 cushions is the largest, because of the law of cushion pressure, the cushion pressure of the sitting bone The pressure at the nodule is the greatest, and as the center, the pressure expands smoothly from big to small, so the pressure at the nodule of the sciatic bone of the cushion with protruding front is the greatest when relaxing sitting posture. In the case of rectified sitting posture, the pressure on the two sides of the cushion ischial tubercle is the smallest, which is more comfortable for the ischial tubercle. The contact area of the cushion is smaller than that of the whole body in the relaxed sitting posture, and the contact area of the person-cushion in the relaxed sitting posture is larger than that in the rectified sitting posture in three different surface shapes. In theory, the overall comfort of rectified sitting posture is better than that of relaxed sitting posture, and the six states of cushion are more comfortable. The two sides of protruding cushion under rectified sitting posture are more comfortable.

5 Conclusion

Throughout the subjective and objective research on comfort degree of high-speed rail chair surface, static comfort degree research situation, straightening sitting position is more comfortable than relaxing sitting position experience, but passengers in high-speed rail operation behavior, relaxing sitting position occurs most frequently; three different curved surface shape cushions, flat cushion and the rest of the subjective evaluation. Compared with the other two, the front protruding cushion is more comfortable. In objective index evaluation, the front protruding cushion has a certain effect on improving the uniformity of cushion pressure distribution. The flat cushion has the smallest SPD% and the most uniform pressure distribution, which is more comfortable than the other two. Under long-term conditions, the simple index based on comfort score and body pressure data is not the same. It can fully characterize the comfort of high-speed rail chair surface, and in the future, EMG sensing and scene simulation can be added to the experimental study.

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Quantitative Investigation on Dynamic Comfort in Automotive Seats: A Ride and Drive Study

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Abstract Dynamic comfort has been a heated topic within the automotive industry. Compared to the conventional static comfort assessment conducted in a laboratory setting typically used, an on-road dynamic comfort test provides more realistic and comprehensive investigation of the interaction between the automotive seat and occupant. Therefore, the goal of this study was to understand what were the major contributors to dynamic comfort and whether the occupant could perceive a difference in comfort between different seat cushions. In order to address these topics, a quantitative study including both objective and subjective evaluations was carried out. Eight participants were recruited for a 1.5-2 hour driving course that consisted of different road profiles. Each participant completed two rounds of driving with two different seat cushions installed. Participants were asked to provide subjective feedback via a questionnaire before, during, and after the driving course. The seats were also tested in the laboratory for standard objective mechanical comfort characterizations. Results showed that most participants experienced discomfort and fatigue during the entire course of driving, while a few of the participants reported muscle soreness and tailbone pain or numbness. The cushion vibration transmissibility contributed to the comfort loss during the driving. One seat cushion that was initially softer had a higher compression rate, leading to a harder feeling after the 2 hours driving course and a further decreased comfort at the end of the road test. This study supported that the short term static comfort evaluation should not be the sole decision maker when it comes to automotive seating comfort, as the participants' comfort deteriorated after a long term dynamic ride. The work presented laid a foundation for future development of automotive seats with better long term dynamic comfort.

Keywords: Dynamic Comfort, Ride and Drive, Vibration Transmissibility, Automotive Seats

1 Introduction

Seating comfort has long been discussed in the automotive industry. Comfort, by definition, not only means the "absence of discomfort", but also represents an overall wellbeing physically, physiologically and psychologically [1]. The common practice of evaluating comfort includes the assessment of the seat and the assessment of the occupant. The seat comfort evaluation dealt with the seat design and the seat mechanical properties which have been standardized by SAE J2896 in the US [2]. The occupant comfort assessment involves both objective measurement (such as body pressure distribution), and subjective evaluation which is normally recorded by questionnaires [3]. Conventionally, most of the seating comfort evaluations take places in a laboratory setting, and are either taken under static environment, or only measured within a short period of time ("showroom comfort") [3]. Recently, increased research on seat fidget has indicated that the long term dynamic fatigue plays significant role in the riding comfort. It has been reported that most people started to feel discomfort in a vehicle after 45 minutes to 1 hour of driving [4, 5], and the vibration being transmitted to the occupant over an extended period of time also has chronic impact to the occupant physiologically [6]. Therefore, it is important to carry out a ride and drive study that is longer than 45 minutes to evaluate the dynamic comfort perception of the seat.

Seat cushion foam, which provides the most direct support to the occupant, is a key player in seating comfort. The standardized measurement of the foam properties does not require the foam to be loaded over long periods of time [7] and therefore creates a gap when evaluating the long term mechanical properties of the foam and the occupant seating comfort.

In order to better understand the overall comfort performance of the seat, a dynamic ride and drive study with both subjective and objective measurements is needed to quantitatively evaluate the differentiable comfort contributors of automotive seats. Hence, the goals of this study were to investigate: 1) the major contributors to dynamic comfort; 2) the influence of seat cushion foam to occupant comfort over a long term driving period.

2 Method

A mid-sized 4-door sedan at a medium price range was chosen to be the test vehicle. Two different cushion foams (here in after referred as Foam A and B) were selected as the comparative targets for this study. These two foams were made from different chemical formulations but kept the same density. Foam A was slightly softer than Foam B per standard test results. The mechanical properties of the foams per ASTM test method [7] are listed in Table 1.

Table 1. Mechanical Properties of the Two Cushion Foam Pads

Foam ID	*25% Indentation Load (N)*	*50% Indentation Load (N)*	*65% Indentation Load (N)*	*Hysteresis Loss (%)*	*Thickness (mm)*
A	293.03	528.78	905.72	31.04	73.5
B	295.43	542.65	959.51	29.98	72.7

Three 3-axis accelerometers (TLD356A15, PCB Piezotronics, USA) were instrumented on the seat (Figure 1): one at the front end of the seat track; one at the rear end of the seat track; one hidden underneath the trim cover towards the rear end of the cushion foam. A handheld 12 channel data acquisition device (Coco-90, Crystal Instruments, USA) was used to collect the vibration data while on the road. In this study, we focused on the comfort impact of vertical vibration, therefore the vibration transmissibility was calculated as the ratio of the vertical acceleration power density between the cushion and the seat track.

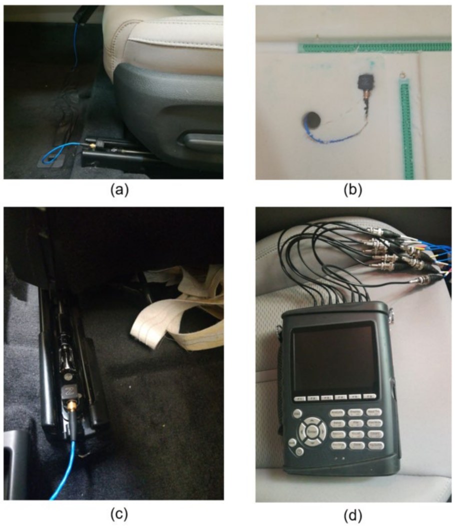

Fig. 1. Instrumentation of the ride and drive study: a) accelerometer at the front of seat track; b) accelerometer in the seat cushion; c) accelerometer at the rear of seat track; d) handheld data acquisition device

Eight participants (6 male; 2 female) were recruited in this study on a voluntary basis. None of the participants had known existing health conditions that would prevent them from driving for 2 hours continuously. All of the participants drove on a daily basis and their daily commute time varied between 20 minutes to 1 hour and 45 minutes one way (home/work). The average height and weight information of the participants are listed in Table 2.

Table 2. Participant Information

Sex	*Number*	*Ave. Height (cm)*	*Ave. Weight (kg)*
Male	6	177.0	77.1
Female	2	165.1	55.6

The driving route chosen for this study consisted of different road profiles: city street, highway, dirt road, freeway, and suburban roads (Figure 2). The total distance of the entire route was 88 kilometers.

A customized questionnaire was designed and used to collect subjective feedback before, during, and after the driving course. Due to concerns of inducing fatigue to the participants, the ride and drive test for each participant was taken in two rounds, i.e. the participant drove the vehicle with Foam A in the seat first, then drove the vehicle with Foam B on a separate day. Since comfort is a measure of overall well-being [8, 9] and is affected by not only physical but also physiological factors, we asked the participants to provide a rating of their overall general comfort feeling (in addition to seat comfort ratings) both at the beginning and the end of each round of the driving test. Therefore, instead of having the participant make preferential evaluations between Foam A and Foam B, the study aimed to provide a direct comparison by calculating the comfort level decrease at the end of driving test for Foam A and Foam B respectively. During the drive evaluation, the same set of questions was repeated for each road profile to see which road condition caused most discomfort for the participant.

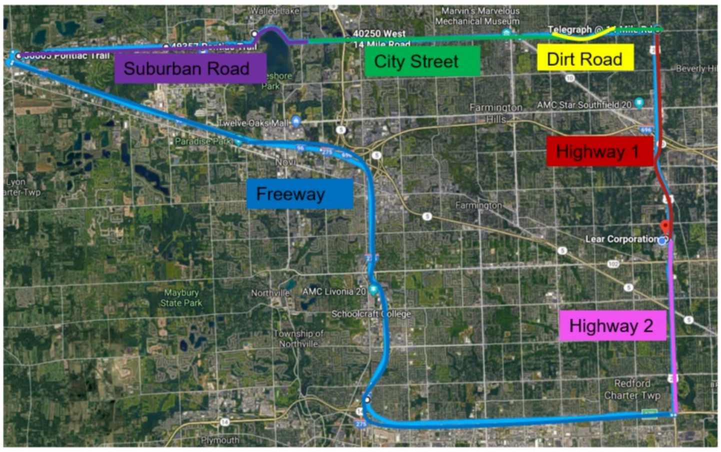

Fig. 2. Different road profiles in the driving course.

In order to gain both objective and subjective insights for the comfort performance of the seat cushion, the standardized mechanical testing for both seat cushions was performed according to SAE J2896. Additionally, a special vibration transmissibility test was carried out: after the initial J2896 vibration transmissibility test, the seat was continuously loaded with 50kg weight for 2 hours and then repeated with the J2896 vibration transmissibility test. Therefore, by comparing the vibration performance change over the 2-hour loaded period, it provided the ability to correlate the objective measure with the subjective scores from the ride and drive study.

3 Results

The ride and drive vibration transmissibility was presented as the ratio of peak acceleration Auto Power Density (APS) between the seat cushion and both of the front and rear seat tracks. The on-road comparison between Foam A and Foam B in vibration transmissibility is shown in Figure 3. It can be seen that both foams yielded good vibration absorption (lower transmissibility) performance. On the dirt road, Foam A had higher transmissibility than Foam B. However, no significant difference was observed.

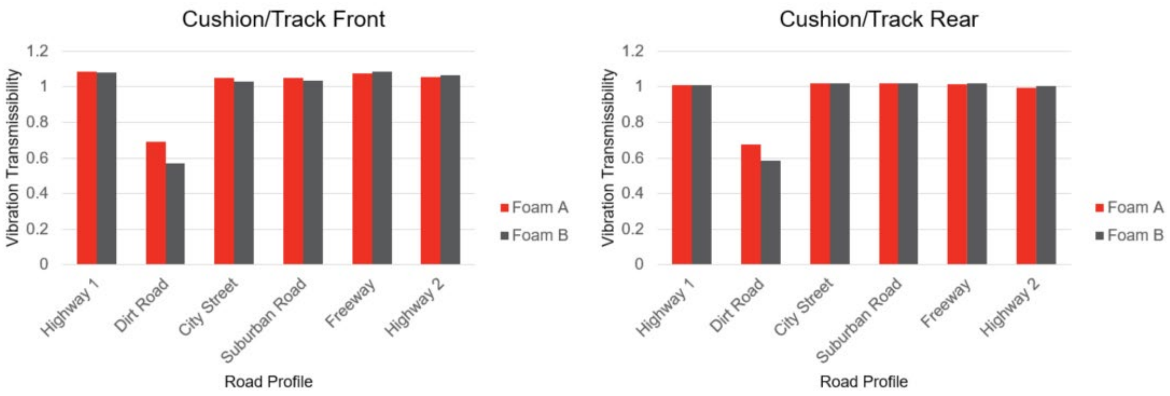

Fig. 3. Vibration transmissibility comparison between Foam A and Foam B on different road profiles

Figure 4 shows the subjective comfort rating change after the 1.5~2 hour drive. Foam B exhibited less comfort loss when compared to Foam A. In other words, Foam B maintained more comfort compared to Foam A after 2 hours.

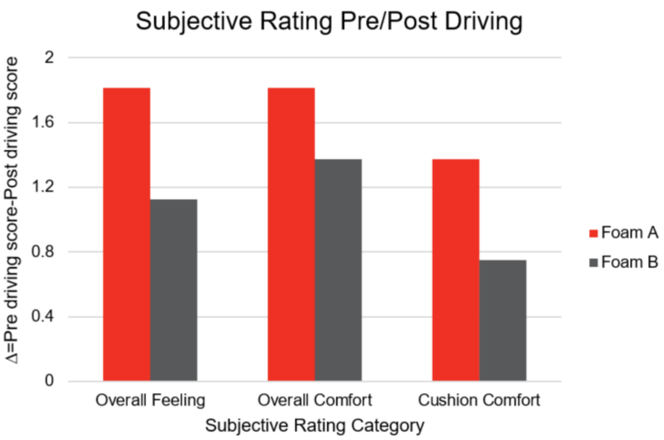

Fig. 4. Change in subjective rating before and after driving test

Additionally, during the specially designed 2-hour in-lab vibration transmissibility test, we have found that both foams had increased transmissibility after sustaining the 50kg load for 2 hours. Foam A had a higher increase in the transmissibility than Foam B. This result provided a possible explanation for the larger comfort loss of Foam A when compared to Foam B at the end of the ride and drive study. From the overall hardness testing, based on SAE J2896 methodology, we also found that Foam A had significant increase in the hardness after 2 hours' loading. This could be a result of air being pushed out from the open cell foam, increasing the stiffness of the foam. The increased stiffness also led to the increase of resonance frequency of the foam pad, as can be seen from Figure 5. These 2-hour mechanical performance results were echoed by the subjective feedback: half of the participants reported the cushion hardness feeling had changed for Foam A at the end of the driving, and one participant reported a sinking feeling of Foam A at the end of the drive evaluation.

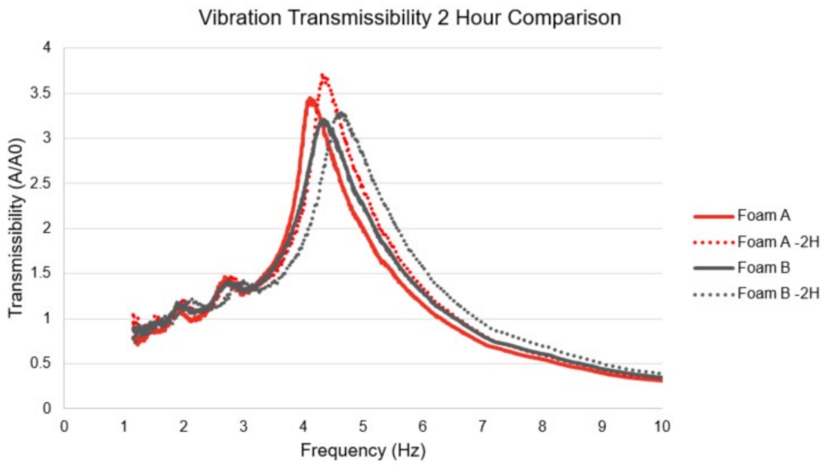

Fig. 5. Vibration transmissibility comparison of Foam A and Foam B before/after 2 hours loading

All eight participants reported body fatigue with Foam A and six of the eight participants also felt fatigued with Foam B. The most reported fatigue and discomfort types include numbness in the buttocks, lower back muscle soreness, and tailbone burning sensation. Only two participants reported discomfort from vibration on dirt road, this could be because the dirt road occurred at a relatively early phase of the drive route.

4 Conclusion and Discussion

Dynamic seating comfort has raised more and more awareness in the automotive industry, especially with the increased focus on interior design leading into the autonomous vehicle era. The study presented here quantitatively compared both objective and subjective ratings of the two different cushion foams and provided insights into the lead contributors to seated occupant comfort during long-term driving experience.

The results indicated that the foams' mechanical properties (both overall hardness and vibration transmissibility) would change over extended periods of time when under a loaded condition. These data supported that it is important to differentiate between showroom static comfort and long-term driving comfort. Additionally, the long-term performance of the seat cushion is perceivable by the occupant as participants did report changes in the feel of cushion firmness. Hence, a long term dynamic comfort evaluation is needed to provide a comprehensive assessment of automotive seat comfort.

We would like to point out that one of the innovative approaches used in this study was the instrumentation of the accelerometer in the seat cushion. Traditionally, researchers have been using a transmissibility pad to measure seat transmissibility. However, we have found out that the pad itself would cause extreme discomfort even under static condition. As the goal of this study was to evaluate the dynamic driving comfort, we wanted to maintain the vehicle interior condition as close as possible to the realistic driving condition.

5 Limitation and Future work

The major limitation of this study was the limited sample size for both seat samples and number of participants. In this study, two cushion foams were used. Although these two foams had the same density and similar firmness, there might be other material properties that contributed to the comfort but were not taken into consideration in this study. Additionally, due to the availability of the participants, we had constraints on the driving time. Some participants commented the comfort feeling could change depending on the time of the day or the day of the week.

Even with the limitations discussed above, we were able to see a meaningful difference between the two foams during long term driving. This study laid a foundation for comprehensively understanding the seat dynamic comfort performance. We would like to continuously adopt a similar methodology and collect more data in the future to enhance our knowledge base in long term dynamic ride and drive comfort.

Acknowledgments The authors would like to thank all the participants who took part in this study voluntarily.

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The experience of comfort is related to profession. Or is it linked to visual perception?

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Abstract The words "comfort" and "discomfort" are part of our daily life and are widely used by several cultures; their meanings and correlations are objects of continuous study in several scientific areas. We can have an experience of comfort or discomfort when using products or being in certain environments. Thus, the aim of this study was to attest whether the perception of comfort is influenced by one's profession, assuming that technical knowledge on the subject differs among professionals from different areas. Online questionnaires were sent and 242 Brazilian workers from different professions answered questions about their experience of comfort in various situations. The Kruskall Wallis statistical test was used to categorize the answers into groups by similarity of professional knowledge. The results suggest that the type of profession is not a significant variable as to influence people's perception of comfort. It was concluded that the variable "visual perception", although it was not the subject of this research, stood out in the results as being extremely significant, which confirms data in the literature pointing to the fact that the visual perception influences our experience and perception of comfort.

Keywords: General relativity, comfort, comfort model, products, expectations

1 Introduction

Comfort is present in our daily lives. Humans experience comfort in wearing clothes, lying in bed, using hand tools and kitchen appliances, dealing with computers and being in their workstations as well as in seats in cars, trains, buses and airplanes. Discomfort can also be experienced in our daily life and it has a relationship with the presence of musculoskeletal complaints [1]. Furthermore, both comfort and discomfort are often studied within the scientific domain. Vink and Hallbeck [2] found 104,794 papers mentioning discomfort in 30 years' time. Bazley [3] studied 318 scientific papers with the word "discomfort" in the title in a period of 10 years.

Comfort is an experience that involves a sense of subjectivity and well-being [4]. On the other hand, discomfort is related to physical factors [5] and can be associated with a sense of objectivity.

Several factors may influence the perception of comfort or discomfort, such as: how services are provided and received by the user [2], psychological (intellectual and emotional) factors [6], visual perception [3], temperature, noise, level of lighting, space of the environment, furniture and product design [7]. This complexity of factors that influence comfort and discomfort poses a great challenge when it comes to designing comfortable products and work environments.

Scientific articles on comfort usually correlate different variables. Some common examples are: the relationship between satisfaction and comfort [4]; comfort and emotion [8, 9]; comfort and product design [10]; comfort and ergonomics [10, 11, 12, 13]; comfort and safety [14]; comfort and productivity [15]; comfort and discomfort [2, 16, 17, 18]; comfort and health [19]; comfort and built environments [3]. However, research on the relationship between the user's perception of comfort and their profession is not common, perhaps because this brings another variable that is the expectation. According to Kamp et al., [20] the nature of expectations is subjective and of great importance for the experience of comfort. Theories about expectations are relatively underdeveloped.
Some comfort models, such as Vink and Hallbeck [2], indicate that expectation has a strong link with comfort. Taking this as a premise, the research question of this research was: Do professionals involved in the humanities or in the technological fields have different perception of comfort?

2 Methods

2.1 Participants

This study was conducted in Brazil and involved 242 participants, of whom 81 were men and 161 were women of different professions.
The age range of participants was from 17 to 66 years, with the largest number of participants (97) being concentrated in the age group between 30 and 40 (table 1).

Table 1. Age groups of participants.

Age	Count	Percentage
17-30	24	9,92
30-40	97	40,08
40-50	59	24,38
50-60	44	18,18
>60	18	7,44
	N=242	

2.2 Methods

Participants received the consent form along with the online questionnaire via GoogleDocs. The questionnaire contained 24 questions, 22 closed questions with answers within a comfort and discomfort scale ranging from 1 to 7. And 2 open-ended questions requiring the respondent to describe, with at least 03 words, the idea of comfort and discomfort. The goal of the questionnaire was to check participants' expectations and perception of comfort when viewing images of different products and whether this perception of comfort or discomfort would be more significant for professionals involved in the humanities or in technological areas. The evaluated products were: bed, hammock, airplane seat, train seat, office chair, foam pillow and feather pillow, different models of travel pillow, military boots, sneakers and situations like standing in a long line.

2.3 Statistical Analysis

This study used the Kruskall Wallis test in order to confirm the hypothesis of the research question. The Kruskall Wallis test is a nonparametric method for testing whether samples originate from the same distribution. This test is used to compare two or more independent size samples. When the Kruskall Wallis test is significant, it indicates that at least one sample randomly dominates another sample [21].

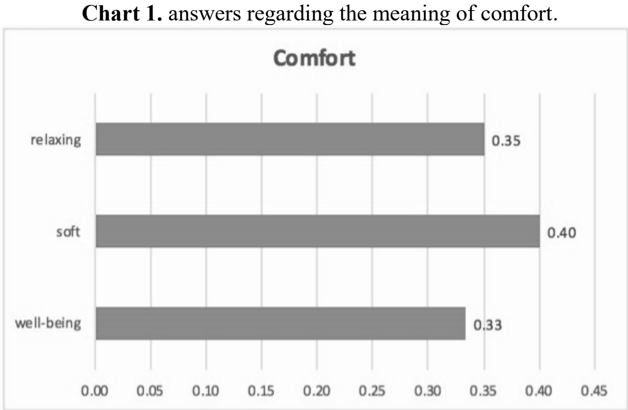
3 Results

The 242 answers to the questionnaire showed that, among the tested variables, a small difference was significant for the following variables: *age* and *gender* in relation to the *perception of product comfort*. Moreover, the variable *visual perception* produced very significant statistical results. No statistic difference was found regarding the correlation between variables *area of profession (humanities or technology)* and *perception of comfort*. This correlation was the object of the research question of this article. Thus, only the variables *age*, *comfort perception* versus *professional area* will be described in this research because they are relevant to what is proposed in this article.

3.1 Comfort

As a criterion of inclusion of the answers in the chart, we adopted the premise that the word to describe comfort or discomfort should appear at least 3 times in the answers. Thus, the words that appeared most in the answers regarding the idea of comfort were: relaxing, soft and well-being (chart 1).

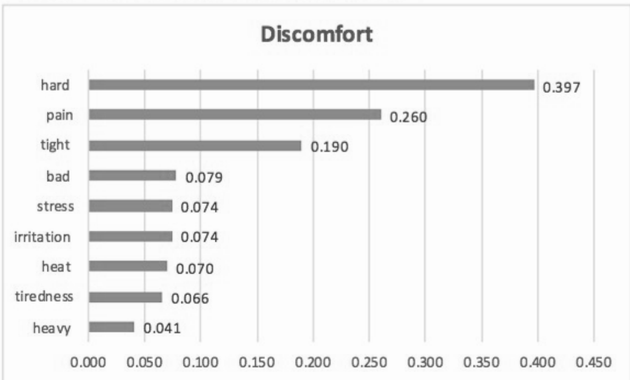
Chart 1. answers regarding the meaning of comfort.



3.2 Discomfort

Participants were also asked to provide words or expression that they associate with the idea of discomfort. The ideas provided by respondents to this question was: hard, pain, tight, bad, stress, irritation, heat, tiredness, heavy (chart 4).

Chart 2. answers regarding the meaning of discomfort.

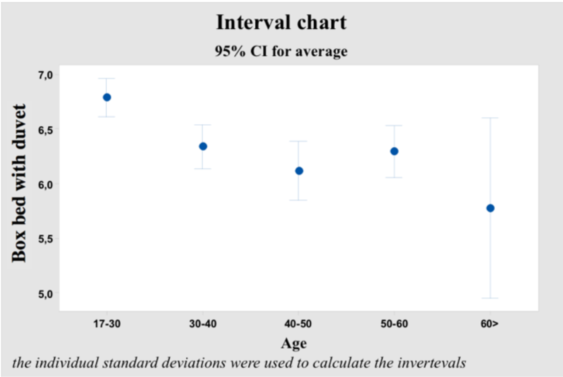


3.3 Age

3.3.1 Product | Bed

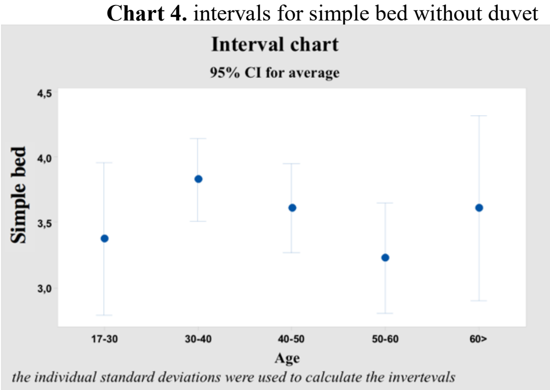
When requesting the participants to compare photos of two beds: a box bed with duvet (picture 1) and a single bed without a duvet (picture 2), the box bed with duvet ranked higher in comfort perception in the older age groups. Statistically, a significant difference was found for box bed with duvet (picture 1) in relation to age (Kruskall Wallis test, p value = 0.026). But in practice, the differences are small: <30 = 6.8, 30-50 = 6.3, > 50 = 6.2. (charts 3 and 4).

Chart 3. intervals for box bed with duvet



Picture 1. box bed with duvet

Chart 4. intervals for simple bed without duvet



Picture 2. simple bed without duvet

3.3.2 Product | Pillow

Regarding pillows, participants had to report their perception of comfort by choosing between a goose feather pillow (picture 3) and a latex pillow (picture 4). The difference was statistically significant for the goosefeather pillow with respect to age (Kruskall Wallis test, p value = 0.035). But in practice, the differences are small: <30 = 3.4, 30-50 = 3.6, >50 = 3.

Picture 3. goose feather pillow

Picture 4. latex pillow

3.4. Professional area versus Perception of Comfort

The professionals who participated in this research were categorized into two large groups. Group A comprising professionals whose knowledge is framed in the area of humanities and group B containing the professionals within the areas of technology. The Kruskal Wallis test was used to check if there was any correlation between the perception of comfort and the professional areas of humanities and technology (groups A and B). There was no statistically significant difference between groups A and B. Table 2 shows the statistical results of the comfort perception of professionals in groups A and B in relation to images of the different products contained in the questionnaire.

Table 2. Averages and p values (Kruskal Wallis test) for comfort vs professional area.

Variable	Profession	Average	StandDev	minimum	median	maximum	P value
Simple Bed	A	3,67	1,39	1,00	4,00	7,00	0.383
	B	3,56	1,48	1,00	3,00	7,00	
Box Bed+Duvet	A	6,32	1,09	1,00	7,00	7,00	0.361
	B	6,26	0,97	1,00	6,50	7,00	
Hammock	A	4,21	1,58	1,00	4,00	7,00	0.275
	B	4,47	1,54	1,00	5,00	7,00	
Large Aircraft Seat	A	5,19	1,48	1,00	5,00	7,00	0.386
	B	5,32	1,51	1,00	6,00	7,00	
Small Aircraft Seat	A	3,35	1,50	1,00	3,00	7,00	0.563
	B	3,24	1,57	1,00	3,00	7,00	
Spacious train seat	A	4,15	1,37	1,00	4,00	7,00	0.787
	B	4,17	1,60	1,00	4,00	7,00	
Tight train seat	A	2,91	1,38	1,00	3,00	7,00	0.515
	B	3,04	1,44	1,00	3,00	7,00	
Tight train seat 3 hours	A	2,46	1,49	1,00	2,00	7,00	0.592
	B	2,69	1,80	1,00	2,00	7,00	
Wood Backless seat	A	1,37	0,72	1,00	1,00	4,00	0.585
	B	1,57	1,21	1,00	1,00	7,00	
Foam Backrest seat	A	5,17	1,13	2,00	5,00	7,00	0.912
	B	5,17	1,14	1,00	5,00	7,00	
Line	A	1,96	1,39	1,00	1,00	7,00	0.226
	B	1,79	1,39	1,00	1,00	7,00	
Side pillow	A	3,58	1,54	1,00	4,00	7,00	0.219
	B	3,35	1,53	1,00	3,00	6,00	
Neck Pillow	A	4,34	1,48	1,00	4,00	7,00	0.796
	B	4,29	1,52	1,00	4,00	7,00	
Around neck pillow	A	2,86	1,64	1,00	3,00	7,00	0.104
	B	2,51	1,53	1,00	2,00	7,00	
Goose feather pillow	A	5,17	1,55	1,00	5,00	7,00	0.676
	B	4,99	1,80	1,00	5,00	7,00	
Latex pillow	A	4,57	1,74	1,00	5,00	7,00	0.472
	B	4,73	1,73	1,00	5,00	7,00	
Boots	A	2,57	1,32	1,00	2,00	6,00	0.754

	B	2,67	1,48	1,00	3,00	6,00	
Sneakers	A	6,16	0,91	2,00	6,00	7,00	0.736
	B	6,17	0,98	2,00	6,00	7,00	

3.5 Visual perception of the product versus expectation of comfort

Some statistically significant differences were found in the product comparison responses, as can be observed in table 3.

Table 3. Visual perception of the product versus expectation of comfort

Product 1	Product 2	Kruskall Wallis	Respective median
Simple bed without duvet	Box bed with duvet	p value = 0.00	4 against 7
Small aircraft sear	Large aircraft seat	p value = 0.00	3 against 5.5
Tight train seat	Spacious train seat	p value = 0.00	2 and 3 against 4
Wood Backless seat	Foam Backrest seat	p value = 0.00	1 against 5
Side pillow	Around neck pillow	p value = 0.00	3 and 4 against 2
Foam pillow	Goose feather pillow	p value = 0.08	4.5 against 5
Military boots	Sneakers	p value = 0.00	1 against 5

4 Discussion

The 242 participants in this study chose the following ideas to describe comfort: *relaxing, soft and well-being*. In regard to discomfort, the main words were *hard, pain* and *tight*. All terms associated with comfort and discomfort highlight concerns with physical issues. It should be remembered that people have a personal opinion about comfort [7] and that the experience of comfort or discomfort is different among people [3]. *Age* was a variable in this study which suggests that the more mature a person is, the more demanding she will be in regard to comfort issues. The results of this study also demonstrate that there is no relation between perception of comfort and *professional area*, as described in table 2. However, the variable *visual perception*, which implies a pre-experience of comfort, has a statistically significant correlation with comfort. These results are aligned with the literature on this subject [2,10] and specifically with the research by Bazley et al. [22], which reports that, in the user's pre-comfort experiences, the variable *visual perception* is the most significant one influencing the perception of comfort and it will, therefore, affect our experiences.

4.1 Limitation of the study

The sample of this study (n = 242) was limited to professionals in the areas of humanities and technology. Future studies involving professionals from other areas are suggested.

5 Conclusion

The research question of this research was: Do professionals involved in the humanities or in the technological fields have different perception of comfort? And the answer is no. This study showed that it does not matter if the professional is in the area of human or technology sciences and suggests that visual perception is the most contributory factor in the perception of comfort. The variable visual perception was not the object of this research; however, it was shown to be extremely significant in the perception of comfort, in agreement with other studies reporting that the first idea of a product is communicated visually [22].Also the results of this study suggest that the age factor may be an important variable in the perception of comfort.

This study contributes to reinforce the importance of product design, which should always include the concepts of usability and comfort.

6 Acknowledgements

I am thankful to all the people who answered the questionnaires and in this way contributed to this research.

7 Declaration of interest

The author states having no commercial relationship with the manufacturers of the products surveyed, as well as receiving any payment from these companies as compensation for the research.

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Car Control knob usability: a posture based comfort assessment

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Abstract Today, people spend much more time in the car, especially the ones that drive for job (taxi driver, couriers, truck drivers, etc.); for this reason, several studies have been performed on car interiors in order to improve the driver and passenger comfort experience. The aim of this study was the evaluation of perceived comfort while using the infotainment board system inside a C-segment car MY2012. The Car manufacturer claims to guarantee connectivity to its users, but also to ensure the same "web comfort" of a PC or smartphone even when it is on the go. To prove that, a sample of twenty-three students performed three different tasks in a Mercedes class A180 CDI EXECUTIVE. Postural angles of students had been acquired non-invasively by cameras and processed by KINOVEA® software. A further virtual-postural analysis had been realized with a DHM (Digital Human Modeling) software. Subjective postural comfort has been evaluated through questionnaires by which participants were asked to rate on a 10-point Comfort scale the expected comfort before beginning the test and on a 9-point Likert scale the perceived comfort after using the knob. Objective postural comfort had been gathered through CaMAN® software. Finally, a large multivariate analysis had been done to evaluate the correlations among the data (anthropometric data, subjective and objective postural comfort). Results showed which could be the most comfortable position of the knob and which body-part mostly contributed to global perceived comfort.

Keywords: Postural comfort, Expectation, Car control knob, Car interiors

1 Introduction

Four decades ago, there was not a great technology level for the automobile instrument panel. Indeed, its functionality was reduced into simple operations, thus the number of interaction between the driver and dashboard was very low. Forty years later, the technology improvement was amazing: the dashboard assumed an important role and its design was more complexed. As a matter of fact, the number of required functions has increased, and there were laws requirements (e.g. Law 81\08 in Italy [1]) to respect.

Nowadays, customers expect to have advanced devices inside their cars, which they can use or interact with even while they are driving. Such devices provide useful information, entertainment, and connectivity.

The potential for such technology is great, as web applications, location-based services, and passive and active safety systems become standard in vehicles. These devices provide to drivers and passengers both the capacity for enhanced efficiency and productivity and technologies to prevent potential problems due to distraction and unexpected events. Consequently, there are increasing safety concerns regarding the interaction with devices that may increase visual load and cause the driver to shift his/her gaze from the road [2–5]. As result of a literature analysis of the last ten years, vehicle design and its ergonomics/comfort correlated issues are one of the main topic of both academia and industries researchers.

Manufacturers and suppliers recognize ergonomics as an important aspect of vehicle planning and design, while interior designers focus their attention on comfort analyses. Many studies were published on ergonomics/comfort topics and most of them concerns about seat comfort, controls reachability and understandability, mental load and aesthetics.

In the field of research about the comfort, for example, Reed et al. [6], Kolich [7–9], Fazlollahtabar [10], dealed with the anthropometric measures as one of the most important aspects in vehicle design process; in Naddeo and Memoli [11], and Naddeo et al. [3], driver comfort was studied to assess postural comfort, reachability and usability; in Vergara & Page [12], the sitting comfort was evaluated through the relationship between comfort and back posture and mobility; in Seoke et al. [13], and in Kolich and Tabourn's [14] the evaluation of driver's discomfort and postural change was made using dynamic body pressure distribution; in Reed et al. [6] and in Kolich [7], the seat's geometry, breathability and rigidity were considered the most important indexes of driver comfort.

During the driving experience, the driver needs to interact with a high number of elements (steering wheel, pedals, knobs, etc.).

Dashboard and cockpit's elements concur to make the vehicle cockpit more or less comfortable [5] with their characteristics as shape and dimensions [15], position [3,5,16–18] and orientation [19]. Dauris et al. [20] studied discomfort due to vibrations that can increase the level of irritability, lack of attention and postural overload. In these studies, the authors focused on infotainment system that, nowadays, is often common in vehicles. Currently, almost every new car is equipped with at least an entertainment system and/or a navigation system. Applications during driving are, for example, making a call, manually adapting the driving route to the traffic situation or merely changing the music, receiving and sending messages and e-mails. Nevertheless, even if the use of some infotainment tasks is not allowed when driving, drivers are generally not willing to stop their cars and tend to use these systems in parallel to the driving task instead [21]. Therefore, many of these systems have been especially optimized for this purpose [22]. One of the purposes of this paper was the evaluation of perceived comfort while using the infotainment board system inside a C-segment car (Mercedes-Benz W176). Virtual prototyping and Digital Human Modeling (DHM) were used to perform several simulations to assess the required performance of an in-vehicle "product", i.e. the knob, under the human factors and ergonomics [5,23,24] point of view.

Predictive studies were coupled with broad test sessions, using human subjects to test both hard (physical mockup) and hybrid (virtual/physical mockup) prototypes. In this research, the objective and the subjective comfort were estimated for the use of a specific car part, the use of the knob for the infotainment system, and at the same time, in order to understand the "comfort-zone" inside the car; during the tests, the interaction of the driver with steering wheel and gear shift were also evaluated.

2 Material and methods

2.1 Experimental sample

Twenty-three students of University of Salerno, 17 males and 6 females, took part to the experiment. All students enjoyed good health. **Errore. L'autoriferimento non è valido per un segnalibro.** shows anthropometric data of participants.

Table 1. Demographic data of the participants.

	Age (years)	*Height (mm)*	*Arm (mm)*	*Forearm (mm)*
Mean	*25,7*	*1720,9*	*319,4*	*272,7*
Std. Deviation	*2,2*	*70,4*	*27*	*15,5*
Minimum	*22*	*1540*	*251*	*240*
Maximum	*31*	*1860*	*379*	*300*

2.2 Experimental setup

A camera system to identify and evaluate posture angles for describing the entire body posture was used. Three Nikon D3300 cameras were placed in order to acquire: driver's right (A), driver's left (B), driver's back (C) as shown in Fig. 1:

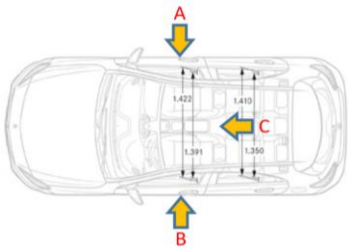

Fig. 1. Camera system.

Each shot was taken using the same camera positions, so even without a reference point, we could superimpose the differences in posture for all subjects. A correction for distortion (fish-eye effect) was applied to each photo image.

2.2 Protocol

In this study, the purpose is to estimate the postural comfort due to the use of knob, steering wheel and the gear shift and, at the same time, to understand the subjective perception of different users. This leds to seek two different comfort indexes: postural comfort (by virtual-objective assessment) and perceived comfort (by a subjective assessment).

The test procedure was the following:

(1) During the experiments, the subjects performed sequentially three main tasks: the subject holds both hands on the steering wheel; the subject reaches the push button on the knob with his right hand and keeps his left hand on the steering wheel; the subject makes the gear changes while holding the left hand on the steering wheel and the right on the gearshift;

(2) After the use of the knob control, subjects were asked to fill the comfort questionnaire;

(3) For each task, the postures of the subjects were acquired via photo acquisition (Fig. 1);

(4) The photos were processed using Kinovea® software to acquire the angles of the joints;

(5) The angles were then used as input into Delmia® to simulate each posture;

(6) The upper limb angles were processed by CaMAN® to objectively rate the upper limbs comfort indices and, the global comfort index, in order to correlate them to the subjective perception and validate the results. In this study, shoulders, neck, hands and elbows behaviours were investigated because the upper limbs are mainly involved in this kind of interaction.

2.3 Evaluation Technique for General Comfort

To acquire the subjective perceived comfort perception while using the infotainment system, a comfort questionnaire was used in which students were asked to rate

- the expected comfort before starting the experiment, on a 10-point scale;
- the perceived comfort for each part of the upper body, involved in the task (neck, back, shoulder, arm, forearm, hand), on a 9-point scale from 1 (Not comfortable) to 9 (Extremely comfortable);
- the overall perceived comfort, on a 10-point scale.

2.4 Technique for Body Angle Measurements

Human-joints' angle measurements were performed using photogrammetric analysis; this analysis, processed by Kinovea® software rel. 0.8.7, allows to acquire data about three-dimensional points' coordinates simply by analyzing photos [1]. In Fig. 2, two examples of the cameras' shooting angle can be observed.

Fig. 2. Angles acquisition during control knob use

Data processing by Kinovea® required the following data to be acquired:

1. Steering wheel: shoulder flexion, elbow flexion, wrist flexion and neck frontal flexion;
2. Gear shift: shoulder flexion, shoulder abduction, elbow flexion, wrist flexion and neck frontal flexion;
4. Knob control: shoulder flexion, shoulder abduction, elbow flexion, wrist flexion and neck frontal flexion.

Some angles such as arm medial rotation, forearm pronation/supination and hand flexion/extension, radio-ulnar deviation were not available through the photographic acquisition and were simulated and calculated through Digital Human Modelling (DHM) in CATIA® V5R16. Car interiors were modelled in CATIA® environment too.

DELMIA® DHM software was used for modelling the virtual twin of each participant thanks to the acquisition of anthropometric measurements [2] [3] [4] [5] [6] [7]. Few small modifications on the angles acquired by Kinovea® were carried out to guarantee the accuracy of the manikin's postures, according to the photographic acquisition.

Acquisition precision has been evaluated in [1] and [8]. Fig. 3 shows an example of the three postures involved in the analysis.

Fig. 3. Simulations carried out in DELMIA®

2.5 Evaluation Technique for Postural Comfort

Comfort evaluations were performed by CaMAN® [9–13] software that takes the angles describing operator posture as input, and which gives an index of postural comfort (CI) whose output value is in the range of 1-10. For each posture and each participant, both body-parts (neck, shoulder, elbow and hand) and entire body postural comfort indexes were obtained.

3 Data analysis

For each participant and for each task, the global postural comfort index, obtained by CaMAN® software, is shown in Fig. 4.

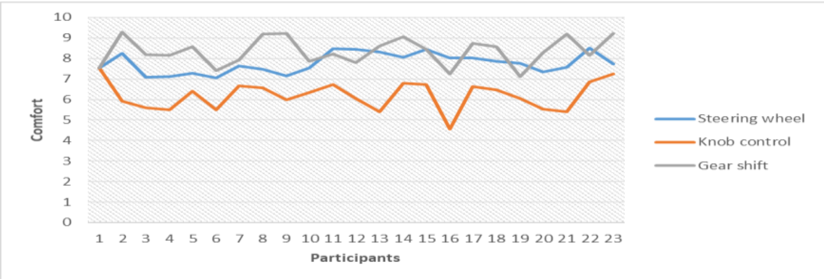

Fig. 4. Global comfort index related to the three tasks involved in the study

In order to assess the contribution of body-parts to the global comfort, the mean values of the objective comfort (by CaMAN®) were taken into account.

Table 2. CaMAN® index

	Neck		Elbow		Shoulder		Wrist	
	Flex/Rot	Lateral	Flex/Ext	Pron/Sup	Flex	Abd	Flex/Ext	Radial Dev.
Gear shift	9,07	9,90	8,29	6,24	9,08	5,14	7,59	6,82
Knob control	6,72	9,90	6,20	6,26	2,18	5,15	6,42	6,66
Steering wheel	9,18	9,90	8,01	8,78	7,18	8,78	8,33	6,96

The data analysis (Fig. 4) shows that, dealing with global comfort, the worst rated task is the knob reaching while the best rated is the steering wheel use.

This result was expected because, in the steering wheel use, arms were extended forward and are supported by the steering wheel itself, the wrists assumed a posture nearly the geometric zero and the rotation of the neck was low to look straight to the road. Contrarily, in the knob task, the subjects showed a reachability issue due to the knob's backward position: right shoulder and elbow had to move backwards and the wrist was far from neutral position (Table 2).

3 Correlations

The knob-reachability task was under investigation though statistical methods.

Data were gathered to evaluate:

1. the impact of the anthropometric measures on the objective/subjective comfort scores, both on the overall comfort and on the comfort of each bodypart;

2. the correlations between the objective comfort indexes (CaMAN®) and the subjective ones (questionnaires).

SPSS rel.13 was used to perform statistical analyses and Pearson index was used to find statistical correlations among investigated parameters.

Errore. L'autoriferimento non è valido per un segnalibro. shows the significant correlations between the subjective comfort indexes obtained by the questionnaires and the subjects' anthropometrics data.

Subject's height and arm length are positively correlated with shoulder, elbow and wrist comfort. This results were expected because higher subjects were easily able to reach the knob.

Table 3. Correlation between the anthropometric data and comfort perception obtained by the questionnaires

Variables correlated	Pearson Indexes
Height –elbow questionnaire	,435*
Height –wrist questionnaire	,433*
Height –global questionnaire	,507*
Arm – elbow questionnaire	,465*
Arm – shoulder questionnaire	,519*
Arm – wrist questionnaire	,424*
Arm – global questionnaire	,490*

*** The correlation is significant at level 0.01 (2-queues)*

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

Table 4 shows the most significant correlations between the objective comfort indexes obtained by CaMAN® and the subjects' anthropometrics data.

Table 4. Correlation between the anthropometric data and comfort indexes obtained by CaMAN®

Variables correlated	Pearson Indexes
Height – CaMAN® elbow	,533**
Height – CaMAN® shoulder	,506*
Arm – CaMAN® shoulder	,553**

*** The correlation is significant at level 0.01 (2-queues)*

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

The Table 5 shows the most significant correlations between the subjective and objective comfort indexes.

Table 5. Main correlations between comfort index obtained by CaMAN® and those extracted from the questionnaires

Variables correlated	Pearson Indexes
CaMAN® neck – elbow questionnaire	*,543***
CaMAN® neck – shoulder questionnaire	*,459**
CaMAN® neck – wrist questionnaire	*,534***
CaMAN® neck – global questionnaire	*,423**
CaMAN® elbow – elbow questionnaire	*,534***
CaMAN® elbow– shoulder questionnaire	*,421**
CaMAN® elbow – global questionnaire	*,566***
CaMAN® shoulder – neck questionnaire	*,505**
CaMAN® shoulder – shoulder questionnaire	*,454**
CaMAN® global – shoulder questionnaire	*,484**

The results showed an absence of correlation for the wrist, between CaMAN® and questionnaire, during control knob use.

The photographic acquisitions revealed that the posture assumed by the majority of participants was strongly unnatural: the flexion/extension and the radio-ulnar deviation of the wrist were very far from the wrist comfort range of motion [9,10]. This condition had a negative effect both on objective comfort and on subjective comfort of the wrist.

Furthermore, the results showed that the subjective comfort (obtained by questionnaires) was lower than the objective one (obtained by CaMAN®). The absence of correlation was linked to the fact that CaMAN® considered only the posture, instead, the participants evaluated both the posture and the difficulties to carry out the task. During the control knob use, the posture hindered the implementation of the task and this had a damaging effect on the perceived comfort. Furthermore, the use of the knob in this unnatural position caused a fatigue effect on the ulnar-flexors (muscles) that activate the fingers for using the knob, and this added effects further decrease the perceived comfort of the wrist.

4 Conclusions

In this work, both the postural comfort related to the use of a car control knob, steering wheel and the gear shift and the overall subjective perception of different users were investigated.

The method used to analyze the postural comfort was based on photo/video recording and photogrammetry, image processing using Kinovea® software, coupled with the use of DHM commercial software (CATIA® for modelling, DELMIA® for simulation) and comfort rating software developed by the authors for the evaluation of non-subjective comfort (CaMAN®).

A preliminary analysis showed that, dealing with global comfort, the worst rated task was the knob reaching while the best rated was the steering wheel use.

Via a statistical analysis, performed with SPSS-Statistics®, the impact of the anthropometric measures on the objective/subjective comfort scores and the correlations between the objective comfort indexes (CaMAN®) and the subjective ones (questionnaires) was investigated.

The results showed that the height and the arm length were correlated with the comfort indexes related to the shoulder, elbow and wrist; and an absence of correlations, between CaMAN® and questionnaire, of the wrist. The absence of correlation was explained through the limitation of CaMAN® use; CaMAN software is able to take into account only the postural aspect of an interaction while, in the performed tests, the subjects gave answers to the questionnaire considering both their posture and the difficulties to carry out the task (usability) and the difficulties to reach the knob control (reachability). The implementation of the task resulted not only hindered but also caused a local discomfort.

Obtained results can be a useful support during the problem solving and directly suggest, to designers, easy solution to re-place the knob. The analysis showed that a possible solution was to place the knob near the gear shift. The proposed solution takes into account the characteristics of the tasks that the subjects have to carry out and the subject's anthropometrics characteristics.

In order to verify the solution, the method used in this work can be reused for performing a comfort driven re-design session, both in virtual and in physical environment. The acquisition method is very cheap and easy to use. The precision of the acquisition method, as well as the fact that by not using complicated, expensive acquisition methods, gave the possibility to reach a very good level of numerical/experimental correlation, that are important results revealed by this paper.

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EUROSPEC Seat Comfort – spread academic news in the railway world

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Abstract The comfort of train seats is highly disputed within the railway industry. Reports of unhappy passengers lead to expensive changes and redevelopments. Before the end of 2019, the EUROSPEC Seat Comfort focusing on seat ergonomics is due to be published on http://EUROSPEC.eu/. This paper describes the need for a train operator driven specification and how academic knowhow is being transferred to the railway industry.

Keywords: Seating comfort, specification, public transport, railway.

1 Introduction

The Railway Industry as a whole currently lacks a common understanding of comfort of seating. Operators, Train Manufacturers and Seat Manufacturers apply a broad spectrum of requirements when specifying seat comfort. These specifications are typically based on the best available information within each organization, but more often these specifications are copied from the previous specifications for lack of a better one. Typical specifications refer to European legal requirements for seats. These are called Technical Specifications for Interoperability, TSI in short. In these legally binding texts comfort is required but not specified. Precursors of the TSI legislation written by the International Union of Railways (UIC) also mention comfort without specifying it in total.

The Railway Operators part of the EUROSPEC initiative identified a gap in the common knowledgebase regarding comfort. Therefore a Working Group was put together to create a common specification for Railway Seat Comfort. The Working Group identified the latest scientific research in the Seat Comfort field and applied the most relevant to a set of specifications. The result of this effort is a common specification based on the latest scientific understanding of what Seat Comfort for Railways Seats should be.

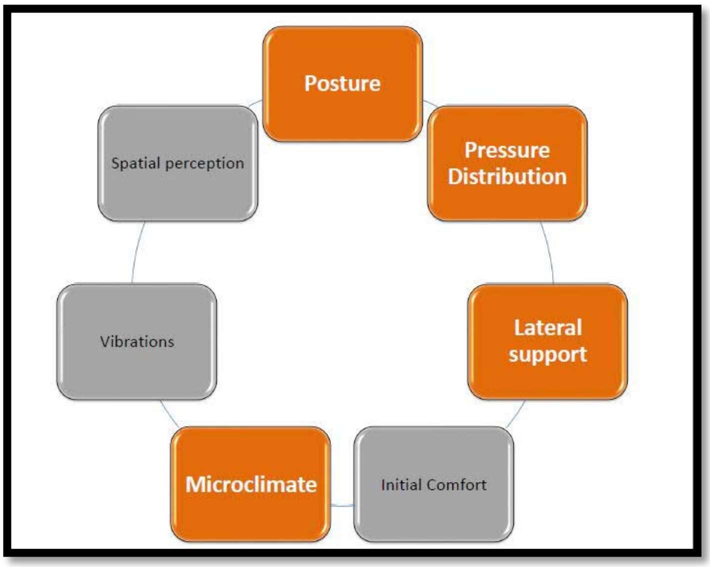

Fig. 1. Basic principles of seat ergonomics development process.

As a first contribution towards potentially a wider range of EUROSPEC seat comfort specifications, the first edition covers the areas “posture”, “pressure distribution”, “microclimate” and “lateral support” to describe the ergonomics of passenger seats on trains. It focuses on “conventional” seats for day trains, i.e. no sleeping, business class, tip-up seats or similar.

2 Approach

The members of the EUROSPEC Seat Comfort Working Group are all responsible for writing the seat functional and technical specifications for Railway Seats for their corresponding organizations. These specifications are all different in layout and content. On the contrary, the EUROSPEC initiative has a standardized approach for the creation and use of syntax for a specification. Standard EUROSPEC Excel and WORD templates have been used to draw up the initial specifications. Multiple specifications from all the organizations were copied into the EUROSPEC formats without bias or filter. A typical seat specification consists of legal, safety, technical, functional, operational and procedural requirements that have a SMART syntax. In SMART the letters generally mean Specific, Measurable, Achievable (or attainable), Relevant and Time-bound.

To better understand the concept of Comfort all Working Group Members consulted with Dr. Barbara Held. A workshop by Dipl.-Ing. Ulherr (Technische Universität München) and a Master Class by Prof. Dr. Vink and Dr. Mastrigt (Technical University of Delft) added to the knowledgebase of the Working Group. Personal interviews with Vink and Mastigt deepened the understanding.

Identification of the work by Vink, (2016) [1] led to the identification of work done by Mastrigt, (2015) [2] which led to work by Carcone & Keir, (2007) [3] Franz, et al., (2011) [4], Goossen & Snijders, (1995) [5], Groenesteijn, et al., (2014) [6], Hartung, (2006) [7] Kamp, Kilincsoy, & Vink, (2011) [8], Kilincsoy, Wagner, Vink, & Bubb, (2016) [9], Korte, (2013) [10], Mergl (2006) [11], Molenbroek, (2019) [12], Naddeo, (2017) [13], Nijholt, Tuinhof, Bouwens, Schultheis, & Vink, (2016) [14], Vink & Lips, (2017) [15], Zenk R. ,(2008) [16] and Zenk, Franz, Bubb, & Vink, (2012) [17].

All these works were scanned for possible requirements. Where requirements are normally identified by the syntax “shall” in technical specifications, the word “should” is mostly used in academic works. Scanning the identified works for sentences containing “should”, and copying these sentenced added to the preliminary requirements set. The preliminary requirements were categorized to a major component part of a seat, according to EN 15380-2:2006. Component parts like seat pan, seat back, reclining, armrests, footrest etc. Additional categories like legroom, width of passage and sensory analysis were added to the specification to complete the framework.

The Working Group initially set out to create a SMART technical requirements set by categorizing train types, travel times, classes, body measurements etc. The goal was the making of a SMART table containing required seat comfort levels (i.e. levels 1 to 5) in relation to train type, mission statement, population, classes, and travel times. It was recognized that what is “metro” or “urban” in one country did not correspond with “metro” or “urban” in another country. A “Regional Express” in Germany can have longer travel times than an “Intercity” in the Netherlands or Switzerland. With a similar travel time the London Urban Metro has a totally different kind of seat applied. This meant that creating a table that lists European seat comfort levels in relation to train-types, mission statements, travel times, classes and population would not result in one universally applicable categorization. The conclusion was drawn that a SMART technical specification only would never capture the know-how of the academic works identified.

The Working Group adopted the idea that the specifications should to be true for any population. Comfort cannot be described by specifying any one fixed measurement valid for all Europeans since all Europeans are not identical. Europeans can however be subdivided into populations. Identification of the intended population and corresponding anisotropic dataset (i.e. [12]), including weight, was added to the specification. Identification of the desired passenger activities and intended travel time was added to the specification.

The 2D parameters, see fig. 1, of a seat describe the basic dimensions of a seat like width, height and depth. For internal body measurement the P5 Female is prescribed. For external body measurements the P95 male is prescribed. For the measurements between armrest and seat pan width the external P95 female is used. All technical requirements were rewritten to not mention one SMART fixed measurement but to reference either the P5 female, P50 male or P95 male. P5 female was applied to all “internal” measurements like “Seat Pan Height, Sitting”. P95 male was applied to all “external” measurements like “Seat Back Height, Sitting” but also for requiring i.e. the minimal pitch or table height. P50 male is almost never used in the EUROSPEC Seat Comfort. The “mean” of the population is ignored based on the idea that 95% of the population is “comfortable” when using the P5 and P95 percentiles. The external body measurements also prescribe the available space needed behind and below front facing seats. Here the P95 male is expected to be able to stretch his legs and extent them below a seat in front. By extending the legs the P95 male can achieve an optimum in the pressure distribution on the seat pan. Adjustability of the seat pan height would increase the potential of a seat to be comfortable for P5 and up passengers.

Identification of postures [6] is based on the intended activities. The postures result in the necessary seat back and seat pan angles [2] [5]. When postures result in multiple seat back and seat pan angles, adjustability of the seat back and seat pan is a necessity. The relationship between the seat back angle and the preliminary seat pan angle is given by minimizing the shear forces acting on the body [5]. This is also true for a reclined seat, therefore selection of the most favourable rotation/translation “point” during reclining is necessary. The friction coefficient of the upholstery should profile enough friction to prevent involuntary sliding of the passengers in the seat while traveling, accelerations and going through switches.

To compensate the difference in body measurements adjustments should be able to be made by the passenger. Adjustment of seat pan height, head rest height, headrest angle, seat pan depth, etc. are recommended in the requirements set, but not required. Here available budget and intended comfort levels can affect the choices made for the needed adjustability. Further optimization of the seat can be achieved by providing adjustability to the tables and armrest orientation and contour. These adjustments are specified as optional since the costs of implementation can be significant.

Requirements for adjustability were added to the specification as “design recommendations” or “options”. When applied, the adjustability (see i.e. [13]) of seat features allow passengers to adjust the seat to their personal needs between the P5 - P95 range. Giving passengers something to adjust not only provides comfort to the body, but also to the brain. A sense of control over one's environment will increase comfort perception [13].

Design evaluation and optimization by pressure mapping [7] [9] [11] [15] [16] [17] of the seat pan contour [2] [4] has been added to the specification. Here optimal pressure distribution, gradient, maxima and prevention of hotspots are specified. Combined with requirements for body contour [2] [4] [14], limitation of shear forces [5] [15], by choosing the correct seat angles [2] and by choosing the shape of lumbar support [3] [10] and head support further optimization of comfort can be achieved, also while reclining. Starting from scratch or based on previous know how any 3D contour geometry can be the basis for further development. Optimal pressure distribution can be achieved by iteration of evaluation and contour optimization. It should be noted that a sports car seat pan and seat back will most likely not meet the postures requirements for railway seats. Multiple techniques are available to the suppliers to achieve this goal. Combined with the questionnaires in the requirements set the improvements in comfort, after each iteration, can be made insightful. The travel times intended by the customers, selected population and intended postures can be used as input for the evaluations.

Generally accepted Railway Standards were scanned to identify applicable requirements. The section for microclimate as described in the UIC 567:2004 [18] is referenced to by the specification. These requirements ensure temperature and humidity control behind the back and below the buttocks. The section for upper limits to hand operating forces was identified in UIC 566:1990 [19]. This will limit the forced needed to operate the adjustable features of the seat.

The application of the measurements required by the EUROSPEC Seat Comfort do not include constraints to seat dimensions imposed by EU Commission Regulation TSI PRM 1300/2014 [20]. A Statement in the EUROSPEC Seat Comfort is provided that the requirements in the TSI PRM 1300/2014 (or any future versions) supersede the EUROSPEC requirements.

The measurable requirements in the EUROSPEC offer the first set of requirements. The second set of requirements is meant to evaluate the perception of comfort. See figure 2.

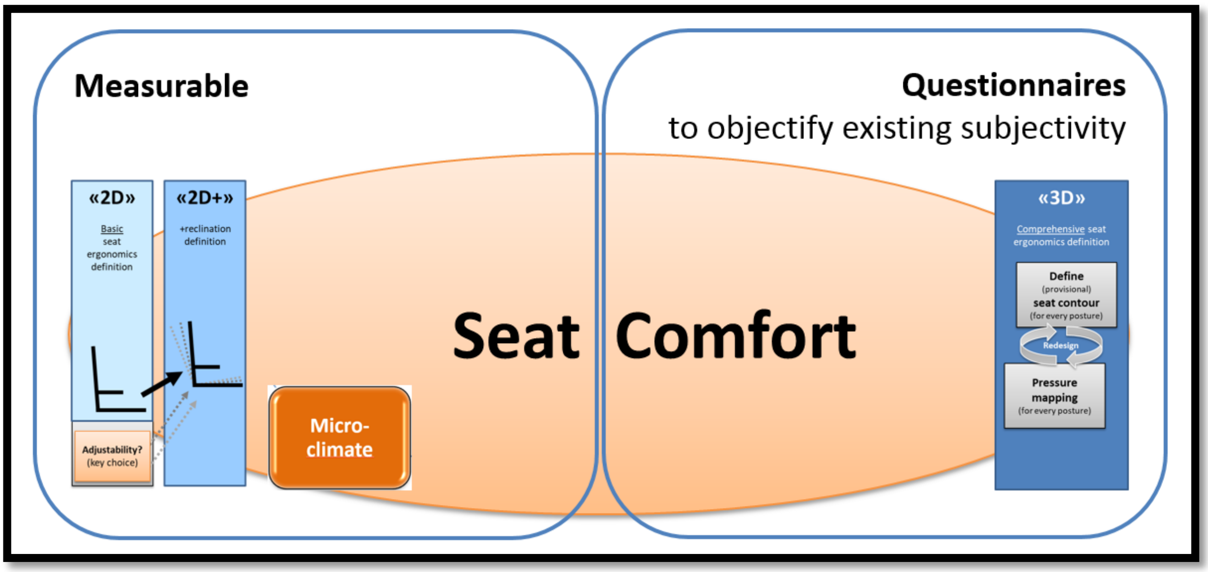

Fig. 2. Basic principles of seat ergonomics development process.

To objectify the subjective comfort perception the evaluation is procedurally standardized in the EUROSPEC specification. Statistical analysis should be applied to quantify the evaluation. The evaluation can be used to optimize the comfort by redesign. Questionnaires based on [2] [21] to [38] were identified as widely applied in academic works. These were added, unchanged, to the specifications in an attempt to procedurally harmonize comfort evaluation. Depending on the project phase these questionnaires will allow seat manufacturers and operators to evaluate the seats and possibly identify points of improvements.

Application of ISO standards [39] to [44] for Sensory Analysis of Foodstuffs has been identified as applicable to the procedures used for the sensory analysis of seat comfort. Since sensory perception of the skin/muscle/body is processed basically the same as the sensory perception of olfactory information created by the nose and mouth the ISO standard for foodstuffs [39] to [44] could also be made applicable to sensory evaluation of the skin / muscles / body. Specific ISO standards used in the food and beverages industry have detailed descriptions of how to prevent observational bias. Other ISO standards detail the environment in which an unbiased evaluation of, in this case, seat comfort can be best achieved. Further ISO standard detail statistical analysis methodologies that should be applied in combination with the before mentioned Questionnaires to draw better conclusions. See https://www.iso.org/ics/67.240/x/ for an overview of Sensory Analysis standards.

All the specifications were discussed. Irrelevant, double and non-comfort related requirement were removed from the requirements set. The requirements were reorganized, per section, to state “Requirements” (RE) first, then Design Recommendations (DR) followed by “Options” (O). Application of just the Requirements will set a new minimum comfort level for Railway Seats. Applying design recommendation and options will further increase comfort perception of the seats.

These requirements should allow seat manufacturers to optimize the seat components in an iterative way. Once experience has been gained with application of these requirements the optimization process cost should be reduced.

3 Evaluation

Part of the EUROSPEC creation process is evaluation by experts. The international Railway Technology Fair INNOTRANS in Berlin, 2018 was used to identify Railway Seat Manufacturers that will serve as experts for the evaluation of the initial version of the EUROSPEC Seat Comfort. All manufacturers acknowledged and welcomed the EUROSPEC initiative. Together with the feedback of the UNIFE members the EUROSPEC seat comfort will be updated. The final document will have achieved the goal to spread academic news in the railways world.

4 Results

The result of the work done by the Working Group is a draft specification that lists exactly one-hundred requirements.

These requirements cover key inputs, a basic seat ergonomic definition, a reclination definition and comprehensive seat ergonomics definition. By following the process in figure 3 and applying the referenced scientific works to the development process the resulting a seat will be as comfortable as possible for the chosen population, postures and travel times.

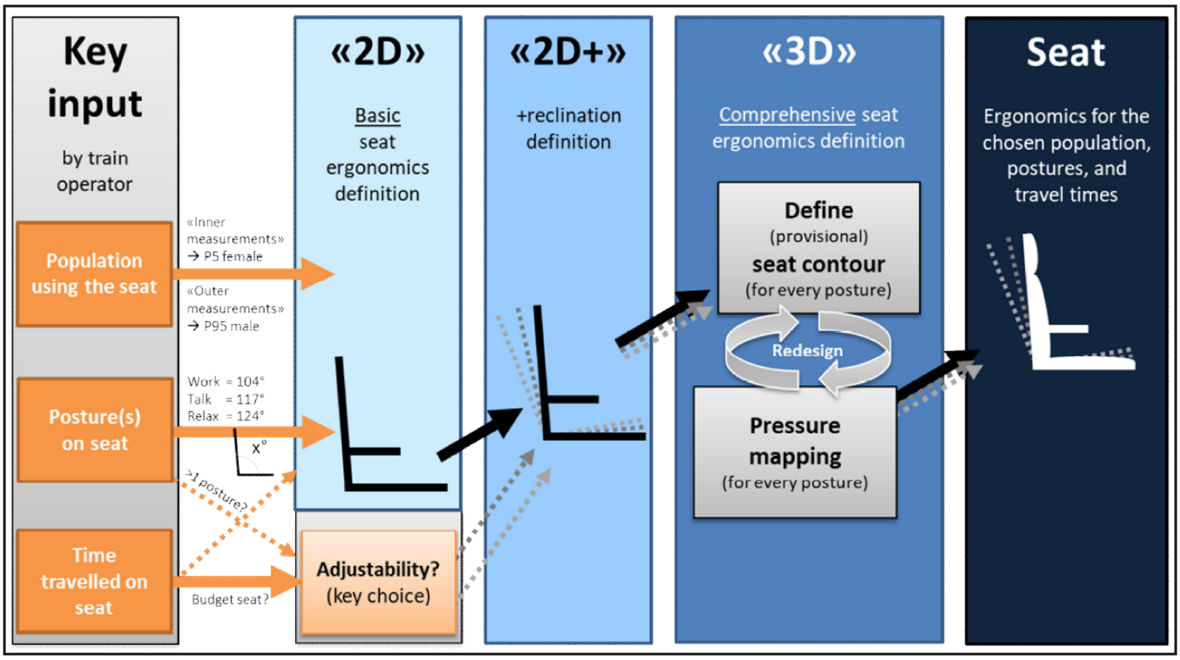

Fig. 3. Basic principles of seat ergonomics development process.

The combined requirements set in the EUROSPEC Seat Comfort represent a common framework for rolling stock operators, OEM engineering departments and Seat Manufacturers.

5 Discussion

The Working Group identified slightly different ideal pressure distributions in the academic works [1] [2] [7] [9] [11] [15] [16] [17]. Since most of the studies were performed on custom rigs, car seats or aircraft seats it is unclear what the ideal pressure distribution should be for railways seats. The technology of pressure mapping used is identical, but the ideal pressure distribution may be different since the activity of steering a car does not apply to railway passengers. The difference in postures for railway passengers may result in slightly different ideal pressure distribution and further study should be done to identify if a specific railway ideal pressure distribution exists.

During the application of the ideal pressure distribution in one project the seat manufacturer identified that the current academic works seem to lack guidelines on how to project the ideal pressure distribution on any given seat. The best guidance the Working Group could find was used by Kilincsoy [9], but even this study mentions the lack of guidance. Further guidance should be provided in future updates of the EUROSPEC Seat comfort.

Depending on the population the differences in anisotropic measurements between P5 and P95 for the Seat Pan Height, Sitting may result in un-ergonomic conditions for the P95 persons. The EUROSPEC Seat Comfort offers no guidelines for this eventuality at this point in time other than to state that proper ergonomic choices may supersede EUROSPEC Seat Comfort requirements. This is particularly true for persons with reduced mobility as identified in EU Commission Regulation TSI PRM 2014/2004.

1 on 1 application of the Goossens [5] Shear Force lines (1995), while at the same time applying the ideal Mastigt seat pan and seat back angles [2] may result in a contradictory EUROSPEC Seat comfort requirements set.

Nijholt [14] and Mastigt [2] detail how seat contours can be optimized. Alas the contours described are not publically available in a digital format. Therefore the seat manufacturers cannot use the contours provided as a starting point. Seat Manufacturers will either use the pressure mapping techniques to optimize their own current contours or repeat the studies to create a reference contour.

Application of traditional Go/No Go, Pass/Fail requirement management style is not suited for the evaluation of EUROSPEC seat comfort requirements. Since comfort perception is not binary the evaluation of meeting the EUROSPEC seat comfort requirements is also not binary. The (RE / SHALL) requirements seem to offer a binary evaluation opportunity, but even these should be evaluated on a sliding scale. For example. Not meeting the P5 female seat pan depth, but meeting P10 female, will not make the seat uncomfortable in a binary sense. It will make the seat less comfortable. Even this less comfortable level of comfort may be acceptable when evaluating against the principle of AHARP, as high as reasonably possible. AHARP being the opposite of ALARP, as low as reasonably possible, which is a well-known methodology within the Railway industry.

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The influence of desktop light on the comfortable use of computer screen

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Abstract In the evening, a high contrast between a bright computer screen and a dark ambient environment may cause discomfort to the users, especially on their eyes. The objective of this research is to identify the optimal desktop illumination condition for the comfortable use of the computer screen in a dark environment. For this, an experiment was designed where seven illumination conditions were introduced for the users to perform their daily tasks on a computer screen. Fifteen healthy subjects were invited to the experiments. During each session, the blink, the fixation duration and the length of saccade of the eye movements of the user were recorded by an eye tracker, and his/her neck and trunk movements were recorded by a motion tracking system as well. Comfort/discomfort questionnaire, Localized Postural Distribution body map, NASA Task Load Index and the computer user questionnaire were used to subjectively measure the overall comfort/discomfort, the local perceived physical discomfort, the cognitive workload, and general/eye health problems, respectively. Subjective and objective measurement results indicated that users felt more comfort with high intensity warm lights. We also identified that the eye fixation durations and the lengths of saccades, as well as the scores of some questions in the computer user questionnaire, were significantly correlated with comfort/discomfort. It was concluded that the warm (3000K) and high intensity (1500 lux) reduced the visual and cognitive fatigue of the user and therefore improve the comfort of the user during the use of the computer screen.

Keywords: Illumination, comfort, computer screen, eye fatigue

1 Introduction

In an information era, using a computer or laptop is becoming a daily activity of many people. Making the environment more comfortable for using a computer is an important topic in ergonomics. In daytime, the lights in public places, either as the primary or the secondary sources, are more likely to be designed for people to stay alert or enhance their working efficiency[1]. However, in the evening, lights and bright computer screens become the primary light source, and the purposes and content of users using the computer screen are also more diverse compared to daytime. All of these elements post challenges on the design of lights for the use of computer screens in the evening.

Good lighting conditions could improve productivity, while in contrast, inappropriate lighting conditions may cause discomfort, decrease task performance and even result in health problems [2]. Many researchers studied the influence of the quality of light on humans in different condition, for instance, Juslén and Tenner [3] investigated the influence of different lighting environments in workplaces, e.g. factories and offices, on the performance of workers. They conclude that the light intensity and the color temperature of the light may affect human's mood, alertness and may lead to differences in performance. However, extensive literature search did not reveal enough studies about the comfortable illumination conditions for using a computer screen in the dark environment.

The objective of this research is to identify the optimal desktop illumination condition for comfortable use of the computer screen in a dark environment. Our main scientific contributions are: 1) we identified the comfortable illumination condition for using a computer screen in a dark environment, and 2) by correlating different measurement results, we identified the relations between different types measures and the comfort experience, which highlights the possible focus for designing for comfortable use of computer screens.

The remainder of the paper is arranged as follows: In Section 2, we briefly reviewed different aspects of comfort/discomfort and related subjective and objective measures. Section 3 presents the materials and methods of the experiment, and the experiment results are shown in Section 4. Section 5 discusses results from both comfort use and the measurement methods points of view and finally, a short conclusion is drawn in Section 6.

2. Literature review

Comfort and Discomfort

Vink and Hallbeck [4] defined comfort as "*a pleasant state or relaxed feeling of a human being in reaction to its environment*" and they also defined discomfort as "*an unpleasant state of the human body in reaction to its physical environment*". Those definitions indicate that comfort consists of more factors than discomfort, which is mainly caused by the physical interactions. Comfort has many aspects [5] and during the use the computer screen, the feeling of comfort/discomfort can be influenced by multiple factors, e.g., the context, the emotion, the expectations and the content on the screen. Zhang et al. [6] identified the factors that may influence comfort like relaxation, neutral feeling, well-being, energy, environmental and social/psychological factors. On the other side, discomfort is more connected to pain, soreness and numbness, fatigue, environmental factors and anxiety. The effects of those factors are often interrelated, e.g., Hiemstra-Van Mastrigt [7] et al. identified that passengers can be distracted from feeling discomfort by providing food and drinks.

In the long-term use of a computer screen, fatigue can be an important factor influencing a decreased level of comfort and an increased level of discomfort. Fatigue could be induced by physical and physiological causes [8][9] and in the context of using computer screens, it can be categorized to three types: the physical, the visual and the cognitive fatigue. The physical fatigue was defined as "*the reduction in capacity to perform physical work*"[10]. Performing activities that requiring physical efforts may lead to physical fatigue, e.g., maintaining certain postures and moving the mouse for playing a computer game. The World Health Organization (WHO) defined visual fatigue, or visual strain, as a subjective visual disturbance [11]. Visual fatigue often occurs after a long period visual activity, featured by pain around the eyes, blurred vision or headache [11]. Cognitive fatigue and mental fatigue sometimes can be replaced by each other. In behavioral studies, cognitive fatigue can be described as "*the unwillingness of alert, motivated subjects to continue performance of mental work*" [12]. A long duration of cognitive activities will contribute to mental fatigue which results in decrement of cognitive and behavioral performance [13]. The physical, the visual and the cognitive fatigue are not isolated phenomena [14], e.g. little physical exertion is likely to improve the mental performance while heavy physical exertion may reduce it [15].

Measures of comfort/discomfort

A variety of evaluation methods have been used to assess the comfort of users for a better understanding of the ergonomics of different situations. For the overall feeling of comfort/discomfort, 10 point scale comfort/discomfort questionnaires were proven to be effective in many studies [16][17]. Regarding the measurement methods of different factors which contribute to comfort/discomfort, they can be categorized in four types: subjective measures, performance measures, psychophysiological measures and analytical measures [18]. In the context of reading a computer screen in the dark environment, subjective measures and psychophysiological measures can be addressed as for many tasks, there is no clear task objective.

Subjective measures are designed to collect the opinions from the operators about the workload/human effort, satisfaction, preference, user-experience, etc. In spite of the criticism on the validity and vulnerability to personal bias of those self-reporting methods, subjective measures with the low cost and ease of administration, as well as adaptability, have demonstrated their advantages in a variety of domains, including healthcare, aviation, driving, etc. The LPD body map [19] is a widely used instrument in many applications for subjectively evaluating the physical discomfort of different parts of the body. For visual fatigue, there are questionnaires about user's feeling after using a computer screen including visual fatigue, e.g., the 10-item questionnaire about symptoms of vision [20], the Computer User Questionnaire (CUQ) [21], Computer Vision Syndrome Questionnaire (CVS-Q) [22]. Subjective measures can also be studies by indirect methods in the measurement of cognitive load where the NASA-Task Load Index (NASA-TLX)[23] is an typical example. It was designed to measure the perceived workload of the subject within six dimensions: Mental demand, physical demand, effort, performance, temporal demand, and frustration, and has demonstrated a high reliability and sensitivity in many studies [24].

Psychophysiological measures are physiological measures used to index psychological constructs [25]. For instance, Goldberg and Kotval [26] were among the pioneers of investigating the usage of eye tracking measures when browsing different types of web-pages. In this research, we broaden psychophysiological measures to objective measures [27] as physical activities are important indicators of comfort/discomfort, e.g., Brachynskyi [28] evaluated the comfort of sitting postures while using touch displays by 1) a motion capture system and 2) a custom built chair which measured the forced applied by the user in various directions. For visual fatigue, there are studies that evaluated visual comfort/fatigue [29] using eye tracking devices based on the length of saccades, the fixation durations, and features related to blinking, etc. In the evaluation of cognitive workload/fatigue, Shriram [30] discovered that electroencephalography (EEG) measures were useful in finding and evaluating the relative contributions of workload that are not detected by other indexes.

In summary, many subjective and objective measures have been applied to identify different issues and proposed design suggestions regarding comfort/discomfort, and outcomes of those measures are often interrelated [27]. However, selecting the proper measures and combining the outcomes of those measures for choosing proper illumination conditions for comfortable use of computer screens are still challenging questions.

3. Materials & Methods

Materials:

For identifying an optimal illumination condition for the comfortable use of computer screen in a dark environment, an experiment was designed with different illumination conditions. The experiment was carried in a dark room where the (natural) light was shielded by curtains. The light sources are restricted to the screen of laptop and the light of a desktop lamp. During the experiment, only a researcher and the participants stayed in the room where the researcher gave instructions and adjusted light conditions following the protocol. The height of the desk is 720 mm, which was the height that participants were used to. The humidity and temperature of the room were kept same throughout the experiment. The light intensity of the laptop screen was set at 400 cd/m^2 and the angle of the screen was adjusted perpendicular to the eyesight of the user. The desktop lamp was adjusted to such an angle that for the participants, there was no direct viewing of the light source. The color temperature and the light intensity of the desktop lamp were adjustable, resulting in 7 possible conditions (Table 1).

Table 1. 7 conditions of the illumination conditions

	Condition 1	*Condition 2*	*Condition 3*	*Condition 4*	*Condition 5*	*Condition 6*	*Condition 7*
Color temperature (K)	N/A	5000 K	3000 K	5000 K	3000 K	5000 K	3000 K
Light Intensity (Lux)	0 (Off)	1500 lux	1500 lux	375 lux	375 lux	675 lux	675 lux

Participants:

Fifteen healthy subjects (mean age = 23±3.2) were invited to the experiments. Among them, 6 were males and 9 were females. All participants' dominant hand was the right hand and their native language was Chinese, and they met the following criteria: 1) in good health condition (without mental or physical disorder); 2) with normal visual acuity (with or without vision correction equipment); 3) experienced with using laptops; 4) had enough rest before the experiments; 5) were able to read and comprehend Chinese and English text.

Evaluation measures

a. Objective measure of the process

Three objective measures were used to measure the use of the computer screen in a dark environment. The ProMove® MINI [31], which is a body movement tracking device, was used to record the movements (rotation) of the neck and the trunk of users during the experiments. The average fixation time, the average length of saccade and the blinking times of eyes were measured a Tobii® X2-30 eye tracker[32]. A camera was deployed next to the user to record the experiment scenario as well as the postures of the participants.

b. Subjective measure of the process

In the experiment, each participant was asked to complete a set of questionnaires using the same computer. Among those questionnaires, the Comfort/Discomfort questionnaire [16] was used to evaluated the overall feeling of users regarding their comfort/discomfort experience. The LPD body map [33] allowed users to point out the discomfort part of their body. The NASA-TLX [24] was used for assessing mental workload on the use of the computer screen. The users were also able to report general and eye health problems by the CUQ [21]. A laptop was used for performing reading tasks and filling in questionnaires electronically utilizing the ErgoLAB3.0 platform. Figure 1 presents the setup of the experiment.

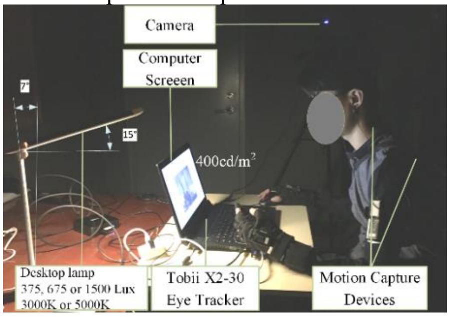


Fig.1. Setup of the experiment

Protocols

A pilot test was conducted to verify the setups and guarantee that all materials had a similar cognitive complexity, the colour saturation and the brilliance. Prior to the experiment, the informed consent was acquired from the participant participating in this study. The participant was then asked to adapt himself/herself to the lighting environment for 5 minutes. Meanwhile, with the help of the researcher(s), he/she wore the motion capture modules. Each experiment consisted of 7 sessions in a randomized sequence, corresponding to the 7 illumination conditions (Table 1), respectively.

Before the first session, the researcher(s) introduced the content of the experiment and the procedure. The contents of the 7 sessions were similar, each had 4 reading/watching tasks. The first one was reading a recent news in Chinese, covering the fields of science and technology, health/medicine, or culture/history. All chosen news was recent news, they had similar length (~4000 Chinese characters), amount of illustrations and difficulty, which was evaluated by the researchers in the pilot. In the reading task, each page of the news was played for 20 seconds, then the next page was displayed automatically. In total it costed approx. 3 minutes to display every page of the news automatically. Then the respondents were asked to fill the first NASA TLX.

The second task was to read comics. The comics are excerpted from *Peanuts* by Charlie Schutz (10 pages). Each page included one comic strip and it was played for 10 seconds (in total 100 sec. for 10 pages). In the third task, the participants were asked to read a piece of scientific article in English, which has 300 words and displayed in 3 pages. Similar to Task 1, those (pieces of) scientific articles were selected by the researchers to guarantee that the participants were familiar with the topics and the length and the difficulties were similar. After this task the participants were asked to finish the second NASA TLX questionnaire. The last task was to watch a part of the BBC documentary movie "*The Planet*" for 3 minutes. After finishing this task, participants were asked to finish two questionnaires: the comfort/discomfort questionnaire and the CUQ.

After finishing a session, the participant was given 10 minutes to take a rest while the researchers were changing the illumination condition and finishing administrative tasks. Eyewash was made available for the participant to prevent serious eye fatigue during the experiment.

Data processing methods

All collected subjective data were preprocessed before analysis. Using the minmax scaler [34], we normalized data in the same category to a range from 0 and 1 regarding each subject, i.e., for a score on the level of comfort, 0 is the minimal and 1 is the maximal level of comfort. The Student t-test was used to identify the statistically significance between two sets of data and the Pearson correlation coefficient was used to determine the linear correlation between them. Linear regression is used to model the relations between predictors and a criterion variable, e.g., the level of comfort. In data visualization, the violin plot, which is combination of boxplot and kernel density estimate[35], was introduced to present the statistical distribution of the acquired data.

4. Experiment results

The results of comfort/discomfort questionnaire indicated the overall comfort/discomfort feelings of the participants for each condition. In Fig.2, the violin plot of comfort/discomfort of the users regarding the 7 conditions is presented where the scores were normalized to a value between 0 and 1. Regarding comfort, it was found that Condition 2 (mean = 0.61±0.32), Condition 3 (mean = 0.71±0.32), Condition 5 (mean = 0.68±0.26) and Condition 7 (mean = 0.65±0.29) scored higher, and they were statistically significantly better (p=0.001, 0.009, 0.004 and 0.007, respectively) compared to Condition 1 (pure dark environment, mean = 0.28±0.31). For discomfort, similar results were observed where Condition 2 (mean = 0.37±0.34), Condition 3 (mean = 0.22±0.30), Condition 5 (mean = 0.24±0.28) and Condition 7 (mean = 0.24±0.25) were statistically significantly better than Condition1 (mean = 0.82±0.29).

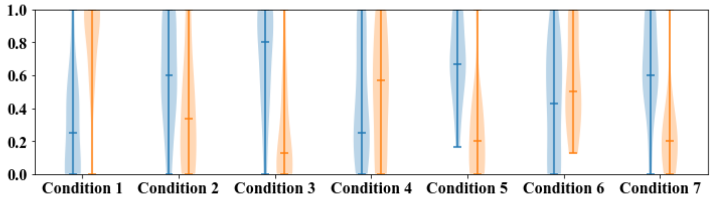


Figure 2: Comfort (Blue) and Discomfort (Orange) of participants in 7 conditions, for comfort, the vertical axis stands for the level of comfort (1 = high comfort), for discomfort, the vertical axis stands for the level of discomfort (1 = high discomfort)

Figure 3 presents the normalized mean score of the LPD body map regarding 7 conditions. It can be found that participants experienced similar discomfort regarding 7 conditions. Nearly all users reported discomfort in the buttock (O, P), the hip (C, V), the neck (S) and the shoulder (T, Y). Though Condition 1 and Condition 2 performed slightly better regarding the neck, and the shoulder, while these were not statistically significant.

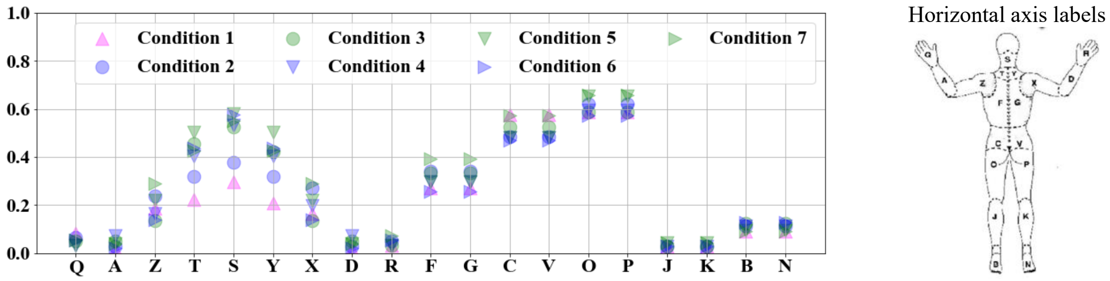
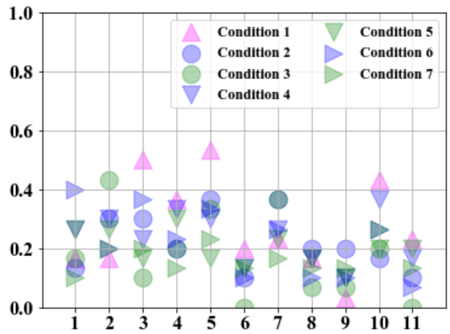


Figure 3: The normalized results of the LPD questionnaire regarding each illumination condition (right: the correspond part of each letter regarding the body, vertical axis: level of discomfort and 1 = high discomfort)

The normalized results of CUQ (Fig.4) indicated the users' subjective feeling regarding different aspects of using the computer screen in the 7 conditions, especially on their eyes. Based on the figure, it can be found that Condition 1 gave the users the most negative feelings except for question *2 (Overall bodily fatigue or tiredness)* and 9 *(Letters on the screen run together)*. And regarding question *3 (Burning eyes)* and *6 (Squinting helps when looking at the computer)*, Condition 3 was statistically significantly better than Condition 1 ($p \leq 0.05$). The users appreciated Condition 3, 4 and 5 more than Condition 2, 4 and 6, which can be observed that the green markers are lower than purple markers in nearly all answers.



Horizontal axis:
1.Headaches during or after working at the computer;
2.Overall bodily fatigue or tiredness;
3.Burning eyes;
4.Distance vision is blurry when looking up from the computer;
5.Dry, tired, or sore eyes;
6.Squinting helps when looking at the computer;
7.Neck, shoulder, or back pain;
8.Double vision;
9.Letters on the screen run together;
10.Driving/night vision is worse after computer use;
11."Halos" appear around objects on the screen

Fig.4. The normalized mean results of the computer vision questionnaire (Vertical axis: Normalized scores of CUQ, 1 = high discomfort)

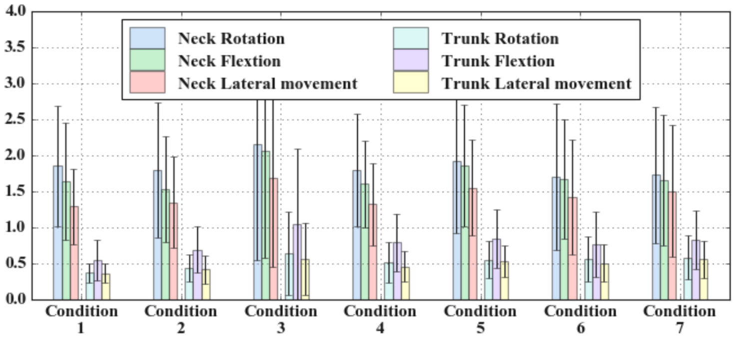
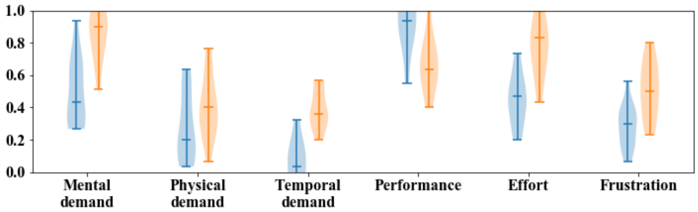
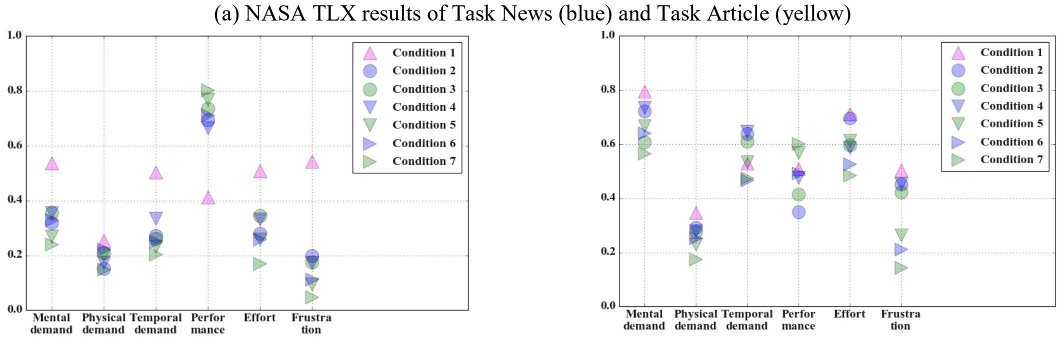


Fig.5. Mean movement speed of the user (Vertical axis unit: degree/second)

Figure 5 presents the mean movement speed (in degree/second) of the neck and the trunk of the users during the experiments regarding 7 conditions, respectively. The users moved their neck much more than the trunk. Regarding different conditions, users moved slightly more in Condition 3, followed by Condition 5. However, the differences were not statistically significant.



(a) NASA TLX results of Task News (blue) and Task Article (yellow)



(b) Result of NASA TLX regarding reading task 1 (b) Result of NASA TLX regarding reading task 2

Fig.6. Normalized results of the NASA TLX questionaires (vertical axis: 0 = lowest and 1 = lighest regarding the question)

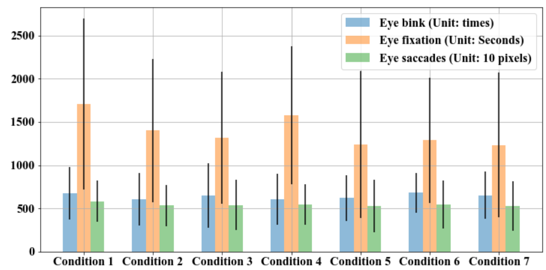


Fig.7: Results of eye movements (Verical axis units are illustrated in the legend)

Two reading tasks were conducted by participants in the experiment, one was reading a Chinese (native language) news (*Task News*) and another is reading (part of) an English (secondary language) article (*Task Article*). For all participants, the cognitive workloads were different and it can be reflected in the violin plot of NASA TLX regarding two tasks (Fig.6a). In the figure, it can be observed that participants agreed that *Task News* had less mental demand, had less physical demand, they read it faster, performed better, spent less effort and had less frustration. Regarding the cognitive workloads in 7 different conditions, participants rated *Task News* and *Task Article* differently as Fig.6(b) and (c), respectively. Generally, for *Task News*, all participants rated that Condition 2, 3, 4, 5, 6 and 7 better than Condition 1 and except the physical demand, those differences were statistically significant. Among Condition 2 to 7, Condition 3, 5 and 7 (green markers) were slight less demanding than Condition 2, 4 and 6. For *Task Article*, there was no statistically significant difference among all conditions. Condition 3, 5 and 7 (green markers) were slight less demanding regarding mental demand and physical demand, and participants considered they performed slight better and had less frustration. Eye tracking data (Fig.7) also indicated that during the experiment, participants had similar eye blink times and length of saccades, but in Condition 3, 5 and 7, participants had less eye fixation durations.

5. Discussions

In the process of reading the laptop screen under different illumination conditions, three types of fatigues, namely visual fatigue, cognitive fatigue and body fatigue, may have influenced the comfort of the user. In the design of the experiment, regarding the body fatigue, we utilized the LPD body map to detect subjective feelings of discomfort and motion sensors to detect the movements of the body. Visual fatigue and cognitive fatigue can be difficult to separate in terms of human perception. We utilized the CUQ to detect the subjective feeling of visual fatigue, and eye tracking was used to detect the activities of eyes. In the cognitive side, the NASA TLX was used to subjectively evaluate the cognitive demand of the tasks. Finally, the comfort/discomfort questionnaire was used to acquire the overall comfort feeling of the participants in the process.

General comfort vs illumination conditions

Fifteen participants experienced using computer screen in 7 different illumination conditions. Regarding general comfort, Condition 1 (dark environment) was the least preferred choice of the participants. In the rest conditions, Condition 3, 5 and 7 performed (slightly) better than Condition 2, 4 and 6. By grouping all conditions according to the color temperature and the light intensity, Fig.8 presents the levels of comfort and discomfort of these two groups, respectively. The participants preferred the warm light (3000K) more than cold light (5000K) as the left in Fig.8 (statistically significant: comfort: p=0.004; discomfort, p=0.001). For the light intensity, participants preferred strong light (1500 lux, Condition 2 and 3) more than the medium (675 lux, Condition 6 and 7) and low light (375 lux, Condition 4 and 5) conditions as the right of Fig.8.

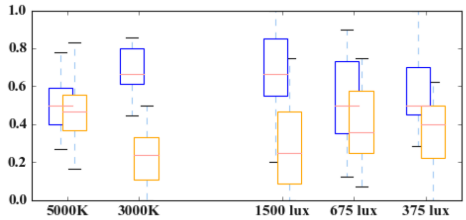


Fig.8: Comfort (blue) /discomfort (orange) regarding color temperature and light intensity (for comfort, the vertical axis stands for the level of comfort (1=high comfort), for discomfort, the vertical axis stands for the level of discomfort (1=high discomfort)

Body fatigue vs illumination conditions

In the experiment, the ergonomics setups of the chair, the table and the computer were fixed. Therefore, the LPD body map did not show significant differences of discomfort for different parts of the body among different conditions. However, in the shoulder, the back, the hip and the buttock, participants reported in Condition 1 (dark environment) was less discomfort. This interesting phenomenon will be explained in the following section *Relations of measures*. Regarding the physical movements of the body, we found that the average rotation speed of the head was three times more than the trunk in reading task. However, we did not find significant difference regarding different illumination conditions.

Visual and Cognitive fatigue vs illumination conditions

Illumination condition is more likely to directly affect visual fatigue while cognitive fatigue has more correspondence with the content of reading material (the language, the difficulty and the fields it covered). In the experiments, *Task News* and *Task Article* had different cognitive workloads, where the latter was heavier. Users reported differences on these two types of cognitive workloads regarding the 7 conditions. For the *Task News*, all participants reported that in Condition 1, the mental and temporal demands were higher. It took more effort, they performed less good and had more frustration. However, this effect was not observed in the *Task Article*. In this task, participants fully concentrated on the content of the task and they were not fully aware of the influence of the illumination conditions.

Besides the problems with CUQ question *3. Burning eyes and 5. Squinting helps when looking at the computer* in Condition 1, where no illumination was provided, the color temperature of light also influences the visual and cognitive fatigue of the participants. In Condition 3, 5 and 7 (warm light), participants had less eye fixation durations than other conditions, which indicated that warm light helped the user finishing the cognitive process in shorter time. This can also be reflected in the scores of the NASA TLX regarding both tasks, where the green markers are slight lower in mental demand, efforts and frustration, and slightly higher in performance.

Relations of measures

Condition 1 (dark environment) was the least comfortable among all conditions, however, in the LPD body map, participants reported that Condition 1 was better regarding discomfort in the shoulder, the back, the hip and the buttock. Meanwhile in the CUQ, participants reported that they encountered problems with *Burning eyes and Squinting helps when looking at the computer* in Condition 1. This phenomenon can be explain by that "*Pain will emerge over other demands for attention*" [36]. The participants reported less discomfort as they experienced more problems with their eyes. This finding is in accordance with the literature [37] where passengers felt less discomfort when food and drinks were provided.

Parts of the results of CUQ were correlated with the results of the comfort/discomfort questionnaire. Scores of Question *3.Burning eyes* and *10.Driving/night vision is worse after computer use* had statistically significant negative correlations with the values of comfort, scores of *3.Burning eyes, 5.Dry, tired, or sore eyes;* and *10.Driving/night vision is worse after computer use*, had statistical significant positive correlations with discomfort. Details of the correlations are presented in Table 2.

Table 2: Correlations between scores of CUQ and the values of comfort/discomfort (*P≤0.05)

CUQ	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Comfort	-0.33	0.623	-.904*	-0.665	-0.740	-0.647	0.239	-0.209	0.457	-0.856*	-0.469
Discomfort	0.289	-0.588	0.937*	0.662	0.813*	0.614	-0.144	0.222	-0.449	.800*	0.442

Using the linear regression method, we modelled the relationships between the comfort/discomfort and the scores of CUQ. In the regression, the scores of Questions 3, 5 and 10 (P≤0.05) were used as predictors, and scores of comfort and discomfort were used as criterion variables. Eq.1 presents the model where the coefficients in column 1 to 3 are associated with CUQ question *3. Burning eyes*, 5. *Dry, tired, or sore eyes* and *10. Driving/night vision is worse after computer use*, respectively. Column 4 is the constant of the model. Based on the values of the coefficient, it can be found that Question 3 in the CUQ has the largest influence on the level of both comfort and discomfort, followed by Question 10 and Question 5, which indicates that burning eyes is the major reason of the lower level of comfort levels and higher level of discomfort levels, respectively. It is worth mentioning that the absolute values of coefficients regarding discomfort are higher than that of the comfort, which is in accordance with the conclusion made by Vink and Hallbeck [4] that the causes of discomfort are mainly physical factors where for comfort, the causes can be more complicated.

$$\begin{bmatrix} Comfort \\ Discomfort \end{bmatrix} = \begin{bmatrix} -0.711 & -0.013 & -0.776 & 0.949 \\ 1.001 & 0.298 & 0.736 & -0.141 \end{bmatrix} \begin{bmatrix} 3.Burning\ eyes \\ 5.Dry, tired, or\ sore\ eyes \\ 10.Vision\ is\ worse \\ 1 \end{bmatrix} \quad (1)$$

Subjective and objective measures

Subjective and objective measures were used in the experiment to measure different types of fatigue influenced by various elements. For instance, we measured the cognitive process using eye tracking and NASA TLX, and the overall process was measured by comfort/discomfort questionnaires. In Table 3, the correlations between the eye fixation durations and the length of saccades, and the comfort/discomfort are presented. It shows that the longer the fixation durations are, the lower the comfort is. A similar phenomenon was identified in the length of the saccades. Therefore, conditions in which fixation durations and lengths of saccades were shorter, the comfort improves and discomfort reduces.

Table 3: Correlations between eye fixation, saccade and the values of Comfort/discomfort (*P≤0.05)

	Eye fixation durations	*Length of Saccades*
Comfort	-0.783*	-0.849*
Discomfort	0.794*	0.891*

Eye fixations and saccades were also correlated to the scores in the NASA TLX. Table 4 lists the Pearson correlation coefficients between them. Eye fixation durations were correlated (P≤0.05) to Mental demand, Physical Demand and Frustration. Regarding the length of saccades, it was correlated (P≤0.05) to Physical Demand, which reflected the physical movements of eyes in the reading process.

Table 4: Correlations between eye fixation, saccade and the values of NASA TLX (*P≤0.05)

	Mental demand	*Physical demand*	*Temporal demand*	*Performance*	*Efforts*	*Frustration*
Eye fixation	0.880*	0.830*	0.374	-0.240	0.641	0.802*
Saccade	0.715	0.827*	-0.006	-0.107	0.566	0.625

Limitations

In this study, we investigated the comfort experience using a computer screen in a dark environment. For simulating the use of computers in the leisure time (evening), the designed tasks were easy and without a clear objective, tests [38] were not arranged as well. Considering that the real reading condition can be more complicated, there are more factors to be investigated in a natural environment, e.g., colors of the environment, ergonomics of the chair and the table, ambient noises. Besides, in order to prevent eye fatigues of participants, we limited our experiments to 7 discontinuous sessions, which may also influence the comfort/discomfort of the users. Additionally, it is known that with longer durations comfort reduces further and discomfort increase [39], but it is also known that humans move more when they are longer in one position [40]. This means that it is hard to extrapolate these results under laboratory conditions to natural environments and further research is needed on how this can be translated to daily life. On the other hand, it is clear that there are preferred conditions like warm light and not completely dark, which are easy to implement in daily life.

6. Conclusion:

Using subjective and objective measures, the overall comfort/discomfort of the users in 7 different lighting conditions was recorded as well as three types of fatigues: the body fatigue, the visual fatigue as well as the cognitive fatigue. The results indicated that the strong warm light (1500 lux, 3000K) illumination condition reduced the visual fatigue and the cognitive workload of the users, and it is correlated to the improved the comfort of the user. Regarding the measures, we identified that the eye fixation durations and the lengths of saccades, as well as the scores of some questions in the computer user questionnaire, were significantly correlated with comfort/discomfort, which cast a new lens on the comfort/discomfort experience of the users.

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Comfort and Discomfort While Smart Phoning in Bed

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Abstract The number of smartphone users worldwide from 2014 to 2020 was increased from 1.57 to 2.87 billion, respectively. Moreover, the internet of Things (IoT) connected devices trend predicts to increase to 75.44 billion in 2025. People can continuous do more by the smartphone. However, people use smartphone continuously for long times, which could contribute to discomfort or muscle pain as it could result in awkward postures. The areas for using the smartphone could be the bed and on the sofa. The awkward postures in test areas could affect the comfort and discomfort using the smartphone. To study the comfort and discomfort of a smartphone in bed and how the posture is influenced by smartphone use 52 participants were asked to use the smartphone in the bed with a backrest, that can be adjusted in 6 steps 177, 162, 142, 120, 99, 75 degrees respectively. 26 subjects started from 3-105 degrees, and 26 subjects started from 105 to 3 degrees. The results of this study were analysed by Independent-Sample Kruskal-Wallis Test to see if comfort of participants differed for different back support angles. The results showed that the distribution of comfort is significantly different across categories of backrest angles. The participants prefer an angle of back support of 142, 120 (these were not significantly different) followed by 162, 177, 99 (which also did not differ), followed by 75 degrees. The best of the six positions were asked again, and subjects had to report in which body part they feel most discomfort and most comfort. The body discomfort showed that 53.84%, 32.69 %, 11.53%, and 11.53% of the participants had discomfort at lower back, neck, shoulder and lower arm respectively when using the smartphone in bed. The comfort of body region was mentioned most in the legs (34.6%). , 26.92%, and 19.23% felt comfort at upper back and shoulders when using the smartphone in bed. The size and weight of smartphones and the duration of the test could influence the comfort and discomfort, which is of interest for a follow up study.

Keywords: Comfort, Discomfort, Posture, Smart phone, Bed

1 Introduction

Observing passengers in a train showed that 40-50% of the passengers use their smartphone at the moment of observing (Kilincsoy & Vink, 2018). Among others, it could be texting, listening to music, reading, or web browsing. Much effort is devoted to optimizing the systems and mechanisms of smartphones to increase productivity (e.g., Jewell, 2011; Lee and Lee, 2011). New versions of smartphones are often introduced in the market. The number of iPhones sold from Q3 2014-Q3 2018 is 40 million each quarter of the year (https://www.textrequest.com/media/2320/iphone-sales-2007-2018.png). Assumably, the new version probably has much more features, which probably stimulates to use the smart phone more. However, the relationship between smartphone comfort and body posture is seldom mentioned, while this might be more important taking into account what the newer versions of the smartphone can offer. Also, in the bed, the smartphone is used. Fifty percent reports to frequently use the smartphone in bed in the study of Honan (2015). Some beds are adjustable and can be inclined. The semi-Fowler position is used in hospitals, in which the upper part of the bed is raised, resulting in a position with the head and trunk raised to 30 degrees. This semi-Fowler's position was more effective than supine position in hemodynamic stability of patients with head injury (Kim et al., 2015). The question is, however, what position is best for smart phoning in the bed. A flat position might give too much strain in the neck for bending the neck, and a fully upright position might result in too much stretching of the back or hamstring muscles. This paper was aimed to identify the back position that is appropriate when people using a smartphone in bed.

2 Materials and Methods

To answer the research question “what is the best angle of the backrest for using the smartphone in the bed” an experiment was performed.

2.1 Participants

30 men and 22 women of different nationalities (European, American, and Asian) all of higher education participated in the study. The lengths of participants varied from 153 to 197 cm. an average stature was 175 cm.

2.2 Protocol

The research started with the introduction of the experiment and signing an informed consent. The participants were separated into 13 groups of 4 persons. In the first 15 minutes, the 1st person of the group settled on the bed and takes 6 positions (different back rest angles). In each position, which took a few minutes, a message is sent to the manager group, and the comfort is scored. The comfort score is asked by the 2nd of the four others and written in an electronic questionnaire. In the questionnaire the area of discomfort is marked as well. The 3rd person takes a lateral picture of each person. The 4th of each group is managing the whole process. The subjects take a position on a reclining sunbed and adjust the reclining mechanism in the following angles 177, 162, 142, 120, 99 and 75 degrees. 26 participants were asked to start with the flat position (177degrees), and others were asked to start in the upright position (75 degrees).

2.3 Questionnaire

A questionnaire was used to evaluate each position having a different angle of back support. Each participant was asked to rate comfort on a scale from 1-7. A 7 points Likert scale was used to assess discomfort (1 = No no comfort at all and 7 =extreme comfort). After scoring each position the participant had to take the most comfortable position and score on a body map the discomfort on each body area. In this case the LPD-method

(Localized Postural Discomfort) (Grinten, 1992) was used for scoring the discomfort for the neck, shoulder, upper back, lower back, upper arm, lower arm, wrist, and leg.

2.4 Analysis

The analysis consisted of calculating the mean, standard deviation of the comfort and discomfort score and were plotted in a graph for each angle 177, 162, 142, 120, 99, 75 degrees respectively. Statistics consisted of applying the Independent-Sample Kruskal-Wallis test were used to compared comfort of participants when using the smartphone in each angle for answer the research question "what is the best angle of the backrest for using the smartphone in the bed." For the local postural discomfort percentage of the total were calculated to get an impressin where comfort and discomfort is experienced.

3 Results

The body length of the participants (22 females and 30 males) varied from 1530 cm to 1970 cm, the age was between 22 and 30 years and all had higher education.

3.1 The results of back support angle.

The comfort results show that the participants prefer an angle of back support of 142, 120 (these were not significantly different) followed by 162, 177, 99 (which also did not differ), followed by 75 degrees (see figure 1 and table 1)) with average comfort levels rated at 4.8,4.8,4.4,3.3,3.2 and 1.8 respectively (an extremely high comfort level is 7, and no comfort at all is 1). The answer to the research question which is the best angle of backrest that the users prefer to use was 142 and, 120 degrees. The data are shown in figure 1.

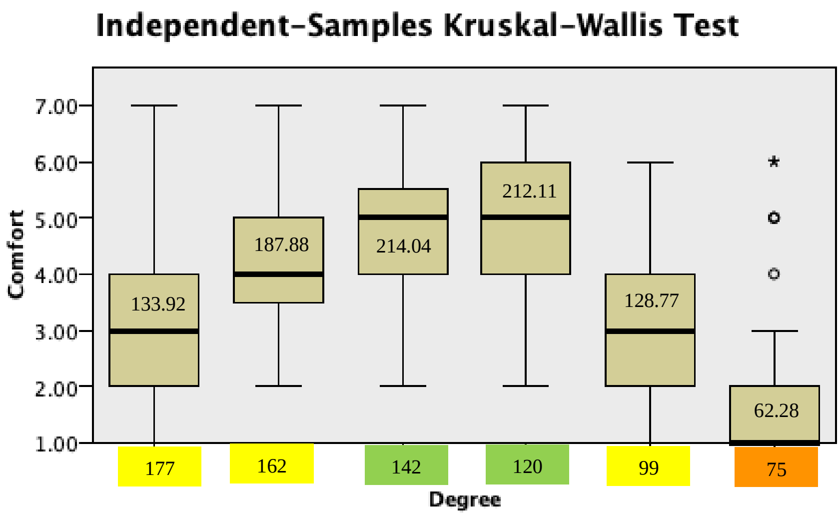

Figure 1. The results of comfort levels separated by an angle of back support

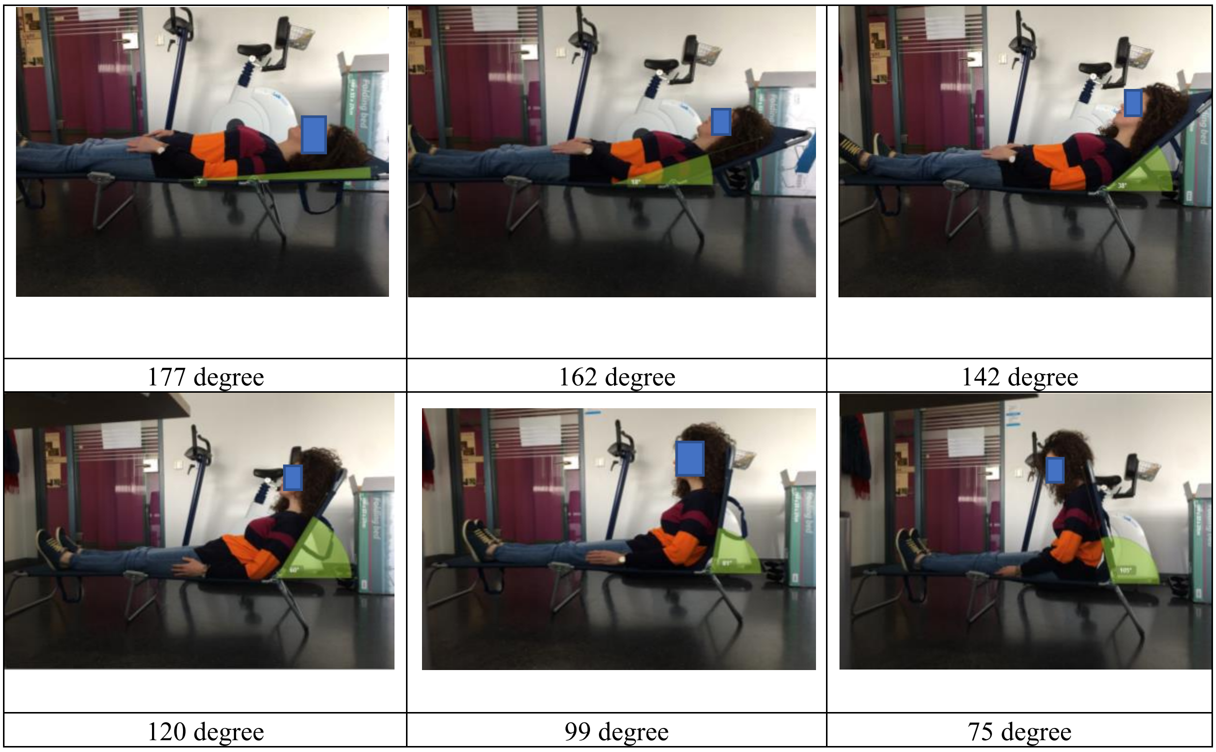

Figure 2. The different angles in which the participants had to use the smart phone

The Independent-Sample Kruskal-Wallis Test showed that the comfort values at 142 and 120 did not differ significantly, but these were different from 162, 177 and 99. These again did not differ from each other, but they did differ significantly from the75 degrees.

Table 1. The results of mean range separated by the degree of backrest

Part of body	*Degree of an ankle*					
	177	*162*	*142*	*120*	*99*	*75*
Mean range	133.92	187.88	214.04	212.11	128.77	62.28

The results of Pairwise Comparisons node Degree each node shows the sample average rank of degree. The 75 degree was showed the fell comfort of participants that significant difference with all other degrees. The 99 degrees reported significant difference with 120, 142, and 162 degrees while no significant difference between 99 and 177 degrees. Besides, the results found that the comfort feel of the subjects was a significant difference between 177 degrees and 120,142 and 162 degrees respectively. Moreover, 162 degree was a difference from 120 and 142 degrees but not significant level. Finally, the participants were rated the comfort level between 120 and 142 was not a significant difference.

3.2 The results of comfort and discomfort by body region.

For the best of the six positions, which was taken again by the participants LPD was rated as well as comfort. . The body discomfort experience shows that 53.8%, 32.7 %, 11.5%, and 11.3% of the participants reported discomfort in the lower back, neck, shoulder, and lower arm, respectively (see table 2). While, the comfort was high by 34.6% in the legs. 26.9%, and 19.2% felt comfort in the upper back and shoulders respectively when using the smartphone in bed.

Table 2. The percentage of the participants mentioning comfort and discomfort for the different regions.

The part of body	*Feel of participants*	
	Comfort (%)	*Discomfort (%)*
Neck	7.69	32.96
Shoulders	19.23	11.53
Upper arms	15.38	5.76
Lower arms	3.85	11.53
Wrist	0.00	1.92
Upper back	26.92	1.92
Lower back	7.69	53.84
Legs	34.61	5.76
Totally	**	**

** Remark : some people prefer more than one angle.

Moreover, 63.5% used two fingers and 30.8 used one finger and 5.8 used other method for typing.

4 Discussions

In answering the research question "what is the best angle of the backrest for using the smartphone in the bed" it is clear that there is not one preferred angle, but a range of angles in which the comfort is better . The participants experienced a high comfort when using the smartphone in bed at a 142 to 120 degree backrest angle. Groenesteijn et al. (2009) mentions that the adjustable backrest was better for adapting to the human and the task. She found a back rest angle of 132 degrees while reading in an office chair in a relaxed position. Of course this is not laying in bed, but the results show similarities. Probably the position of the arms and neck play a large role in determining the most comfortable back rest angle. This certainly needs further research. Of all participants, 34.61% mentions the comfort legs in this position and, 26.92%, and 19.23%, felt comfort at upper back and shoulders. The dis-comfort recordings showed that 53.84%, 32.69 %, 11.53% and 11.53% of participants felt discomfort at lower back, neck, shoulder and lower arm respectively when using the smartphone in bed. .

A disadvantage of the study is that the participants only use the smart phone a few minutes. It could be that longer use leads to other preferences. Smulders et al. (2016) and Sammonds et al. (2017) showed that sitting longer in one position does lead to higher discomfort ratings.

5 Conclusions

Regarding the research question "what is the best angle of the backrest for use the smartphone in the bed" the 52 participants showed a preference for two angles, which did not differ significantly. The participants experienced a high comfort when using the smartphone in bed at a 142 to 120 degree backrest angle. The participants prefer these angles, but still have discomfort. a 53.8%, 32.7 %, 11.5% and 11.5% of participants mention discomfort at the prefered backrests angle at lower back, neck, shoulder and lower arm respectively. While, the comfort when using the smartphone in bed at the prefered backrests angle was mentioned by 34.6% regarding the legs and 26.9%, and 19.2% regarding upper back and shoulders respectively.

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Development of a Rail Passenger Seat Comfort Specification and Performance Scale

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Abstract In recent years, there has been a public and media perception of a decline of train seat comfort levels in Great Britain. This is reflected by passenger satisfaction scores, which are below the national target of 90% by 2035. As seat comfort is a contributing factor to overall passenger satisfaction with rail journeys, focus on improving these scores is an important area for research. Seat comfort is complex and has been found to be very difficult to quantify, due to its subjective nature and the multitude of factors that can impact upon an occupant's levels of comfort and discomfort in different contexts and environments. The rail industry does not have a standardised method to assess and score the comfort of seats in order to make an informed decision in the procurement and specification stages of design. This research produced a seat comfort selection process by identifying the minimum seat comfort dimensions, minimum seat pad thickness and hardness requirements and developing a seat comfort attractiveness survey. A pre-weighted scoring system was developed to assess multiple features which can impact upon comfort, which was validated with subjective feedback. A validation test with 7 existing train seats showed a positive correlation between objective comfort rankings, following the method proposed by this research, and the subjective comfort rankings from participants. The results indicate that the seat comfort selection process this research delivered is repeatable and can provide a reference point for industry.

Keywords: Passenger Comfort; Train Seat Design; Performance Scale; Customer Experience

1 Introduction

It has long been recognised that seating should not be viewed as a luxury, but as a fundamental requirement [1]. This is pertinent to the rail industry, with over 1.7 billion passenger journeys recorded in 2017/18 [2]. Whether it be leisure passengers or commuter passengers, who typically use trains as an extension of their working environment, comfort of the seat and the seating area demands attention. A consistent approach to seat specification and performance has not been established for rail passenger comfort.

Whilst passenger journeys in rail is high, 2017/18 saw the first drop in GB numbers since 2009/10 [2]. Furthermore, public dissatisfaction stemming from annual fare increases places pressure on the industry to deliver on all aspects of the customer experience. Passenger comfort during rail travel is an important aspect of the customer experience, and forms part of the rolling stock vision for comfortable and attractive train interiors.

Furthermore, a key aspect of passenger comfort is attributed to the seat and the seating area, which contribute to the overall impact on customer satisfaction. The 2018 passenger satisfaction scores revealed that 64% of passengers were satisfied with the current comfort of seats across the network as a national average [3]. This was below the national average of 79% passengers satisfied with their journey [3], and 26% below the industry wide target of achieving 90% satisfaction by 2035 [4]. Therefore, it can be assumed that improvements in seat comfort may contribute to reaching this target, by offering passengers better value for money and comfort during their journey.

Given the public and media perception of a decline of seat comfort levels in Great Britain, the rail industry needs the development of a robust and measurable seat comfort assessment [3]. The objective is for this new seat comfort assessment process to enable the industry to make informed decisions when specifying and procuring seats for rolling stock. This would give seat manufacturers a defined set of requirements with a testing method in order to achieve more comfortable seats.

Designing comfortable seating is challenging, especially given that humans are more comfortable in an open posture, typically when standing. Indeed, muscle efforts required for a sitting task are significantly greater than for a standing task [5]. Furthermore, quantifying seat comfort is a complex area that depends on the human, the product, and the environment [6]. Consequently, it is dependent on a whole host of parameters. In fact, De Looze explicitly states that: (a) comfort is a construct of a subjectively defined personal nature; (b) comfort is affected by factors of a various nature (physical, physiological, psychological); and (c) comfort is a reaction to the environment.

Transport research has identified 3 key considerations when thinking holistically about seat comfort and the onset of discomfort. These include:

- Static factors, e.g. seat dimensions, legroom, anthropometry
- Dynamic factors, e.g. vibration, seat pad material/composition and compression
- Temporal factors, e.g. variation in journey length.

Static and dynamic factors are equally important when considering seat comfort, as the presence of motion and vibration will increase discomfort even when the seat static factors (e.g. dimensions) have been well designed for the user population. Indeed, in automotive research this has been described in a model for assessing seat discomfort [7]. Research into rail vehicle seating has identified that the most important source of variability between seats, which affects the transmittability of vertical vibration, is individual seat differences (e.g. wear and tear), rather than occupant factors (e.g. posture) [8]. This may indicate that a reliable manufacturing process twinned with a robust method to test the durability of seats can help to manage and design for the dynamic factors associated with a comfortable seat.

The length of the journey is crucial, as previous studies have shown that the perception of overall discomfort increases with the duration of exposure [9]. Perceptions of comfort and discomfort occur through the interaction between the passenger and seat within a context. As such, the activities performed while sat in the seat (e.g. reading, sleeping, working on a laptop) can have a bearing on the level of comfort experienced. This aligns with length of the journey, which often determines the type of activities that a passenger will perform whilst travelling.

Another contributory factor to seat comfort is the opportunity for changing posture and the length of time sitting in the same seated position. Humans instinctively fidget and search for the body posture allowing the lowest expenditure of energy within the limits of that which is physiologically and biomechanically possible [10]. In automotive seat comfort research, a higher rate of seat fidget movements (SFMs) have been shown to correlate with higher levels of discomfort during a laboratory experiment [11]. This highlights that the opportunity for changing postures (thus changing the muscle groups which are supporting the body weight) is just as important as a comfortable fit [12].

Whilst physical parameters affect an occupant's comfort, the perception of comfort is also influenced by psychological factors. Literature suggests that a person's first impression of a seat can have an influence on perceived comfort [13]. The way in which we process information means that the amygdala part of the brain reacts quickly and emotionally, which ultimately gives a person their first impression of a product. Furthermore, aesthetics can play an important role during the first 0-40 minutes of sitting [14], demonstrating that those first impressions count. It is important to acknowledge when developing a seat comfort model that a person's pre state of mind, based on factors outside of the seat's comfort, is likely to influence perceived seat comfort [15].

It is expected that by assessing and scoring the physical (static and dynamic) factors, the influence of time and the impact of perception, seat comfort can be quantified, and a seat comfort selection process can be developed, tested and validated. The aim of this research was to establish if this quantified selection process based on objective measures can correlate with subjective comfort ratings of participants during a validation fitting trial and seat ranking exercise. This paper will outline the approach that was taken to develop a robust test method and seat scoring system and a validation test with existing rail seats.

2 Development of a seat comfort selection process

Findings from a detailed literature review were used to define the minimum seat comfort requirements, which considered seat dimensions, seat accessories, seat pad thickness and hardness, and the perception of comfort. A recommended weighting was given to each of the individual components which make up the comfort selection process:

- Seat dimensions – 50% of the overall score
- Seat pad thickness and hardness – 35% of the overall score
- Seat attractiveness survey – 10% of the overall score
- Seat accessories – 5% of the overall score.

2.1 Minimum seat dimensions

There are several seat dimensions that are integral to accommodating the 5th to the 95th percentile population, in terms of fit. For example, the seat width (distance between the armrests) needs to be wide enough for a passenger with a 95th percentile hip width to physically fit in the seat. Seat parameters and the corresponding body dimensions are detailed in Table 1.

Table 1. Seat parameters and corresponding body dimensions considered.

Seat parameter	*Body dimension*
Seat height	Lower leg length
Seat depth	Buttock – Popliteal length
Seat width (distance between armrests	Sitting hip breadth
Seat width (longitudinal seating)	Elbow to elbow breadth
Backrest width	Shoulder breadth
Armrest height	Sitting elbow height
Underside of headrest to seat	Sitting shoulder height
Point of contact – nape of neck	Cervicale height
Angle of seat	n/a
Angle between seat and back	n/a
Legroom (including height, clearance under table/flip down tablet)	Buttock – Knee length, knee height, thigh clearance

The minimum seat comfort requirements for passengers of non-limited mobility were based on anthropometric dimensions of people from 'BS EN ISO 7250-2:2013 [16]. UK anthropometric data on offer is quite outdated and often based on estimations using children's data and limited anthropometric survey data. Although there is currently no UK data in this standard, the UK population has a very similar profile to that of Germany, and so the German data was used for reference. The minimum seat comfort dimensions were intended to encompass the 5th to the 95th percentile female and male passenger profile, with allowances for clothing, shoes and the ability to ingress and egress the seat.

To accurately measure the seats under load, a weighted chair measurement device (CMD) was used, in accordance with ISO TR 24496:2017 [17], as seen in Figure 1. The CMD replicates the weight distribution of a human being and provides adjustable seat and back panel, with integrated measurement rules to provide accurate measurements. This CMD has been used to measure chair dimensions for office seating and provides a robust method for measuring seats.

Fig. 1. CMD used to measure seat dimensions (ISO TR 24496:2017).

2.2 Accessories

Accessories that are synonymous with train seating and train journeys, which can influence overall passenger comfort, were selected and incorporated as part of the proposed test method. In order to determine which seat accessories are most useful for different journey types, a confidential survey was conducted with staff across the UK (n=440). The survey asked respondents to rate the level of usefulness for each seat accessory for Metro, Regional, Inter-City and Very High Speed/First class train seats. The selected accessories included, but weren't limited to, armrests, footrests, flip down tablets, and seat spacers between seats.

2.3 Seat pad thickness and hardness

A minimum seat pad thickness of 50mm and a minimum back pad thickness of 25mm was specified for comfort requirements. The seat pad thickness includes any combination of seat cushion interlayers, including the outer fabric, fire barrier materials, foam, mesh and compression springs. It does not include the thickness of the rigid seat shell structure. To determine the minimum seat pad hardness requirements, the pad is required to provide enough compression for a lighter 5th percentile female to feel comfortable, and enough pad hardness to accommodate a heavier 95th percentile male without bottoming out i.e. the occupant feeling the ridged structure beneath the pad and receiving no support from the pad itself. To achieve this, the following method was used:

- A force of 500N applied to the seat pad using a Ø200mm indenter for 30 seconds. The seat pad shall compress to a minimum of 40% of the overall seat pad thickness.
- A force of 1100N applied to the seat pad using a Ø200mm indenter for 30 seconds. The seat pad shall compress to a maximum of 70% of the overall seat pad thickness.

2.4 Seat attractiveness survey

A seat attractiveness survey was designed as an optional element of the test method. This was designed to give train operating companies (TOCs) and rolling stock owners (ROSCOs) the opportunity to present a selection of the seats, which have already met the minimum seat dimension, pad thickness and hardness requirements, to passengers. This method promotes passenger engagement and customer feedback, but also caters for individual perceptions of comfort. An example of a question for the survey was:

Question: When approaching the seat, how attractive does it look?

Considerations: Shape of seat; Size of seat, width and height; Accessories; Colour/pattern and the fabric/leather.

2.5 Comfort rating scale

A comfort rating scale was developed to score seats and ascertain their comfort level, shown in Figure 2. Each seat feature that influences comfort can be tested, measured and scored, including seat dimensions, seat accessories, seat pad hardness and thickness. The individual scores for each seat feature can be added together to calculate an overall seat comfort score. The scores are pre-weighted based on the importance and effect that each seat feature has on seat comfort. For example, where minimum fit is essential for comfort, that seat feature would have a higher weighting. This scale also considered findings from the literature around adjustments and the ability to change postures, by having higher scores for seat dimensions that enabled the user population to adjust themselves within the seat.

Seat Width (distance between armrests) - Minimum Dimension					460mm	
Score	0	0.75	4	4	3.5	3
Dimension	<440mm	440-459	460-481	482-503	503-524	>525mm

Fig. 2. Seat comfort scoring performance scale for seat width (distance between armrests).

To validate the objective minimum seat comfort dimension scores, and the assumed link that comfort is based on anthropometry and physical fit, it was necessary to test a range of dimensions for each seat feature with a pilot trial. An adjustable seat rig was designed and constructed. The rig allowed the dimension of each seat feature (e.g. seat depth, seat width etc.) to be adjusted incrementally to assess how dimensional changes affect comfort. Additionally, different pad thicknesses could be added and removed from the rig for testing.

Participants (n=7) covering a diverse anthropometric population were recruited. An ergonomist evaluated and recorded how each seat feature fitted the participants when set in different incremental dimensions. Each participant was then asked to rate each seat feature dimension in order of preference. The results from this pilot identified several adjustments to the score weighting needed to be made for certain features. For example, the tolerance for seat height was increased to 440mm ±15 (from 440mm ±5mm) to account for the popularity of 425mm as a height. Lower than 425mm would begin to be more uncomfortable for 95th percentile occupants and higher than 440mm would prevent 5th percentile occupants from being able to place their feet flat on the floor.

The seat and back pad thickness tests were achieved by combining foam sheets to achieve the required thickness. The seat and back pad thicknesses were adjusted to reflect the minimum seat comfort requirements and associated comfort scores. Additionally, thicknesses deemed to be uncomfortable were assessed. Once each participant had experienced each seat pad thickness, they were asked to rank them in order of preference. The results showed that thicker seat and back pads were perceived to be more comfortable than thinner pads, and so the scoring and score weightings were reviewed to reflect this.

3 Comfort validation with existing train seats

The minimum seat dimensions and the seat pad thickness and compression tests were conducted as part of this validation trial. The scoring of accessories and the seat attractiveness survey were not included in the trial, as the seats were assessed independently and were not installed in their respective train carriage environment. Participants (n=12) were asked to sit in seven different train seats sourced from TOCs and seat manufacturers. The participants were asked to rank the seats in order of comfort (1 being the least comfortable to 7 being the most comfortable). The seat dimensions and seat pad hardness were then objectively measured and scored by the researcher and combined to calculate an overall seat comfort score. To determine if there was a correlation between objective and subjective seat comfort scores, a Spearman's Rank correlation coefficient test was used. This technique is used to summarise the strength of a relationship between two variables, with the results always being either positive or negative.

4 Results and discussion

The seat comfort testing and scoring test resulted in the high end of a moderate positive Spearman's Rank correlation of 06.43, shown in Figure 3. This result indicates alignment between the objective measurement of seat comfort (seat dimensions and seat pad compression hardness tests) and the subjective assessment of seat comfort.

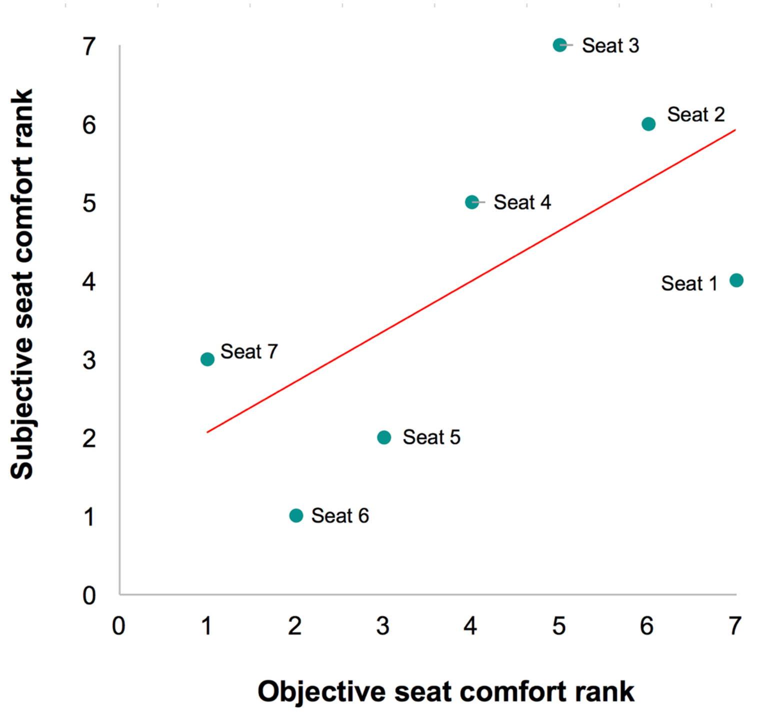

Fig. 3. Correlation between objective and subjective seat comfort ranks.

It was observed how a single individual parameter such as seat width, armrest height, and seat pad hardness influenced the participants views on overall seat comfort. This highlights the effect that each seat feature has on overall comfort. It also demonstrates that unless some of the seat features are adjustable, the fixed dimensions are often a necessary compromise to accommodate the 5^{th} and 95^{th} percentile body sizes.

The development of this specification and performance scale indicates that, whilst complex, a method considering a multitude of factors can produce a robust starting point for assessing seat comfort. Furthermore, as a comfort model, this specification has been developed with the individual, the product and the environment in mind [6]. Not only does this method outline key features to consider, but it also provides a robust methodology to reliably measure and test these based on existing ISO standards. This is important when accounting for repeatability in the rail industry's seat manufacturing. Passengers require and expect a certain level of seat comfort for different journey and train types. To ensure the level of seat comfort is appropriate for the type of train journey, the expected comfort rating range has been mapped against 4 distinct train journey types, shown in Figure 4. This allows the seat manufacturer or TOC to design and select a seat that is appropriate for their operational requirements. It is recommended that this specification and performance scale is reviewed periodically to account for innovative seat design developments and comfort level expectations across the industry.

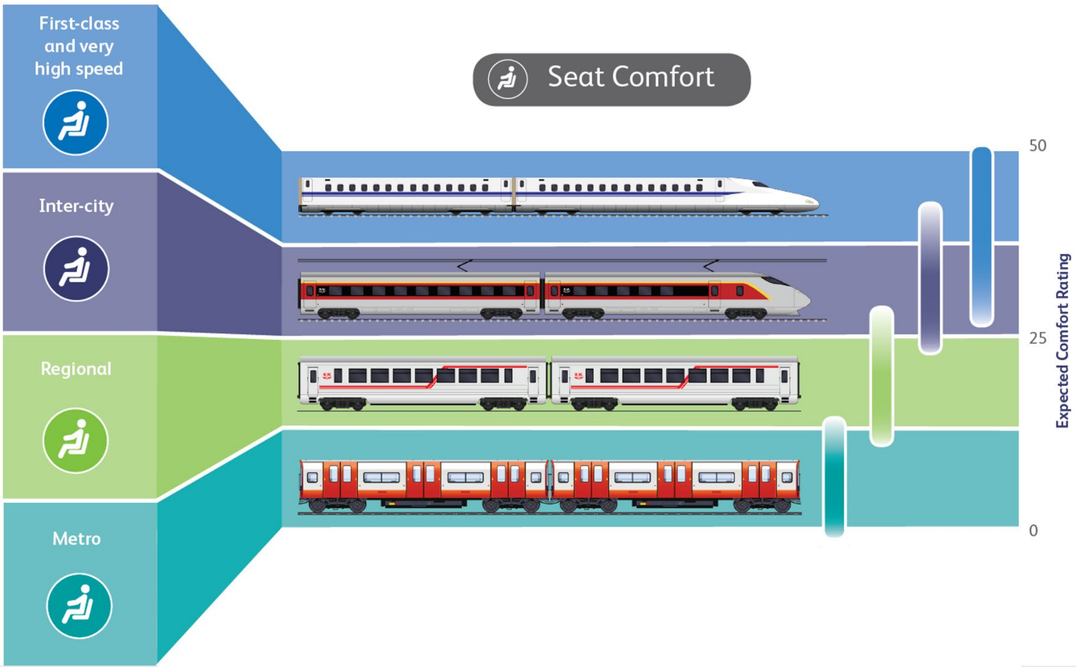

Fig. 4. Expected seat dimension scoring range for seats across journey types.

5 Conclusions

This research aimed to develop a robust seat comfort scoring system with a repeatable test method. The seat comfort requirements and scoring system are based on objective anthropometric dimensions and weights of passengers, combined with more subjective feedback on the perception of comfort from people. This was validated by assessing existing train seats with a positive correlation. The method of testing utilises robust test methodologies and equipment developed for ergonomic and compression testing used in other seating industries and was shown to be repeatable for industry stakeholders. Passengers expect different levels of comfort for different train journey types and the seat comfort scoring system provides different target scores for different journey categories.

The seat comfort selection process will provide stakeholders such as train TOCs, ROSCOs, and train seat manufacturers with a reference figure or percentage of how comfortable a seat is. Furthermore, having individual seat feature scores will allow stakeholders to understand which features can be refined to improve the overall seat comfort score on existing seats. Having identified areas for improvement, operators can integrate seat comfort in to planned refurbishments of their trains. Also, this enables stakeholders to make informed decisions when specifying seat comfort requirements in the procurement of new trains and new seats. Finally, this enables stakeholders to objectively assess seat comfort on existing trains, giving a better understanding of key issues driving customer dissatisfaction.

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Objective and Subjective Evaluation of a New Airplane Seat with an Optimized Foam Support

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Abstract Thanks to a fully adjustable experimental seat, data of the preferred seat profile and compressed seat pan surface were collected from 36 differently sized people. Parametric models were developed to predict optimal seat profile parameters such as seat height, seat pan length, back profile angle as well as optimal compressed seat pan surface (C-surface) in function of a sitter's body size for a given set of seat pan and back angles. Using a population simulation approach, the distribution of the preferred seat profile parameters could be estimated. We proposed a so-called 95%tile C-surface, which encompasses 95% of individually optimized compressed seat pan surfaces of a target sitter population, as foam support to reduce amount of foam while maintaining a good pressure distribution. The present study aimed to verify if seats with the proposed pre-shaped foam support could improve seating comfort for airplane passengers. The 95%tile C-surface was used to define two new seats with two different cushions with a same thickness of 45 mm, one slightly softer and the other harder. 19 volunteers, selected by stature and BMI, tested the two new seats and a reference existing seat randomly. After an assessment of initial discomfort for five different postures (neutral, erect, relaxed, frontal sleeping and side sleeping), participants were instructed to watch a TV series for 50 minutes to experience a longer sitting. A same questionnaire was used to assess both initial and longer-term discomfort. In addition to the contact forces measured by the experimental seat, contact pressures at the back and seat pan were also measured by two Xsensor pressure maps. Pressure distributions and postural changes during the long sitting were analysed. The two new seats were globally preferred with a lower discomfort rating than the existing reference seat in agreement with the number of postural changes during the long sitting watching a movie. Properly pre-shaped surface as the one we suggested could be used as foam support to reduce the amount of foam while maintaining seating comfort.

Keywords: Discomfort, Aircraft seat, Pre-shaped foam support, Pressure distribution, In-chair movements

1 Introduction

An airplane passenger seat, like other seats in transportation, is used by thousands or millions of people. The seat should be designed to accommodate the maximum number of a target population by taking into account the variability of body size as well as the environment's constraints. Aircraft seat manufacturers are facing two strong requirements from airline companies: to reduce seat weight while continuously increasing seating comfort. In order to provide quantitative guidelines for improving seat design, data of the preferred seat profile and compressed seat pan surface were collected in function of seat pan and backrest angle from a sample of differently sized participants using a reconfigurable experimental seat we built recently (Beurier et al., 2017). Parametric models were obtained to predict optimal seat profile parameters in function of a sitter's anthropometric characteristics, seat pan angle and seat back angle (Wang et al., 2018). Using a population simulation approach, a sample of 500 males and 500 females from the CAESAR US civil population (Robinette et al., 2002) were generated randomly based on the distribution of relevant anthropometric dimensions. The distribution of the preferred seat profile parameters, such as seat height, seat pan length, back profile angle as well as optimal compressed seat pan surface (C-surface), was obtained by virtual population simulation (Wang and Beurier, 2018). We proposed a so-called 95%tile C-surface, which encompasses 95% of individually optimized compressed seat pan surfaces of a target sitter population, as foam support to reduce amount of foam while maintaining a good pressure distribution. We have hypothesized that the optimal C-surface as foam support could:

- reduce the amount of foam needed for a pressure distribution
- use a uniform foam without varying foam thickness and stiffness, thus simplifying cushion manufacturing process

As the optimal seat profile and C-surface were obtained from an initial comfort assessment approach with a very short sitting experience, it is therefore necessary to verify if the proposed optimal seat parameters are well perceived for a longer sitting duration.

In the present study, two new seat configurations were defined based on the proposed optimal seat parameters. The objective of the present study was to evaluate these two new seat configurations with respect to an existing reference seat Z300. Our hypothesis is that the two new seats with an optimal profile and pre-shaped foam support surface should be better than Z300 in terms of both subjective perception and objective measurements.

2 Materials and methods

2.1 Participants

Nineteen subjects participated in the experiment. They were selected by stature and BMI (body mass index)

- 6 short females (3 with BMI<24 (FSH), 3 with BMI>30 (FSO))
- 6 average height males 3 with BMI<26 (MAH), 3 with BMI>30 (MAO))
- 7 tall males (4 with BMI<26, (MTH), 3 with BMI>29 (MTO))

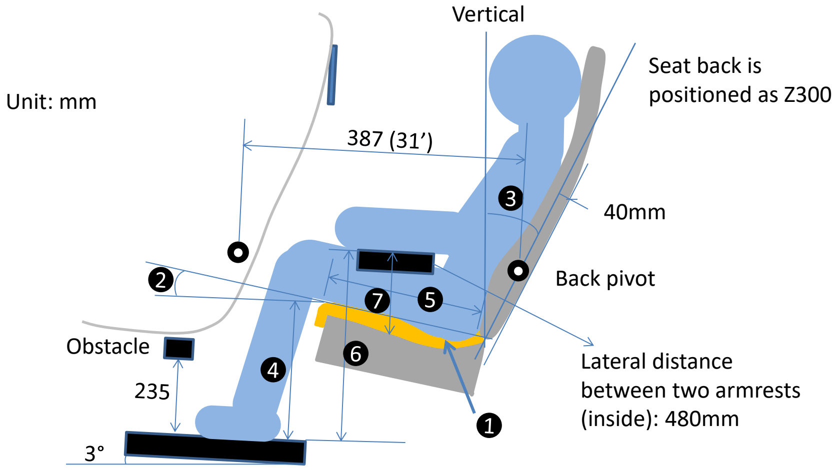
Prior to the experiment, participants were screened using a health questionnaire. They should already have a travel experience in an economics class long haul and be in good health condition for air travel. Participants who experienced any back injury or pain in the previous 3-months were excluded. The experimental protocol was approved by IFSTTAR (French Institute of Science and Technology for Transport, Development and Networks) ethics committee and informed consent was given prior to experiment. Prior to experiment, main anthropometric dimensions such as stature, weight, sitting height etc. were measured for each participant. They were asked to dress with their own clothes for air travel.

2.2 Test conditions and experimental procedure

The optimal C-surface was used to define two seat configurations with a same pre-shaped support covered by two different foams with a thickness of 45 mm

- Cushion 5560: slightly softer
- Cushion 5580: slightly harder

The seat back of the reference seat Z300 was used for all test conditions. For the two new seat configurations, a slightly more inclined seat was used based on the preferred angles observed previously. Corresponding back angle was 22.4° slightly more reclined than Z300. The seat back was fixed on the upper support panel of the IFSTTAR experimental seat. Three seat pans could be put on the seat pan support of the experimental seat. In order to create a realistic environment, a frontal seat was added with an iPad tablet. Figure 1 shows the definition of the three tested seat configurations.



Cushion (1)	Seat pan angle (2)	Back angle (3)	Frontal edge height (4)	Seat pan length (5)	Armrest height (6)	Armrest height (7)
Z300	3.7°	20.0°	450	445	600	170+50*
5560	4.1°	22.4°	446	445	618	175+50*
5580	4.1°	22.4°	450	445	618	178+50*

Fig. 1. Definition of three seat configurations. Units are degree for angles and mm for length or height. A same Z300 seat back was used for all three seat configurations. All these parameters were measured when the seats were not occupied.

2.3 Experimental procedure and measurements

The experiment was organized in two sessions for each seat configuration: initial and long term assessment. An initial comfort was assessed for the 5 postures (Neutral, Relaxed, Erect, Frontal Sleeping, and Side Sleeping) during a short duration (<2 minutes). The posture 'neutral' was always tested the first and the responses from the questionnaire were collected. Four others were tested in a random order; only the global discomfort was rated. After the initial comfort assessment, participants were instructed to watch a TV series for 50 minutes. No specific instruction was given regarding the posture. After having watched the movie, the same questionnaire was proposed so that participants could assess the discomfort after a long term sitting experience.

Between two seat configuration tests, participants were asked to take a break of at least 10 minutes. Drinks and biscuits were proposed. The test order of these three conditions was randomized. The total duration including the welcoming and anthropometric measurements was about 4h30.

The questionnaire was composed of two parts, one for assessing the seat and the other for assessing body part discomfort. A multiple-choice question was designed for assessing the following seat parts: position of headrest and lumber support, seat pan length, seat pan cushion hardness, seat height, seat pan inclination, backrest inclination, space under the frontal seat, knee space, armrest position. The categorical partition scale CP50, from 0 (imperceptible) to 50 (extremely strong) or more (Shen and Parsons, 1997) was used for assessing the perceived discomfort of 8 body parts (neck, top, middle and low part of the back, buttock, middle and distal part of the thighs, calf) and the global perception.

In addition to the subjective responses from the questionnaire, the following objective variables during a trial were measured: contact forces at the foot support, seat pan, back support and armrests by the experimental seat, contact pressures at the back and seat pan by two Xsensor pressure-mapping systems (PX100.48.48.02, distance between two adjacent pressure cells 12.7 mm). The measurement frequencies for both experimental seat and pressure maps were respectively 25 and 2 hz for initial and long sitting sessions. Nine markers were attached on the shoulder, the belt, the knees and the shoes. Their positions were measured by a Vicon motion capture system at 30 Hz. A trigger device was used to generate starting and ending analog signals that could be recognized by both Vicon and force sensors from the experimental seat. In addition, a wand equipped with two markers visible by Vicon was used to press a specific area of the seat pressure pad for synchronizing Vicon and Xsensor measurements. All trials were also recorded by a video camera for visual inspection.

2.4 Data processing and analysis

The questionnaire responses were analyzed with help of STATGRAPHICS Centurion 18. Multi-factor ANOVA was performed on the CP50 ratings of the global discomfort as well as those of body parts, with explicative factors being sitting duration, seat configuration, and subject group. For the initial discomfort assessment, effects of sitting posture were also analyzed. For the categorical responses on the assessment of seat and its surrounding, contingency tables were generated and Chi-square test was used for comparing the responses between different test conditions and subject groups.

Concerning objective measures of seating discomfort, normal and shear forces on the seat pan as well as pressure distribution parameters for the neutral posture and postural changes or in-chair movements (ICM, Fenety et al., 2000, Sammonds, 2017) during the time of watching movie were investigated. Similar to the ones proposed by Zemp et al. (2016), more than 55 parameters were extracted from pressure distribution including peak pressure, mean pressure, standard deviation of pressure distribution, maximum gradient, mean gradient, standard deviation of the gradient, area for the whole contact area, the pressure profile and the four sub contact areas defined in Fig.2. Postural changes during the time of watching movie were detected by comparing the contact forces at the feet support, seat pan, back and armrests as well as in the row and column positions of centers of pressure (COP) on the seat pan and back between two adjacent frames. All contact forces were normalized by body weight. If one of these eight parameters had a change greater than their corresponding threshold, an ICM started until to the frame the changes of all eight parameters with respect to the previous frame became smaller than their respective thresholds. In the present work, the thresholds were 1% of body weight for the four contact forces and 1 unit (12.7 mm) in both row and column directions for two COPs.

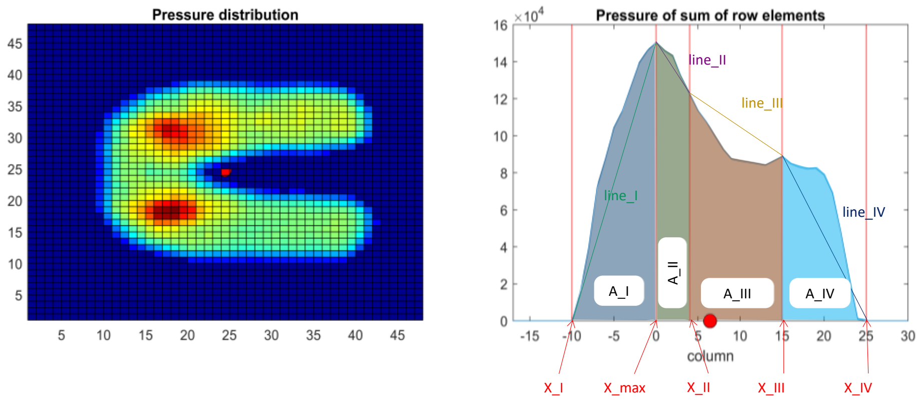


Fig. 2. Seat pan pressure distribution parameters. The pressure profile, defined as the sum of pressures by the sensors of each column, is centered at the peak pressure and divided into four sections. X_I and X_IV correspond to the border of the contact area, X_max the peak pressure position. X_II is the position of the point separating the two thigh contact areas. X_III is the mid point between X_II and X_IV.

3 Results

3.1 Questionnaire responses

Significant differences in initial discomfort CP50 ratings between 6 subject groups and 3 seat configurations were found. The seat configuration 5580 had the lowest discomfort rating, significantly lower than Z300. The subject group MAO (average height male obese) had the lowest discomfort whereas the groups MTO (male tall obese) and FSO (obese short female) had the highest discomfort. However, no significant difference in CP50 was found between five sitting postures. When comparing the initial CP50 ratings of the neutral posture with those after 50 minutes sitting; only sitting duration had a significant effect, whereas no effect was found for both subject group and seat configuration. Slightly but significantly higher discomfort rating was obtained after 50 minutes sitting. On average, the discomfort ratings were 15.9 and 19.7 respectively for initial and longer sitting assessments.

As for the global discomfort rating, sitting duration significantly affected the perception of all body parts except for the neck and calf. Higher discomfort was generally perceived for longer sitting. No significant difference between three seats was observed except for the neck. Significant differences between six subject groups were observed almost for all body parts except for the neck. Lower discomfort was perceived in the buttock and thigh for the participants with higher BMI.

Main effects of sitting duration, seat configuration and subject group were analyzed by comparing the frequencies of the categorical responses to the questions posed in the questionnaire. Concerning the effect of sitting duration, only the responses regarding the seat hardness differed significantly (P-Value=0.0193). Higher percentage of 'a little bit too hard' and 'too hard' were obtained after 50 minutes sitting. When comparing three seat configurations, only the responses concerning the seat hardness (P-Value=0.023), seat height (P-Value=0.006) and seat inclination (P-value=0.0106) significantly differed. The highest percentage of the responses 'good hardness' and 'good seat pan inclination' was obtained for 5580, followed by 5560 and Z300.

3.2 Seat pan contact force and pressure distribution parameters

The seat pan contact forces and pressure distribution parameters of the short sitting trials for the four left-right symmetric postures 'NE', 'RL', 'ER','FS' were analyzed. Participant group and posture affected most of these dependent responses. When comparing three seat configurations, normalized shear forces for 5580 and 5560 were 8.95% and 9.21% on average, significantly lower than Z300 (12.29%). They also more evenly distributed pressure with larger contact area, lower peak force, lower pressure standard deviation, larger contact area (A_III and A_IV) and higher gradient (Grad_IV_std) near the knees.

3.3 Postural changes

547 postural changes were identified over 57 trials (19 participants x 3 seats), with an average less than 10 changes per trial during a 50 minutes sitting. Depending on the pattern of force transfer between four body supports (seat pan, foot support, back and armrests) during a postural change, 27 types of ICM were identified. The first two most frequently observed movements corresponded to changing feet position, resulting in a small variation of contact force on the seat pan. They represent 48.1% of total number postural changes. These postural changes may not be of interest if postural changes due to sitting discomfort are supposed to relieve pressure of compressed body parts. By excluding the postural changes mainly implying feet movements, the numbers of postural changes for the configurations 5560 and 5580 were 82 and 86, well smaller than for Z300, which had 116 (Tab.1). When comparing six participant groups, MTH (male tall healthy) had the highest number of ICM with an average per trial of 7.42, followed by FSH (female short healthy), MTO (male tall obese).

Table 1. Numbers of postural changes and percentages by seat configuration and participant group. Postural changes mainly implying feet movements are excluded.

Configuration	*FSH (9*)*	*FSO (9)*	*MAH (9)*	*MAO (9)*	*MTH (12)*	*MTO (9)*	*Row Total (57)*
5560	23	6	10	8	18	17	82
	8.10%	2.11%	3.52%	2.82%	6.34%	5.99%	28.87%
5580	13	6	15	16	27	9	86
	4.58%	2.11%	5.28%	5.63%	9.51%	3.17%	30.28%
Z300	19	8	6	19	44	20	116
	6.69%	2.82%	2.11%	6.69%	15.49%	7.04%	40.85%
Column Total	55	20	31	43	89	46	284
	19.37%	7.04%	10.92%	15.14%	31.34%	16.20%	100.00%
Average per trial	6.11	2.22	3.44	4.78	7.42	5.11	4.98

** Number of trials*

4 Concluding remarks

In the present work, two new airplane seats with an optimized foam support were compared with an existing reference seat by 19 differently sized volunteers. Both subjective and objective measures were investigated. The two new seats exhibited smaller shear force and more uniformly distributed pressure on the seat pan, as expected. Interestingly, lower number of postural changes during a 50 minutes siting was also observed for the new seats, though no significant difference in global discomfort rating were observed between new and existing seats after a 50 minutes sitting. Objective measures tended to show that the optimally pre-shaped foam support (Wang and Beurier, 2018) and preferred seat profile (Wang et al. 2018) we obtained experimentally are useful for improving design. Further studies are needed to optimize foam characteristics (density, thickness etc) in combination with the proposed pre-shaped foam support. Sitting duration longer than 50 minutes is certainly necessary for assessing proposed new seats.

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Comfort voice instructions for MI-BCI rehabilitation

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Abstract

The quality of the voice instructions may influence the process as well as the outcomes of a Motor Imagery - Brain-Computer Interface (MI-BCI) based rehabilitation procedure. In this paper, three types of voice instructions, which utilize different types of background noise, were introduced to the MI-BCI rehabilitation and compared against the original synthesized voice instruction regarding the comfort experience of the user. An experiment was designed where 22 participants were invited. The Local Pressure Distribution (LPD) body map, the NASA Task Load Index (NASA-TLX) and the Positive And Negative Affect Schedule (PANAS) were utilized as subjective measures of the comfort experience of the subjects. Meanwhile, the Heart Rate Variation (HRV) and the skin conductance of the subjects were also recorded throughout the rehabilitation process as objective measures. Experiment results indicated that there were significant differences regarding the comfort experience among using different types of background noises in the voice instructions, where using the rain sound as the background noise provided a higher level of comfort based on the outcomes of the subjective and objective measures. Therefore, it can be recommended to the MI-BCI intervention.

Keywords：

MI-BCI, comfort, voice, background noise, rehabilitation

1. Introduction

An estimated 75% of people who have had a stroke will survive for at least a year [1]. Among the survivors, about one-third of them will have moderate to severe disabilities in the movement, the speech, the concentration, and/or the cognition [2]. These affects the activities of daily living (ADL) of the patients. With effective rehabilitation, most of these patients could (partially) regain their motor control and perform their ADL [3], which may significantly improve their Quality of Life (QoL) and reduce the burden of caregivers as well as the societal cost.

Among different rehabilitation methods, the brain-computer interface (BCI) based rehabilitation attracted attentions of many researchers in the past decade [4], mainly due to its effectiveness in precisely interpreting human brain signals. Via a BCI, physicians/researchers were able to acquire brain signals, analyze them, and translate the results to effective interventions [5]. For instance, based on the collected electroencephalography (EEG) signals, researchers is able to extract the event-related (de)synchronization (ERD/S) features [6] and associate them with motor execution (ME), motor imagery (MI), and/or motor observation (MO) functions. Here the ERD is a relative power decrease during ME/MI/MO, whereas the ERS is a relative power increase after the termination of ME/MI/MO [7]. Based on these two features, the ME/MI/MO of the patients can be detected in real-time. Interventions, e.g., assistive movements by the exoskeleton, can be deployed consequentially in order to help patients in the neurorehabilitation. Currently, BCIs were adopted in many rehabilitation/assistive devices, such as the exoskeleton[8], the powered-wheelchair [9] , and the P300-based speller [10].

Most of research on the BCI based re-habilitation focused on theoretical and technical aspects of the BCI, including the effects of vocabulary, data acquisition and signal processing [11][12], conceptual applications/novel prototypes [13][14], etc. While these topics are necessary to ensure the functions and the reliability of the BCI technology, few attention was paid on the ergonomics of using the BCI and the comfort experience of the user [15]. This is especially important that with the growing uses of the BCI equipment in research and applications, the number of users is continuously increasing. For instance, in a MI-BCI rehabilitation procedure [16], it was found that subjects often lost concentration, were frustrated or even dropped out of the sessions. Although the reason behind might be complicated, users did point out that in the process of using MI to trigger endogenous tasks, the sound of the synthesized voice instructions was one of the key reasons of the lower level of comfort.

Meanwhile, in different application fields, researchers [17] identified that listening to white noise may improve different aspects of the cognitive performance of healthy subjects. Evidence also indicated that using white noise can improve the task performance of subjects with attention deficits and/or Attention Deficit Hyperactivity Disorder (ADHD) [18]. However, most of these studies focused on physiological aspects of the subjects, the comfort experience of the subjects and the related physical, cognitive and emotional effects of using voice instructions with different background noise, especially in the MI-BCI intervention, was not discussed.

Aiming at improving the comfort experience of the users during the MI-BCI based rehabilitation, this paper explores the effects of using voice instructions with different background noise, i.e., the white noise, the rain sound, the sinusoidal pure tone and no background noise, in the rehabilitation process. The major scientific contributions of this paper are that: 1) we identified that using rain sound as the background noise of voice instructions improved the comfort level of the users, therefore it can be recommended to the MI-BCI intervention and 2) through objective and subjective measures, we discovered that besides physical and cognitive aspects, emotion also played an important part of the comfort experience of participants.

2. Materials & Methods

2.1 Participants

The experiment was conducted in the EEG laboratory, School of Academy of Medical Engineering and Translational Medicine, Tianjin University, China. Prior to the experiment, the content and the protocol of the experiment were approved by the Medical Ethics Committee of Tianjin People's Hospital in accordance with the Helsinki Declaration. Twenty-two healthy subjects (14 males and 8 females, mean age 24.4±3.35) participated in the experiments with remuneration. Informed consent was obtained from each participant before the experiment.

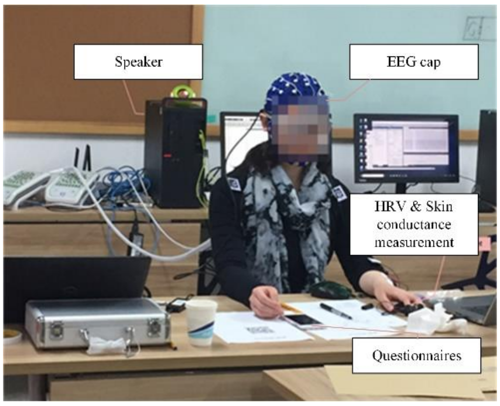

Fig.1. The setup of the experiment, photo was taken by the camera in front of the user

2.2 Materials

An EEG cap with 64 active electrodes (Brand: NeuroSky) was prepared for simulating the clinical setup. A Heart Rate variability (HRV) and skin conductance recorder (Brand: Ergolab) were prepared for measuring the HRV and the skin conductance of each participant, respectively. For recording the scenario, a camera was setup in front of the user. Four types of voice instructions were prepared as: 1) using synthesized voice instructions only, 2) using standard white noise as the background of the synthesized voice instructions, 3) using rain sound as the background of the synthesized voice instructions, and 4) using sinusoidal pure tone as the background of the synthesized voice instructions. In all types of voice instructions, the amplitude of the synthesized voice instructions was adjusted to 70 db where the background (if any) was adjusted to 50 db. Those instructions were played by a speaker which was installed 1.5 meters behind the user.

A set of questionnaires was prepared for measuring the subjective opinions regarding different setups. They include: the Comfort/Discomfort questionnaires (2 questions) [19], the Localised Postural Discomfort (LPD) body map (20 questions) [20][21], the NASA Task Load Index (NASA-TLX, 6 questions) [22][23], the Positive And Negative Affect Schedule (PANAS, 20 questions) [24]. Among those questionnaires, users were able to fill in the NASA-TLX, PANAS, Comfort/Discomfort Scales, and the self-designed questionnaire (in total 28 questions) using a mobile device. The LPD (20 questions) was prepared on paper due to its graphical nature. Figure 1 presents the setup of the experiment.

2.3 Protocols

Before the experiment, each participant received a short instruction about: 1) the purpose of the experiment; 2) the specific MI activities (right-hand grip and relaxation), 3) materials will be used in the experiment and 4) the protocol of the experiment. Then the participant was invited to sit at the designated position. The EEG cap was worn with the help of the researcher(s) to simulate the actual procedure. At the same time, Ergolab physiological measurement equipment was attached to the left hand of the researcher for recording the HRV and the skin conductance of the subject.

During the experiment, the voice instructions were given by a speaker, and its position was fixed regarding the subject. Following the instructions, participants were required to complete four sets of rehabilitation training sessions, each 10 minutes. During each session, a specific type of voice instructions was used to guide the subject to perform MI. The sequence of using different types of voice instructions was randomized regarding each participant. At the end of each session, the questionnaires were filled to evaluate the perceived comfort/discomfort, workload and emotion effect. The complete experiment lasted about 50 minutes for each subject.

2.4 Data analysis

Prior to the data analysis, all collected subjective data was preprocessed regarding each subject where the minmax scaler was used to normalize all data to the span from 0 to 1, e.g., for the question “comfort level”, 0 is the minimal level of comfort and 1 is the maximal. The student t-test was used to identify the difference between two sets of data. Besides, the swarm plot was introduced as an add-on of the box plot for a better visualization of the distribution of the data.

3. Experiment results

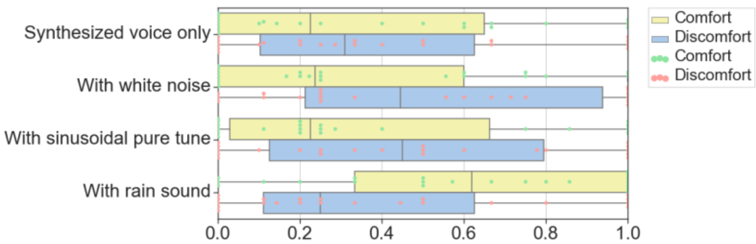

Fig.2: Comfort/discomfort regarding the four types of voice instructions (horizonal axis: the levels of comfort/discomfort, 1 = high comfort/discomfort regarding the two measures, respectively)

3.1 The results of comfort/discomfort questionnaire

The normalized results of the comfort/discomfort questionnaire regarding four types of voice instructions are presented in Fig.2, which is a combination of a box plot and a swarm plot. In the figure, yellow stands for the value of the level of comfort and blue stands for discomfort. It can be observed that *with rain sound as background* (mean =0.59, STD = 0.37) performs significant better (p=0.012) than using *synthesized voice only* (mean=0.37, STD=0.37) regarding comfort. In other two options, the means of both had slightly difference than *synthesized voice only* (*with white noise as background*: mean = 0.35, STD = 0.35; *with white noise as background*: mean =0.36, STD = 0.38), however, not statistically significant. Regarding discomfort, the mean and the standard deviation of the four setups are: 0.39±0.36 (synthesized voice only), 0.50±0.38 (with white noise), 0.46±0.38 (with white noise) and 0.38±0.37 (with rain sound). Though *with rain sound* performed slightly better (scores lower), it was not statistically significant.

3.2 The results of the LPD body map & NASA questionnaire

Figure 3 and 4 presents the results of the LPD body map and the NASA TLX, respectively. It can be found that participants rated similar results regarding the four types of voice instructions, which indicated the physically and cognitively, there was no significant difference among the uses of four types of voices instructions.

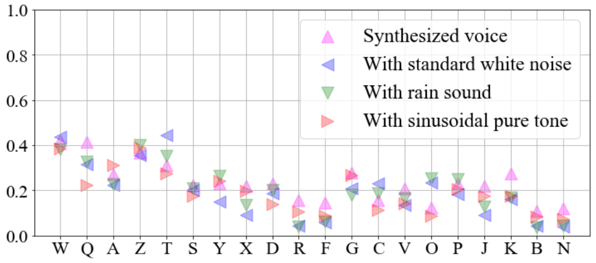

Fig.3. The scores of LPD regarding the uses of four types of voice instructions (vertical axis: discomfort, 0 = minimal level, 1 = maximal level, horizonal axis definitions can be found in [20], except W = head)

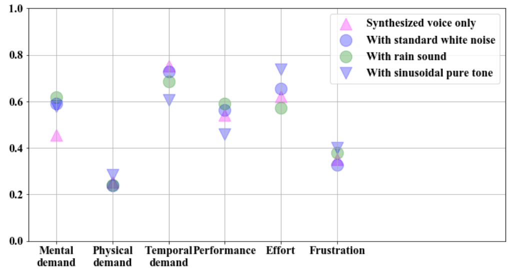

Fig.4. The scores of NASA_TLX regarding the uses of four types of voice instructions (vertical axis: the normalized scores, 1 = maximal and 0 = minimal)

3.3 The results of the PANAS questionnaire

Table 1 lists the results of the PANAS questionnaire. Analysis of results indicates that *with rain sound* stimulated the users' positive emotions, followed by *with sinusoidal pure tone*, *with standard white noise*, and the *synthesized voice only* was ranked last. On the other hand, the negative sentiment caused by *with sinusoidal pure tone* was higher, followed by *with rain sound*, *with standard white noise* and *synthesized voice only*.

Table 1: The results of the PANAS questionnaire

	Positive emotion	*STD*	*Negative emotion*	*STD*
Synthesized voice only	15.5	5.3	16.2	6.9
With standard white noise	15.9	4.1	16.6	8.0
With rain sound	16.3	4.9	17.1	8.6
With sinusoidal pure tone	15.9	4.9	21.1	11.0

3.5 Effects on the HRV index and skin conductivity

Four different voice instructions had different effects on the subjects' HRV data (as in Table 2), which can be observed by the differences in the SDNN (Standard Deviation of the Normal, Normal (R-R) intervals), RMSSD (Root mean square of the successive differences), and PNN50 (Proportion of NN50 divided by the total number of normal to normal (R-R) intervals), respectively. The results show that regarding SDNN and RMSSD, *with rain sound* scored higher than the rest three. *With standard white noise* scored highest on PNN50, but it was not statistically significant. *With sinusoidal pure tone* was lowest on SDNN and RMSSD, but slightly better regarding PNN50. Regarding the skin conductance, *with rain sound* performed the best with the lowest skin conductance, followed by *with standard white noise*, *with sinusoidal pure tone* and *synthesized voice only*.

Table 2: The mean HRV of using four different types of voice instructions

	SDNN (ms)	*RMSSD (ms)*	*PNN50(%)*
Synthesized voice only	133.80	167.04	26.67
With standard white noise	156.96	188.43	29.62
With rain sound	167.63	192.03	29.15
With sinusoidal pure tone	133.70	150.86	29.4

Table 3: The skin conductance of using four different types of voice instructions

	Mean (μS)	*Max (μS)*	*Min (μS)*
Synthesized voice only	1.93	2.67	1.55
With standard white noise	1.82	2.45	1.47
With rain sound	1.58	2.40	1.18
With sinusoidal pure tone	1.70	2.44	1.36

4. Discussions

4.1 Comfort/discomfort experience

Vink and Hallbeck [19] defined comfort as "*a pleasant state or relaxed feeling of a human being in reaction to its environment*" and discomfort as "*an unpleasant state of the human body in reaction to its physical environment*". They also indicated that comfort consists of more factors than discomfort, which is mainly caused by physical interactions. The discovery in this paper is in accordance with this conclusion. With nearly the same level of discomfort regarding different parts of the body (results of LPD body map), *using the rain sound as the background noise of voice instructions* had significant positive results regarding the comfort experience of the user, which is also reflected in the subjective measure (PANAS) and objective measures, e.g., the HRV and the skin conductance.

4.2 HRV & comfort

Previous studies had indicated that the HRV could be an objective measure for assessing emotional responses [25][26][27] as the HRV index has significant correlations with happiness and sadness [28]. Experiment results suggested that *using the rain sound as the background noise of voice instructions* appeased the users and triggered their positive emotions during the experiment. On the other side, *Using the sinusoidal pure tone as the background noise of voice instructions* brought sadness, impatience and other negative emotions to the subject, therefore it was the least preferred choice.

4.3 Skin conductance & comfort

The skin has electrical properties and it is able quickly change in the level of seconds. Meanwhile, studies have shown that those changes, e.g., the changes of the skin conductance, are closely related to psychological processes. Research had indicated that the fluctuations of the skin conductance have strong relations to the stress level of the subject [29]. Based on the measurement results of the skin conductance in the experiment, it can be seen that among the four types of voice instructions, *using the standard white noise as the background noise of voice instructions* led to the lowest mean skin conductance, which can be interpreted as that the subjects were more relaxed. And for *synthesized voice only*, subjects were relatively more nervous.

4.4 Limitations

Wearing an EEG cap with 64 active electrodes in this experiment was only used as a simulation. The sizes of the cap were limited, and each participant may have different comfort experience regarding the selected size. The HRV and skin conduction measurement devices were attached to the left hand of the subject, which may also influence the level of comfort of the subjects in the experiment. Due to time constraints, we only selected the standard white noise, the rain sound and the sinusoidal pure tone as the background noise. Using other natural noise, e.g., pink noise [30], as the background can be explored as well.

5. Conclusions

A comfortable rehabilitation experience may help the patients overcome of the long and tedious procedure to achieve a better clinical outcome. In this paper, using four types of voice instructions, named *Synthesized voice only*, *Synthesized voice with standard white noise as the background noise*, *Synthesized voice with rain sound as the background noise*, *Synthesized voice with sinusoidal pure tone as the background noise*, we simulated the MI-BCI based rehabilitation procedure and measured the overall comfort/discomfort experience, the discomfort of each part of the body, the cognitive workloads, the emotion, the HRV and the skin conductance of each participant. Subjective and objective measures indicated that in this context, there were significant difference regarding the comfort experience of the participants, which was mainly caused by the emotion. This discovery highlights the importance of the emotion aspect in the comfort experience and based on experiment results, the voice instruction which utilizes *Synthesized voice with rain sound as the background* is recommended to the MI-BCI procedure, as it is able to appease the users and trigger their positive emotions during the procedure.

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Comfort Rating for Upholstery Systems

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Abstract Nowadays long-distance drives or sitting workplaces are normal. As consequence a human sit up to 7.5 h per day. Therefore, the comfort while seating is getting more and more important. The comfort of upholstery systems such as car seats, office chairs or upholstered furniture is influenced by different ergonomic properties in particular the thermophysiological comfort.

On one hand, the thermophysiological comfort of an upholstery system can be characterized by Hohenstein Skin Model (sweating guarded hot plate) according to ISO 11092(1). With the Skin Model the specific thermophysiological quantities of textiles as layers are determined. Under stationary measurement of the Skin Model the water vapor resistance R_{et} is determined, which characterizes the insensible sweating. Higher sweating rates (sensible sweating) can be described by buffering capacity of water vapor F_d and buffering capacity of liquid sweat K_f(2, 3). In the next step a sitting human can be simulated by the sweating buttocks model or thermal, sweating manikin "Sherlock" (Newton type by Thermetrics). By combining these measurement systems with humidity sensors within in the upholstery the moisture management of an upholstery system can be determined.

On the other hand, the contact area of the human on the seat and pressure distribution on the seat are important aspects which influenced the ergonomic comfort of upholstery systems, too. The pressure distribution of a sitting person can be qualified by measurements with a pressure pad. Handheld scanner systems like Artec Eva, Creaform Revscan and or low-cost devices as the Kinect sensor offer the opportunity to scan objects like seats. The three-dimensional information of seats, chairs or furniture can be compared with 3D data of target groups. As a result, the contact area can be identified in regard of size and shape.

Keywords: seat comfort, comfort, 3D scanning, pressure pad, clothing physiology

1 Introduction

Comfort is not uniformly defined. From physiological point of view, comfort is a multidimensional concept influenced by several factors e.g. physical, physiological, psychological and environmental aspects. One theory says that comfort is the absence unpleasant feeling (discomfort)(4).

Nowadays the comfort while sitting is getting more and more important. Depending on the clothing the human body is in direct contact with the upholstery system e.g. vehicle seat, office chair, couch. More precisely shoulders, back, buttocks, thighs and lower legs have contact areas with such an upholstery system. Further long-distance drives or sitting workplaces are getting normal. As consequence a human sit up to 7.5 h per day(5). Hence, the comfort of upholstery systems is important. For the comfort characterisation of upholstery systems while sitting different aspects should be considered: sensorial, thermophysiological and ergonomic comfort.

2 Methods und Discussion

2.1 Sensorial comfort characteristics

The sensorial comfort characteristics are mainly determined by the textile's surface structure, which can be characterized by specific quantities.

If a fabric is clinging on moist skin, this is felt as uncomfortable by the wearer. The intensity of "wet cling" on the skin can be expressed by a **wet cling index i_K**. For measurements a special apparatus mainly consisting of a sintered glass plate is used, which in its surface roughness equals human skin. The porous surface of the sintered glass plate is moistened with distilled water. The force, which is necessary to draw the sample horizontally across the sintered glass plate describes the wet cling index i_K(6). The lower values, the less uncomfortable wet cling is felt. Particularly i_K should be below 15.

Under heavy sweating a textile worn next to the skin is felt the more comfortable, the faster liquid sweat is transported away from the skin. This sorption speed can be determined of a water drop of defined size falling above the sample onto the fabric's inner surface. By measuring the contact angle of the water drop the time lapse can be extrapolated, after which the water drop has been completely absorbed by the sample. This time lapse yields the **sorption index $i_{B(7)}$**. About its sensorial comfort a fabric must be judged the better, the smaller i_B. Particularly i_B should be below 270.

On one hand a textile is felt as too smooth on the skin on the other hand as too rough or scratchy. This characteristic is given by the **surface index i_o**. Therefore, the number and length of the fiber ends protruding from the fabric's bulk is measured(8). Regarding sensorial comfort a fabric must be judged as good if the surface index i_o lies between 3 and 15.

A fabric is felt less sticky to the skin, the smaller its contact area with the skin. This contact area is mainly determined by the fabric's surface structure, particularly by the distant keeping fiber ends protruding from the fabric's bulk. Quantitatively a fabric's contact area with the skin can be expressed by the **number of contact points n_K**. This number is determined optically with a topograph, which gives a 3-dimensional picture of the textile surface(9). A fabric is less sticky, the smaller the number of contact points n_K. Particularly n_K should be below 1500.

The **stiffness s** of a fabric can be expressed by the bending angle against the perpendicular direction of a fabric sample(10). The stiffness s describes, whether a fabric is felt as comfortable or as too flabby or too stiff. By this definition s can assume values between 0 (completely flabby) and 90 (completely rigid). In order to yield good sensorial comfort for sportswear fabrics s should lie between 5 and 27.

2.2 Thermophysiological comfort characteristics

Skin Model

The thermoregulatory model of human skin (Skin Model) simulates the dry as well as the sweating human skin. With the Skin Model the specific thermophysiological quantities of textiles as layers, relevant to physiological comfort, can be determined. So, the thermophysiological comfort can be characterized. Under "normal" or "stationary" conditions the moisture flux from the skin appears as water vapor (insensitive sweating). In this stationary case the water vapor resistance R_{et} including short-time water vapor absorbency F_i can be measured according ISO 11092(1). Further the thermal resistance (thermal insulation) R_{ct} is determined under these stationary conditions. In general upholstery systems more specifically their material combinations are rated the better, the lower water vapor resistance R_{et} and higher the short-time water vapor absorbency F_i.

For the clothing physiological properties of textiles not only their stationary thermo-physiological properties are important but also the capacity to buffer sweat pulses which are occurring quite frequently in the practical use of textiles and clothing. Concerning the buffering capacity, it must be distinguished between two mechanisms:

Buffering capacity of water vapor (moisture regulation index F_d): This measurement describes the wear condition where the wearer is already sensibly sweating, but the sweat is still evaporating within the channels of the skin's sweat glands. In the clothes' microclimate an increased water vapor pressure is occurring but still no liquid sweat(2).

With the buffering capacity of liquid sweat (buffering index K_f) a wear condition is comprehended where the wearer is sweating so heavily that there is liquid sweat on his skin(3).

Like the stationary wear conditions, also the instationary conditions can be simulated with the Skin Model. A description of the test procedures is given in the Standard-Test Specification BPI 1.2(2, 3). Therefore, higher sweating rates while sitting during a long-term drive can be described by F_d- and K_f-value. Both thermophysiological characteristics must be rated better with higher values.

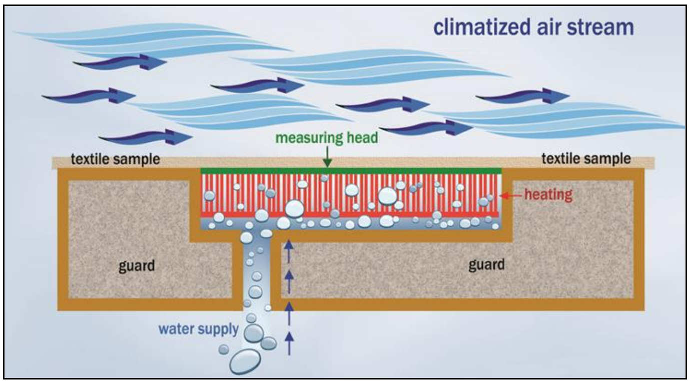

Fig. 1. Schematic structure of the sweating guarded hot plate (Skin Model).

Sweating buttocks

Measurements with the Sweating Buttocks Model (Institut für Holztechnologie Dresden gGmbH) or Seat Test Automotive Manikin (Thermetrics) determine sweat management (moisture accumulation, moisture transport, moisture degradation) of 3-dimensional cushion compositions following real conditions (Fig. 2). Thus, a deeper understanding of the thermophysiological comfort of upholstery systems can be gained.

The Sweating Buttocks Model is placed on the sample with a load of 400 N, which simulates an adult standard man. Further sweating while sitting can be simulated by the Sweating Buttocks Model. There are combined temperature and moisture sensors built-in the measuring head of the Sweating Buttocks Model. These sensors detect the temperature and moisture within the microclimate between Sweating Buttocks Model and cover of the upholstery system. By adding combined temperature and humidity sensors into the material combination of the upholstery system, additional information about the heat and moisture distribution can be obtained.

During the measurement the initial heat flux H_{ci} is detected. It represents the situation of a person sitting on a cold or hot upholstery system compared to skin temperature. In the moment of contact the maximum heat flux $H_{ci\ max}$ from the human body to the cold upholstery or from the hot upholster to the human body (negative values) take place. For a good thermophysiological comfort the amount of $H_{ci\ max}$ should be less than 85 W/m². So, there is no uncomfortable fleeing during the first contact with the upholstery and the upholstery is perceived as hot or cold. A comfortable feeling results with $H_{ci\ max}$ < 64 W/m ². Further the time span for aligning the skin temperature and the temperature of the upholstery should the short. Th initial initial heat flux H_{ci} is mainly influenced by the cover material of the material composition.

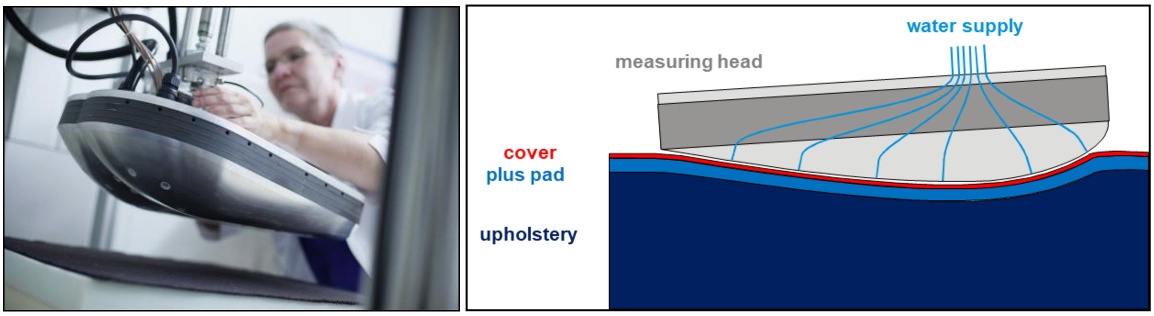

Fig. 2. Sweating Buttocks Model in climatic chamber (left), anatomically shaped measuring head on cushion composition (right).

Thermal, sweating Manikin

For measurements of complete ready-made clothing systems or upholstery systems thermal, sweating manikins were developed since 1980s. Thus, heat and moisture management of a human body can be simulated while taking the shape of the human into regard. In comparison to the thermal, sweating body segments (e.g. Sweating Buttocks) the manikins are highly variable in use.

The thermal resistance R_c and water vapor resistance R_e measurements of ready-made systems can be performed with thermal, sweating manikins. The thermal, sweating manikins Newton and Andy by Thermetrics are the only commercially available sweating manikins (11). Newton is available with 20, 26, 34 or 35 independent thermal and sweating segments. A skin-tight sweat suit distributes the water homogeneously over the manikin's surface. Newton has a wide range of body motions e.g. running, sitting, lying (Fig. 3).

In general, thermal resistance measurements R_c are carried out under non-isothermal conditions and water vapor measurements R_e under isothermal conditions. The measurement of water vapor resistance R_e with a thermal, sweating manikin is standardized in the ASTM F2370(12). Further an ISO standard is in process(13). For calculating the thermal and water vapor resistance for more than one segment there are different calculation models available: the parallel, the serial and the global calculation model.[88] The results of the different calculation models differ significantly for a given clothing system(14). In general, the standards contain an indication which of these models is to be used for the specific application.

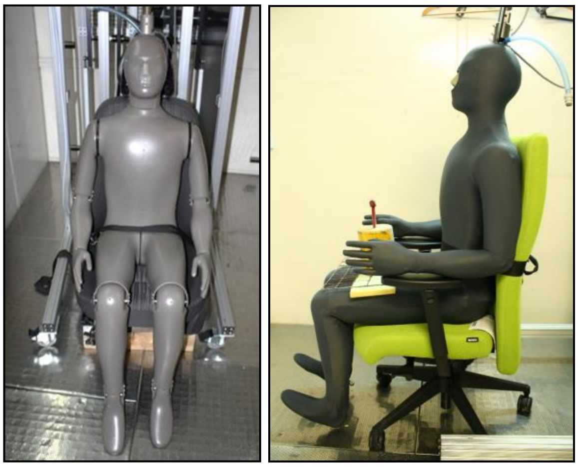

Fig. 3. Thermal, sweating Manikin Sherlock (Newton type, Thermetrics) in sitting position.

2.3 Ergonomic comfort characteristics

Pressure pad

Dealing with the comfort while sitting the ergonomic comfort is important, too. Therefore, the contact area between human and seat as well as the pressure distribution on the seat should be investigated. The pressure distribution of a sitting person can be qualified by measurements with a pressure pad. Fig. 4 shows for example the pressure distribution of a sitting person on a car seat. Further this measurement provides information about the contact area between human and upholstery system.

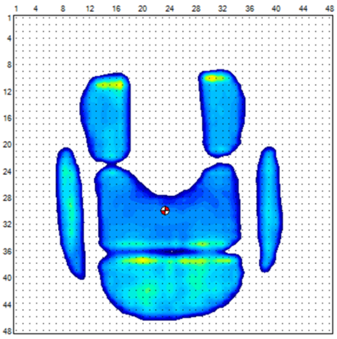

Fig. 4. Pressure distribution and contact surface of a human sitting on a car seat.

3D-Scanning

In fields like automotive it is common practice to analyse seating situations with 3D simulation software for many years(15-17). These tools enable to simulate realistic positions of seat users with the aim to improve safety, efficiency and comfort. Performing human-centered design is based on virtualized human bodies and products. On the one hand digital human models are created by adapting existing manikins in regard of body measurements via parameter setting. Similarly, products are developed and moulded in CAD software. On the other hand, test persons or products are 3D scanned with full body or handheld scanner systems like Artec Eva, Creaform Revscan and or low-cost devices as the Kinect sensor. The three-dimensional information of seats, chairs or furniture can be compared with 3D data of target groups. Amongst other issues the following points can be analyzed:

- Is the seating surface long and wide enough?
- Is the backrest high and wide enough?
- How does the contact area look like in regard of size and shape?
- Are adjustment handles ease to reach?
- Are adjustments efficient?

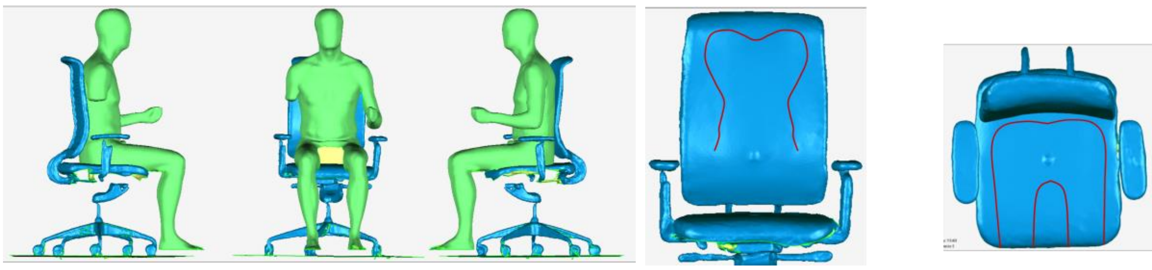

Fig. 5. Comparing individual 3D body scan with office chair.

To perform these analysis, real person's body scans give many advantages. The body forms are realistic. Parametric models tend to look not like real human beings. Although simulation software improved enormously, there are still problems with the visualization of the body surface due to movement. The research in the field of scanning in motion (4D scanning) and capturing human bodies in different postures will lead steadily to enhanced performance of simulation software(18-20). Furthermore, creating a data pool of full body scans in different positions combined with socio-demographic questions allows to choose focused target pool representatives (factory or office workers, specific age groups or BMI cluster etc.). Or, in a next step calculate average manikins with not only average body measurements but as well average body geometry and posture.

3 Conclusion

In conclusion it can be stated that the comfort while sitting is important. It is possible the characterise different aspects of upholstery systems.

The sensorial comfort describes mainly the textile surface structure of the face fabric by five specific quantities: wet cling index i_K, sorption index i_B, surface index i_O, number of contact points n_K and stiffness s.

The thermophysiological comfort can be described by measurements with the thermoregulatory model of the human skin – Skin Model for short. It can simulate the human dry as well as the sweating skin. Under stationary measurements thermal resistance R_{ct} and water vapour resistance R_{et} are determined. For the clothing physiological properties of textiles next to the skin not only their stationary thermophysiological properties are important but also the capacity to buffer sweat pulses which are occurring quite frequently in the practical use of textiles and clothing. Concerning the buffering capacity, it must be distinguished between two mechanisms: Buffering capacity of water vapour F_d and buffering capacity of liquid sweat K_f. A deeper understanding of the thermophysiological comfort of upholstery systems can be gained by measurements with three dimensional systems such as the Sweating Buttocks Model or thermal, sweating manikins.

The ergonomic comfort can by characterized by pressure pads, which determine the contact area between human and seat as well as the pressure distribution. Further the seating situations can be described with 3D simulation software. These tools can simulate realistic positions of seat users with the aim to improve safety, efficiency and comfort.

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Identifying Aircraft Passenger Postures and Factors Influencing Body Part Discomfort

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Abstract Aircraft passengers' physical activity levels are often limited during flight for extended periods of time, which can have serious impact on health, comfort, and passenger experience. Passengers are generally advised to walk around the plane and do certain exercises, especially in mid- to long-haul flights, to increase blood flow and reduce discomfort. However, several factors, such as limited personal space and social factors, can make doing these exercises difficult.

In this paper, we introduce sources of discomfort that passengers face in medium to long-haul flights as identified during a simulated flight study. Participant behaviour and postures identified in the study as contributing to participants' reports of discomfort and pain will be described. Twenty-nine participants sat in an aircraft simulated cabin for 180 minutes and periodically performed in-seat exercises. During the trial, they completed a questionnaire every twenty minutes. The questionnaire collected data on demographic information, self-reported discomfort scores for multiple areas of the body, which types of exercises participants performed, and qualitative comments about discomfort. Participants were photographed and video recorded in order to evaluate their postures, movement direction, and other behavioural and physical sources of discomfort. A body mapping analysis was used to identify which parts of the body experienced discomfort in terms of frequency and severity. Body part areas identified as receiving highest scores of discomfort ratings were: back of the neck, back-left shoulder, back-right shoulder, back-left buttock, and back lower back. This work will be used to understand the design of immersive technology intervention for encouraging passengers to engage in physical activity during flights.

Keywords: Passenger Experience, Comfort, Body Part Discomfort, Data visualization.

1 Introduction

Due to increasing amounts of air travel, developing new ways to improve passenger comfort in restricted physical spaces is crucial for aircraft manufacturers and airline companies (Vink, 2011). Furthermore, aircraft passenger comfort is an important factor in passenger's acceptance of the transportation system and therefore, their tendency to choose a flight with the airline again (Jacobson, 2007). Comfort level has also been closely associated with passenger health during flight, with constrained cabin seating spaces being linked both to discomfort and negative health outcomes such as deep vein thrombosis (Brundrett, 2001). In order to reduce health risks during flight and to improve comfort, passengers are often advised to walk around the plane and do exercises to increase blood flow (Budd et al., 2011).

Comfort and discomfort have been investigated in several studies in the context of air travel (Ahmadpour, 2017). Vink (2011) defined the concept in relation to three conditions of comfort: DISCOMFORT in which participants experience discomfort; NO DISCOMFORT in which participants experience no discomfort; and COMFORT in which participants experience outstandingly more comfort than expected. There are many factors which might affect passenger comfort and discomfort, including physical, psychological, object, environmental and contextual factors (Menegon et al., 2017). The passenger interaction with the aircraft environment can be associated with high levels of comfort but it can also generate discomfort which is typically associated with pain (Menegon et al., 2016).

Advances in digital technology, such as systems involving virtual reality, offer potential benefits to improving passenger comfort in flight, but in order to design systems that leverage these benefits, a greater understanding of the experience of physical discomfort in flight is needed. Previous work has indicated that virtual and interior spaces may help to evoke the illusion of increased space, and as a result, the level of comfort may increase (Aaltonen et al., 2014). Virtual reality technologies has been used to create environments which distract participants from their main source of discomfort by displacing them from the real-world environment and into a novel context, for instance, a flying carpet ride (D'Cruz et al., 2014).

This paper presents the findings from a study in which participants were asked to perform exercises at regular intervals during a 3-hour flight simulation, with specific focus on which exercises passengers tended to do most, what difficulties they faced while doing these exercises, and reported levels of discomfort in different body areas.

2 Method

In this section, participants, study materials and procedure will be explained.

2.1 Participants

29 participants (18 male, 11 female) from the University of Nottingham community took part in the study. The participants' mean age was 27.58 years and the standard deviation was 8.64. Participants were asked to choose their seat, remain in the same seat for entire study which was three hours representing medium haul flights, complete the questionnaire every twenty minutes and perform in flight exercises periodically. Ethical approval for the study was granted by the University of Nottingham Faculty Of Engineering Ethics Committee.

2.2 Study Materials

The study took place in a controlled laboratory setting. Participants were allowed to choose their seats during the study but they were not permitted to change the selected seat until the end of study.

Six seats were employed for this study. On each row, three seats were available. Configuration of the seats was arranged as shown in figure 1. Two cameras were mounted in the study laboratory to observe the participants. One of them was located on the right and front side of the seats and the other was located on left side to have a complete view of all participants. The researcher carried out limited observations during the study from behind. Based on Kim et al. (2016) the seat pitch for this study was set as a typical seat pitch in economy seats of 31 inches, where seat pitch is the distance between a point on one seat and the same point on the seat in front.

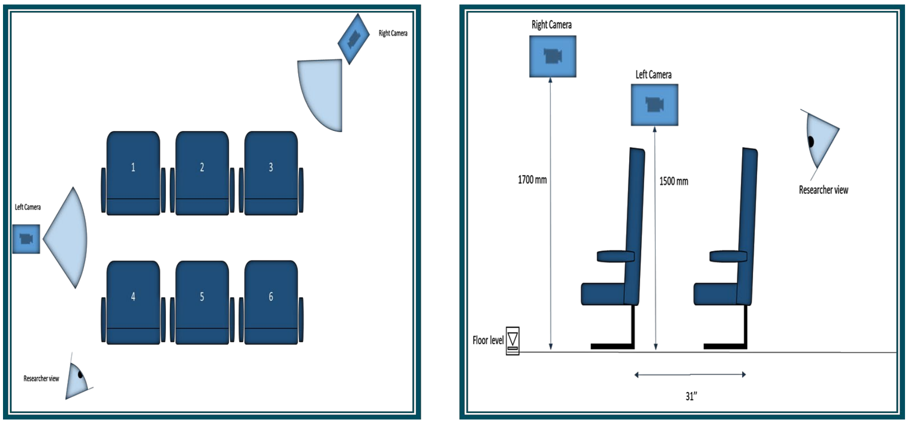

Fig. 1. Plan view and side view

2.3 Procedure

The study took place over the course of three hours, during the majority of which participants remained seated. They were asked to complete the questionnaire at the beginning of the study and every 20 minutes during the 3-hour period. Before the start or at the end of the study, the following anthropometric measurements were taken for each participant: height, lower leg length, upper leg length, shoulder breadth, hip breadth and sitting eye/head height. Height measurements were taken with them wearing their shoes using a stadiometer. All other measurements were taken in a seated position, with them wearing the clothes they arrive in (coat removed) using an anthropometer, board and tape measure. During the study, researchers observed their seated postures and recorded their general activities (e.g. reading, listening to music, sleeping). If they left their seats, a researcher made a note of the time they got up and the time that they return to their seat and what they did while they were away from their seat.

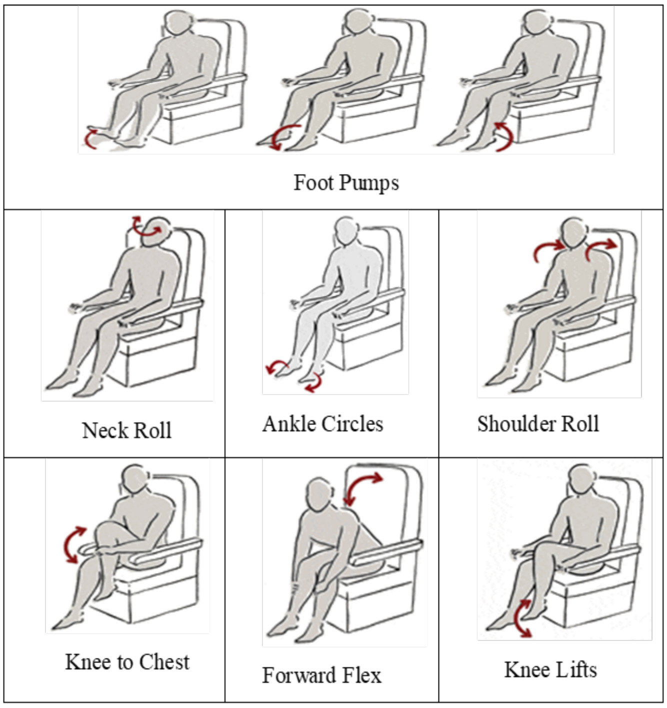

Fig. 2. In-flight exercises (Qantas The Australian Way Magazine, n.d.)

Videos were used to analyse data such as the postures participants adopted during different activities or at different times. Participants were provided with guidance on seated exercises recommended for in-flight use and were asked to select and perform these exercises during the course of the study as many as they like, as shown in Figure 2.

The main data collected during the study were measurement of relevant anthropometric dimensions of participants, user choice of seating position, periodic ratings of comfort and discomfort, frequency of doing in-flight exercises and qualitative feedback on aspects of discomfort.

3 Results

The results of the study will be discussed in the following parts.

3.1 Anthropometric measurement

In order to evaluate the sample's representativeness, data collection involved collecting details of relevant body dimensions in standing and seated positions. Seated measures were taken with the participants sitting on a chair. The participants were measured without their outerwear such as coats and jackets. The main measures included standing height, sitting height, shoulder breadth, hip breadth, upper leg length, lower leg length. Table 1 shows what percentiles the participants represented in alignment with the broader population. As shown in Table 1, the sample was representative of the broader population.

Table 2. Anthropometric data representing 5th and 95th percentile values obtained from the participant sample, compared with respective population values in centimetres (Norris. et al., 1998)

		Male				*Female*			
		5% sample	*5% population*	*95% sample*	*95% population*	*5% sample*	*5% population*	*95 % sample*	*95% population*
Standing Height		169.925	164.69	187.865	186.65	155. 75	152.78	178.35	173.73
Sitting Height		54.26	85.45	91.30	97.19	75.75	79.53	88.00	91.02
Shoulder Breadth		41.91	47.740	53.345	62.06	36.5	41.47	43.90	52.84
Up per leg length	But- tock to front of knee	53.28	56.90	64.145	66.47	50.00	54.21	61.00	63.98
	But- tock to back of knee	42.895	54.55	52.625	45.81	42	44.00	50.75	52.77
Lo wer leg Length	Pop- liteal height	52.685	39.46	61.63	47.63	51. 50	35.13	59.55	42.94
	Top of knee height	41.17	51.44	47.235	61.57	43.00	47.40	54.00	56.02
Hip Breath		32.75	30.97	44.445	37.65	32.8	30.78	42.4	38.15

3.1 Most frequent exercises

The number of times each exercise was performed during the study by all the participants is shown in Figure 3; this was collected via the routine questionnaire. Analysis revealed that the most frequent in-flight exercises were foot pumps and neck roll manoeuvres.

Participants indicated in open-ended responses that lack of physical space prevented them from doing several of the exercises. As Figure 3 demonstrates, participants more frequently did the exercises which required less physical space. Comparison to anthropometric measurements indicated that especially tall participants and those who were sitting in the middle seat may have also performed these space-constrained exercises more frequently.

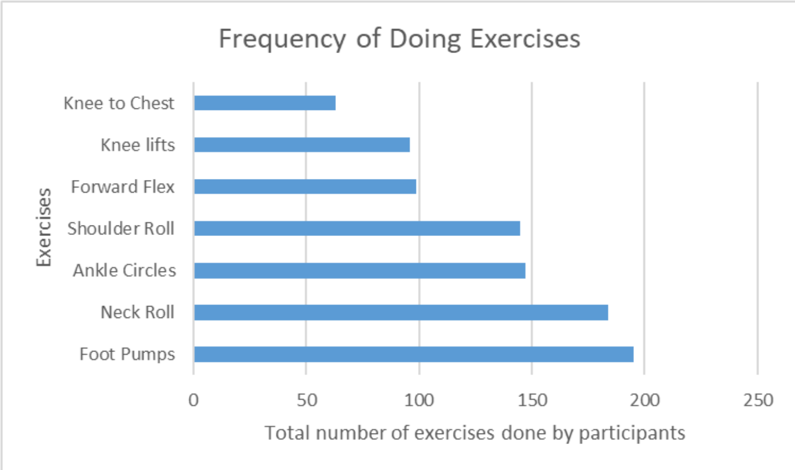

Fig. 3. Most frequent exercises

3.2 Participants' overall levels of comfort

Ratings were collected at 20 minutes intervals during the study, using the following question: How satisfied are you with your current level of comfort? Participants were asked to rate this on a 1-9 scale where 1 was extremely dissatisfied and 9 was extremely satisfied. Mean recorded comfort rating over time is illustrated in Figure 4.

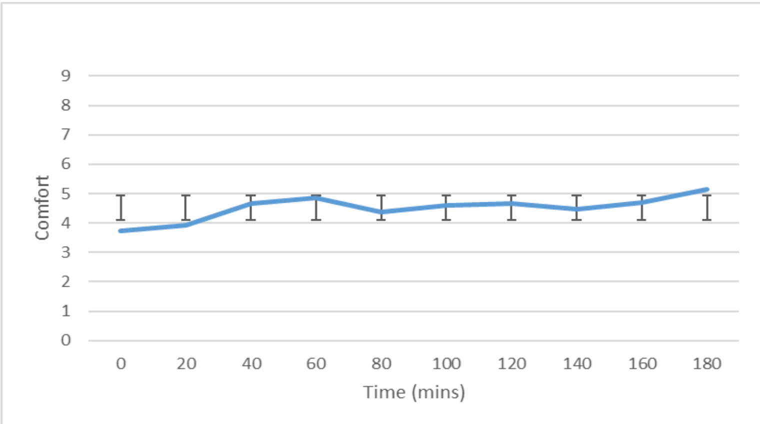

Fig. 4. Participants' mean comfort rating (error bars = 1SD)

3.3 Body Map Analysis

Participants were asked to indicate their discomfort in different body parts every twenty minutes. During the study, each participant gave the rating of 0 to 9 in which 1 referred to slight discomfort, 9 referred to extreme discomfort, and 0 indicated that the participant did not experience discomfort in that body part. Representation of the data was made using a heat map visualization method (Fisher & Marean, 2017).

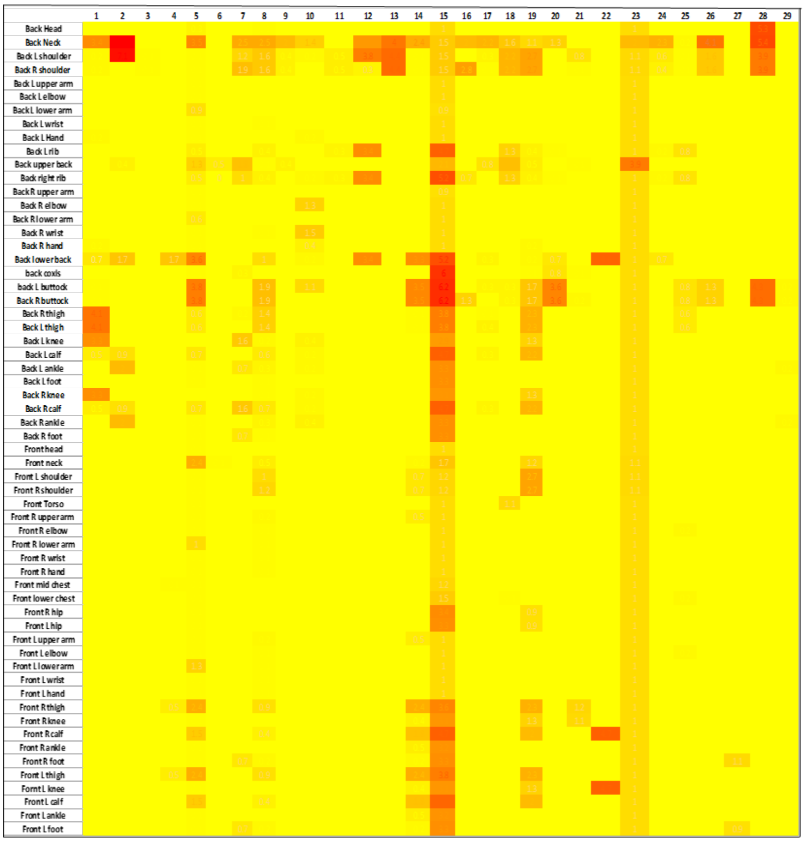

Fig. 5. Overall Heat Map visualization

Figure 5 shows the data for all participant self-reported discomfort ratings over the three hour period, calculated by the mean rating per participant and body part. In this heat map, the colour key is indicated with yellow as 0, the lowest rating and red as 9, the highest rating in the heat map. It can be interpreted from the overall heat map that the darker colour is mostly located on the back part side of the body, such as the back of the neck, the back-left shoulder, the back-right shoulder, the back-left buttock, the back-right buttock and the lower back.

The heat map analysis indicates that although there were individual differences in participant experiences during the study, several body parts were commonly associated with discomfort. After analysing the data the six body parts that were associated with discomfort were identified. These body parts discomfort consist of the back of the neck, the back-left shoulder, the back-right shoulder, the back-left buttock, the back-right buttock and the lower back.

4 Discussion

In this study, we aimed to explore the association among passengers' comfort levels, the body parts affected by discomfort during a simulated medium haul flight, and the range of exercises which passengers performed. Passengers most frequently performed exercises which were easy to achieve in the confined space, and subjective feedback indicated that reasons for not engaging in movement included limited space and embarrassment, a finding that aligns with previous research (Aaltonen et al., 2014). Among the recommended inflight exercises, foot pumps, neck rolls, ankle circles and shoulder rolls were the most frequently chosen, likely because they did not need much space. As the exercises that participants chose to perform reflects the range of motion available to them in the cabin seat environment, these findings can be used to indicate the spatial envelope available for comfort- and health-promoting activities during flight. This is envisioned to be of particular use in the design of interventions, such as virtual reality applications, where exploiting the alignment between the physical and virtual world can be used to influence sensory perception (Tennent et al., 2019).

The exploratory nature of this work provided insight into the physical experience of discomfort during medium haul flights while identifying the range of movements frequently selected by passengers. The body mapping analysis indicated that, although experience varied widely across individuals, discomfort reports were frequently associated with the back of the neck, the left and right shoulders, the lower back, and the left and right buttock. As such, this suggests an opportunity for interventions to support passengers in improving their comfort in these specific areas. Building upon this work, future research will explore participants' behavioural patterns and postures associated with discomfort during the study.

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Investigating the effects of two fragrances on comfort in the automotive context

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Abstract What is this the impact of olfactory and visual factors on overall comfort? Can these factors have an effect on the perception of thermal comfort? These questions are particularly interesting in the context of a vehicle car cabin, since it leads to the possibility of visual or olfactory cues being used to maintain passenger thermal comfort at a lower energy cost. In this work, human subject trials (n=47) were performed in a temperature-controlled environment varying air temperature, ambient light (none, yellow, blue) and scent (neutral, peppermint, orange & cinnamon). Multiple linear regression shows olfactory factors to have a larger effect on overall comfort perception than visual factors. Either scent improved thermal perception in a slightly cold environment, while only peppermint improved thermal perception in a slightly warm environment. These results suggest that the use of visual and olfactory factors have the potential to increase car cabin comfort and / or improve the energy efficiency of the car climate system.

Keywords: overall comfort, olfactory comfort, thermal comfort, scent diffusion, fragrance diffusion, automotive context

1 Introduction

EU-funded project DOMUS (www.domus-project.eu) aims at increasing the range of electric vehicles by 25% under a variety of ambient conditions without considering possible improvements on the battery and/or electric engine itself. The research directions include for instance minimizing consumption of components, reducing losses, and removing unnecessary consumptions. The car cabin's heating and cooling system is the car's largest auxiliary load, and this system is closely related to personal comfort. When optimizing the energy consumption of the cabin it is therefore of high importance to monitor the changes made on occupants' comfort level and their implications. The research introduced by this paper contributed to the efforts deployed by the consortium to collect experimental data in order to model personal comfort in a more holistic way. Although the methodology presented is illustrative of the approach taken by the DOMUS project, it is important to highlight that it only presents partial results: all the new comfort factors considered are not shown in the literature review section and the experiments presented consist of only one fifth all the jury tests to be conducted (the majority of them were not yet conducted at the time this paper was submitted).

In the next section, a brief literature review regarding comfort will be introduced. Experimentation will be presented first and will be followed by a presentation of results and analysis. The last section will discuss these findings and the next steps.

2 Literature review

2.1 Thermal comfort

In the automotive context existing thermal comfort model could be integrated with considerations on the human perception factor. Precursors of this approach include Fanger's Predicted Mean Vote (PMV) [5], the Berkeley model and Nilsson's equivalent temperature [13]. While the latter models, particularly PMV, have lasted well and are widely used, they are currently not optimized for holistic comfort representing the relevant multiple comfort dimensions. The factors considered by these models are mainly related to the heat exchanges happening between a human body and its environment (due to air temperature, surface temperature, radiation, and insulation). Their limitations become evident when considering cognitive moderating factors of thermal comfort (e.g. mental state, expectations) as well as non-thermal dimensions of comfort (e.g. acoustic, visual, olfactory) that are mainly absent.

2.2 Overall comfort of the body

Comfort models such as the one proposed by Vink & Hallbeck [16] based on neurosciences are representative of the cognitive process resulting from sensory stimulation. They have been used as inspiration by Loriquet et al. [9] to create a representation of passenger's appreciation (Figure 1) illustrating how human cognitive process resulting from sensory stimulations can lead to comfort, discomfort or to a neutral sensation. The aforementioned representation also considers additional inputs (e.g. attention, memory, mood or expectations) acting as comfort moderating factors. Vink & Hallbeck [16] argue that the output is not one form of comfort or discomfort experience but a wider range of appreciations and that both comfort and discomfort can even be experienced simultaneously (e.g. discomfort originating from the seat and feeling of comfort created by a nice flight attendant).

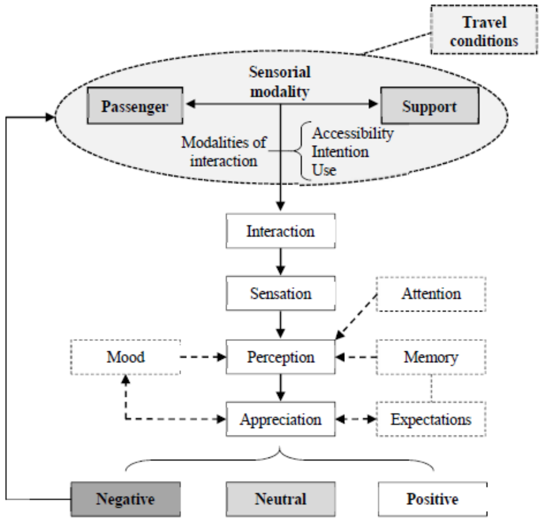

Fig. 1. Comfort of the body: local sensory interaction between the passenger and his environment [9]

Bubb [2] has also discussed the interactions between comfort from different sensory stimulations and overall (dis)comfort in the automotive context. His analysis led to a pyramid-shape figure (Figure 2) inspired by the Maslow pyramid. A discomfort sensation from sensory parameters situated on the lower part of the pyramid are able to convey an overall discomfort regardless of the sensation provided by parameters situated above. According to Bubb, in a bad smelling but thermally comfortable environment, one would feel uncomfortable because of odors: the thermal environment having no influence on the overall comfort perception in this context. The discomfort thresholds for which these kind of interactions apply have nevertheless not been defined.

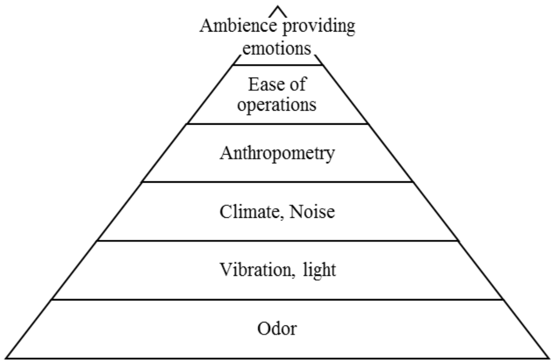

Fig. 2. Comfort dimension (translated from [2])

Other researchers suggest that certain sensory stimulation themselves - such as light illumination and color, air pollution, noise [3] as well as ambient scent [8] - can act as comfort appreciation moderating factors of thermal comfort. Experimentations conducted in room [6] and aircraft cabin [17] environments have shown that the color of lighting can significantly impact thermal comfort appreciation. From a physiological perspective, research has also suggested that light stimulation stops the synthesis and release of melatonin which has a major role in regulating body temperature [11]. Morita et al. [10] suggested that this is one of the causes why preferred ambient temperature is significantly lower when exposed to light (i.e. body temperature is higher) than when it is not (i.e. body temperature is lower). Neuroscience has shown that perceived odors have a strong link to memory, attention, reaction times, mood, and emotion [1]. More specific researches on the impact of fragrances (e.g. coffee - warm, mint - cold) on the perception of thermal comfort have also been undertaken with so far undisclosed results [8]. The experiments presented in this paper examine similar research questions applied in context of an automotive vehicle.

3 Experimentation

3.1 Factors considered

In this work, three experimental factors were considered: “ambient scent” and “ambient light colour” (within-subject variables: multiple conditions experienced by each respondent) as well as “air temperature” (between-subject variable: one condition experienced by each respondent), These factors are highlighted in Table 1.

The ambient light colours tested (“no light”, “blue” and “yellow”) and air temperature (close to comfort according to thermal comfort models) followed guidelines of similar experimentations in building interior [3][6] and aircraft cabin contexts [17]. In order to select the ambient scents for the experimentation a pilot study was conducted. Eight scents (essential oils presented in diffusers) were evaluated by a panel of 5 persons according to their pleasantness and propensity to convey warm or cold sensations. The two fragrances selected were “peppermint” (above average pleasantness score + conveys a cold sensation) and “orange & cinnamon” (above average pleasantness score + conveys a warm sensation). The “neutral” scent condition was achieved using a neutral deodorizer (“Envii Bed Fresh” - selected following subjective assessment) and ventilating the cabin for 2 minutes.

Many other factors were controlled in order for the data collection to be comparable with other DOMUS experimentations. The list of factors to consider, their baseline value (noted [BL] in the table below) as well as measurement methods were aligned among DOMUS consortium members. This information is summarized in Table 1.

Table 1. Description of main factors considered

Factor investigated	*Test case 1*	*Test case 2*	*Test case 3*	*Test case 4*	*Test case 5*	*Test case 6*	*Test case 7*
Ambient scent	Neutral [BL]	Peppermint	Orange & cinnamon	Neutral [BL]	Neutral [BL]	Peppermint	Orange & cinnamon
Space lighting	Dimmed (<800lux) white (3000-4000K) light [BL]						
Ambient light color	No [BL]	No [BL]	No [BL]	Blue	Yellow	Blue	Yellow
Thermal env. – air T°C	Between subject variable (17.1°C, 19.5°C, 22°C [BL], 23.5°C, 24.6°C)						
Thermal env. – else	No additional radiation source, controlled air velocity (<0.2m/s), controlled relative humidity [BL]						
Sound env.	Recording of EV car at constant speed at given loudness [BL]						
Seating	Automotive seat [BL]						
Attention	Standard task: Mobile Tacking Task [BL]						
Participant	Minimum 8 participants per test case, between 20 and 70 years old, both genders represented (min. 3 participants per test case) [BL]						
Participant state	Preconditioned to thermal environment, standard clothing (0.76clo), controlled metabolic rate (1.2 MET) [BL]						

3.2 Set-up and protocol

Forty-seven participants took part, each undergoing an hour individual session. They all worked at Toyota Motor Europe in Belgium. Following the DOMUS guidelines, both genders were well represented (female [38%], male [62%]). Attention was also paid to have a diverse panel coving all subregions of Europe (Northern [13.5%], Western [42%], Eastern [13.5%], and Southern Europe [31%]) and a wide range of age groups (20-29 [46%], 30-39 [26%], 40-49 [19%], and 50-59 [9%]). The experimentation took place in a thermal chamber. They went through the protocol described in Figure 3 in order to evaluate five to seven test cases (described in Table 1). Test case 1 to 5 were administrated first in a random order. The two last ones were considered only if time allowed it. This means that they all experienced at a given temperature different ambient light colors and scents. Each day a new temperature was set and attention was paid to have at least 8 participants a day and an homogenous gender distribution. As this paper focuses on interaction between thermal and olfactory perception only results from the test cases labelled 1, 2, and 3 will be discussed in the next sections.

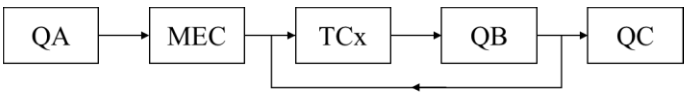

Fig. 3. Simplified experimentation protocol

Each section of the protocol is introduced below:

QA (questionnaire A) consisted in the collection of participants' demographical data, noise and thermal sensitivity as well as temperature history.

MEC consisted in the calibration phase of the magnitude estimation method [15]. It allowed them to understand and familiarize with the unusual format of this method. It was selected to assess and compare the comfort sensation from different sensory channels because it gives more freedom and flexibility to participant when assessing and comparing these abstract notions. In practice it consisted in expressing each comfort sensation felt by drawing a straight line and writing a positive number (longer line and higher number correspond to higher comfort) .

TCx (test case x) represent the moment participants experienced a specific test case in a car cabin. Each test case consisted of a two minutes period within which participants were instructed to perform a task on a tablet while listening to an EV car noise through a headset (more details in Table 1). Before each test case, when participants were not yet in the vehicle, the experimenter set the environment of the cabin to correspond to the next test case planned. Questionnaire B were distributed at the beginning of each test case.

QB (questionnaire B) consisted in the evaluation of the test case experienced. It was filled in the cabin and is composed of three sections. The first section focused on thermal sensation with 7-point scales from cold to hot [7]. The second section consisted in a comfort assessment of five sensory components (thermal, acoustic, seating, visual environments, and seating) as well as overall comfort using the magnitude estimation method

[15]. The last section of this questionnaire consisted in a 9-point hedonic scale aiming to gather a liking score for each sensory channel [4] to complement the comfort rating collected in previous sections.

QC (questionnaire C) consisted in an evaluation of the task. The questionnaire used for this section was the NASA Task Load Index [12].

4 Results and initial analysis

4.1 Overall comfort components

In total, 303 test cases have been evaluated by the 47 participants. A confusion matrix was created (Figure 4) based on thermal and overall comfort scores reported by participants in QB. According to it, thermal and overall comfort scores are correlated in only 58.8% of the cases. It is also interesting to observe that only 47.5% of the test cases for which overall comfort was achieved were also reported as thermally comfortable. At the other end of the spectrum, when overall comfort was not achieved, participants felt thermally uncomfortable in only 61.9% of the cases. This shows that, at least in the experimental setup, holistic comfort is much more than thermal comfort. For a good understanding of the confusion matrix (Figure 4), it is important to note that in "comfortable" corresponds to evaluations of "like slightly" (6^{th} on a 9-point scale) and higher, and that "uncomfortable" corresponds to evaluations of "neither like nor dislike" (5^{th} on the 9-point scale) and lower.

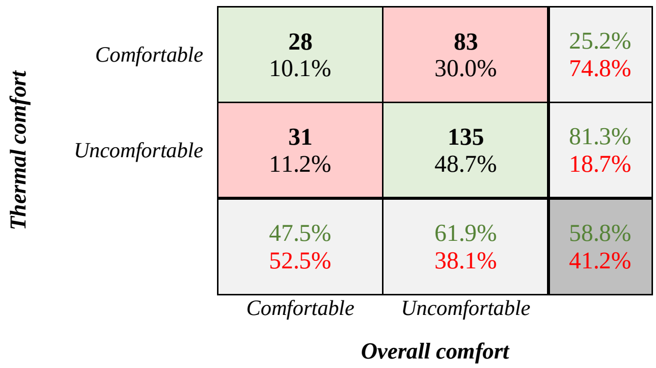

Fig. 4. Confusion matrix

Based on all participant evaluations, the overall comfort score (reported by participants in QB) has been expressed as weighted sum of each sensory comfort score (also reported in QB) using a linear regression (1). Given the coefficient of determination (R^2=0.916), 92% of the variability of the dependent variable *Overall (comfort)* is explained by the 5 explanatory variables. Given the p-value (< 0.0001) of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is significantly better than what a basic mean would bring. Model parameters are presented in table 2. The model therefore fits relatively well the comfort scores expressed by the participants in the condition of the experiment: static lab context, no extreme conditions (e.g. very cold temperature, scents commonly accepted as unpleasing). It is therefore to be interpreted with care.

$$Overall = -4.239 + 0.316 \times Olfactory + 0.273 \times Thermal + 0.200 \times Visual + 0.185 \times Acoustic + 0.179 \times Seating \quad (1)$$

Table 2. Model parameters

Source	*Value*	*Standard error*	*t*	*Pr > |t|*	*Lower bound (95%)*	*Upper bound (95%)*
Intercept	-4.239	1.336	-3.173	0.002	-6.868	-1.610
Olfactory	0.316	0.027	11.802	< 0.0001	0.263	0.369
Thermal	0.273	0.028	9.864	< 0.0001	0.218	0.327
Visual	0.200	0.031	6.453	< 0.0001	0.139	0.262
Acoustic	0.185	0.026	7.066	< 0.0001	0.133	0.236
Seating	0.179	0.031	5.786	< 0.0001	0.118	0.240

In equation (1) an emphasis has been made on the comfort sensations related to the three variables of the experimentation (i.e. air temperature, ambient light color, ambient scent). Comparing their relative weight, it can be observed that olfactory (dis)comfort appears to be the most influential. Notably, in Bubb's model (Figure 2), olfactory discomfort was also presented as having the most influence on overall discomfort. The second component having the most weight appears to be thermal comfort with visual comfort placing third on this relative comparison. Acoustic and seating comfort will need complementary experimental data (planned by other partners in the DOMUS consortium), with test cases focusing on other experimental factors, in order to be discussed in the relative comparison.

4.2 Effect of liked olfactory environment on thermal and overall comfort

In the previous sub-section it has been seen that, in the context of the experimentation conducted, olfactory (dis)comfort was the main component of overall (dis)comfort. The discussion will now shift to the influence of both fragrances (i.e. "peppermint" and "orange & cinnamon" essential oil) on thermal sensation as well as on thermal and overall comfort for two thermal environments: slightly cold (below 22°C) and slightly warm (above 23°C). In order to keep the analysis concise and relevant only test cases for which the fragrances diffused were perceived as neutral or were liked by the participants (reported in QB – hedonic scale) will be discussed in this section. It should be noted that although a pilot test has been conducted, the liking of both fragrances appeared very subjective as they were both disliked (rated from "dislike slightly" to "dislike extremely") by approximately 50% of the respondents. Notably, fragrances were generally more appreciated by female participants as this percentage decreased to 40% for this subgroup. Furthermore, it has been observed that the thermal environment does not influence the liking rate (e.g. "peppermint" fragrance is not more appreciated in warmer thermal environments).

The analysis was made possible by the fact that air temperature was a between-subjects variable. It was therefore possible to compare participants' evaluation of the test case with a neutral scent (Test case #1 in Table 1) with their ratings of the same environment with only the scent changed (Test case #2 & #3 in Table 1). Due to limited sample size, we will not be able to further discuss diversity sensitivity (gender, age, region) in this paper. This will only be possible once all DOMUS experimentations will be conducted.

Figure 5 shows the mean influence of the presence of each fragrance on appreciation of thermal comfort (i.e. 9-point scale from "dislike extremely" to "like extremely") and thermal sensation (i.e. 7-point scale from "cold" to "hot") for temperatures set below 22°C. Both fragrances appear to improve the appreciation of the thermal environment (left on Figure 5), with orange & cinnamon further contributing to improving the thermal sensation felt by the participant in this context (i.e. feel warmer). On the contrary peppermint returns a colder thermal sensation which corresponds to the observation from the pilot test. No significant differences could be observed when comparing participants' evaluation of test cases with fragrance and with neutral scent. The observations have therefore to be considered as tendencies.

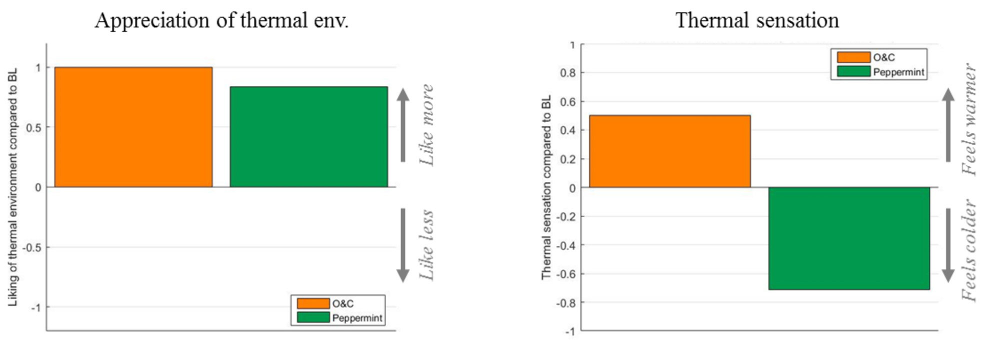

Fig. 5. Effect of peppermint and orange & cinnamon scent on thermal perception in a slightly cold environment

The interactions between olfactory, thermal environments and overall comfort discussed above as well as in section 4.1 have been visualized in Figure 6. When possible, circled schematic graph have been inserted in order to represent existing relationships between items (e.g. linear). The symbol "+" indicates that the fragrance has a positive impact on the evaluation it is related to, whereas "~" represents a neutral impact, and "-" a negative impact. The red cross (marked "X") indicates that the thermal environment did not appear to have an influence on olfactory comfort appreciation (as further described previously). Particular attention have been given to individuation of eventual links between the two. As it can be seen, when liked, the presence of the two fragrances tested affects the thermal sensation and the thermal comfort appreciation.

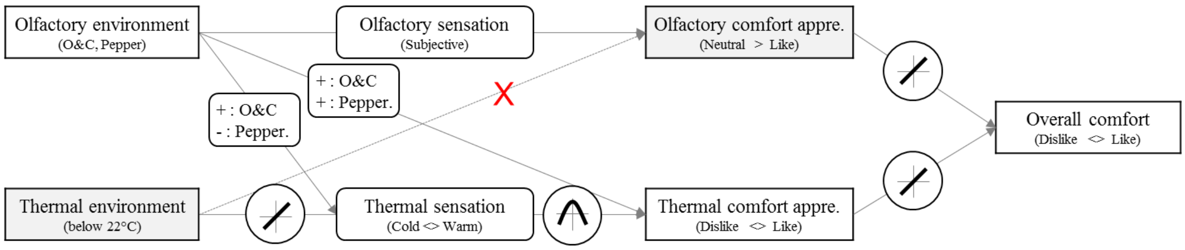

Fig. 6. Thermal and olfactory interactions in a slightly cold environment

A similar analysis than the one described previously has been conducted for the test cases at slightly warm temperatures (23-25°C). It has been summarized in the figure 7. In this context, it appears that the introduction of fragrances in the car cabin has no effects on thermal sensation. The olfactory sensation given by peppermint contribute though to increased thermal comfort appreciation.

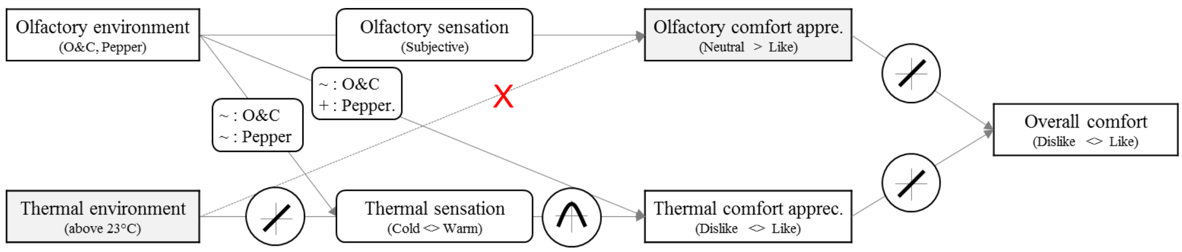

Fig. 7. Thermal and olfactory interactions in a slightly warm environment

5 Discussions and next steps

Analyzing participants' comfort scores, we observed that overall comfort is more than just thermal comfort. They indicate that olfactory (dis)comfort is another major component of overall (dis)comfort. The linear regression model obtained with the data from 303 test case evaluations showed that from this experimental context it even had the most weight. Liking a scent is nevertheless a very subjective matter as both fragrances tested were disliked by about 50% of the participants.

The second step of the analysis focused on the other half of the respondents (liking or being neutral about the fragrance) as in a real situation only them would be more inclined to have the scents diffused in their vehicle. For them, scents appeared to have an interesting effect on thermal sensation and comfort in both slightly warm and slightly cold environments. In slightly cold environments, the presence of either one of the two fragrances tends to improve the thermal comfort, whereas this observation is only valid for "peppermint" in slight warm environments (stable for "orange & cinnamon"). When comes to impact on thermal sensation, influences from scents could only be observed at colder temperatures. In this context, results were in line with the hypotheses formulated after the pilot study: "orange & cinnamon" fosters a warmer sensation, whereas "peppermint" yields a colder sensation.

Customers already have today various possibilities to diffuse scents in their vehicle (accessory modules, embedded in some recent vehicles). The findings of this research suggest that these can be effective solutions to improve overall comfort of vehicle occupants (assuming that the fragrance diffused is appreciated by the occupants). Additionally, such systems might be able to improve thermal comfort before an appropriate temperature is reached or to maintain the level of comfort while lowering the energy consumption of the HVAC unit.

Complementary studies covering additional use cases (e.g. transient thermal environment), a larger participant panels (allowing representative results regarding diversity sensitivity), a more natural environment (e.g.

while driving), and a wider range of fragrances are envisioned as next steps. Beyond comfort considerations, fragrances have shown to be effectively changing occupants behaviors (e.g. calm, energized), shaking off drowsiness or conveying certain messages [14]. It would therefore also be valuable to integrate such considerations (when applicable) in future comfort studies.

The experimentation described in this paper was part of a collaborative effort to model comfort in automotive vehicles taking into account new factors. Additionally to air temperature and ambient scent (discussed in the paper), factors such as ambient light color (collected in the experimentation described) but also irradiation, task load, noise or thermal asymmetry will be inputs to the DOMUS holistic comfort model. It will be presented in an upcoming deliverable from the DOMUS project and in publications from the partners involved.

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Perceived Onboard Passengers' Experience: Flight Attendants' Point of View

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Abstract Cabin research is mostly based only on passenger reports of their own experiences. However, service plays a very important role in influencing passenger experience. Consequently, it is also important to consider the perceptions of flight attendants as onboard service providers, since they can convey a complementary view shedding light on important aspects related to passenger experience. Therefore, this study focuses on analyzing flight-attendants' perception of passengers' inflight activities and experience, as part of a broader study on cabin design optimization for enhancing passenger experience. The study was initiated with a brainstorming session involving 10 human-centered design experts that, through retrospective knowledge elicitation, enabled to identify twenty-three main activities that passengers most often do onboard during long-haul commercial flights. Based on these activities, we then designed a 10-question survey and submitted it to flight attendants. Twenty-seven flight attendants participated in this survey. Respondents were asked to rate on Likert scales, from "not at all important" to "extremely important" their perception of how important the above-mentioned activities are to passengers. Similarly, they were also asked to rate their perception on how satisfactory these activities are to passengers, ranging from "not at all satisfactory" to "extremely satisfactory". Finally, the survey included a complementary open-feedback question on innovative solutions for the future of commercial aviation from the flight attendants' point of view. An analysis of flight attendants' ratings of these passenger activities was performed. In addition, a comparison of both passengers' and flight attendants' perceptions was carried out in order to identify possible relationships between the perspectives of these two populations

Keywords: passenger satisfaction, activities, cabin design, passenger experience, flight attendant

1 Introduction

Passenger experience is a recent interesting topic in air travel (De Lille et al, 2016). Despite the industry focus and attention for airport passenger experience, very little is known about passenger needs in flight (Harrison et al., 2012); (Popovic et al, 2010). It is important to understand these needs since they play an important role in airline profitability. Inflight activities represent measurable components of passenger experience (Torkashvand et al, 2019). For airliners to expand their knowledge on what impacts the passenger experience, it is mostly common to focus on passengers themselves as users of the cabin and the services. While focusing on passengers for eliciting knowledge is critical in understanding passenger experience, there is an additional way to define and assess passenger experience; This includes eliciting knowledge from flight attendants as subject matter experts. This target group can provide valuable key information on passengers' perceptions of various activities and the overall related experience. This expert knowledge is the result of their regular interactions in the cabin when providing services to passengers. They observe passengers in the cabin, listen to their complaints and comments and provide them with the services they ask for. They can convey a complementary viewpoint on important aspects that impact passenger experience.

2 Methodology

The study was initiated with a brainstorming session involving 10 human-centered design experts that, through retrospective knowledge elicitation, enabled to identify twenty-three main activities that passengers most often perform onboard during long-haul commercial flights, Table1.
Based on these activities, we then designed a survey of 10 questions and submitted it to flight attendants. Twenty-seven flight attendants participated in this survey. Respondents were asked to rate on 5-point Likert scales, from "not at all important" to "extremely important" their perception of how important the above-mentioned activities are to passengers. Similarly, they were also asked to rate their perception on how satisfactory these activities are to passengers, ranging from "not at all satisfactory" to "extremely satisfactory". These results were later compared with the other results from a previous research study on passengers' perception of inflight experience related to various activities (Torkashvand et al, 2019). The passenger-perception study implemented a survey of 26 questions which were answered by 93 respondents. For comparing if there is a significant difference between flight attendants and passengers in perception of passenger experience, Fisher's F-tests for assessing the equality of variances were initially conducted. The tests assess the null hypothesis on whether two normal populations have the same variance. If the variances are equal, we then used the two-sample t-test with equal variences. This way we could determine if the means of two sets of data are significantly different from each other or not. For the significant F-test results, we used Welch's t-test, or t-test with unequal variances.

Table 1: Twenty-three activities that passengers perform during long-haul flights

Activities	
1. Resting/Relaxing	
2. Sleeping	13. Walking in the cabin (exercise)
3. Listening to Music	14. Taking care of family/kids
4. Reading books/magazines/e-reader	15. Being physically active/stretching
5. Talking to other group-mates	16. Looking outside of the window
6. Talking to neighbors	17. Egress in/out of the seat
7. Eating/drinking	18. Using the restroom
8. Thinking and observing	19. Listening to flight communication
9. Working on laptop, tablet.etc	20. Boarding
10. Playing, working with cell phone	21. Deboarding
11. Watching in-flight movies	22. Interacting with flight attendant
12. Checking real-time flight info.	23. Adjusting seat features

3 Results

Overall, flight attendants perceived activities 'resting/relaxing', 'sleeping' as well as 'using the restroom' as the most important passengers' activities, while activities 'talking to neighbors' and 'thinking and observing' were the least important ones, Figure 1. On the other hand, they perceived the highest passenger satisfaction for activities 'resting/relaxing' and 'sleeping' as well as 'watching IFE'. Moreover, they think of activities 'talking to neighbors' and 'being physically active' as the least satisfactory ones to passengers, Figure 2.

The t-test analysis showed that there seems to exist a significant difference between passengers' perception of the importance of activities and the flight attendants' perception of their importance to passengers. For activities 'Talking to other groupmates', 'Listening to Music', 'Looking outside the window', 'Working on laptop/ tablet' and 'Taking care of family and kids' there is a significant difference observed, Table 2. Flight attendants considered the importance of 'Talking to other groupmates' more than what the passengers themselves thought. Similarly, they considered more importance for the activities 'Listening to Music', 'Working on laptop/ tablet 'and 'Taking care of family and kids' than the passengers themselves. On the other hand, activity 'Looking outside the window' is considered less important to passengers compared to flight attendants.

Regarding the perception of satisfaction, the t-test analysis showed more similarity between the two groups of participants. Except for the activity 'Listening to Music' satisfaction perception is not different in both groups, Table 3. Flight attendants' perception of the satisfaction raised by the activity 'Listening to Music' however, is higher compared to the passengers' assessment of their satisfaction with the mentioned activities.

Figure 1: Perceived importance of activities by flight attendants

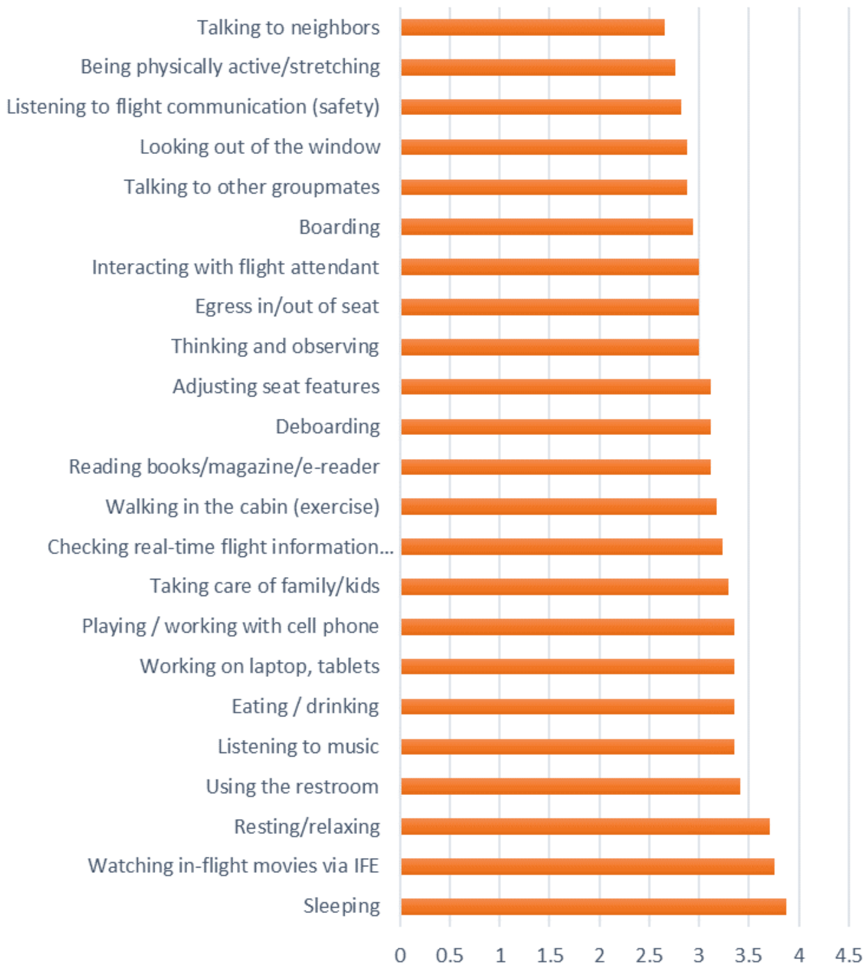
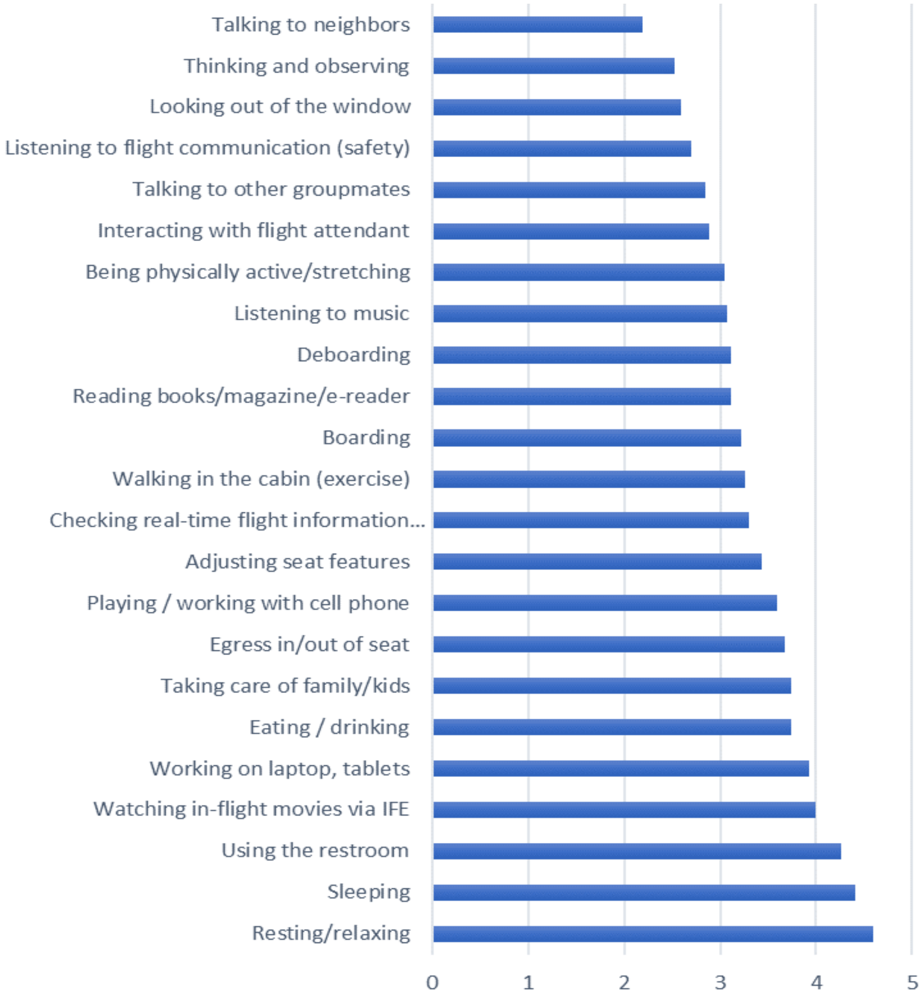


Figure 2: Perceived satisfaction by activities by Flight attendants



4 Conclusions

The results of the comparison between the two populations of service providers and end users of the cabin confirm some assumption that companies' knowledge about their customers' satisfaction by products and services can be considered reliable. However, this knowledge is mostly not reliable about real customer needs. This means that finding needs is not possible without having customers involved in the need-finding design thinking stage. This is also a very basic fundamental in the human-centered approach, i.e. involving users in the design process from the very early stages of design by using techniques such as co-design, concept testing, usability testing, etc. Furthermore, the importance of knowledge elicitation from domain experts is crucial, especially for complex systems such as air travel, including inflight passenger experience.

Table 2: Two sample t-test for comparison of passenger and Flight attendants on importance of activities

Activities	*F- test P-value*	*t-test P-value*	*Mean 1**	*Mean 2**
Talking to other groupmates	**0.0008**	0.249	-0.345	-0.148
Listening to Music	**0.008**	0.921	0.054	0.074
Looking outside of the window	**0.033**	0	0.436	-0.407
Working on laptop, tablet.	**0.035**	0.013	0.381	0.925
Taking care of family/kids	**0.039**	0.898	0.709	0.74

Reading books/ magazines/e-reader	0.052	0.867	0.072	0.111
Egress in/out of the seat	0.053	0.609	0.763	0.666
Walking in the cabin (exercise)	0.146	0.035	0.781	0.259
Checking real-time flight info.	0.155	0.657	0.4	0.296
Playing, working with cell phone	0.197	0.067	0.072	0.592
Watching in-flight movies	0.238	0.082	-0.853	0.053
Resting/Relaxing	0.254	0.073	1.345	1.592
Eating/drinking	0.303	0.086	1.072	0.74
Talking to neighbors	0.386	0.88	-0.781	-0.814
Using the restroom	0.516	0.567	1.363	1.259
Interacting with flight attendant	0.516	0.053	0.309	-0.111
Deboarding	0.566	0.014	0.69	0.111
Sleeping	0.607	0.047	1.072	1.407
Thinking and observing	0.627	0.00E+00	0.454	-0.481
Being physically active/stretching	0.641	0.00E+00	0.945	0.037
Adjusting seat features	0.648	0	1.127	0.444
Listening to flight communication	0.906	0.238	0.054	-0.296
Boarding	0.975	0.115	0.618	0.222

1: Passengers   2*: Flight Attendants*

Table 3: Two sample t-test for comparison of passenger and Flight attendants on satisfaction by activities

Activities	*F- test P-value*	*t-test P-value*	*Mean 1**	*Mean 2**
Listening to Music	**0.002**	0.591	0.254	0.352
Eating/drinking	0.061	0.527	0.2	0.352
Looking outside of the window	0.138	0.192	0.218	-0.117
Talking to other groupmates	0.212	0.317	-0.24	0.73
Talking to neighbors	0.255	0.279	-0.09	-0.352
Reading books/magazines/e-reader	0.312	0.806	0.181	0.117
Playing, working with cell phone	0.343	0.328	0.072	0.352
Thinking and observing	0.368	0.125	-0.108	0.872
Taking care of family/kids	0.434	0.418	0.072	0.294
Working on laptop, tablet etc.	0.477	0.356	-0.755	0.275
Adjusting seat features	0.485	0.244	-0.2	0.117
Sleeping	0.507	0	-0.327	0.882
Deboarding	0.511	0.8	0.181	0.117
Watching in-flight movies	0.581	0.184	-0.771	0.151
Egress in/out of the seat	0.613	0.262	-0.272	0
Boarding	0.713	3.40E-01	0.2	-0.058
Checking real-time flight info.	0.714	0.606	0.363	0.235
Interacting with flight attendant	0.72	0.123	0.327	0
Using the restroom	0.738	0.911	0.381	0.411
Listening to flight communication	0.787	2.99E-01	0.109	-0.176
Being physically active/stretching	0.79	0.808	-0.163	-0.235
Walking in the cabin (exercise)	0.833	0.507	-0.018	0.176
Resting/Relaxing	0.893	0.004	-0.072	0.705

1: Passengers   2*: Flight Attendants*

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Better passenger boarding experience by light guiding

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Abstract The passenger experience while boarding an airplane can be low. To improve the experience a light guiding system was developed which allocates and displays the passengers luggage space in the overhead bin. The allocated space is guided by a light strip in front of the display that blinks when a passenger comes close to their allocated luggage space. A test was done with groups of 18 passengers to compare the traditional way of boarding with the new way of boarding and the experience was significantly improved. The system has potential, but more studies with larger groups and in a real flight are needed to check if this effect is still there.

1. Introduction

Almost all of us might recognize that boarding in an airplane and finding a spot for your hand luggage might be a bad experience The comfort in an airplane is lowest when boarding and during cruise flight according to a study by Bouwens et al. (2017). This is shown in figure 1. This is probably because of the stress finding your seat, placing the hand luggage and the uncertainty of being able to place the hand luggage in the overhead bin. According to Broek (2015), none of the narrow body airplanes have sufficient capacity to stow a hand luggage trolley for every passenger on a fully booked flight. Besides, when passengers place the luggage randomly in the bins near their seat, they most likely do not make optimal use of the available space in the bins. For this, an improved system was developed (a guiding hand luggage system: GHL-System) and a user test was performed to compare the new system with the current boarding process.

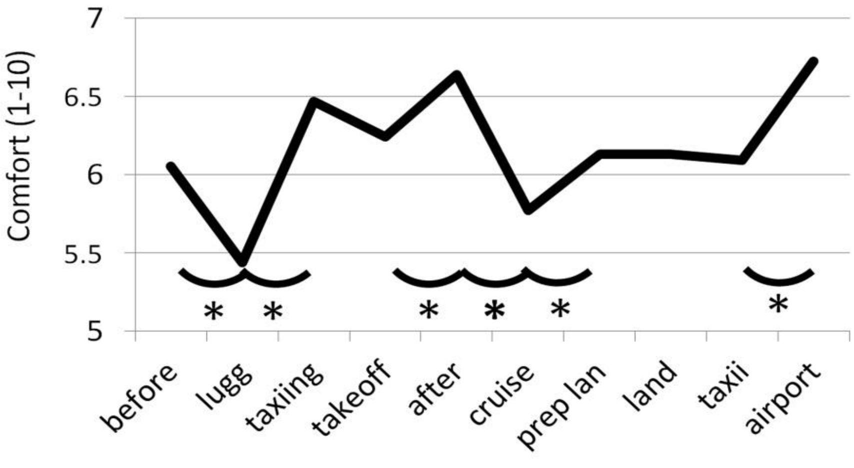

Figure 1. *The comfort on a scale from 1-10 in the different phases in the flight. * means significantly different from the phase next to the pheseant hand (Bouwens et al., 2017)*

1.1. Research Question

The goal of the guiding hand luggage system is to improve the overall boarding experience. The main question is whether this system has a significant effect on passenger experience. Therefore, the following research question is formulated:

Does the developed Guiding Hand Luggage System influence boarding experience?

2. Method and Materials

1.2. Guiding Hand Luggage System

A GHL-System was developed that guides passengers in placing the hand luggage. It has lights that increase the intensity when a passenger comes closer to the place where the hand luggage should be placed. When the hand luggage is placed correct in the bin a green light lights up and when it is place the wrong way it will turn into red. The bins also consist of flexible screens that show the seat number that is on the ticket of the passenger (see figure 2).

Before being able to find the best spot and the optimal loading of the bins, passengers are asked to provide the airline with their hand luggage dimensions while booking their ticket or checking in (on the application, the website, or at the check-in desk). Passengers who provide the airline with this information can/will board first. An algorithm calculates the optimal hand luggage division in the overhead bins to make these fit. Passengers, for whom the luggage will not fit, will be asked to check-in their hand luggage.

Figure 2. Luggage divisions including a light strip, an outline, seat number, and icon.

1.3. Test

Two groups of 18 participants were asked to board a Boeing 737 test fuselage on the campus of Delft University of Technology (Delft, the Netherlands) on two occasions; 'regular' (i.e., boarding without the guiding system, and according to a 'new' boarding process using the guiding (including pre-reserved luggage spots for the passengers, guiding light effects and both visual, and textual luggage divisions in the overhead bins). Participants were assigned a seat out of four rows of six seats, with corresponding overhead lockers located exactly above the seats on each side. Next to the two groups who boarded the plane twice, a third group participated as a control group and boarded twice according to the regular boarding process to determine a possible learning effect. The passengers carried luggage. Twelve normal suitcases, 2 small suitcases, 4 backpacks and 7 jackets were used as luggage, which was the same in all three trials.
The participants were either student or staff from TU Delft. Different nationalities were represented with participants coming from India (41.5%), The Netherlands (24.5%), Spain (7.5%), Indonesia (5.7%), the USA (5.7%), Great-Britain (3.8%), Iran (3.8%), Italy (3.8%), Finland (1.9%), and South Korea (1.9%).
Before the test an informed consent was given and after each boarding round, all participants were given a questionnaire and a pencil. Questions were asked regarding feeling stressful, rushed etc. using a 7 point Likert scale (Likert, 1932). Differences between the groups were tested using the Wilcoxon signed rank test. ($p<0.05$) (SPSS, 2013).

3. Results & Discussion

Table 1 shows that there is a significant difference in the rating of positive experience ($p=0.048$), easy to board ($p=0.020$), easy to store luggage ($p=0.017$), and fast boarding ($p=.024$). However, in comparison to regular boarding, the guided boarding showed a significant difference ($p<0.01$) on all examined criteria. In other words, participants favoured all the tested aspects of the guided boarding experience compared with regular boarding.

Table 1: Values for the control group (first boarding vs second boarding n=17) and Group 2 & 3 (old vs new, n=36). Significant differences were calculated using the Wilcoxon signed rank test.

	Stressful	*Rushed*	*Positive Experience*	*Easy to Board*	*Fast Boarding*	*Long Queue*	*Easy to store luggage*	*Easy to Find seat*
Significance Control group (1st boarding vs 2nd) (n=17)	0.192	0.127	0.048*	0.020*	0.024*	0.131	0.017*	0.066
Significance Group 2 & 3 (old vs new) (n=36)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0.001*	<0.001*	0.013*

This study showed that the guiding system has potential as the passenger experience while boarding is better with it. This study showed that the guiding system has potential as the passenger experience while boarding is better with it. A more extensive description can be found in a paper of Vendel et al.(2019).

4. Limitations

Drawbacks of kind of studies is that there is alsways a learning effect. The second time boarding is often faster (Coppens et al., 2018). Also, in a real situation the stress could be higher as this is not a real flight. On the other hand it is a within subject design, which means that both situation are not in a real flight.
Another limitation could be that the study was done with groups of 18 participants and common flights have more passengers. The effect could be even larger on a larger scale or it could be more confusing with more peoples. Therefore, it is advised to study this with a complete aircraft with 150-180 passengers as well in the future.

5. Conclusion

The light guiding system did convincingly improve the passenger experience during boarding. However, future research is need in real flights and with larger study groups.

6. Acknowledgements

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New experimental research of the quasi-vertical driving position

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Abstract The paper presents new contributions to the study of the unconventional driving position of the car - called by the author as "quasi-vertical driving position." Firstly the quasi-vertical driving position offers significant advantage of reducing the loads in the buttock (pelvis) area by partially redistributing them to the shins (knee area) and soles. Quasi-vertical position involves a new configuration of the seat of the car and a new architecture of the cockpit. The paper further presents some important elements of the experimental methodology applied, the description of the original equipment (the stand) for determining the distribution of the loads on the driver seat for a large diversity of the body positions and also some significant results of the experiments. Starting from these experimental data it will be possible to formulate new recommendations in the field of the comfort and it will open new research perspectives in the field of unconventional driving positions.

Keywords: Quasi-vertical Driving Position, Future Urban Car Architecture, Experimental Ergonomic Research.

1 Introduction

Over more than a century of evolution, the car has not experienced a radical change in its operating principles, including the working position of the driver / passenger. However, in the last decades marked by a growing concern for the evolution of society in the perspective of sustainable development, there was a spectacular evolution of research into the means of people's mobility. In the context of urban agglomerations, the dimensions and architecture of the automobile has become key factors in optimizing mobility performance. Today, there is a growing need to reinvent the car as an important component of the transport system adapted to the needs of the future [1].

In this respect, the author proposed the concept of quasi-vertical driving / travelling position applicable to urban car [2]. The new concept can strongly influence the architecture and appearance of the future cars, their size, architectural style, how to use them and the level of comfort provided to the users as well as their transport capacity. Thus, the new concept will lead to reducing the specific dimensions of cars and, in particular, the external dimensions related to the number of passengers and thereby increasing their specific transport capacity and indirectly the mobility in crowded urban areas [3]. On the other hand, the quasi-vertical driving position will require the definition of new conditions that must be met to ensure a proper comfort for the driver and passengers. It is possible that the new perspective proposed for driving / travelling posture will stimulate the design and development of new types of cars or other urban transport systems that will contribute to meet the growing need for mobility in the future [1].

2 Quasi-vertical position - a possible driving /travelling posture adopted for the urban automobile. The main features

It is known that the interior architecture of the current car is based on the principles originally formulated during the study of comfort for the cockpit of the WWII hunting planes. Further in-depth studies on car comfort were made over many decades and have led today to a much deeper understanding of the conditions necessary to ensure comfort and the multiple responsible causes that can influence it. So, the resemblance between the sitting posture in the airplane chair and the similar one in the car seat is not accidental.

Much less is known about other possible driving/traveling positions in the car, given the relatively small diversity of the cockpit architecture configurations of the various existing vehicles. Today, the dominant driving/traveling position is obviously the „classic" sitting position in the airplane.

Intuiting an opportunity to reduce the size of the cockpit, the author proposed the original concept of "quasi-vertical driving position" for the driver but also applicable to the passengers. This position is defined by the almost vertical posture of the user's trunk with the back and buttocks supported by a special chair or support device and having the possibility for the soles of the feet to reach the floor. The knees area must also be in contact with a special adapted support. In this way the body weight could be discharged in different proportions on each of these four contact surfaces [3] (Figure 1.a).

3 Testing the quasi-vertical driving position

Based on the previously presented principles, a series of tests were conducted on a testing stand that basically simulates a seat adaptable to very different driving postures - including the quasi-vertical driving position described above.

To explore the possibilities of using new driving / travelling positions it is necessary to determine the multiple interactions between human body and the body support system (the chair) which can influence the comfort. The present study aims at dealing primarily with the mechanical interaction between the user and the chair, initially in static conditions. It seeks to deepen the understanding of how the weight of the human body is distributed on each of the seat support surfaces.

Determining the principles of body weight distribution on the seat support surfaces is difficult because the human body can be considered as a multibody system of great complexity due to the nature and mechanical behaviour of the organic substance it is made of. It is obvious a disadvantage to work with such a multiple undetermined system (the human body), but even here it can be a chance to discover original ways in which the chair provides unprecedented comfort.

3.1 The equipment for testing the quasi-vertical driving position

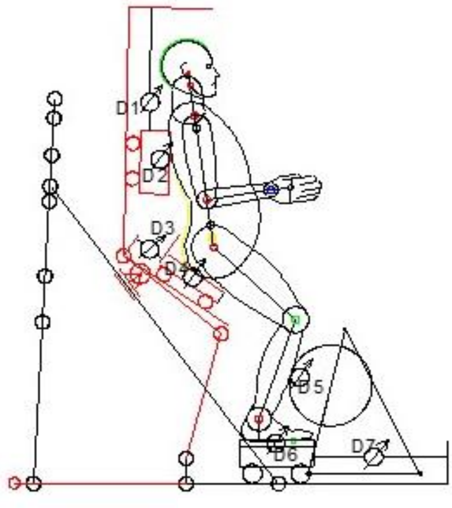
Unlike the usual driving position in which the seat supports the weight of the body predominantly in the buttocks and back of the thighs, the study suggests a quasi-vertical position where, due to the almost vertical position of the body and multiple support surfaces, the weight is distributed on several areas: back, buttocks and back of the thighs, knees area and soles of the feet.

To test this type of multiple support, the test bench simulating a driver's seat adapted to the quasi-vertical driving position was designed to measure the normal and tangential forces with which the user's body acts on the seat. As characteristic features - the stand is provided with a special device that supports the tibia and another device where the soles rest on.

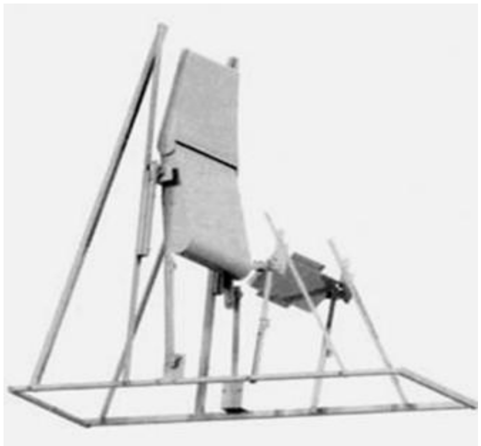
The testing stand has been designed so that its geometric configuration can be modified relative easely according to a wide range of driving postures that should be taken into account during the tests (Figure 1.b).
It provides some important possibilities of adjustment of the seat position such as: seat cushion inclination and height, backrest inclination, the positions of the knee and sole supports in relation to the seat cushion.

The test is carried out in static conditions for various configurations / driving positions, using different human subjects with different anthropometric dimensions.

The seat cushion, the backrest, the tibia / knee support and the sole support are considered supporting elements of the chair. These elements and the dynamometer systems (D1,…,D7) attached to each of them have been designed and adapted so that normal forces (measured by D2, D4, D5 and D6) and tangential forces (measured by D1, D3 and D7) can be measured independently (Figure 1.a).



a)



b)

Fig. 1. The functional scheme of the forces measurement system (a) and the basic structure of the testing stand for quasi-vertical driving position (b).

3.2 Principles used to test the quasi-vertical driving position

The mechanical stresses to which the seat is subjected by the user as well as the mechanical stresses to which the user's body is subjected (in return) by the seat will be determined by measuring normal and tangential forces. The way in which the body weight is distributed on the surfaces of the seat is determined directly by the working position adopted through the choice of geometrical configuration of the chair type support.

As an approach, this may be considered as a first step in the study of comfort for the unconventional quasi-vertical driving posture, followed by the study of other physiological and psychological effects on the user's state. The comfort state is also influenced by other factors that may prove important, such as the relative position of the limbs, the general body position, the duration of the test, the test conditions (static, dynamic, vibration, etc.), the place and context in which the test is made (indoor / outdoor, in traffic, in the laboratory), the quality of the contact between the body and the supporting elements. Obviously, the state of comfort is determined by a number of factors, and actually it represents an element of synthesis.

It is desirable to determine the existing relationship between the specific position of the body, the human body loads on the elements of the seat and the corresponding values of the significant parameters responsive for ensuring the comfort state of the user in the quasi-vertical working / driving position in the vehicle. This issue will be the subject of further studies.

One of the most important advantages offered by the testing stand during the experiments is the possibility to make large adjustments of the seat geometry corresponding to the range of driving/working positions studied (Figure 2.a).

An important parameter taken into account when performing the experiments is the angle of inclination of the seat cushion (α_{sc}) because it has the greatest influence on the working posture in direct association with the angle of inclination of the femur. A second important parameter is the inclination angle of the tibia (α_{tibia}). The two angular parameters α_{sc} and α_{tibia} represent the reference elements in the study of the working postures (Figure 2.b).

Thus, the cases determined by the angle α_{sc} (= 12^0 ...84^0) were analyzed, taking into consideration for each of them the values of the angle α_{tibia} =33^0, 16^0, 3^0 and -20^0. Positive values for α_{tibia} mean the tibia and the soles are directed backwards (Figure 2.c).

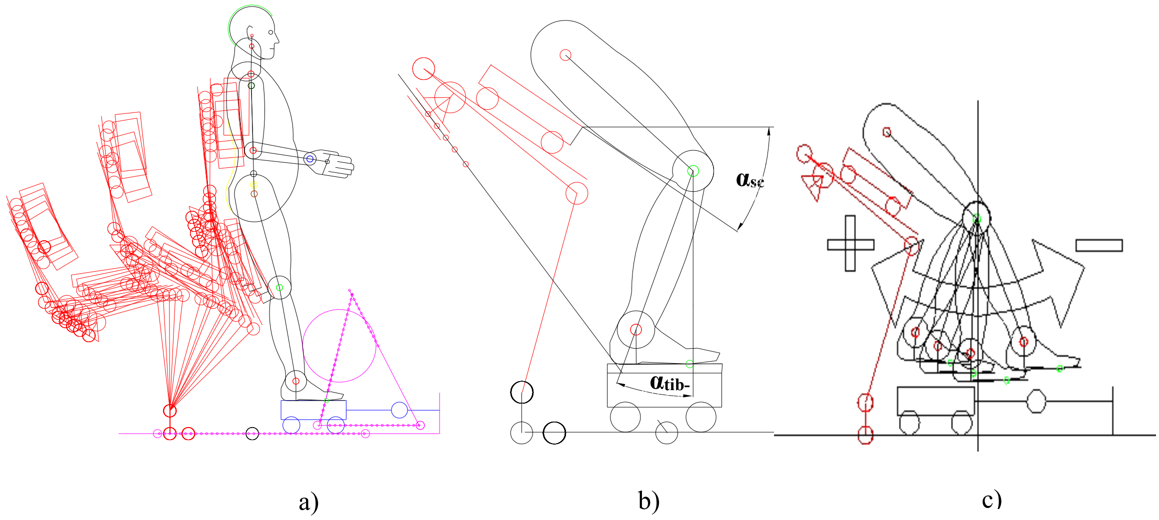


Fig. 2. The range of driving/working positions possible to be studied starting from α_{sc} and α_{tibia}

According to the existing comfort recommendations and following the observations made by the author during the experiments, the quasi-vertical working position implies a low inclination of the backrest. This explains the low values of both normal and tangential body pressure on the back of the seat measured during experiments and thus a seemingly low impact of the backrest in terms of working conditions. This led to the temporary ignoring of the backrest, which does not mean giving up the study of the influence of the backrest in this working position. On contrary, for the future this could represent a new direction of research and an important resource for innovation.

For each of the working positions defined by the parameters α_{sc} and α_{tibia} three working hypotheses were considered (Figure 3):

1 - the situation where the seat cushion is connected to the fixed frame of the seat by means of a dynamometer which records the tangential force with which the seat cushion is actuated - let say "in a passive way" (Figure 3.a);

2 - the situation where the seat cushion is not connected to the fixed frame so that there is no (theoretically) any tangential component of the human - chair interaction force at the seat cushion level (Figure 3.b);

3 - the situation where the seat cushion is operated in a tangential direction with a supplementary "active force" F_{sup}. It will be measured the influence of that supplementary force on the distribution of the human body loads on the chair (Figure 3.c).

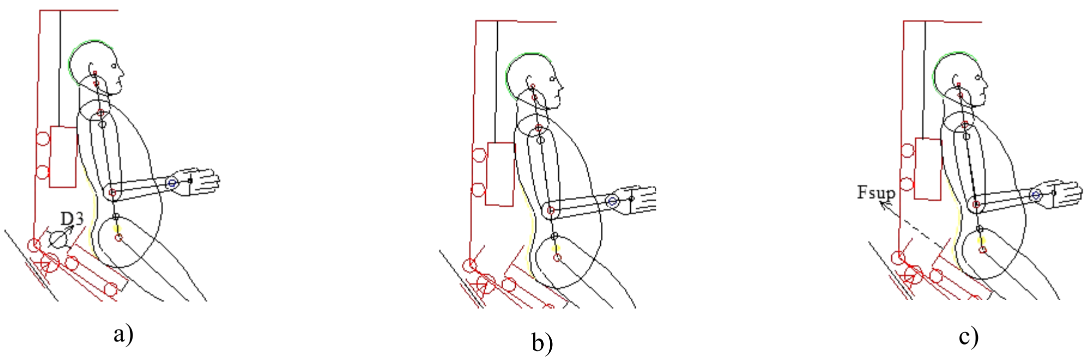


Fig. 3. The working hypotheses for the tests

For each of the cases, measurements of the normal and tangential forces were made on the stand by means of the D3, D4, D5, D6 and D7 dynamometer devices. The forces were represented graphically for a better interpretation of the research results.

As an example, for the first case (seat cushion connected to the fixed frame), if $\alpha_{tibia} = 3^0$ and $\alpha_{sc} = 12^0...84^0$, the following data resulted from the measurements on the testing stand (**Table 1**).

Table 1. Normal and tangential forces measured on the testing stand.

α_{sc}	*D3*	*D4*	*D5*	*D6*	*D7*
12^0	3,5 [kgf]	60,8	12,3	17,7	1,82
20^0	4	57,8	16,6	22,5	1,68
36^0	8	51,8	31,6	21,2	5,1
50^0	8,5	39,2	39	28,7	6,74
71^0	7,5	35,8	45,7	46	9,87
84^0	7	35,6	46	50,9	11,9

Graphically these data can be represented in several significant ways. In the Figure 4 it can be observed the variation of the normal loads (D4, D5 and D6) and tangential loads (D3 and D7) measured on the seat elements as a function of the variable α_{sc} ($\alpha_{sc} = 12^0...84^0$). It can also be observed the share of each load in the set of forces acting on the seat elements, as well as the interdependencies of these represented loads depending on α_{sc} values. The loads are expressed both in absolute value ([kgf]) and in percentage ([%]).

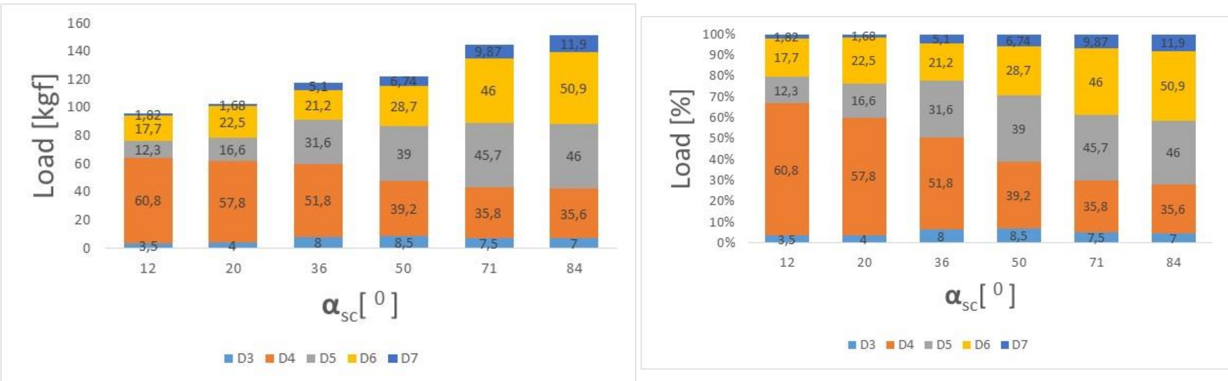


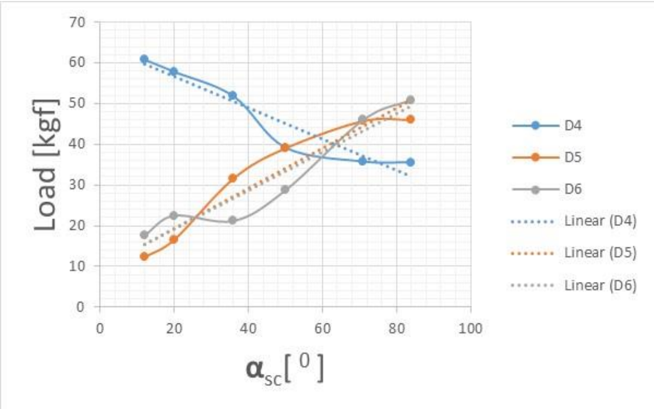
Fig. 4. The variation of the normal and tangential loads measured on the seat elements as a function of the variable α_{sc}

The results of measurements show that the sum of the loads on the seat elements is variable depending on the seat cushion angle and reaches values (151 [kgf]) significantly higher than the weight of the subject (93 [kgf]). This significant increasing may be directly responsible for the comfort or discomfort sensations.

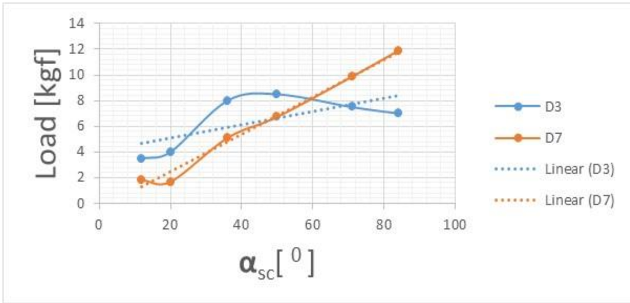
Using another type of chart, the Figure 5.a represents only the normal loads on the seat elements. Similarly, in Figure 5.b are represented only the tangential loads.

As a general trend, it is noticed that the increase of the seat cushion inclination angle ($\alpha_{sc} = 12^0 ... 84^0$) produces a progressive and significant decrease of the normal force on the seat cushion (from 60.8 [kgf] to 35.6 [kgf]) with the progressive increase of both normal forces on tibia (from 12.3 [kgf] to 46 [kgf]) and on soles (from 17.7 [kgf] to 50.9[kgf]).

It is also noted the trend of the total normal forces pressing on the elements of the seat (sum of the normal forces) to increase significantly (from 90.8 [kgf] to 132.5 [kgf]) with the increasing of the inclination angle of the seat cushion α_{sc}. This could mean an extra effort of the body, a more intense aggression on it due to this supplementary interaction with the seat support elements.



a)



b)

Fig. 5. The variation of the normal loads (a) and tangential loads (b) as a function of the variable α_{sc}

4. Conclusions

Different ways of acting of the human body on the seat elements generate specific effects on the user's comfort state that have to be checked by tests. It is assumed that by increasing the inclination of the seat cushion and reducing the normal load in the buttock area a beneficial effect on the comfort state occurs, but at the same time there is an opposite effect due to the increase of normal loads in the tibia and the soles. It remains to be determined which are the optimal comfort conditions that can be achieved in the quasi-vertical position depending on the inclination of the seat cushion and the corresponding generated loads. It can be seen in the Figure 5 that, for the angle α_{sc} around of 60^0 the normal forces (D4, D5 and D6) tend to become equal, but the summed forces exceed the value of the user's own weight. Therefore, it is intended to establish by experiment the criterion of choosing the recommended comfortable working position - possibly the situation when the normal loads on the seat elements are approximately equal to each other („uniform pressure distribution criterion"), or when uneven, the normal forces to be inferior to some specific recommended values.

Even if their size is much lower than the normal forces, it is also necessary to carefully test the influence of the tangential forces (D3 and D7) on the comfort state considering their variation depending on the seat cushion inclination angle. As a preliminary observation on the measurements made on the testing stand, the tangential forces measured at the level of the sole and at the level of the seat cushion tend to become equal for α_{sc} around 60^0. For the angle α_{sc} less than 60^0 the measured tangential load D3 is bigger than D7, and for the angle α_{sc} greater than 60^0 the tangential load D7 becomes greater than D3. This could mean that a balanced distribution of the body mass on the seat elements is achieved around the posture corresponding to $\alpha_{sc}=60^0$, suggesting some research perspectives of this position.

Acknowledgments The research work reported here was made possible also by the collaboration of the students Raluca Stoica, Sorin Ivan and Iulia Ciuntu who brought their valuable and enthusiastic contribution to the realization of the testing stand during the elaboration of their license work.

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Guided seat memory usage - bus drivers acceptance and experiences

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Abstract In public transport buses, the driver's workplace is equipped with an ergonomic seat that allows the driver to sit in a comfortable position that is beneficial to his health thanks to a wide range of adjustment options. In everyday operations, these adjustment options are often not used properly due to a lack of time and/or instruction. With the help of seat memory systems for simplified adjustment of various seat parameters, the optimum individual seating position can be stored on a memory card and automatically recalled. The question therefore arose as to whether a memory seat would prove its worth in everyday operations and actually contribute to an improved ergonomic sitting posture at the bus driver's workplace. In this project, the body measurements relevant for seat adjustment of 24 bus drivers were determined. Subsequently, the personal ergonomically optimised seat settings of these drivers was defined using joint angles proposed by common guidelines and controlled by using the CUELA measurement system. The resulting backrest tilt, seat tilt, seat height and horizontal seating position were set on a seat with memory function and stored on a memory card, which was handed out to the drivers. The settings and changes to the seat settings during driving (400 regular shifts on urban and rural routes) were recorded for subsequent analysis. Daily and final questionnaires were used to determine the experiences with the memory seat and the personal seating position and posture. The specified personal seat settings were initially rated as relatively negative after the trial period. Presumed reasons were, among others, the change of a seat adjustment that had been used for years, getting used to a new driver's seat model with different cushions, vibration damping and surface textures as well as the fact that the seat height could not be adjusted optimally due to an insufficient adjustment range downwards. The electronic storage of the seat settings was very well received; above all, the experienced timesavings at the beginning of a shift and during driver change was positively emphasised. In comparison with the standard seats used, the memory seats scored just positive. An evaluation of the memory seat system directly after the tests resulted in positive evaluations. The repeated survey a few weeks after the end of the test showed a similar picture. Drivers clearly preferred the memory seat system when they were confronted with the fictitious choice between a standard seat and the memory seat. Results also show the importance of being instructed to an ergonomic seating posture by a physician or trainer, due to the required knowledge of measuring joint angles. Successfully, 50% of the subjects reported a change of their former seat adjustments and sitting habits in favour of a more ergonomic sitting posture.

Keywords: Seat memory, bus driver, joint angles, sitting posture.

1 Introduction

Bus drivers report more about musculoskeletal complaints than other employees [1]. Musculoskeletal disorders also account for up to 40% of premature incapacity to drive. Among other things, this was primarily attributed to the posture adopted during driving. The experience of transport companies has also shown that the driver's seat is not optimally adjusted manually by the driver due to the variety of models and the manageability of the adjustment mechanisms. Furthermore drivers complain about a lack of time for seat adjustments during driver changes during operation. The resulting sitting postures can lead to sometimes considerable musculoskeletal stress.

Seat memory systems have been developed for the simple and quick adjustment of an individually optimised seating position and posture. In the project "Ergonomic testing of a seat memory at the bus driver's workplace [2] it has already been shown that such a seat memory system leads to a better ergonomic posture compared to the previously usual manual seat adjustment by the driver and that a few memorised parameters are sufficient to achieve a considerably improved posture.

At the time of the previous study [2], memory functions were still relatively uncommon in vehicle seats. In the meantime, this function has become a standard feature of some car models. However, especially for public transport, with frequent and quick driver changes, an automatic seat adjustment seems to be particularly appropriate. The follow-up project [3] was therefore intended to test whether a memory function facilitates the setting of an ergonomic seating position for the driver and whether a seat memory function is functional when using today's technology widely used in transportation companies. Furthermore, it was examined which acceptance a given sitting posture experiences and how this affects the driver's sense of comfort.

2 Materials and Methods

The driver's seat used (Isringhausen, ISRI 6860/880E NTS2, Fig. 1, left) has numerous adjustment possibilities. Only four of them were used in the project (seat tilt, seat length adjustment, backrest tilt, seat height), as these four memorised adjustment options can be considered sufficient [2] for a seat adjustment according to VDV specifications. All other adjustment options were regarded as additional comfort settings and were not considered in this study. The drivers were informed that these adjustment options were deactivated as far as possible. Three different seat settings can be stored and recalled using the external control panel (Fig. 2). The driver's seats were installed in MAN buses (type NL 263, built 2004, Fig. 1). The buses of two depots operated on different routes with different stopping frequencies in the urban area of Berlin.

The subjects consisted of 24 male bus drivers of the participating transportation company. A selection of ten body measurements of the test persons (anthropometric values according to [4] definition DIN 33402 "Human body measurements") was recorded by occupational physicians trained in the use of anthropometric measuring tools. The individual adjustment of the driver's seat was carried out taking into account the requirements of DIN 33402-1 [5]. These are based on the research results of the ika [6] and are intended to achieve an ergonomically favourable seating position with corresponding physiologically less stressful body angles. During the seat adjustment processes the control of the subjects´ postures and joint angles was carried out by using the posture measuring system CUELA [7] (Fig. 1). This measuring system, which is worn on clothing, allowes the measurement of joint angles to the nearest degree without impairing the subject´s work. Various sensors (potentiometers, gyroscopes, inclinometers, rotary sensors) record the angle of the joints of the extremities and the posture of the upper body at a frequency of 50 Hz.

The seat adjustment data were stored on the personal memory card as seat setting 1. If required, an alternative seat position could be stored (seat setting 2). These seat setting data might have been slightly different but still close the range of the recommended values and could be changed by the driver. Seat setting 3 were basic settings for comfortable entry and exit (backrest vertical, seat in maximum rear position). The subjects were informed that the preset seat setting should be regarded as recommendations and that they can be adjusted manually if necessary. In the system, the seat setting selected by the drivers and the manual seat setting changes were stored in log files and evaluated at the end of the trial period.

The participating drivers were asked to fill out questionnaires before and after a shift on a bus with a built-in memory seat. The questionnaires covered present physical complaints before and after the shift, the duration, adjustments made to the seat by the driver and any difficulties that may have arisen with the memory seat system. At the end of the 6-week test period, a final questionnaire was conducted in which the general experience gained with the memory seat system was asked for and an evaluation of the memory seat system was requested. Using a follow-up questionnaire a few weeks after the end of the experiment, the subjects were asked to compare the memory seat with the standard seats again and to make a further personal assessment of the memory seat system.

Fig. 1. Driver's seat (© ISRI), BVG bus (© Berliner Verkehrsbetriebe), CUELA-System (© DGUV)

3 Results

Four buses equipped with the memory seat system were in service at two depots. Twelve drivers from each depot were instructed in the operation of the seat and familiarised with the various functions. The average age of the drivers was 48 years (SD 7.9), body height 176 cm (SD 7.6 cm), weight 89 kg (SD 16.8 kg), driving experience 22.7 years (SD 9.2 years), BMI 30 (SD 4.7). Ten additionally measured body dimensions (forward reach, body seat height, shoulder height when seated, seat surface height, buttocks/knees length, buttocks/knees length, buttocks/legs length, abdominal depth) largely corresponded to values specified in DIN 33402 [8].

With the available adjustment ranges of the seat in the given installation situation, it was not always possible to achieve a sitting posture with all body angles recommended according to DIN 33402-1 [5], which was largely due to insufficient downward adjustability of the seat height. This particularly affected the thigh angle and resulted in deviations of wider joint angles due to the joint angle chain, e.g. knee angle. Some drivers did not want or could not accept the suggested seat adjustment, which mostly concerned the upper body posture or the upper body angle (and thus also the hip angle), since a more upright sitting posture was generally preferred. The low sitting position resulting from the body angle preferences was also repeatedly criticized by the drivers. The reasons often cited were, on the one hand, a reduced visibility of the area directly in front of the vehicle and a low seating position when in contact with the passengers (e.g. at ticket sales/checks, giving information). According to some test participants, a sitting position at least at eye level with the passengers was also considered as psychologically important.

Table 1. Recommended joint angles [°] and realized percentages of 24 subjects after guided seat adjustment.

N=24	*Knee angle [°]*	*Thigh angle [°]*	*Hip angle [°]*	*Upper body angle [°]*
Recommendation	110-120	0-15	100-115	-20 - -10
< recommended	21%	66%	33%	0%
recommended +/- 2°	71%	33%	58%	96%
> recommended	8%	0%	8%	4%

For the alternative seat setting 2, the optimum areas were left somewhat more frequently. In general, a larger knee angle than recommended was taken, which is probably due to the generally more rearwardly adjusted sitting posture. The thigh angle, on the other hand, was more often within the recommended range (50%). The distribution of the hip angles was almost identical with the distribution in seat setting 1. The most frequent deviation from the optimum range was recorded with the upper body angle. About half of the test persons preferred a less backward inclined, almost vertical posture, of the upper body. This may also be due to compensation of the generally low sitting position in order to achieve a higher head position. In general, the driver's seat for seat setting 2 was moved to a position slightly further backwards and the knee angle was increased while the seat height remained approximately the same. The seat height was generally retained. A change to a lower seat height would not have been technically possible in most cases anyway, since in more than 50% of the cases the lowest setting had already been reached. On average, the backrest inclination was made about 2 degrees steeper. The seat surface inclination, which according to [5] should rise slightly forwards, was set significantly lower in the front (seat setting1 = -2.6°, seat setting 2 = +3.8 degrees), so that the seat surface drops slightly forwards in seat setting 2. Some drivers argued that the force to be applied to the pedals could be achieved more by weight than by muscle power, or that a seat rising to the front would be uncomfortable. On average, the opening angle of the seat has been reduced by about the amount of the change in the backrest tilt. On a total of 24% of all days of use, no subsequent adjustment of the seat position/posture was carried out (Table 2).

Table 2. Questionnaire results regarding physical complaints after the shift [% of n=404 questionnaires]

N=404	*no change*	*better*	*worse*	*N/A*
upper back	73	2	22	4
middle back	84	0	11	4
lower back	83	3	10	4
buttock	88	0	7	4
thigh	80	0	15	4
knee/foot	80	2	14	4

The final questionnaire at the end of the test period was used to determine whether and which of the basic settings of the memory seat (seat setting 1/ 2) were perceived as disturbing or uncomfortable and a comparison should be made between the memory seat and the standard driver seats. Response was 21 out of 24 participants (Table 3).

Table 3. Results of final questionnaire [n=21]

		n
Did sth bother you (regarding seat setting 1/2)?	Yes	13
	No	7
	N/A	1
What did you dislike?	seat height	7
	seat length adjustment	7
	seat tilt	4
	backrest tilt	9
Where did you have complaints?	neck, shoulder, upper back	5
	middle back	3
	mower back	6
	buttock	2
	thigh	3
	knee, lower leg, foot	4
How do you rate the memory seat compared to standard driver seats?	much worse	0
	worse	2
	rather worse	6
	rather better	9
	better	3
	much better	1

A few weeks after the end of the test, the test persons were asked to complete a further questionnaire in order to carry out a reassessment of the memory fit afterwards (Table 4).

Table 4. Results of follow-up questionnaire [n=20]

		n
How do you rate the seat compared to standard driver seats?	much worse	0
	worse	1
	rather worse	8
	rather better	4
	better	6
	much better	1
If you had a choice now, would you choose the tested memory seat?	Yes	13
	No	5
	I do not care	2
Do you now adjust the driver's seat differently than before?	Yes	10
	No	10
	I do not know	0

All adjustment processes were stored in log files. Table 5 shows for each test person the number of shifts driven with a memory seat, the total number different logged seat setting changes, the mean number of different seat positions per shift and the proportion of seat settings stored that corresponded exactly to seat settings 1 or 2. Note, that the percentages unfortunately do not allow conclusions to be drawn about the actual time spent in the respective seat setting.

Table 5. Number of shifts using a bus with seat memory system, number of logged settings during test period, mean number of logged setting changes per shift, percentage of seat settings 1 and 2.

Subj.	*No. shifts*	*No. logged settings*	*Mean set./shift*	*Set.1 [%]*	*Set.2 [%]*	*Subj.*	*No. shifts*	*No. logged settings*	*Mean set./shift*	*Set.1 [%]*	*Set.2 [%]*
1	14	327	23	16	1	13	26	295	11	8	3
2	-	-		-	-	14	12	102	9	12	3
3	5	79	16	9	8	15	17	170	10	34	4
4	28	876	31	41	5	16	15	83	6	14	0
5	6	118	20	14	0	17	15	220	15	20	7
6	10	234	23	4	4	18	26	1021	39	7	0
7	30	1400	47	10	0	19	9	217	24	27	1
8	18	311	17	7	5	20	22	315	14	6	1
9	4	-		-	-	21	-	-		-	-
10	25	183	7	29	7	22	25	174	7	14	0
11	27	501	19	26	9	23	25	186	7	34	34
12	22	710	32	6	2	24	15	85	6	14	1

The log files were used to calculate the distribution of stored seat positions and settings. Besides seat tilt, backrest tilt and seat position, the „opening angle“ of the seat was calculated, as an indicator for the hip angle, by using the values of backrest tilt and seat tilt. The sum of the deviations less than or equal to 4° or 4 mm respectively, which can still be interpreted as within the scope of recommended values, is 73% (seat tilt), 89% (seat height), 71% (seat position) and 68% (seat opening angle) (see Table 5). Although the original setting was changed quite frequently, those changes were only minor for the most part.

Table 6 shows the values for all test persons of all logged seat variables (seat tilt, seat height, seat position and the calculated values for the seat opening angle).

Table 6. Values [%] of all stored seat settings (N=7607) during the test period (396 shifts), deviations from seat setting 1 in classes of ≤1°, >1°≤4° and >4°.

	≤1°	*>1°≤4°*	*>4°*
seat tilt	41	32	27
seat height	72	17	11
seat position	52	19	29
seat opening angle	40	28	32

The seat setting 1, developed together with the drivers, was therefore accepted to a large extent and changed only slightly.

4 Discussion

The 24 bus drivers who took part in the field tests almost completely covered the percentile ranges of the 18 to 65 year old male population in Germany specified in DIN standard 33402 with their body dimensions. The distributions regarding the abdominal depth and the body weight show a clear right shift towards higher values. In view of the low-movement activity profile of a bus driver this is not a surprising result and a representative sample can be assumed for the anthropometry of the subjects.

The desired driver seat adjustment was based on the VDV234 guidelines, which recommend an optimal posture for seated driving from an occupational medicine point of view in low-floor buses. However, it was not always possible to achieve all recommended body angles without exception. This was based on the one hand on the seats spatial position in the buses and on the other hand on the subjective sensations of the drivers, who were partly unable and/or unwilling to accept the recommended body posture and joint angles. The former largely concerned the seat height, which would have had to be adjusted significantly lower several times in order to achieve the required thigh and knee angle. An extended adjustment range towards a lower seat position would have been necessary. For five subjects only, the minimum adjustable seat height was changed upwards at all. This also explains the low correspondence (33%) of the required thigh angle (Table 1) with the actual thigh angle in seat position 1. 66% of the subjects had a larger than required thigh angle in setting 1. The apparently high acceptance of the seat height must be relativized under these conditions. The required lower seating position also stands in contrast to the opinion repeatedly expressed by the drivers that the lower seating position restricts the view to areas directly in front of the vehicle and also has an unfavourable effect on contact with the passengers. The knee angle of the stored seat setting 1 corresponded in 71% of the cases to the VDV recommendation of 110°-120°. 21% of the subjects requested a slightly smaller knee angle. The required upper body angle of -10° to -20° was set and accepted by almost all subjects (96%) in sitting position 1. A larger percentage deviation had to be realized with regard to the hip angle (agreement in 58% of the cases of seat setting 1) (VDV recommendation 100°-115°). 33% of the subjects demanded a more upright posture with a smaller hip angle. This is reflected by the number deviations of more than four degrees for seat opening angle (32%, Table 6) as well.

The log files of the memory seat systems, in which each seat adjustment was recorded during shifts, indicated that the seat adjustment system was used extensively, which also corresponds to the information provided by the subjects (daily questionnaires). On average, 17 seat adjustments were registered per shift (MIN 7, MAX 47). This is proof that once the seat adjustment has been adjusted, it was not permanently used but preferred "active sitting" with several different seat settings. Of all stored seat settings during driving, 4% to 41% of each driver's seat position corresponded to seat setting 1. On average, seat setting 1 was taken in 17% of all seat settings and was thus remarkably more accepted than seat setting 2 (MW 5%, Min 0%, Max 34%), which was preferred by drivers during the seat adjustment procedure. The results of all stored seat configurations (Table 5) show that the preset settings with deviations of up to 4° or 4mm account for 70% (seat opening angle), 73% (seat surface inclination), 88% (seat height) and 70% (seat position), i.e. were generally accepted as far as possible and changed only slightly. The results of the follow-up survey a few weeks after the end of the test also show a relatively high acceptance of the suggested seating position, since 50% of the test persons stated that they would now adjust their conventional standard seat differently than before the test series. This can also be interpreted as an indication that drivers in public bus services should be offered training in seat adjustment for an ergonomic sitting posture, possibly at intervals of several years. Such time-consuming and personnel-intensive training can, however, be substituted, as shown in this study, by a driver seat system with memory function. The time required to use a seat memory system is then limited to the procedure for individual seat adjustment. In order to simplify such a procedure, it would be very useful if the seat adjustment could be determined based on the drivers' anthropometric data solely. However, the correlation matrices of the anthropometric data and the corresponding seat positions and posture/joint angles suggested that simple correlations between body dimensions and seat positions are not useful [3].

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Investigating subjective comfort with aircraft seat via ordinal regression

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Abstract In the scientific literature, the debate about how define and evaluate seat comfort is still open, but three points are not in question [1]: 1. comfort is a construct of a subjective nature; 2. comfort is affected by factors of various nature (physical, physiological, psychological); 3.comfort is a reaction to the environment. The subjective nature of the comfort experience is universally recognized; any comfort analysis cannot disregard subjective methods ('directly asking people about how comfortable they are'), which can be regarded as the most direct way to detect subjective feelings of comfort and/or discomfort. This paper focuses on the assessment of aircraft seating comfort based on subjective comfort responses collected during laboratory experiments. During each experimental session, participants were asked to express their overall seat comfort perception and to evaluate specific seat design features. Comfort responses were analyzed with the aim to relate the perceived overall seat comfort to some design features, as well as to the user anthropometrical characteristics and feelings. The adopted statistical modeling approach is based on generalized linear mixed models. Differently from the traditional strategies used for the analysis of subjective sitting comfort data (e.g. correlation analysis, non-parametric hypothesis tests), the model-based approach allows to investigate and quantify the relationship between overall seat comfort and specific seat/user characteristics. The results show that the overall comfort perception is significantly influenced by age, lumbar support, height of seat pan and reclining.

Keywords: seat comfort, repeated evaluations, laboratory experiments, ordinal regression

1 Introduction

Over the years, commercial air traffic and number of passengers have been constantly increasing and airlines are facing a fiercer competition in the international context. Being strictly related to passenger's satisfaction and willingness to pay, comfort improvement has become a major strategic goal for the airline management [1]. A variety of definitions of passenger comfort have been provided in literature and the scientific debate about the main factors impacting on it and the relationship with discomfort is still open [2-9].
Despite the variety of positions, it is undoubted that comfort perceptions are the outcomes of subjective experiences resulting from a reaction to the environment, influenced by psychological, physiological and physical factors. It is thus evident that any comfort analysis cannot disregard subjective methods ('directly asking people about how comfortable they are'), which can be regarded as the most direct way to detect subjective feelings of comfort. Large survey studies have been proposed in literature to investigate factors impacting on passenger perceptions of comfort/discomfort. Vink et al. [10] analyzed the online trip questionnaires of more than 10000 passengers in order to identify the critical factors influencing comfort experience during a flight; Amadhpour et al. [11] investigated whether the factors underlying the passenger experience of comfort differ from those of

discomfort; Bowens et al. [12] surveyed a sample of students about their aircraft sensory experiences and relate them to a feeling of comfort or discomfort. Most of the available studies evidence that seat comfort is one of the most important factors impacting on passenger on-board experience and a main driver for flight selection [13]. In order to attract and retain more passengers, airlines need to distinguish their offer from the competitors by providing a better seat comfort experience. However improve the design of aircraft seat for economic class is maybe one of the most difficult challenge for manufacturers since many necessary yet conflicting expectations and requirements have to be fulfilled (*e.g.* increase aircraft capacity, improve comfort and living space, lighten aircraft and meet safety requirements).

An effective strategy to collect and process comfort data is crucial to detect the seat design features which mostly impact on passenger perceived comfort and thus provide a *diagnostic* assessment of seat comfort.

Laboratory experiments allow to collect aircraft seat comfort data by involving potential passengers in simulated flight experiences [*e.g.* 14-16]. During these experiments, participants reveal information about their "real time" comfort feelings (e.g. thermal comfort, noise, cabin comfort, seat comfort, legroom); indeed, they are focused on the undertaken experiment rather than recall retrospective flight experiences like it happens for surveys. The main advantages of laboratory experiments are that: 1) researchers can control the environment under which potential passengers make their evaluations and also can compare different seats and/or aircraft environments; 2) a small sample representative of the passenger target population can be considered; 3) it is possible to learn more about aircraft seat experience with a significant reduction in costs and time for data collection and analysis [17-18]. Besides these advantages, experimenters are well aware that human responses in experimental research can be difficult to measure: 1) personal characteristics (*e.g.* demographic like age, nationality, income; physical like body size; physiological like blood pressure, state of health and general well-being; psychological linked to memory of previous flights, expectations about future experiences and personal preferences) make people experience different levels of comfort (or discomfort) in identical environments [*e.g.* 17-22]; 2) different personal experiences can cause people to react to the same situation in different ways and makes it difficult to measure the human responses to different stimuli (*i.e.* experimental treatments); 3) individual differences in rating scale usage cannot be neglected; 4) the same participants generally test several items (e.g. physical products or concepts) and, of course, these evaluations cannot be assumed independent; 5) subjective comfort data are collected via ordered categorical scales, in which scores are meaningful for comparison only.

All these factors and their interdependencies cannot be neglected in order to end up with reliable and robust comfort analysis [23]. Specifically, the first three criticisms may impact on the reproducibility and replicability of the study and they can be addressed by detailed experimental protocols and appropriate experimental design; the last two criticisms, instead, impact on the interpretation of comfort data and can be addressed by a suitable statistical modeling.

The approach adopted in this paper is model-based and accounts for both subjective (user anthropometrical characteristics and perceptions) and objective (seat features) covariates.

Comfort evaluations were modeled through a cumulative link mixed models (CLMMs), an extension of linear mixed models for ordinal data whose model specification and interpretation are more complex due to the discrete nature of the data and the nonlinearity in its parameters [24, 26]. The higher computational complexity of CLMMs is counterbalanced by the higher flexibility. Indeed the adopted CLMM accounts for the ordinal nature of the overall comfort response as well as the potential correlations among repeated comfort evaluations collected in laboratory experiments using a panel of aircraft passengers.

The paper is organized as follows: an overview of the experiment is provided in Section 2; the adopted data analysis strategy is illustrated in Sections 3; the experimental results are reported in Section 4; conclusions are drawn in Sections 5.

2 Overview of the experiment

The experiment involved 17 participants who tested 5 aircraft seat conditions. The participants were frequent flyers of working age with no health problems. The main anthropometric characteristics of participants are reported in Table 1.

During each test session, lasting about 40 minutes, each participant was asked to adopt a fixed posture and perform the task of reading/playing a game with the smartphone. At the end of each test session a trained interviewer asked the participant to evaluate the comfort of some seat features using a scale with three ordered categories (i.e. 1: low comfort, 2: medium comfort and 3: high comfort) and score the overall seating experience using an ordinal scale ranging from 0 (i.e. no comfort) to 8 (i.e. extreme comfort).

Table 1. Main anthropometric characteristics of participants.

	Num.	Age [year] [min-max]	Weight [kg] [min-max]	Height [m] [min-max]	BMI [kg/m^2] [min-max]
Males	9	[27-41]	[73-101.8]	[1.60-1.90]	[22.8-34.7]
Mean (SD)		35 (4.4)	88(8.53)	1.77 (0.08)	28.03 (3.46)
Females	8	[26-44]	[55-75]	[1.55-1.73]	[21.15-27.55]
Mean (SD)		34 (5.9)	66 (5.4)	1.66 (0.05)	24.1 (2.08)

3 Methods

Comfort ratings have been analyzed in a regression setting using a set of covariates representing: 1) objective seat features (*viz*. height of seat, height of seat pan, width of seat pan, backrest configuration, height of backrest, thick of backrest, reclining); 2) user anthropometrical characteristics (*viz*. gender, age, BMI); 3) comfort feelings with specific seat features (*viz*. seat pan, backrest, seat pan padding, backrest padding, lumbar support, lumbo-sacral support).

The cumulative logit model (CLM) is probably the most popular model for ordinal data; it relies on the idea that a subjective evaluation expressed on an ordinal scale (e.g. comfort rating) is actually a categorized version of an unobservable (latent) continuous variable. The CLM uses the cumulative logits to measure how likely the response is to be in a given category or below versus in a category higher than it.

Let Y_i the outcome category selected by subject i for the response variable. Given a set of p covariates, $x_1,..,x_k,...x_p$, the model is defined as follows:

$$\text{logit}\left[P\left(Y_i \le j\right)\right] = \alpha_j + \beta_1 x_1 + ... + \beta_k x_k + ... + \beta_p x_p \quad j = 1,..., J-1 \tag{1}$$

The model in (1) is characterized by (J−1) intercepts and p slopes. Intercepts may differ across the ordinal categories, whereas the coefficients β_k are the same across the categories, meaning that the effect of x_k is assumed to be the same for all the categories of the response Y. The parameter β_k measures the impact of x_k on Y, indeed it can be interpreted as the increase in the log-odd of falling into or below any category associated with a one-unit increase in x_k holding all the other covariates constant. The parameters α_j are the category cut-points on a standardized version of the latent variable and satisfy the condition

$$-\infty = \alpha_0 < \alpha_1 < \alpha_2 < \cdots < \alpha_J = +\infty \tag{2}$$

An extension of this model that includes random effects as well as fixed effects is the cumulative logit mixed model (CLMM). The CLMM allows taking into account both the ordinal nature of the rating scale and the potential correlation between ratings provided by the same subject under different conditions (*e.g.* the same subject testing different seats).

Let Y_{it} denote the overall comfort response over J ordered categories provided by subject i (i = 1, …, 17) for the seat t (t = 1, 2, 3, 4, 5); let x_{1it}, x_{2it} ,.., x_{kit} denote a set of k covariates; let u_i denote the random effect due to subject i for response categories $j=1, 2, ..., J-1$. The cumulative logit mixed model can be formulated as follows [25]:

$$logit\left[P\left(Y_{it} \le j\right)\right] = u_i + \alpha_j + \beta_1 x_{1it} + \beta_2 x_{2it} + \cdots + \beta_p x_{pit} \tag{3}$$

The random effect u_i is assumed normally distributed and centered at zero ($u_i \sim N(0, \sigma_u^2)$).

When a random effect is included in the model, it is important to look at the intra-class correlation (ICC). ICC is defined as the correlation of observations within a group and it is a way to look at how similar these within cluster observations are to one another. The ICC is calculated as follow:

$$ICC = \frac{\hat{\sigma}_u^2}{\hat{\sigma}_u^2 + \sigma^2} \tag{4}$$

where $\hat{s}_u^2$ represents the estimated variance of the random effect, whereas s^2 is the residual variance and assuming the hypothesis of an underlying standard logistic latent variable it can be calculated as $s^2 = p^2/3$. Values of ICC near one indicate that observations within a cluster are very similar to one another, while values close to zero indicate that the random effect can be neglected since observations within a group are nearly independent [25].

4 Results

In the adopted CLMM, the participant effect was assumed to be random and fixed effects included anthropometrical characteristics (*viz*. gender, age, BMI), objective seat features (*viz*. height of seat, height of seat pan, width of seat pan, backrest configuration, height of backrest, thick of backrest, reclining) and comfort feelings with specific seat features (*viz*. seat pan, backrest, seat pan padding, backrest padding, lumbar support, lumbo-sacral support).

A forward selection algorithm was applied in order to obtain the optimal model which includes 4 significant covariates: age (*age;* 1: ≤ 35 year; 2:≥ 35 year); lumbar support (*lumbsu;* 1:low, 2:medium; 3:high); height of seat pan (*heightsp*; 1:low, 2:medium; 3:high) and reclining (*rec;* 0:yes, 1: no).
Table 2 reports the estimated parameters β_k, $k = 1, 2, 3, 4$; the cut-points α_j, $j = 1, 2, 3, 4, 5, 6, 7$ with asymptotic standard error (in parentheses) and AIC index.

Table 2. CLMM fitted on comfort data.

Parameters	β_{age}	β_{lumbsu}	$\beta_{heightsp}$	β_{rec}	α_1	α_2	α_3	α_4	α_5	α_6	α_7
Estimates (Std Error)	0.824 (0.412)	1.478 (0.356)	-0.832 (0.288)	-2.01 (0.474)	-4.001 (1.21)	-3.971 (1.17)	-2.623 (1.15)	-1.262 (1.13)	0.198 (1.11)	1.549 (1.11)	3.257 (1.18)
AIC					292.42						

The coefficient values highlight that overall comfort ratings falling in higher categories are more likely as the values for age and comfort of lumbar support increase; instead overall comfort ratings falling in lower categories are more likely for seat in reclined position and higher seat pans.

The $\hat{\sigma}_u^2 = 0.003$ for the random effects model implies a low effect due to repeated evaluations provided by the same participant (Fig. **1**). Moreover, ICC equals to 0.0009 confirms the substantial independency of observations provided by the same participants for different seat conditions.

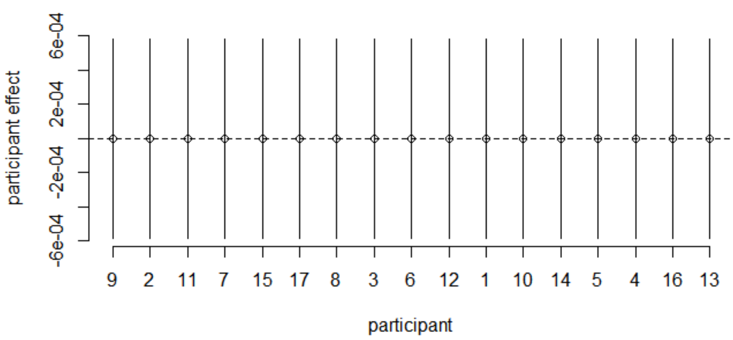

Fig. 1. Participant effect.

5 Conclusions

The adopted model based approach allows to investigate the strength and direction of association in subjective comfort data taking into account their ordinal nature as well as the potential grouping structure of replicated observations, overcoming the hypothesis of independency that is often unrealistic in experimental settings.

The findings highlight that the probability of low overall comfort perceptions is higher for seats in reclined position and seat with a higher seat pan; instead the lumbar support has a significant positive impact on the overall comfort perception. It is worthwhile to note that in our study, participant effect resulted negligible; this finding could be related to the involvement of a group of expert assessors (*i.e.* frequent flyers) who may show less individual psychological biases in the evaluation task. However, since psychological and physiological biases generally affect the subjective assessment in a sample set, assessor's effect cannot be disregarded. Further investigations are necessary in order to check the generalizability of findings outside laboratory setting.

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Applicability of modern correlation tools for ride comfort evaluation and estimation

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Abstract The automotive world is currently shifting focus towards electric vehicles (EVs) and the market of connected, autonomous vehicles (CAVs) is steadily growing. Vehicle ride comfort is an attribute which for years now have been a factor which has a significant influence on vehicle development programmes. Due to the complexity of ride comfort, achieving a good correlation between measured data and perceived comfort is a challenging task. Creating well-handling vehicles with pleasant ride characteristics is becoming not enough, as nowadays customers expect bespoke, tailored solutions such as active suspension systems instead of more traditional, passive solutions. The presented study aims to analyse the usability of modern correlation tools, such as artificial neural networks for objective and subjective data correlation, evaluation and explore the possibility of prediction of subjective responses based on the measured data. Data for the study was gathered on the HORIBA MIRA proving ground and public roads. Measured parameters consisted of the vehicle accelerations, anthropometric data of the experiment participants and subjective evaluations of perceived vibration magnitudes. Subjective responses were gathered using a group of 22 participants. The obtained dataset was divided into training and validation sets in the ratio of 80/20. Collected data was used in a correlation study using artificial neural networks (ANNs). The created model achieved a high correlation level of R=0.91. Presented study proves that correct use of advanced correlation techniques utilising artificial neural networks can create comfort models allowing for subjective comfort response estimation. Such an approach could significantly reduce the time required for the vehicle development process and would allow for more comfortable, bespoke vehicles in the future.

Keywords: Ride comfort, neural networks, whole-body vibration

1. Introduction

Vehicle ride comfort is an important characteristic, which is evaluated and tuned during the vehicle development process. Optimal vehicle comfort is achieved by balancing the shape and structure of the chassis and suspension characteristics[1]. With developments in technology, delivering higher comfort without compromising other valuable vehicle parameters such as handling, or stability has gotten easier as the suspension solutions used in the automotive industry became more sophisticated. Nowadays, the increased popularity of vehicles equipped with active and adaptive suspensions operated pneumatically or hydraulically can be observed[2]–[4]. Increased attention is being given towards autonomous vehicles (AVs)[5], which means that methods of evaluating ride comfort should be re-evaluated as the industry is slowly moving from a driver-centric model to more passenger-centric approach. Guidelines for ride comfort assessment can be found in ISO 2631:1997[6]. These guidelines are widely used and have been adopted by various manufacturers. Proper design of a vehicle suspension must balance two components, which are vehicle ride and handling. A significant amount of time during vehicle development is given to achieve the right balance between these two parameters. Therefore, it would be beneficial to automate that process. Ride comfort evaluation of any vehicle consists of two types of measurements[7]. The first one is the measurement of acceleration values that are transmitted from the road to the body of the driver or the passengers, which is referred to as objective data. The second type is the subjective measurement, which is obtained through questionnaires. Correlation between those two datasets is completed using statistical analysis. Studies have shown that a satisfying level of correlation can be achieved[8]. However, it requires many participants. It is common that during development stages of new vehicles discrepancies between objective and subjective data emerge [9]. Therefore, it would be beneficial to support the decision-making process based on previously gathered data [10]. Such an approach could be completed with existing tools such as artificial neural networks[11]. Authors of this paper explore the possibility of using modern correlation techniques involving artificial neural networks for correlation of objective and subjective data.

2. Methodology

The study presented in this paper has been divided into several stages. These were: data collection, analysis, preparation of the data for neural network training where the data were divided into training and validation sets, training of the data classifier using neural networks and validation of the trained classifier using validation dataset. Data collection was conducted with the cooperation of HORIBA MIRA from Nuneaton, UK. The researchers consulted vehicle dynamics team to utilise road sections which are used for vehicle ride comfort evaluation (fig. 1). To gather objective and subjective ride comfort data, a B segment vehicle was chosen. To minimise the influence of environmental parameters during testing, a professional driver was driving the car, and the data was collected from subjects seated in the passenger seat.

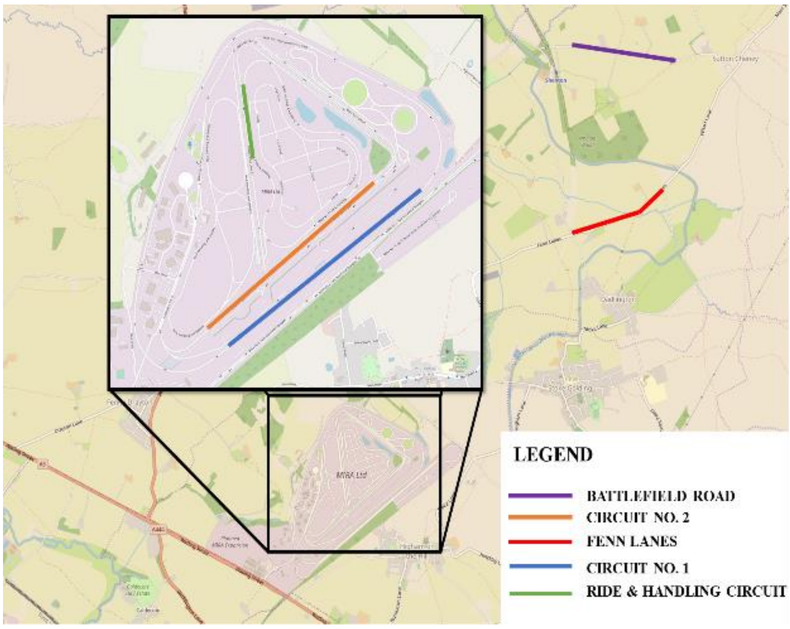

Fig. 1. Location of data collection road section.

Before data collection commenced, the vehicle was equipped with accelerometers. Total of 7 accelerometers was used. Four accelerometers attached to the bottoms of the suspension struts to measure the direct inputs from the road surface – the influence of the tire damping was neglected. To ensure minimal variance in collected data due to tire damping, the tire air pressure was controlled throughout the data collection phase. One accelerometer was placed on the seat rail beneath, and two accelerometer pads were placed on the seat – seat pad and seatback. Before data collection, calibration of the logging equipment was completed. The equipment used in the trials consisted of Bruel&Kjaer accelerometers connected to LMS SCADAS data logging equipment connected to a PC. Data was logged at a sampling rate of 1024Hz. Fig. 2 presents the power spectral density of the road sections used in the experiment.

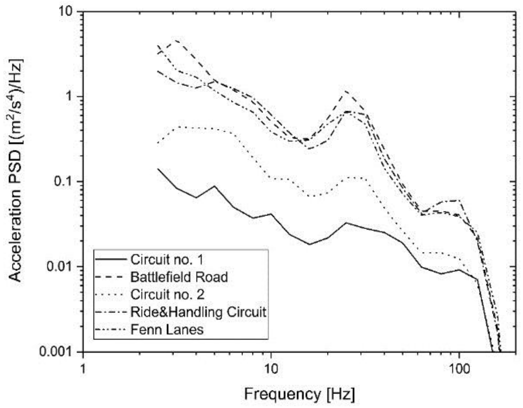

Fig. 2. Measured power spectral density of acceleration on test road sections.

Collected accelerometer measurements were analysed using MATLAB software. The data analysis procedure was based on the guidelines which can be found in the whole-body vibration standard and in the literature. Data were filtered using 6th order bandpass Butterworth filter from 0.8Hz to 150Hz and weighted using weighting functions found in the ISO2631:1997[12]. Weighted acceleration and vibration dose values were calculated using the equations (1) and (2).

$$a_w(t_0) = \left\{\frac{1}{\tau}\int_{t_0-\tau}^{t_0}[a_w(t)]^2 dt\right\}^2 \quad (1)$$

$$VDV = \left\{\int_0^T [a_w(t)]^4 dt\right\}^{\frac{1}{4}} \quad (2)$$

Besides the objective measurements, a subjective evaluation was conducted. Study participants were asked to rate several ride comfort metrics using SAE J1060 scale (fig. 3)[13]. The subjects were presented with vibration stimuli from the smoothest road section – chosen according to the data recorded and shown on the PSD graph above (fig. 2), to the harshest. The industry divides overall ride feel into several thresholds which are linked with respective vibration frequencies. Vibration occurring within 1-6Hz is referred to as primary ride[14], 6-20Hz as secondary ride. Any abrupt motions of the vehicle due to encountering potholes or bumps are referred to, like a jerk. The subjects used provided scales to assess the level of comfort of these conditions as well as overall perceived comfort during the ride.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
UNACCEPTABLE				BORDER LINE	ACCEPTABLE				
CONDITION NOTED BY									
ALL OBSERVERS		MOST OBSERVERS		SOME OBSERVERS	CRITICAL OBSERVERS		TRAINED OBSERVERS		NOBODY
Intolerable	Severe	Very Poor	Poor	Marginal	Barely Acceptable	Fair	Good	Very Good	Optimal
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Fig. 3. Subjective comfort scale, according to J1060 standard.

Twenty-two participants (N=22) took part in the experiment. Apart from objective acceleration data, anthropometric measurements of the test subjects were recorded as the literature suggests that there are biodynamic differences between differently sized subjects occurring while experiencing ride conditions [15]–[17]. Averaged subject data is presented in table 1.

Table 1. Mean data of all 22 subjects participating in the study.

	Standing height	Sitting height	Sitting shoulder height	Buttock popliteal length	Knee height	Shoulder breath	Hip Breadth	Age	Weight
Abbrev.	SH	SiH	SiSH	BPL	KH	SB	HB	-	-
Mean	179,7	105,9	77,2	51,1	53,3	45,7	36,4	35,8	80,6
SD	8,3	5,5	5,8	6,5	4,7	3,4	5,4	12,9	13,7

3. Ride comfort evaluation results

Some of the results obtained from the collected data are presented below. Figure 4 shows the on the left, the weighted acceleration values measured on each of the sections of road for the 22 participants. It is visible that the data shows a high level of consistency. To the right of the box, plots mean values of measured, weighted accelerations are presented. Fenn Lanes and Battlefield Road show the similar result of 0.75 and 0.77 m/s^2 respectively. Ride and handling circuit measured at 0.66m/s^2 mean weighted acceleration between all subjects, and the lowest scores were Circuit 2 and Circuit 1.

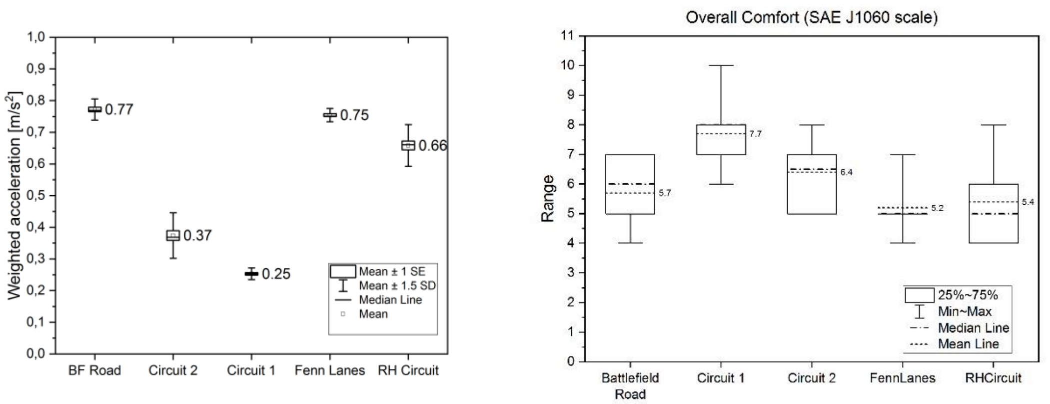

Fig. 4. Measured weighted acceleration and overall comfort scores between road sections.

In figure 4 on the right results of the subjective assessment are presented. The best mean score achieved on Circuit no. 1 (7.7), followed by Circuit no. 2 (6.4), Battlefield Road (5.7), Ride&Handling (5.4) and Fenn Lanes (5.2) respectively.

Table 2 shows current whole-body vibration standards guidelines regarding likely reaction to the vibration of absolute acceleration magnitude. Measured weighted acceleration values can be compared according to that table, to estimate likely subjective reaction. To increase fidelity and decrease the time required to conduct the subjective evaluation, we would like to propose an approach based on artificial neural networks, which is presented in the next subsection of this paper.

Table. 2 Likely reactions when exposed to vibration as per ISO2631:1997.

Weighted acceleration magnitude a_w [m/s^2]	**Likely reaction when exposed to vibration**
<0.315	not uncomfortable
0.315 – 0.630	a little uncomfortable
0.50 – 1.00	fairly uncomfortable
0.80 – 1.60	uncomfortable
1.25 – 2.50	very uncomfortable
>2.00	extremely uncomfortable

4. Deployment of neural network

Collected and analysed ride comfort data was used to create a ride comfort classifier based on artificial neural networks. The neural networks have been developed as a generalisation of mathematical models of biological nervous systems [18]. Essential elements of a neural network are artificial neurons which are also referred to as nodes. The connections between the neurons are represented by weights that modulate the input signals. Graphical representation of an artificial neuron is presented in fig 5.

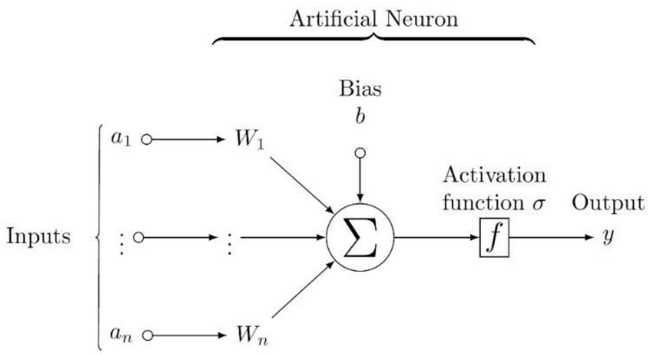

Fig. 5. Graphical representation of an artificial neuron.

The working principle of a neural network can be expressed mathematically as (3):

$$a^{(1)} = \sigma\left(\begin{bmatrix} W_{0,0} & \cdots & W_{0,n} \\ W_{1,0} & \cdots & W_{1,n} \\ \vdots & \ddots & \vdots \\ W_{k,0} & \cdots & W_{k,n} \end{bmatrix} \begin{bmatrix} a_0^{(0)} \\ a_1^{(0)} \\ \vdots \\ a_n^{(0)} \end{bmatrix} + \begin{bmatrix} b_0^{(0)} \\ b_0^{(0)} \\ \vdots \\ b_n^{(0)} \end{bmatrix}\right) \tag{3}$$

This can be shortened and expressed as (4):

$$a^{(1)} = \sigma(Wa^{(0)} + b) \tag{4}$$

Where σ – is the logistic activation function, W represents the weights of the neural network and b the biases.

The firing of the neuron is dependent on the state of the activation function. There can be different activation functions used in a neural network. The simplest activation function is the logistic activation function $\sigma(x)$ (5) which has been used in this case study.

$$\sigma(x) = \frac{L}{1+e^{-k(x-x_0)}} \quad (5)$$

For purposes of this study a multi-layer perceptron (MLP) network was used. MLP is a class of feedforward artificial neural network.

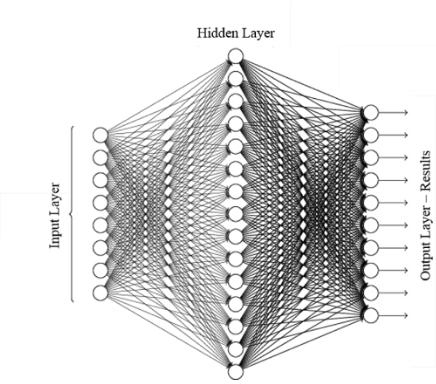

Fig. 6. Graphical representation of a multi-layer perceptron.

Such networks consist of at least three layers of nodes: an input layer, a hidden layer and an output layer (fig. 6) are using tabular data for inputs and outputs which correlates well with the type of dataset that was obtained from the ride comfort studies[19]. This type of network utilises supervised learning technique, called backpropagation for training. In training desired results are fed into the network and weights, and biases of nodes in the hidden layer are optimised in such a way so that the error between estimated result and the actual result is minimal. The calculated error is then backpropagated through the network and is used to modify the weights and biases to achieve optimum. Due to its multiple layers of nodes and non-linear activation function, an example of which has been presented in (5), this type of network is distinguished from a linear perceptron, and it can distinguish data that is not linearly separable.

The data from the data collection phase was analysed and prepared to be used in the neural network training process. As 22 separate datasets of results were obtained, the data was divided into two sets. One set of 16 used for neural network training and the other set of 6 used for validation of the trained classifier. Each set consisted of 19 measured parameters over five sections of road.

The inputs in equation (6), (7) and outputs in equation (8) have been prepared to be used in the neural network training process. A higher number of inputs, than the described minimum in the ISO2631:1997, was used in the input matrix. This data also included the anthropometric measurements of the test participants.

$$I_i = [SH \quad SiH \quad SiSH \quad BPL \quad KH \quad SB \quad HB \quad Weight \quad BMI \quad A_{wx} \quad A_{wy} \quad A_{wz} \cdots \quad (6)$$
$$\cdots MTVV_x \quad MTVV_y \quad MTVV_z \quad VDV_x \quad VDV_y \quad VDV_z]^T$$
$$inputs = [I_1 I_2 I_3 I_4 \cdots I_{80}] \quad (7)$$
$$outputs = [SCV_1 SCV_2 SCV_3 SCV_4 \cdots SCV_{16}] \quad (8)$$

The output (8) consisted of the subjective evaluation results (SCV = Subjective Comfort Value) of test participants collected on each of the road sections.

5. Results of the ride comfort classifier

The neural network was trained on the acquired dataset. As the outcome of the training, due to the nature of the neural networks, may differ between training runs, parametric analysis was conducted. Several parameters of the network, such as performance function or the backpropagation algorithm, were tested. As a result, the researchers concluded that for solving this particular problem the best performing network utilises Levenberg-Marquardt backpropagation algorithm, which combines characteristics of Gauss-Newton method and stochastic gradient descent, for calculating the weights and biases. The parametric study showed that using mean squared error function for calculating the errors will be optimal. The performance of the trained classifier is presented in fig. 7. The trained network has achieved R=0.91.

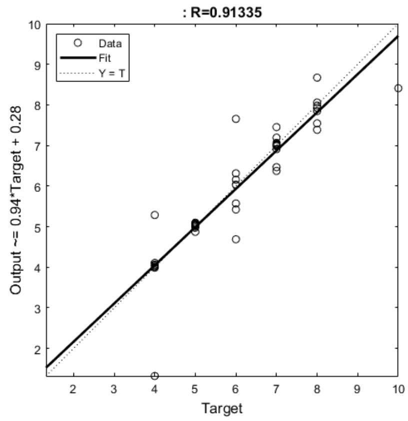

Fig. 7. Linear regression result of the trained correlation model.

To validate the classifier, the validation dataset was used, which consisted of data collected from 6 participants. Trained classifier was presented with measured objective data and anthropometric details of the participants. Calculation of estimated subjective responses was conducted. The error between estimated results and subjective responses given by the test participants are presented in fig. 8.

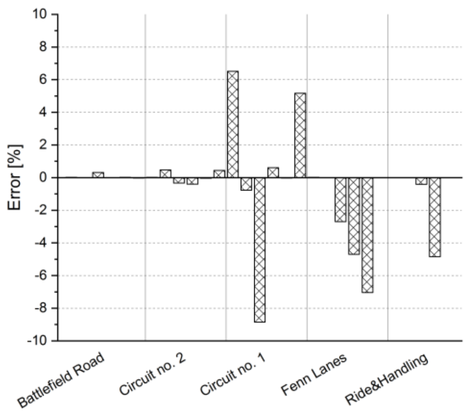

Fig. 8. Measured prediction error when applying the trained neural network model.

Fig. 8 is divided into five sections representing roads the test was conducted on. The percentage of error is visible on the vertical axis of the graph. The trained network performed very well when estimating the results on Battlefield Road section and Circuit no. 2. Calculated subjective responses are less accurate for Circuit no. 1, Fenn Lanes and Ride&Handling Circuits; however, they are still within 10% error from the actual response.

6. Conclusions

The technique presented in this paper shows the applicability of modern correlation techniques, such as artificial neural networks for ride comfort estimation. The presented study shows that implementation of artificial intelligence and neural networks into established procedures could speed up the development process of vehicles. The trained neural network achieved a high level of accuracy, R=0.91. Already automotive manufacturers are gathering vast quantities of data, which could potentially be used to increase the level of comfort of their customers and save money otherwise spent in development stages. The researchers recognise that the presented study can be treated only as a proof of concept. It would require larger dataset and further validation in a variety of environments to ensure the validity of estimated results produced by such an approach. We also recognise that the field bridging ride comfort with computer science is still relatively unexplored and requires further investigation.

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A 3D Anthropometric Approach for Designing a Sizing System for Tight Fitting Garments

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Abstract Current sizing charts on the surfing market have been set up with the use of surveys and optimized based on customer feedback. It might not consider the entire population outside their current customer population. Furthermore, these sizing charts are created based on one dimensional measurements and therefore do not capture the full shape of the human body. The purpose of this study is to develop a new approach in creating sizing systems of wetsuits for the surfing industry, using readily available tools. A good sizing system focusses on the balance between fit, comfort and functionality. The industry has been relying on traditional 2D pattern drawing methods. 3D methods have been introduced for personalization but has is not yet implemented for the design for larger populations. This research provides a 3D anthropometric framework that assesses the natural body shape variations within a given user population. The focus is on gaining the highest level of coverage through determining the right body type classification. As a result, digital mannequins are created that can serve as representation of body types associated with specific apparel sizes. This research addresses the sizing of wetsuits for the European market through a full body 3D anthropometric analysis of over 2000 surfer-like body scans from the CAESAR database. Furthermore, different methods are investigated in classification of body types considering the prioritization of different anthropometric dimensions. The resulting population is divided in groups that would be suitable for a specific wetsuit size. These groups are merged into average and extreme 3D mannequins that can be used in 3D apparel design software such as Clo3D or Optitex. The approach is demonstrated on Italian and Dutch subjects with the goal to pro-vide a good coverage for the European market. It can be trivially extended to other populations when suitable data is available.

Keywords: 3D anthropometrics, wetsuit, digital mannequins, sizing system.

1 Introduction

Within the world of wetsuits, the fit and performance of a wetsuit play a critical role in the level of comfort (Naebe et al., 2013). Wetsuit brands are constantly trying to optimize the fit of their designs to better match the customer population. Yet little is known about the anthropometry of the users. European guidelines, such as EN 13402[2], can serve as a good basis for the sizing of garments. But this standard is based on traditional 2D measurements providing a coarse description of shape and size of the human body. With modern technologies such as 3D scanning it is possible to gain more insight in the complex surfaces of the human body (Robinette et al., 1999). Different studies have been performed showing the opportunities in the creation of wetsuit patterns using 3D scans and 3D flattening methods (Naglic et al., 2016; Naglic et al., 2017). Yet these studies focus on diving wetsuits with the use of individual 3D models. The methods have yet to be used in the design for a larger population. Digital simulations have shown its potential in testing both static and dynamic fit (Wu et al., 2017). Wu et al. assesses the dynamic fit by analyzing static poses. This study will investigate the use of motion tracking to assess the full motion during the wetsuit design process.

The goal is to create digital mannequins that can be used for the creation of wetsuit patterns for the surfing industry. These mannequins will give insight in the anthropometric differences of the intended user population between the different wetsuit sizes. These models might also be used within pattern creation software to design for an optimal fit. The models are created based on the current sizing chart of the wetsuit brand SRFACE[7]. They sell wetsuits focused on European males between the age of 18 and 45. For the creation of mannequins a distinction should be made between people who should fit in a standard size (S, M, L etc.) and people who should fit in a tall (ST, MT etc.) size or short (MS, LS, etc.) size. The height distribution for these sizes is used as basis for the creation of mannequins. This will give insight in the anthropometry of each individual size. The research question is: How can we generate 3D anthropometrical data that serves as representation of the user population for the creation and assessment of wetsuit patterns.

2 Method

The CAESAR[3] database has been used as a representation of the user population. It contains measurements and 3D scans of 3 different populations. A Dutch population with n=1267, an Italian population with n=802 and an American population of n=2387. The scope of this research focuses on the European market as a whole. Table 4 contains the percentile height values of the current SRFACE sizes compared to the different CAESAR populations of men between the age of 20-45 years. The Italian and Dutch CAESAR population has been used as a representation of the intended user population. By using both data collections, a more gen-eral population distribution is acquired.

Table 1. Height percentiles of the male Dutch and Italian CAESAR subjects between 20 and 45 years old.

Ad-hoc	*Height (mm)*	*NL*	*IT*	*NL+IT*
XS	1680	P3	P19	P11
S	1730	P13	P48	P29
M	1770	P26	P69	P45
L	1810	P46	P86	P64
XL	1840	P58	P93	P74
XLT	1890	P80	P92	P88

The body scans within this database were used for the creation of three different mannequins for each wetsuit size. A mannequins that represent a general body type of an average user. And two extreme mannequins that represent body types with the highest and lowest body volume that should still fit the same wetsuit size (re-sults not shown). To create accurate mannequins a selection was made of body scans that classify as a certain garment size. Creating an average body out of multiple 3D scans eliminates the characteristics of the individ-ual scans and will focus the mannequin on common body shape features within the size group.

Body types of people that would most likely not be surfers should were excluded. This resulted in mannequins which are more specific for the target population of surfers. Three different approaches were applied for excluding body types based on the paper based on the work of Barlow et al. (2012). Barlow made a distinction between 3 different surfer categories; professional, intermediate and junior surfers. The junior population, with the age of 15±1 years, were not taken into account. The Quetelet index (Body Mass Index, BMI) was used, for it has a high correlation with body fat percentage (Revicki et al., 1986) and could be calculated with the measurements in CAESAR (Robinette et al., 1999). The results of Barlow et al. (2012) for the subscapular skinfold, triceps skinfold, and BMI were used as criteria. The criteria were set to exclude the top and bot-tom 2.5% of the surfing population. This resulted in the following criteria for excluding body types of non-surfers: body scans with 19<BMI<29, 0<Subscapular Skinfold<20 and 3<Triceps Skinfold<17 will be included for the creation of mannequins.

The resulting population represents possible surfer body types. The most important measurements used in the wetsuit industry are height, chest and waist. In the CAESAR project these dimensions have been measured for every individual. But measured waist is the preferred waist relating to the preferred height at which trousers are worn in the waist area. Within the surfing industry the waist is measured as the thinnest waist located just above the belly button. For the classification, only the height and chest were used, with the height as primary dimension and the chest circumference as the secondary. The sizing chart of the wetsuit brand SRFACE (2019) was used as reference where different classifications were addressed based on chest coverage while keeping the height coverage consistent. Dined[10] was used to map out different classification methods on top of a 2D scatter plot of the height and chest circumference. To enable the combining of body scans New 3D meshes of the CAESAR body scans have been generated in Wrap 3[11] using template wrapping. This resulted in 3D meshes with a consistent amount of faces. The sizing groups resulting from the classification method were then combined into an average body type using Paraview[12].

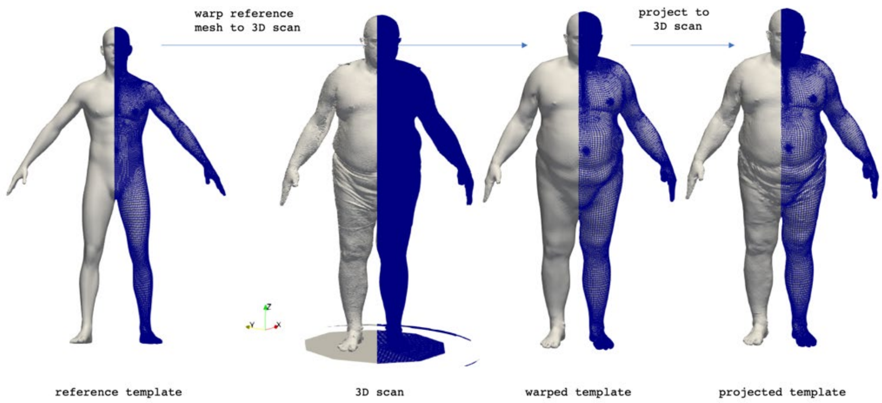

Fig. 1. Template warping workflow.

To be able to test not only the static fit but also the fit during motions (dynamic fit) of garments the static mannequins were animated. Different surfing motions result in different dynamic fit requirements. A selection of surfing motions were captured using the Noitom Perception Neuron[13] to enable designers to analyze a wetsuit pattern. These motions consisted out of, sitting, paddling, duck dive and the pop-up. The pop-up motion incorporated the overall stance on a surfboard. These motions were added as skeletal animations to the medium mannequin.

As a last step, a new wetsuit pattern was created using Clo3D[14]. During this step the usage of the mannequins was put into practice. The new pattern was created in Clo3D based on the current 5/4mm medium sized SRFACE wetsuit (2019). Different types, thicknesses and lining combinations of Neoprene were tested on their physical stress and strain behavior using a tensile tester (Zwick/Roell model Z010, Germany). The results were used to generate digital materials in Clo3D to enable stress and strain simulations of the pattern. The static and dynamic fit were analyzed using the 3D stress and strain maps of Clo3D.

3 Results

Figure X shows the sizing distribution mapped on a scatter plot of chest circumference and stature for the combined Dutch and Italian populations. The plot shows a configuration where the standard sizes (XS, S,M,L, XL are located on the average chest circumference within a given height range. The tall (ST, MT, LT) and short (MS, LS) sizes are located next to the standard sizes with an offset of 3 cm. This distribution has a coverage percentage of 55%, an overlap of around 7% and a chest coverage ranging from 86-104cm.

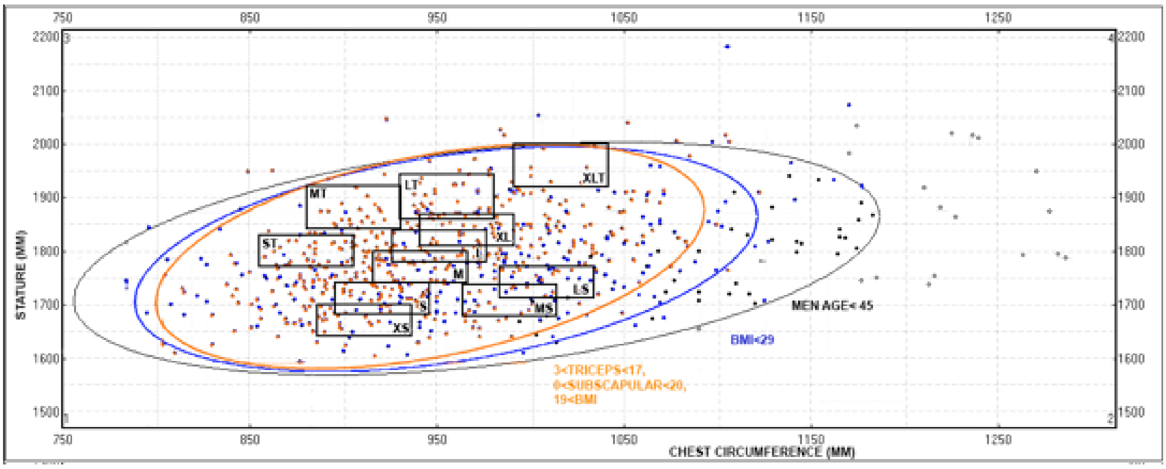

Fig. 2. Classification method used for the creation of mannequins.

Using the classification shown in Figure 2, the CAESAR population is divided into sizing groups. Figure 3 shows the average mannequins created using the average based classification method for the standard sizes ranging from XS to XL, tall sizes ranging from ST to XLT and short sizes ranging from MS to LS.

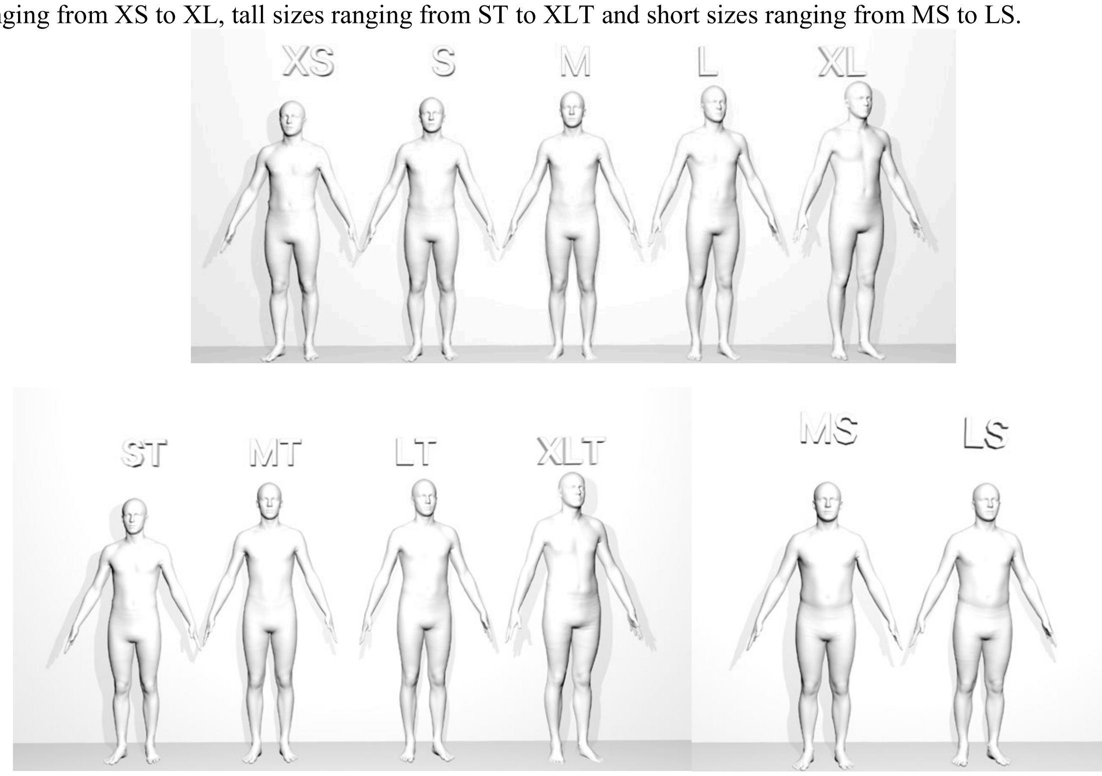

Fig. 3. Average body types for individual sizes.

The medium mannequin has been animated with 4 surfing motions and used to digitally assess the fit of the during the design process of a medium SRFACE wetsuit. Figure 4 visualizes the design process together with the strain mapping of the stretched percentage throughout the wetsuit. Both a static and two dynamic simulations are shown together with the physical prototype. The mannequin shown in figure 4 is created in Clo3D by wrapping the standard mannequin on the medium mannequin shown in figure 3. The resulting mannequin has the same anthropometric dimensions and has been used as demonstration.

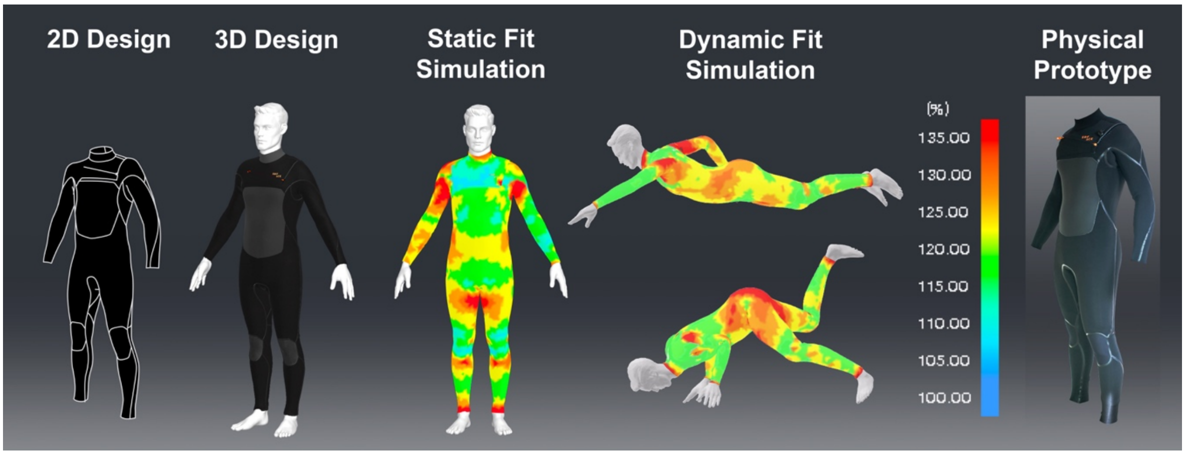

Fig. 4. The different stages of the wetsuit design process.

4 Conclusion & Discussion

The creation of the prototype is done by a designer with no prior knowledge on pattern creation over the course of a couple of weeks. The fit and comfort of the prototype have been assessed by two surfers with a medium body type. Their overall judgement on its comfort turned out to be positive. So the preliminary results show that the use of the 3D mannequins has promising potential for the creation and assessment of wetsuit patterns. The first impression is that this method gives a more readily available design of wetsuits, that may need only minor corrections. It shows potential in reducing the amount of physical prototyping needed to create a finalized product. This can save a lot of time and costs. This is quite a contrast to existing methods for wetsuit design.

Because the prototype is designed for a population group and comfort is a subjective experience, assessment should be made on a larger scale with the use of customer satisfaction and feedback. This step has not been performed inside this study. Based on a primary and secondary dimension a mannequin can be created giving more insight in the overall anthropometry of the users of a specific garment size. The use of such mannequins could be extended to other markets. Any bodily measurement can be extracted from these mannequins for any type of garment.

There are a lot of different classification methods that could be used in the creation of mannequins. Coverage range, market consistency, EU standard consistency and overlap between sizes are important considerations when creating a sizing distribution. The classification method used for the creation of mannequins serves as an illustration. It deviates from sizing charts used in the current market. Using a more consistent distribution will cause less confusion for customers who expect sizing consistency between brands.

The animations captured by the Neuron motion capture suit needed manual adjustments to eliminate artifacts in the motions. The motion capture device used in this work is sensitive to magnetic field disturbances such as caused by metal objects in the vicinity of the subject. In future work, we will eliminate metal objects from the motion tracking environment for improved accuracy. Furthermore, the deformation of the mannequins during these motions should not be seen as accurate human skin deformations. The resulting fit analysis should be seen as approximative simulation. Further work could investigate the opportunities in 4D scanning, weight painting, and muscle-centered skin deformers.

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Analysis and Modeling of Human – Seat Interaction Using Bio and Contact Mechanics

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Abstract Presented in this paper is a method to study the interaction between human body and aircraft seat for the comfortability analysis. First, the human body is modeled using the bio mechanics and divided into a number of body segments connected by joints according to human anatomy. The angles between each body segments are obtained from mathematical analysis from existing bio mechanical research data. The contact forces between human body and the seat are modeled using pairs of bi-lateral point forces. These forces are calculated and located with the analysis of the center of gravity of each body segments and average muscular structure of the human body. The geometry of the human body is derived from the spine curves of the sitting position and average body type. Second, the pressure distribution between the human body and the seat is modeled and calculated using the contact stress theory. The results of the two parts are combined to analyze the comfortability in relation to different posture and backrest recline angles. At the end, the modeling result is compared with pressure sensor data for validation.

Keywords: Bio-modeling, contact modeling, seat-human interaction, seating comfort

1 Introduction

Aircraft passengers' comfort has become an increasing concern for airliners as it greatly affects passenger's travel experience [1]. In recent years, the study of comfortability for cabin environment has been one of the most important topics in this research. The existing studies so far contain measurement and analysis of human muscle activity [2], geometric parameters of seat [3], postural analysis [4-6], with the pressure distribution between the human body and seat identified as the key in the evaluation of sitting comfort [7]. Ideally, the pressure distribution between the human body and seat should be homogeneous, but very often there exist some high pressure areas causing discomfort [8]. The past studies include static and dynamic pressure, with the former being directly associated with comfort ratings [9]. The latter was used to evaluate the human postural change in order to adjust the posture and reduce the discomfort [8,10,11]. Some software, such as AnyBody, OpenSim, PAM-comfort and Adams, has been used to develop human bio-models for seating comfort research [12,13]. These studies are used to calculate the interface pressure and surface friction forces [14]. However, most researches assume the spine as one segment with no consideration of the influence of the spine curve.

The objective of this study is to develop a complete bio-model for sitting comfort through the following steps: 1) put forward a method to model a spine curve in relation to the human contact points with the seat; 2) apply a multi-body dynamics method to model the human forces at the contact points; 3) apply a contact mechanics method to model the contact pressure distribution; 4) validate the proposed model by the experiment.

2 Modeling

2.1 System Description

Fig. 1 illustrates a person sitting in a seat with contact forces at contact points. The human body is divided into nine segments: feet, calf, thigh, pelvis, lumbar, thoracic-2, thoracic-1, cervical and head. For modeling, a global coordinate system O_XYZ is set with the origin at a point in space. $o_0\_x_0y_0z_0$ is the local coordinate system attached to the seat, and $o_i\_x_iy_iz_i$ is a body segment coordinate system. Symbol m_i represents the mass of ith segment, g is the gravitational constant, l_i represents the length of ith segment, θ_i represents the angle of ith segment joint, $\mathbf{w}_\mathrm{i} = [\mathbf{f}_\mathrm{i} \quad \mathbf{m}_\mathrm{i}]^\mathbf{T}$ is the wrench of ith segment including force vector $\mathbf{f}_\mathrm{i}$ and moment vector $\mathbf{m}_\mathrm{i}$. The force vector is decomposed to the normal f_{ni} and tangential force f_{ti}. φ is the recline angle of the seat which is defined between 90-180 degree.

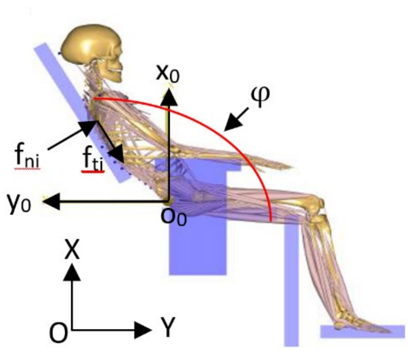

Fig. 1. Human sits on the seat

If a person sits upright, the body weight is mainly supported by the hip and thighs. Once the human leans against the backrest especially when the seat reclines, it will generate the contact forces between the human and the backrest. The first part of this method to model the spine curve in different sitting postures and obtain the joint angles and contact points, based on which the contact forces and pressure distributions can be determined.

2.2 Modeling of Spine Curve

The human spine is modeled by curve fitting the existing bio mechanical research data [15]. The following equations are obtained for different common seating postures. The erected posture is modeled as

$$f_E = -1.525 \times 10^{-10}x^7 + 6.114 \times 10^{-8}x^6 - 9.939 \times 10^{-6}x^5 + 8.389 \times 10^{-4}x^4 - 0.03894x^3 + 0.9667x^2 -$$

$$11.37x + 41.57 \quad (1)$$

The normal posture is modeled as

$$f_N = 1.753e^{-10}x^7 - 4.755e^{-8}x^6 + 4.97e^{-6}x^5 - 0.0002511x^4 + 0.006453x^3 - 0.09109x^2 + 1.072x - 16.78 \quad (2)$$

The slouched posture is modeled as

$$f_S = 1.39\times10^{-10}x^7 - 3.5\times10^{-8}x^6 + 3.214\times10^{-6}x^5 - 1.233\times10^{-4}x^4 + 1.329\times10^{-3}x^3 + 0.02428x^2 - 0.3235x - 10.13 \quad (3)$$

where $x \in [15, 75]$cm represents the spine by connecting the pelvis to the head. For used polynomials, the reason for a particular degree chosen is that the curvature of the curve near the end points of the data doesn't change sharply. It is especially important in this case as those equations are used to calculate the instantaneous radius. The orientation of this base line is related to the recline angle of the seat. The given spine range can be scaled up or down to account for the height difference of individuals.

For force analysis, a spine is segmented according to the position percentage of spine segments: cervical, thoracic-1, thoracic-2 and lumbar. These segments are linearized and connected by lines through the nodal points modeled as revolute joints. Since the length of each segment is known, its coordinate can be determined by

$$L = \int_b^a \sqrt{1 + \left(\frac{df}{dx}\right)^2}\, dx \quad (4)$$

where a and b are the x coordinates of the two end points of each segment. By using our proposed method, the linearized spine model can be determined for the three postures as shown in Fig. 2. The relative angles between adjacent lines are determined to represent the joint angles as listed in Table 1 for the three postures.

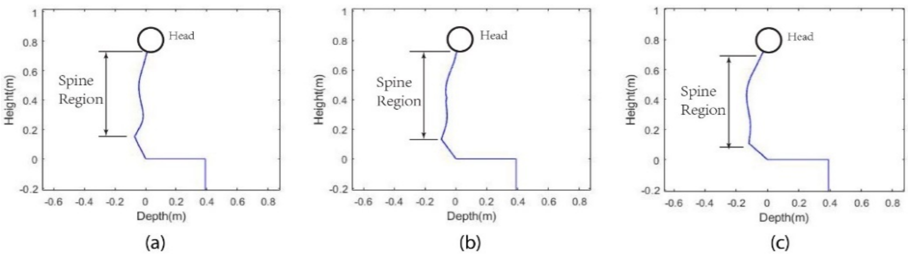

Fig. 2. Plot of the spine curve. (a) Erected posture, (b) Normal posture, (c) Slouched posture

Table 1. Joint angles for different postures

Posture	θ_1 (°)	θ_2 (°)	θ_3 (°)	θ_4 (°)	θ_5 (°)	θ_6 (°)	θ_7 (°)	θ_8 (°)
Erected	0	90	-64.6	-41.6	26.1	-19.7	-4.73	0.1
Normal	0	90	-54.4	-46.45	13.9	-18.3	-0.8	0.46
Slouched	0	90	-52.1	-47.6	5.1	-25.4	-5.8	0.1

Fig. 3 plots the spine model by including the backrest model. It indicates that for the erected and normal posture, initially both thoracic-1 and lumbar have a contact with the backrest simultaneously, but thoracic-2 is at a small distance away from the backrest. Therefore, it is reasonable to consider the initial contact with the backrest through thoracic 1 and lumbar and then progressing to thoracic-2. For the slouched posture, only thoracic-2 and lumbar would be in contact with the backrest. This is a posture that most likely to happen when a person sits up and leans forward for activities like reading and writing. It is quite unnatural for someone to have a slouched posture when leans back to relax. Therefore, the interaction between the human body and the backrest for the slouched posture is excluded.

For the other two postures, the points of initial contact can be estimated using Fig. 3. For the erected posture, it is approximately at 70% and 30% of the base line from the bottom for thoracic 1 and lumbar, respectively. For the normal posture, it is approximately at 50% and 50% of the base line from the bottom for thoracic 1 and lumbar, respectively.

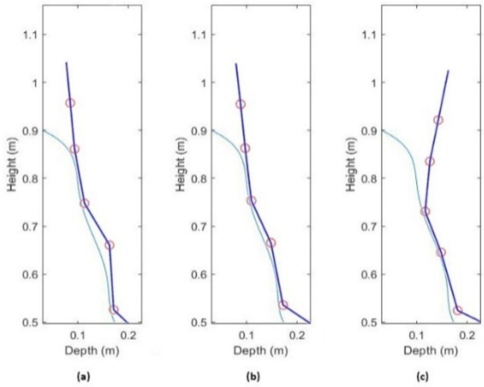

Fig. 3. Plot of segmented spine model against the mid cross-sectional profile of the backrest. (a) Erected posture, (b) Normal posture, (c) Slouched posture

2.3 Modeling of Contact Force

In this section, a multi-body dynamics method is applied to determine the body forces. starting with the segmented spine, which can be represented by links connected by revolve joints. In line with a backward recursive method [16], the forces and moments acting on the *i*th joint can be expressed from the head through the spine segments to the pelvis as

$$\mathbf{w}_i = \mathbf{M}_i \dot{\boldsymbol{t}}_i^J + \mathbf{B}_i + \mathbf{H}_{ii+1}\mathbf{w}_{i+1} + \mathbf{N}_{ii+1}\boldsymbol{w}_{ni} \tag{5}$$

where $\mathbf{w}_\mathrm{i} = [\mathbf{f}_\mathrm{i} \quad \mathbf{m}_\mathrm{i}]^\mathbf{T}$ is the wrench consisting force vector$\mathbf{f}_\mathrm{i}$ and moment vector $\mathbf{m}_\mathrm{i}$ of the *i*th joint, $\mathbf{M}_i = \begin{bmatrix} m_i\boldsymbol{E}_{3\times3} & m_i\tilde{\mathbf{b}}_{Ci}^{S\,T} \\ m_i\tilde{\mathbf{b}}_{Ci}^S & \mathbf{I}_i \end{bmatrix}$ is the generalized mass matrix of the *i*th segment, m_i is the segment mass, $\boldsymbol{E}_{3\times3}$ is the unitary matrix, $\tilde{\mathbf{b}}_{Ci}^S$ is the skew matrix of centroid vector, $\mathbf{b}_{Ci}^S$, $\dot{\boldsymbol{t}}_i^J = \begin{bmatrix} \mathbf{a}_i - \mathbf{g} \\ \boldsymbol{\alpha}_i \end{bmatrix}$ is called twist including linear acceleration vector $\mathbf{a}_i - \mathbf{g}$ and angular acceleration vector $\boldsymbol{\alpha}_i$, vector $\mathbf{B}_i = \begin{bmatrix} m_i\boldsymbol{\omega}_i \times (\boldsymbol{\omega}_i \times \tilde{\mathbf{b}}_{Ci}^S) \\ \boldsymbol{\omega}_i \times (\mathbf{I}_i\boldsymbol{\omega}_i) \end{bmatrix}$ is the matrix includes centrifugal forces and gyroscopic moments, $\mathbf{w}_{i+1}$ is the wrench for the upper (*i*+1)th joint, $\mathbf{H}_{ii+1} = \begin{bmatrix} \boldsymbol{E}_{3\times3} & \mathbf{0} \\ \tilde{\mathbf{b}}_i^S & \boldsymbol{E}_{3\times3} \end{bmatrix}$ is the transformation matrix between two adjacent joints, and $\mathbf{b}_i^S$ is the vector from the *i*th joint to (*i*+1)th joint, $\mathbf{N}_{ii+1} = \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \tilde{\mathbf{b}}_{ni}^S & \mathbf{0} \end{bmatrix}$is the transformation matrix of the contact wrench $\boldsymbol{w}_{ni}$ and $\mathbf{b}_{ni}^S$ is the vector from the *i*th joint to the contact point of the *i*th segment.

For quasi-static case that represents the normal human sitting in the seat, it is reasonable to assume negligible velocity and acceleration, i.e. $\boldsymbol{\omega}_i = 0$, then $\mathbf{B}_i = 0$ and $\dot{\boldsymbol{t}}_i^J = [-\mathbf{g} \quad \mathbf{0}]^T$ Projecting $\boldsymbol{w}_i$ about the rotation z-axis leads to the moment equilibrium equation as

$$\tau_i = \boldsymbol{z}_i \cdot \mathbf{m}_i^T = 0 \tag{6}$$

Substituting the moment vector into Eq. (6) yields

$$0 = \boldsymbol{z}_i \cdot \left(-m_i\tilde{\mathbf{b}}_{Ci}^S\mathbf{g} + \tilde{\mathbf{b}}_i^S\boldsymbol{f}_{i+1}^T + \tilde{\mathbf{b}}_{ni}^S\boldsymbol{f}_{ni}^T\right) \tag{7}$$

For a planar case, the above model can be greatly simplified to determine the normal contact force of the *i*th segment as

$$f_{ni} = \frac{(f_{i+1} b_i \sin(\theta_{i+1}) + m_i g b_{Ci} \sin(\delta_i))}{b_{ni}} \tag{8}$$

where $f_{ni} = \|\boldsymbol{f}_{ni}\|$, $b_i = \|\mathbf{b}_i^S\|$,, $g = \|\mathbf{g}\|$, $b_{Ci} = \|\mathbf{b}_{Ci}^S\|$, $b_{ni} = \|\mathbf{b}_{ni}^S\|$,, δ_i is the intersection angle between the gravity vector and the segment line vector $\overrightarrow{o_i o_{i+1}}$, expressed as

$$\delta_i = \cos^{-1}\left(\frac{\overrightarrow{o_i o_{i+1}} \cdot m_i g}{\|o_i o_{i+1}\| \|m_i g\|}\right) \tag{9}$$

Then, the tangential force can be expressed as

$$f_{ti} = m_i g \cos(\delta_i) + f_{i+1} \cos(\theta_{i+1}) \tag{10}$$

The friction force can be determined as

$$f_{fi} = f_{ni} u \tag{11}$$

where u is the friction coefficient. In terms of the forces passing down from the upper segment to the lower segment, there are two cases. The first case is no contact in that segment $\boldsymbol{w}_{ni} = 0$, then the segment weight will be completely passed down to the next segment. The second case is with contact $\boldsymbol{w}_{ni} \neq 0$, the force in the normal direction will be balanced, but the tangential force will be passed down to the next joint as

$$f_{di} = \begin{cases} 0 & i = 9 \\ f_{ti} + f_{ni} u & i < 9 \end{cases} \tag{12}$$

where i=9 indicates the head. As an example, the force from the head to the neck is described below. Referring to Fig. 4, the normal force, tangential force and friction force on the head can be expressed as:

$$f_{n8} = \frac{(m_8 g b_{C8} \sin(\delta_8))}{b_{n8}} \tag{13}$$

$$f_{t8} = m_8 g \cos(\delta_8) \tag{14}$$

$$f_{f8} = f_{n8} u \tag{15}$$

where $\delta_8 = \cos^{-1}\left(\frac{\overrightarrow{o_8 o_9} \cdot m_8 g}{\|o_8 o_9\| \|m_8 g\|}\right)$. The total force from the head passed to the neck is

$$f_{d8} = m_8 g \cos(\delta_8) + \frac{(0 + m_8 g b_{C8} \sin(\delta_8))}{b_{n8}} u \tag{16}$$

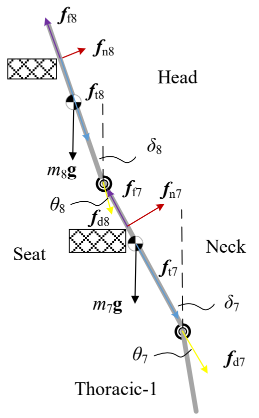

Fig. 4. Case for head and neck

For the neck, the normal force is

$$f_{n7} = \frac{(f_{d8} b_7 \sin(\theta_8) + m_7 g b_{C7} \sin(\delta_7))}{b_{n7}} \tag{17}$$

and

$$\delta_7 = \cos^{-1}\left(\frac{\overrightarrow{o_7 o_8}\cdot m_7 \mathrm{g}}{\|o_7 o_8\|\|m_7 \mathrm{g}\|}\right) \tag{18}$$

The tangential force and friction force are

$$f_{t7} = m_7 \mathrm{g}\cos(\delta_7) + f_{d8}\cos(\theta_8) \tag{19}$$

$$f_{f7} = f_{n7} u \tag{20}$$

The total force passed down to the next segment is

$$f_{d7} = f_{t7} + f_{f7} = f_{t7} + f_{n7} u \tag{21}$$

Note from Eq (13), (17) that if $b_{ni} = 0$ i.e. the point of contact is neat the joint, f_{ni} become infinite. When this happens, an easy way to solve this problem is to further segment the spine so that the point of contact does not get closer to the joint.

2.4 Modeling of Contact Stress

For contact stress analysis, the normal force is used. Since the average human body is concave in the middle along the spine, f_{ni} is divided by 2 (or in more general case, see Eq (32) later in the paper) and placed at bi-lateral locations according to the body shape. For the segment of thoracic 1 the forces are placed on the midpoint of the scapula at the vertical position corresponding to the initial contact. For segments of thoracic 2 and lumbar, the forces are placed at the midpoints of the muscle group erector spinae. While the normal does change at different locations compared to the center of the body, the effect is small.

With the force determined, the pressure distribution can be calculated using the contact mechanics [17-19]. The contact area between two contact bodies forms an ellipse. The maximum stress, located at the initial contact point, can be related to the semi-minor axis of the ellipse with

$$P_0 = \frac{b}{E(k')\Delta} \tag{22}$$

where $E(k') = \int_0^{\frac{\pi}{2}} \sqrt{1 - k'^2 \sin^2\theta}\, d\theta$ is a complete elliptic integral of the second kind, $\Delta = \frac{1}{A+B}\left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}\right)$, $k = \frac{b}{a}$, $k' = \sqrt{1-k^2}$. E_is are the Young's modulus of the contacting bodies and ν_is are their passion ratio. A and B are functions of geometrical properties that largely depend on the principle radiuses of the two contacting bodies, i.e. seat and the human body. k can be determined by solving the equation below numerically as

$$\frac{B}{A} = \frac{\frac{1}{k^2}E(k') - K(k')}{K(k') - E(k')} \tag{24}$$

The stress distribution follows

$$P(x,y) = P_0\left(1 - \left(\frac{x}{a}\right)^2 - \left(\frac{y}{b}\right)^2\right)^{1/2} \tag{25}$$

The applied force is given by

$$F = \frac{2\pi E^2(k')\Delta^2 P_0^3}{3k} = \frac{2\pi b^3}{3kE(k')\Delta} \tag{26}$$

The values of the semi-major axis of the contact area a can be determined with

$$a = \sqrt[3]{\frac{3E(k')}{2\pi k^2}(F\Delta)} \tag{27}$$

Combining this contact stress theory with the force analysis, the applied force in Eq (26) is equal to the normal forces in Eq (8). In order to determine maximum stress with Eq (26), the geometrical data and material properties of the contacting bodies are needed. Starting with the geometrical data, the cabin seat shape is measured to obtain the surface function $f(x, y)$ with curve fitting method. Once this is known, the principle radii can be calculated using the theory of differential geometry [20]. As for the human body, the principle radius in the vertical direction roughly follows the instantaneous radius of the spine which can be easily calculated using Eq (1-3). The principle radius in the horizontal direction can vary greatly based on body type. Strictly speaking, the principle radii of the human body do not follow the vertical or horizontal direction, and their directions change from head to toe. However, making them along the vertical and horizontal direction is a good approximation.

As for the material properties, both seat cushion and the human muscle are hyperelastic material. In this study, the Ogden hyperelastic material is used for cushion, and the ballistic gel is used to simulated the material properties of the human body. The stress-strain curve for both materials were experimentally obtained [21,22] and curve fit to obtain a polynomial equation. Differentiating the stress-strain equation yields $E(\varepsilon)$, i.e. Young's modulus as a function of strain ε. Then, from the original stress-strain data and the function $E(\varepsilon)$, a series of Young's modulus and stress pairs is obtained corresponding to the same strain. There pairs are then curve fitted to obtain $E(\sigma)$ or $E(P)$. The resulting equations are

$$E_s = 2.958 \times 10^{-12}x^4 - 1.549 \times 10^{-7}x^3 + 0.002783x^2 - 8.344x + 65490 \tag{28}$$
$$E_H = 6.383 \times 10^{-12}x^4 - 2.868 \times 10^{-7}x^3 + 0.004635x^2 - 8.545x + 40330 \tag{29}$$

where E_s is the Young's modulus for the seat cushion and E_H is the Young's modulus for the human body. As for Poisson ratio, the archived research shows that for the cushion, this ratio is close to 0, while for the human body, it is close to 0.5.

Now Eq (26) can now be written as

$$\left(\left(\frac{1-\nu_s^2}{E_s(P_0)} + \frac{1-\nu_H^2}{E_H(P_0)}\right)\right)^2 P_0^3 = \frac{3k(A+B)^2 F_{ni}}{2\pi E^2(k')} \tag{30}$$

This can be easily solved numerically for P_0. At the end, the semi-major and semi-minor axis of the contact ellipse can be determined using Eq (26), (27), and the pressure distribution can be plotted with Eq (25). To validate the result, the normal force can be calculated with

$$F_n = \int P(x, y)da \tag{31}$$

and to compare with the normal force calculated with Eq (8)

3 Simulation and Analysis

Based on the methods described above, a simulation system has been developed as shown in the flow chart in Fig. 5. The side sitting position is for when people leaning on one side of their body. When this happens, f_{ni} cannot be simply divided by 2. The left-side normal force f_{ni}^L, and the right-side normal force f_{ni}^R should be calculated with

$$f_{ni}^L = af_{ni}, \; f_{ni}^R = (1-a)f_{ni} \tag{32}$$

a depends on the angle of the tilt.

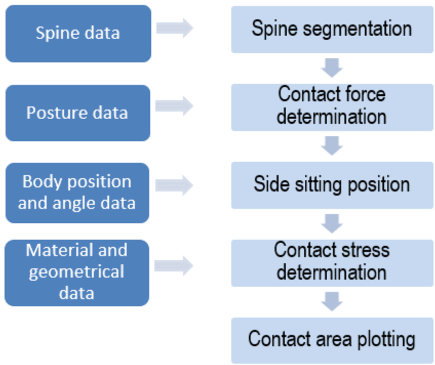

Fig. 5. Simulation flow chart

An average sized athletic human male is selected for simulation with the measurement: 175cm tall, 32-inch waist, 44-inch chest, 85Kg, muscular build, sitting in the seat with 135 degree recline angle. The simulated pressure distribution is plotted in Fig. 6. For the following plots, Fig. (6), (7), (8b), the height axis covers the spine from the neck to the pelvis. In more detail, 0 to 0.08 is pelvis region (partial), 0,08-0.2 lumbar, 0.2-0.35 thoracic-2, 0.35-0.47 thoracic-1, 0.47-0.5 cervical (partial). The entire height axis, 0-0.5, is the range of the backrest.

Fig. 6 shows that the pressure distribution looks similar for both postures in the upper spine, but the lower spine differs. The reason is that the erected posture has the arched-up profile in the lower spine region as shown in Fig. 3.

Fig. 7 shows the pressure distribution with two different backrest recline angles. The pressure of the higher spine region differs, and increases with the recline angle. However, the pressure remains similar in the lower spine region. The reason for this is that the normal force that the body exerted on the backrest, and therefore the pressure distribution is affected by two factors. One is the recline angle, and the other is the force that higher segments applied onto the lower segments, refers to Eq (16). For higher segments of the upper body, the force applied downwards onto them is either low or none. Also, this downward force effect is affected by the joint angle as seen in Eq (8), (17), which are near 0 or small as seen in table (1). This makes the first term in Eq (8), (17) negligible. Therefore, the pressure distribution between the higher segments of the upper body and the backrest is mostly affected by the recline angle as seen in Eq (13). As for the lower segments of the upper body, not only the force applied downwards onto them is higher, but also the joint angle is larger as seen in table (1). This can cause the downward force from the upper segments contribute significantly to the normal force that the lower segments of the upper body applied on the backrest. However, also seen in Eq (16) this downward force reduces as the recline angle increase, since most of the higher segments' weight is supported by the backrest instead of passing down at high recline angle. Because of this, for the lower segments of the upper body, the first term of the Eq (8) decrease while the second term increase as the recline angle increase, and vice visa. This can result the pressure in the lower spine region remain relative constant as the recline angle changes.

Fig. 8 shows the comparison between sensor data and simulation. The pressure sensors developed measures the pressure under the lumbar area. The simulated case is for side sitting, i.e. the human tilts on one side. It can be seen that the trend matches though the actual value differs, perhaps due to inaccurate calibration. In simulation, the force parameters are adjusted according to the tilt (with α in the Eq (32) set to be 0.3) and plotted in Fig. (8b). Comparing the sensor data with the simulation in 0.08 to 0.2 region on the height axis, highlighted in the white box, the simulation shows a similar shape and contrast. This gives some validation to the model.

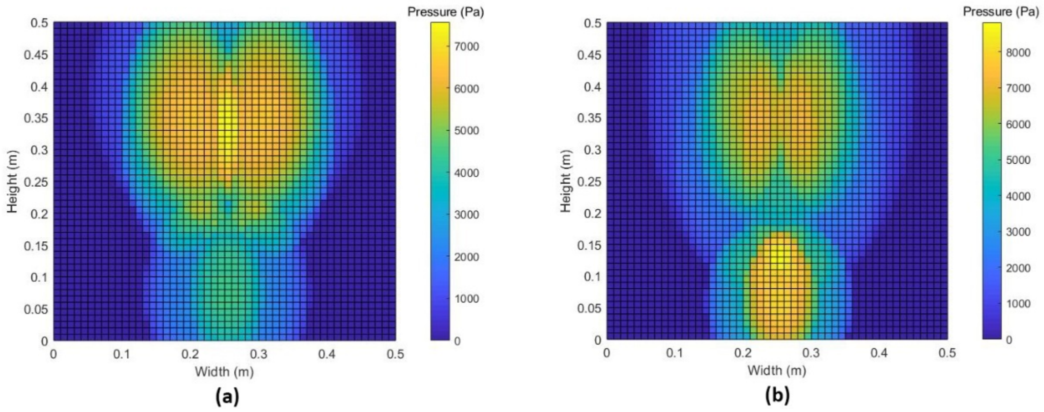

Fig. 6. Plot of pressure distribution. (a) Normal postural, (b) Erected posture.

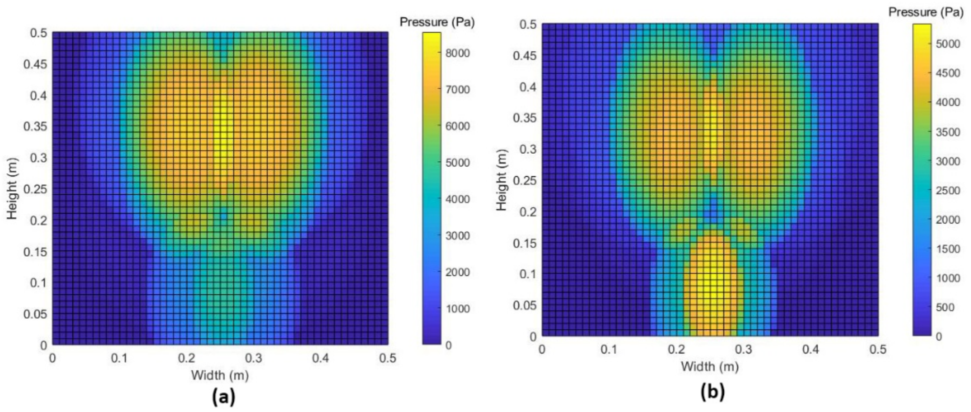

Fig. 7. Plot of pressure distribution (a) 150 degree recline, (b) 120 degree recline

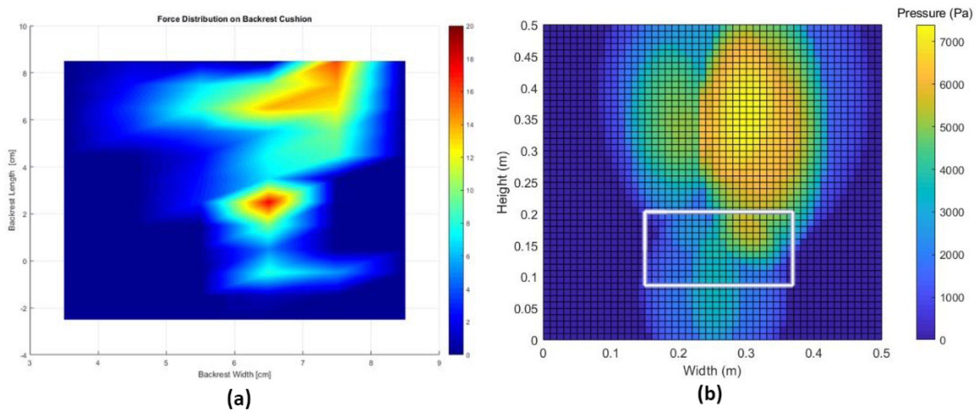

Fig. 8. Plot of pressure distribution. (a) Sensor data of the lumbar area, (b) simulation

4 Conclusion

A method for modeling the interaction between human body and aircraft seat for the comfortability analysis is presented in this paper. The method consists the modelling and force analysis of the human body with bio mechanics, geometrical and material analysis of the cabin seat and human body, and the pressure distribution analysis using contact stress theory. The simulation results show that different spine posture can affect the resulting pressure distribution. Also, when the recline angle changes, its effect on the pressure distribution mostly occurs at the upper body, while the lower body has less effect. The simulation is compared with the sensor measurement to provide a validation to this method.

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Biomechanical Determinants of Sitting Posture

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Abstract Regarding the increase of seating comfort research, the authors indicated that the researches about the human mechanism of seating comfort are needed by a systematic analysis of seating research literature using the framework of the Multispace design model. Seating comfort is influenced not only by the chair but also by sitting posture. It seems that when we sit down, we determine the sitting posture by optimizing the inherent posture determinants among the possible postures under the given conditions. Generally, a good posture is considered to be in low body loads that can continue to sit comfortably for a long time. The aim of this study is to extract the determinants from the biomechanical loads. In this study, the musculoskeletal loads on the sitting posture estimated from the measured data of skeletal posture and chair reaction forces using the 2-dimensional musculoskeletal model. The results showed the average value of chair reaction forces, the concentration of reaction forces and shear reaction forces effected on the posture as contact loads. And, lumbar shear forces, back and leg muscle stress and intra-abdominal pressure effected as biomechanical loads as the determinants of sitting posture.

Keywords: Seating comfort, Sitting posture, Musculoskeletal loads, Contact loads, Biomechanical model.

1 Introduction

A person has spent most of the day in a sitting posture. Therefore, many kinds of research had been done for seating comfort. The authors had done a systematic analysis of seating research literature using the framework of the Multispace design model for extracting the elements considered in the research. The study indicated that the researches about the human mechanism of seating comfort are needed [1].

Seating comfort is influenced not only by the chair or seat but also by sitting posture. In a normal chair design, it was assumed that the chair was seated deeply with the trunk in contact with the backrest, but in reality, there are also many sitting postures observed where the buttocks are moved forward [2]. This sitting posture is considered to be determined by the physical characteristics of the human body under the sitting conditions of the chair properties, such as the dimensions and hardness, and the sitting purpose such as ease or work. In other words, it seems that when we sit down, we determine the sitting posture by optimizing the inherent determinants among the possible postures under the given conditions. Generally, a good posture is considered to be in low body loads that can continue to sit comfortably for a long time. Therefore, in this study, we considered that the inherent determinants are existing in the biomechanical loads.

The biomechanical loads in sitting include contact loads by compression of soft tissue and blood vessels on the body surface and musculoskeletal loads such as muscle and joint loads. Although these biomechanical loads are often analyzed by physiological measurements such as electromyography or surface blood flow, the range of non-invasive measurements is limited. Therefore, it is an effective approach that uses a biomechanical model for estimating internal loads.

Reed et al. [3] used a myoelectric measurement of erector spinae muscles and model analysis of four rigid links from head to lumbar. And, he mentioned the loads on the back and neck muscles and spinal flexion are related to the determination of driving posture in the automobile seats [2]. Goosens et al. [4] indicated the chair design guideline to reduce the shear reaction forces acting on the body from the viewpoint of preventing pressure sores from the analysis of a couch using a four-link full-body model. However, these models have low biomimetic properties, and it is difficult to consider individual differences, and there is a limit to the estimation accuracy of internal loads.

The authors developed a detailed musculoskeletal model for estimating the musculoskeletal loads in sitting from the measured skeletal posture and reaction forces [5]. Using this model, we have shown that the musculoskeletal loads and the contact loads those are smaller in the posture with less physical fatigue for long-term driving, which was determined by experiment [6].

In this study, we investigated factors that are optimized in natural seating posture for musculoskeletal loads and contact loads using the model and extracted biomechanical determinants of sitting posture.

2 Analysis methods

2.1 Methods of internal loads estimation

A musculo-skeletal model shown in Figure 1 was constructed in a sagittal plane for estimating muscle forces and spinal loads on sitting posture [5]. The model consists of 13 rigid segments and 63 muscles. Spinal segments were connected with passive elastic elements representing intervertebral discs and ligaments. The abdominal area was modeled as a balloon. Intra-abdominal pressure was calculated geometrically in proportion to the cross-sectional area of the abdominal balloon. Anatomical parameters were decided based on the literature.

Skeletal postures of the model segments were determined using input data of measured geometrical locations and interpolated lumbar curve. Following forces were acted on each segment; segment weight, seat reaction forces, joint reaction forces, ligament forces, moments of intra-abdominal pressure and intervertebral disc spring. Joint torque for maintain sitting posture were calculated by measured skeletal posture and seat reaction forces under the equilibriums of moment equations around each joint. Using joint torque, muscle forces and joint forces were estimated under the condition of minimum muscle fatigue [7].

Chair reaction forces and acting point coordinates were measured using cushion-adjustable chair shown in Figure 2 that can adjust shape, angles and cushion properties with force plate. Sitting postures were measured at body landmarks using 3D-digitizer (Kosaka Lab., VECTRON VSC-27). Example of measured data (sitting posture and reaction forces) is shown in Figure 3.

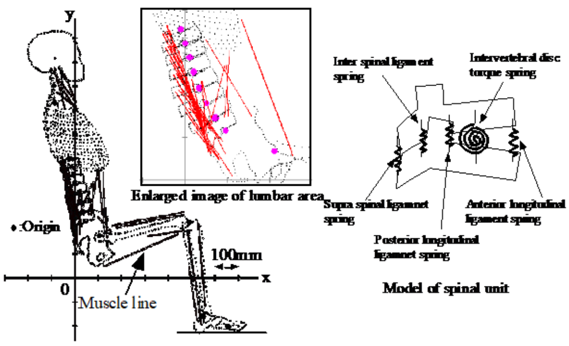


Fig. 1. Musculo-skeletal model.

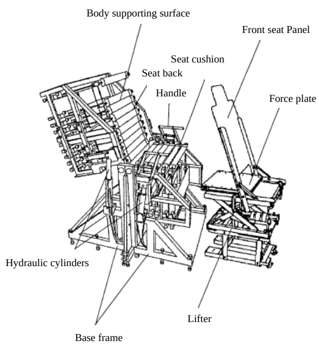


Fig. 2. Cushion-adjustable chair.

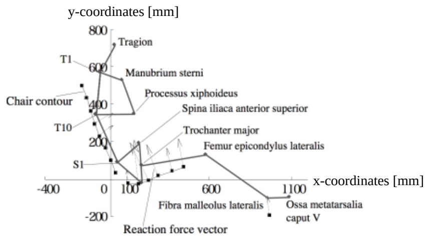


Fig. 3. Example of measured data.

2.2 Experiment conditions

In this study, we focused on automotive seats where it is easy to observe individual preference of their sitting posture in order to maintain a constant posture for a long time. Seat dimensions and cushion properties were set on cushion-adjustable chair for driver's seat condition of M class sedan shown in Figure 4 and rear seat condition of L class sedan shown in Figure 5.

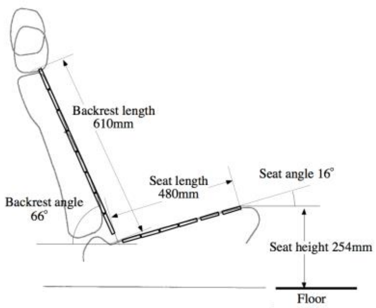


Fig. 4. Driver's seat conditions.

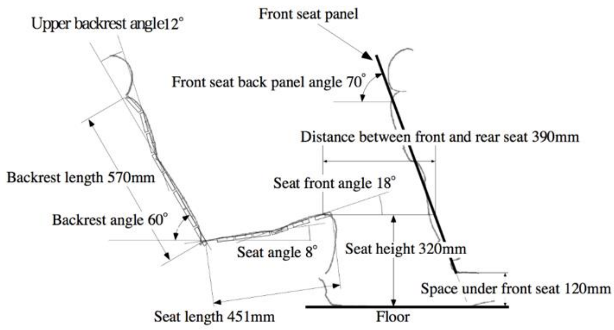


Fig. 5. Rear seat conditions.

The experiment conditions are shown in Table 1. In the driver's seat condition, the subject was instructed that "gaze forward assuming driving, the hands are placed on the thigh". However, no pedals were provided to remove the influence of the driving operation system for posture determination. Also, in the rear seat conditions, a panel equivalent to the back of the front seat was provided, instructed that "gaze assuming looking forward and take a comfortable posture". The sitting postures measured are the following four types, and the sitting duration is about 15 minutes per posture.

Rearward sitting posture: deeply sitting with maximum efforts (instructed).

Forward sitting posture: sitting posture with 120 mm forward at ischial tuberosity from rearward sitting posture (instructed).

Natural sitting posture: naturally sitting posture (no instruction).

Optimal sitting posture: sitting posture after adjustment cushion hardness for maximum comfort from natural sitting posture (no instruction).

Thirty-seven subjects (age: 21 to 30) were examined (height: 171.3±5.2 cm, weight:66.1±7.1kg).

Table 1. Experiment conditions.

	Experiment.1	Experiment.2	Experiment.3	Experiment.4
Chair condition	Driver's seat	Driver's seat	Rear seat	Rear seat
Cushion hardness : backrest [N/mm]	6	12	6	12
Cushion hardness : seat [N/mm]	6	6	6	6
Number of subjects	10	12	12	37
Measured postures	Backward sitting Natural sitting Forward sitting	Natural sitting Optimal sitting	Backward sitting Natural sitting	Natural sitting Optimal sitting

3 Results

3.1 Differences of sitting postures between experiments

Sitting posture and reaction forces on driver's seat (experiment 1) were shown in Figure 6. Following tendency were observed. Pelvis rotated with forward movements of ischial tuberosity. Reaction forces concentrated to around T10 and ischial tuberosity by reducing pelvic support with forward movements of ischial tuberosity.

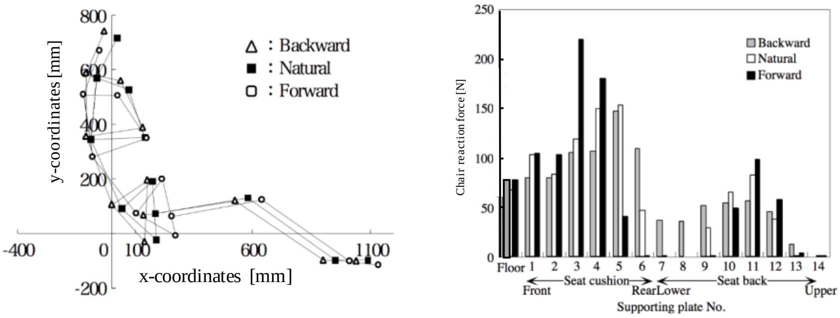


Fig. 6. Differences of sitting posture and seat reaction forces between ischial positions.

Measurement examples of natural and comfort sitting posture on driver's seat (experiment 2) were shown in Figure 7. Thus, differences of both postures were small, seat reaction forces were distributed, and peak position of back reaction forces were changed after cushion adjustment. It seems that contact loads were optimized by cushion hardness adjustments.

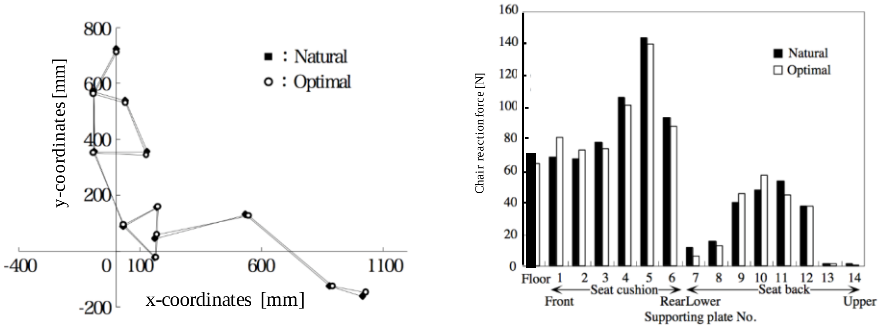


Fig. 7. Differences of sitting posture and seat reaction forces between sitting conditions.

Natural sitting posture on driver's seat (experiment 1) and rear seat (experiment 3) of same participant are shown in Figure 8. Following tendency observed on rear seat that has large reclining angle. Torso were reclined on seat back and pelvis rotated to rearward. And, foot moved to nearside for pelvis by flexion of knee. This was caused by restriction of space by front seat and prevention of pelvis sliding forward. As a result, distribution of reaction forces become same as forward sitting posture.

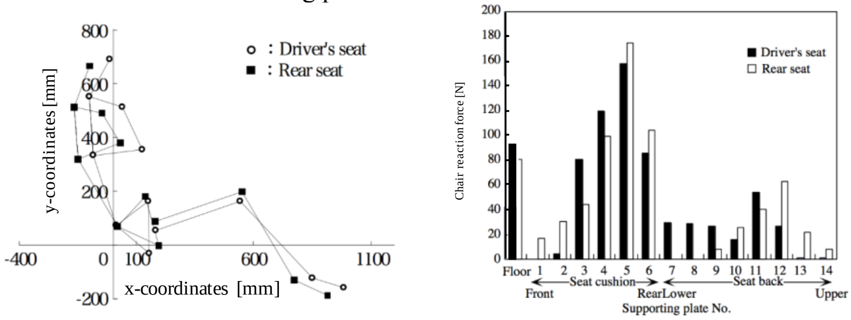


Fig. 8. Differences of sitting posture and seat reaction forces between seat conditions

3.2 Analysis of biomechanical determinants of sitting posture

We analyzed measured reaction forces as contact loads and internal loads calculated from measured postures and reaction forces as musculoskeletal loads. Parameters that minimized at natural or optimal sitting posture were defined as candidate of biomechanical determinants. In this chapter, the in biomechanical loads index value of each subject is compared between posture conditions, and a case where a significant difference of 5% or more is found in the change between postures by the sign rank test of Wilcoxson in the Figure.

3.2.1 Contact loads

Using the reaction force of each supporting surface measured by the cushion-adjustable chair, the following two indices were defined for each of the seat cushion and seat back.

· Reaction force concentration ratio = Reaction force standard deviation/reaction force average value of seat cushion or back

· Average value of reaction force on seat cushion or back

As shown in Figure 9, reaction force concentration ratio of seat and back were minimized (12 out of 10 subjects) at rear seat condition (experiment 3, 4). Average reaction force of seat and reaction force concentration ratio seems to be candidates of determinants. As shown in Figure 10 and 11, Sum of shear forces were minimized on driver's seat condition (experiment 1, seat 6 and back 7 out of 10 subjects). Therefore, shear reaction forces seem candidate of determinants.

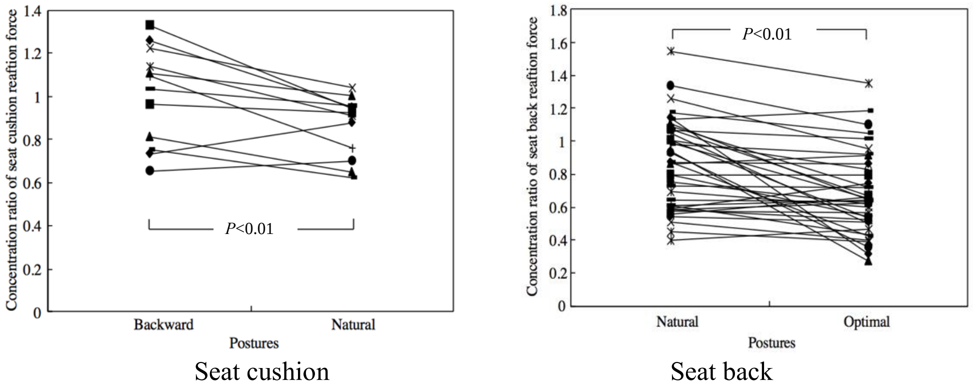
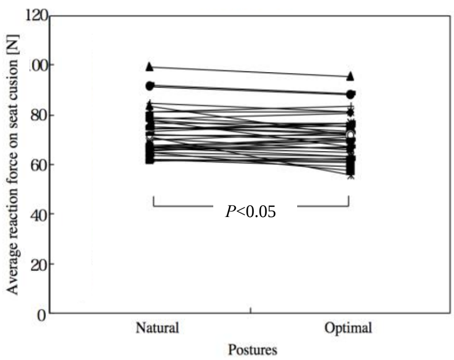


Fig. 9. Reaction force concentration ratio between sitting condition



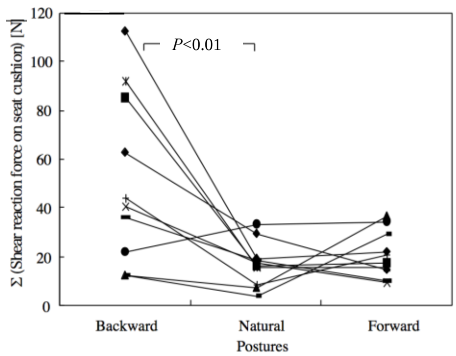


Fig. 10. Average reaction force on seat cushion. **Fig. 11.** Shear forces of seat cushion (Driver's seat).

3.2.2 Joint loads

As shown in Figure 12, sum of lumbar shear forces was minimized at natural sitting posture on driver's seat condition (experiment 1, 8 out of 10 subjects). Sum of lumbar compression forces did not have clear tendency. Therefore, lumbar shear force seems to be candidate of determinants.

3.2.3 Muscle loads

Sum of back muscle stress on driver's seat condition (experiment 1) were shown in Figure 13. Back muscle loads were minimized at natural sitting posture (6 out of 10 subjects). Although differences were relatively small compared with back muscles, leg muscle forces were also minimized on driver's seat condition (experiment 2, 7 out of 12 subjects) shown in Figure 14. As shown in Figure 15, neck muscle loads were minimized only on rear seat condition (experiment 4, 7 out of 12 subjects). This tendency seems to be caused by differences of conditions between driver's and rear seat. No tendency was observed for abdominal muscle forces.

3.2.4 Other internal loads

As shown in Figure 16, intra-abdominal pressure was minimized at natural sitting posture on driver's seat condition (experiment 1). No tendency observed on rear seat condition.

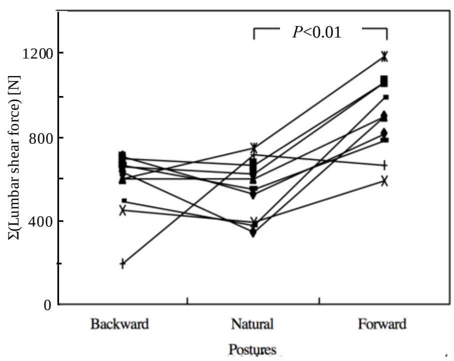


Fig. 12. Lumbar shear forces (Driver's seat).

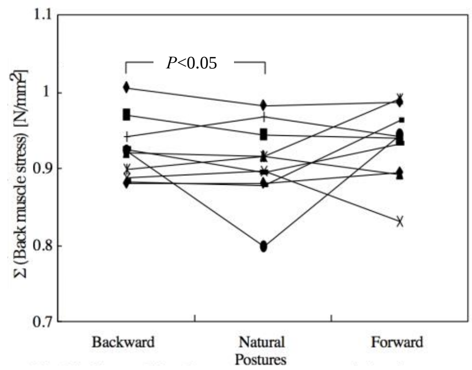


Fig. 13. Back muscle stress (Driver's seat).

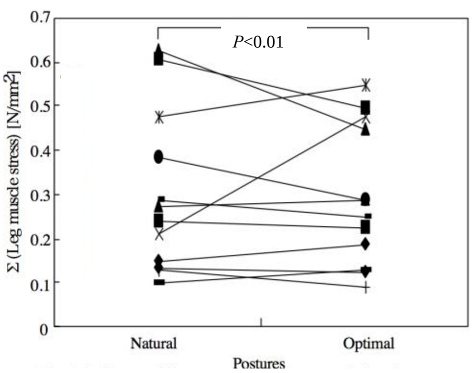


Fig. 14. Leg muscle stress (Driver's seat).

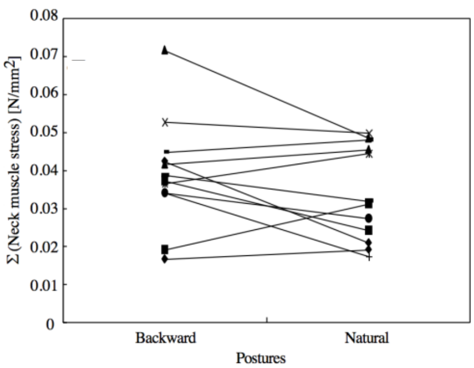


Fig. 15. Neck muscle stress (Rear seat).

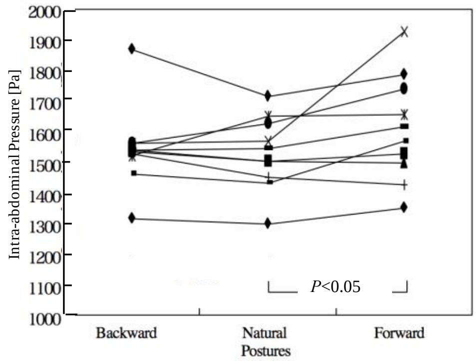


Fig. 16. Intra-abdominal pressure (Rear seat).

4 Discussion

Percentage of subjects and internal loads parameters were shown in Table 2. As a result, following parameters were extracted as biomechanical determinants of sitting posture.

Contact loads: concentration ratio of seat and back, average of seat reaction forces, sum of shear reaction forces of seat and back.

Musculoskeletal loads: sum of lumbar shear forces, sum of back muscle stress, sum of leg muscle stress, intra-abdominal pressure.

Table 2. Percentages of subjects for optimized internal loads in experiments [%]

Load parameters (Sum)	Experiment.1	Experiment.2	Experiment.3	Experiment.4
Concentration ratio of seat cushion reaction force	20	42	**83**	**68**
Concentration ratio of seat back reaction force	20	50	17	**81**
Average reaction force on seat cushion	0	25	25	**68**
Shear reaction force on seat cushion	20	**58**	0	8
Shear reaction force on seat cushion	40	**75**	42	49
Lumbar shear force	**80**	**67**	17	49
Back muscle stress	50	**58**	**67**	46
Leg muscle stress	30	**58**	**58**	**51**
Neck muscle stress	0	33	**58**	49
Intra-abdominal pressure	**80**	25	**58**	41

As for the contact loads, it is indicated that the absolute value of the compression force is important in order to prevent the blood flow inhibition due to the soft tissue compression, and it is better to distribute. This is close to the knowledge [9] about the good pressure distribution conventionally used for chair evaluation. Also, the shear forces agree with the view of Goosens et al. [4]. In addition, the tendency of the reaction force is more prominent in the rear seat condition because the reaction force is bigger due to the trunk reclined backward.

For lumbar intervertebral disc loads, it is considered reasonable to be sensitive to shear forces, as the intervertebral discs are considered to be strong in the compressive component and weak in the shear component. The muscle loads are also consistent with the conclusion of Reed [1], where the spinal muscles are dominant. In addition, the lower leg muscle loads are due to the influence of the bi-articular muscle connecting the pelvis and lower leg such as Hamstrings on the torso posture. The intra-abdominal pressure is particularly observed at the driver's seat conditions because the angle between the seat back and the seat cushion is narrower than at the rear seat.

The tendency in the neck muscle loads was observed in the rear seat condition only. It is considered to be appeared remarkably for maintaining the posture of the head for gazing the front due to the backrest angle. However, in this experiment, since the experiment is not performed including changes of the backrest angle, validations of the layout dependency will be a future subject.

5 Conclusions

In this study, the biomechanical determinants of sitting posture were discussed. The concentration of reaction forces, an average of seat reaction forces, a sum of shear reaction forces of seat and back were extracted as contact loads. Sum of lumbar shear forces, a sum of back muscle stress, a sum of leg muscle stress, intra-abdominal pressure were extracted as musculoskeletal loads.

However, the weight of each index is unclear, and it will be a future task to determine this. If sitting posture is simulated as to optimize these physical load indices, it is possible to evaluate the posture virtually. In addition, if measurements of skeletal posture and chair reaction forces can be obtained, it may be effective to use them directly as sitting posture comfort indices. Identification of the weight for the indices and develop it into a sitting posture simulation in further study.

In conducting all the experiments of this research, the informed consent for an experiment involving human subjects was obtained from the experiment participants with in advance explanations of the experiment.

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A Survey and a Co-creation Session to Evaluate Passenger Contentment on Long-haul Flight, with Suggestions for Possible Design Improvements to Future Aircraft Interiors

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Abstract To study passenger contentment data were gathered from three co-creation sessions and a survey of 128 participants with experience of long-haul flights. Negative observations related mainly to physical discomfort and feelings of boredom. While social interaction was important for some passengers, it was generally superseded by the need for privacy. Relaxation was seen as important as well by the passengers. In-flight entertainment was frequently dissatisfactory, and eating was something passengers looked forward to and viewed as a type of entertainment. Some suggestions are made as to how these findings could be integrated into future aircraft design with special attention for human factors. Our results are largely in alignment with those of previous studies.

Keywords: Passenger contentment, long-haul flight, aircraft interiors.

1 Introduction

Aircraft have been used for long-distance transportation since the early 1900s. Different types and sizes were designed and produced to accommodate the rapidly increasing number of passengers. As a fast and safe means of transportation, air travel became the preferred choice for those taking longer trips. Many redesigns focused on ergonomiocs and human factors have improved in-flight comfort levels over the decades, especially for long-haul flights (i.e., flights with a duration of 6-17 hours) [1]. However, much work remains to be done. While Ahmadpour et al. and Bouwens et al. have shown the need to improve seating, attention is also needed in areas including noise, smell, climate and space [2][3]. The literature outlines some of the current issues, which may be of help in defining future needs. For instance, the limited possibilities to change position and feelings of boredom were issues mentioned by Kremser et al. [4]. As early as 1975, the same authors described how people were concerned with the sense of physically restricted space. In 1999, 930 passengers evaluated different styles of seats, considering various factors including legroom, back support and head support, each of which were rated either poor or very poor by the highest percentage of surveyed passengers. A study by Li et al. confirms these findings [5]. Bouwens et al. have also shown that boredom is an issue for passengers on long-haul flights [6]. Sleeping and the sense of being bored produce the lowest comfort scores, especially in cruise flight.

In terms of future aircraft design, it hence seems there is scope for improvement. Specifically, in terms of future design, the question arises as to what elements allow for a comfortable journey. We envision that automation will be introduced to flying within the next 30 years. AR and VR technology will be widely used in airplanes, and the cabin crew will be a combination of people and robots. Self-service for some simple tasks such as getting drinks and on-board shopping will be permitted.

The interior in question relates to the Flying V – a new type of aircraft that is being jointly developed by Airbus FPO and TUD/FPP. The airplane, which is shaped in a flying wing configuration, holds up to 315 passengers, which is comparable to a typical wide-body aircraft. The body of the Flying V is relatively flat. This includes some space that could not be used for carrying passengers due to its low height. The research question of this paper is thus: What elements of the passenger experience will influence the design of the long-haul aircraft of tomorrow?

2.Methods

Three co-creation sessions were set up to consider the elements that could potentially improve passenger experience during long-haul flights. The aim was to get an overview of the negative aspects of the current flying experience and to establish a direction for future improvements. A survey was then designed and carried out based on data from these sessions. Sanders et al. describe this method as the most useful and effective tool in the front-end design development process [7].

2.1 Co-creation sessions

The goal of these sessions was to discover the negative and positive aspects of passengers' long-haul flight experiences. Three groups were invited to participate. Each group consisted of 3-4 participants and a host (the host was always the same). In total, 10 participants aged 23-31 years participated in the study.

Printed templates showing a time line of the flight were distributed. Visuals of positive experiences using stickers, post-it notes and pens were also employed, and a line was drawn to divide positive and negative feelings.

The session proceeded as follows:

1. The host welcomes the participants and asks them to read and sign the informed consent form.
2. The host gives a brief introduction to the study.
3. The participants are asked to recall their most recent long-haul flight. They are requested to draw their experiences on the template and write down the causes of their feelings on post-its.
4. The whole group discusses their experience, mentioning elements that had a significant impact on their experience.
5. The whole group divides the post-it notes into different categories, which are colour-coded with stickers.
6. Participants point out which elements they think will still be significant in 30 years and beyond.
7. The group discusses new elements that may improve their long-haul flight experience.
8. The host wraps up and ends the session.

2.2 Online survey

A questionnaire was designed based on the results of the co-creation session and given to 128 subjects of different ages. It could be completed online using googledocs. Participants were asked to score five statements based on the negative elements summarised previously. Using a Likert scale from 1-7 (1= totally not agree; 7 = totally agree), participants had to choose five words for their desired experience from the 14 words emerging from the co-creation session. They also had to indicate the extent to which they want to be active and engage in social interaction. In the third part of the questionnaire, two words with opposite meanings (active-inactive; social-isolated) were placed at either side of a 7-point scale. First, participants were divided into active, inactive and neutral categories. The same process was repeated for the social versus isolated. Genders and ages were also recorded for later comparison, and an open question on suggestions for improvement was added. Data were analysed as follows: averages and totals (the number of times a word is chosen) were calculated for age and gender categories. Participants were placed into two groups by age (20-40 and > 50) to see if older passengers have different preferences. T-tests were performed to compare different ages and genders, with $P<0.05$ considered statistically significant.

3 Results

The results of co-creation sessions and the online survey were recorded separately since the online survey was designed based on the results of co-creation sessions.

3.1 Co-creation results

The topics mentioned during the sessions were divided into five categories: entertainment system, physical comfort, food, environment, and personal interaction. Figure 1 shows the number of times each category was mentioned during the session.

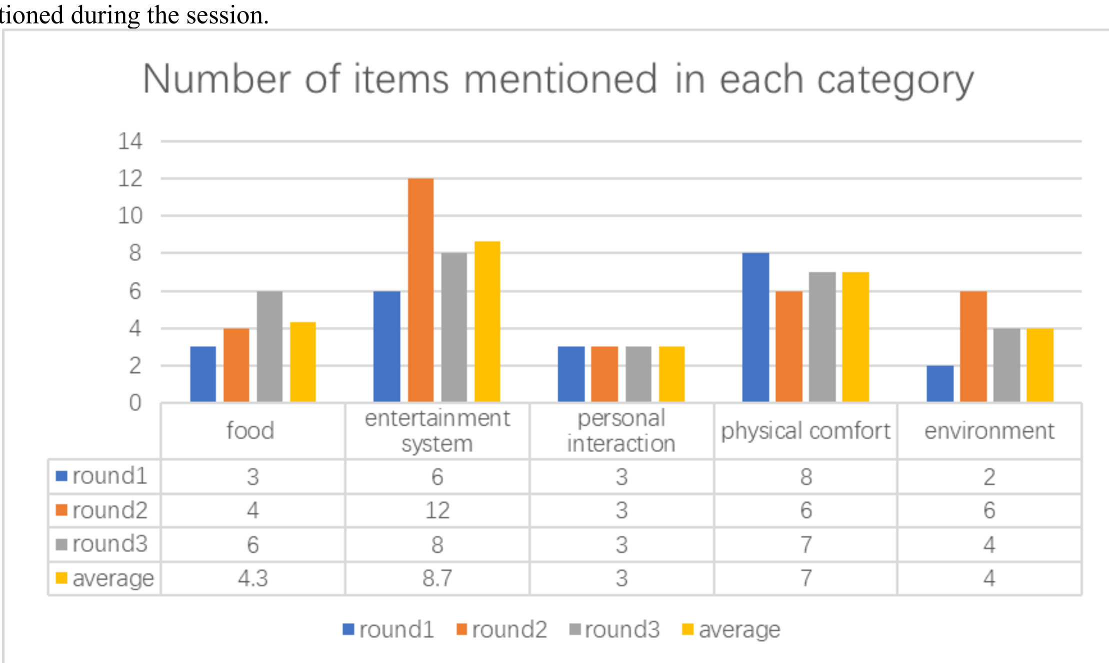

Fig. 1. Number of items mentioned in each category in the three co-creation sessions (n=10).

Entertainment was seen as very important as the flying time is quite long. Although the tablet on the chair in front enables people to watch movies and listen to music, the in-flight entertainment becomes boring after around four hours. If passengers cannot find any interesting material to watch or listen to, they get bored even faster. This situation is very likely to occur, as people have different tastes and the entertainment content cannot cater to the needs of everyone. Feeling bored also makes people more sensitive to their levels of physical comfort, especially the discomfort that is experienced due to restricted motion. In all three sessions, however, it was mentioned that passengers do not want to perform strenuous exercise or exciting activities to prevent static postures. Low-intensity movement such as walking and stretching are deemed sufficient, as the intention is not to work out but to relax and alleviate any stiffness, reducing physical distress. Sleeping in an airplane can also cause physical discomfort. A lack of neck and waist support is the main reason for the low quality of in-flight sleep. During the sessions, participants mentioned that lying down can have the added benefit of reducing motion sickness. Likewise, a positive emotional reaction occurs when people are informed that the food service will start shortly, as expectations lift and they finally have something to look forward to. Most participants (7 out of 10) said that they spend more time on eating in an airplane than they do on the ground, as they consider it a form of entertainment during a long-haul flight and hence want it to last longer. However, this does not mean they want to eat more. Conversely, passengers frequently have a low appetite. A possible reason, which was reported might be that the slower digestion and motion sickness may cause some stomach discomfort. Another reason is that many people would rather avoid going to the toilet during a flight. Airplane toilets are viewed as somewhat unhygienic, and standing in long queues for the bathroom is unpleasant. The queues are especially long after meals and before landing. People's quality of travel is also influenced by their surrounding passengers. Most do not want to interact with others, but space is limited and physical and/or verbal contact is sometimes inevitable. Being in the vicinity of children can also be a negative factor. Around two hours before landing is the most difficult time during a long trip. Physical discomfort is at its greatest, and passengers may feel unrested and already bored with the in-flight entertainment system. They want to escape the airplane, but there is still a relatively long time before landing.

A total of 14 words expressing positive feelings were used during the co-creation sessions (pleasant, relaxed, peaceful, clear-minded, energetic, thrilled, excited, passionate, friendly, calm, joyful, adventurous, fascinated, powerful). Those with the highest frequency were: relaxed, peaceful and interesting. The words pleasant, friendly and calm were also mentioned more than once.

3.2 Online survey results

Figure 2 shows the averages for each age group. The graph indicates that older people are calmer and more tolerant (their answers are more neutral) than the younger group. The difference for the food service is very slight, while the biggest difference is in attitudes to children. Young people care more about this issue than seniors. This may be explained by the fact that seniors have experience of raising children, and are thus more tolerant of their behaviour. Table 1 shows the T-test results for the different age and gender groups. Statistical significance was found for all the statements except for the one about attitudes to food service. However, there were no significant differences regarding gender.

Fig. 2. Average score on the 5 statements for the different age categories (20-40, n=106; > 50, n=21).

Table 1. T-Test results on the five statements.

Statements	*P (different ages)*	*T (different ages)*	*Standard error of deference (different ages)*	*P (different genders)*	*T (different genders)*	*Standard error of deference (different genders)*
You feel bored even though there is an entertainment system.	<0.0001	4.7737	0.343	0.3481	0.9419	0.281
Your mood improves when food is served.	0.9368	0.0794	0.294	0.0665	1.8511	0.214
The kids in the airplane make you feel irritated.	<0.0001	6.0645	0.348	0.0629	1.8765	0.289
You could not get a good rest during the flight.	<0.0001	5.4121	0.315	0.9632	0.0463	0.259
Lack of movement is a big problem for you.	0.0114	2.5674	0.328	0.8018	0.2516	0.249

For the second part of the questionnaire, participants had to choose from the list of 14 words to describe a desirable experience. A tally was made of the number of times each word was chosen (see figure 3). Quality, relaxed, peaceful and pleasant were the most frequently chosen words, which aligned with results from the co-creation sessions. This indicates that on-board activities do not need to be intensive or thrilling. More people aged 20-40 chose the word *energetic* compared to people over 50, while the inverse was true for the word *calm*. However, this difference is not typical. No significant gender differences were found in this area.

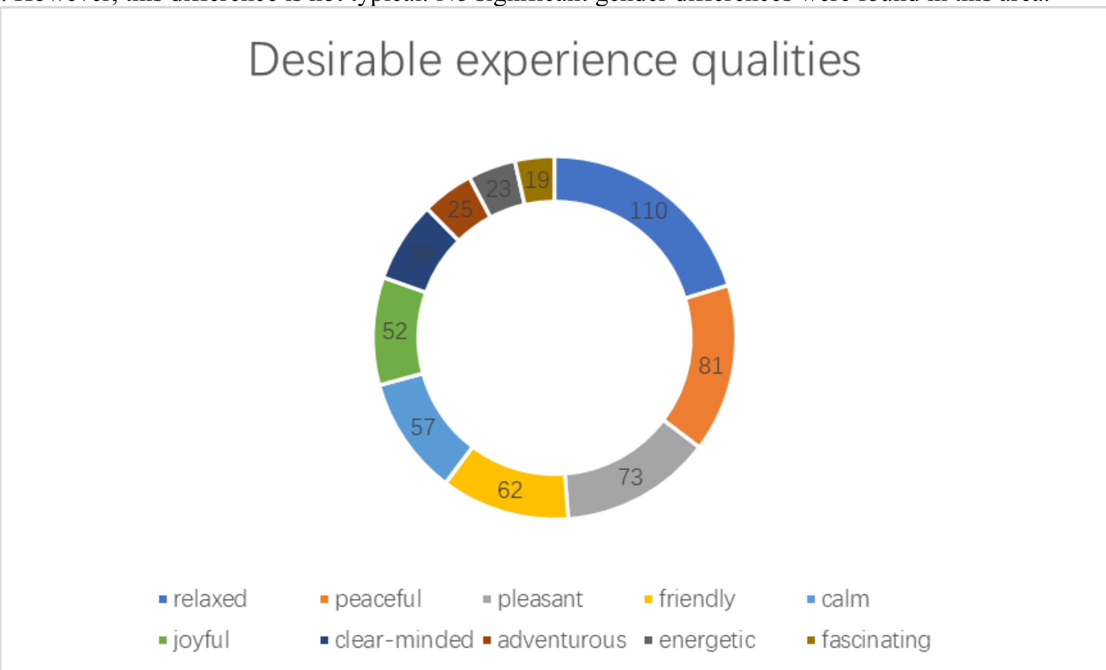

Fig. 3. The number of times each word was chosen for the preferred activity (n=128).

Active-inactive and social-isolated results are shown in figure 4. These indicate that most people want to be both inactive and isolated in the aircraft. However, about one-sixth of respondents anticipated that their future airplane experiences would be more active and socially involved. A significant difference was found between the genders regarding levels of activity. Figure 5 shows that people age 20-40 were more active than people over 50. The level of preferred social interaction depended largely on gender, with males preferring less social engagement (see Figure 6).

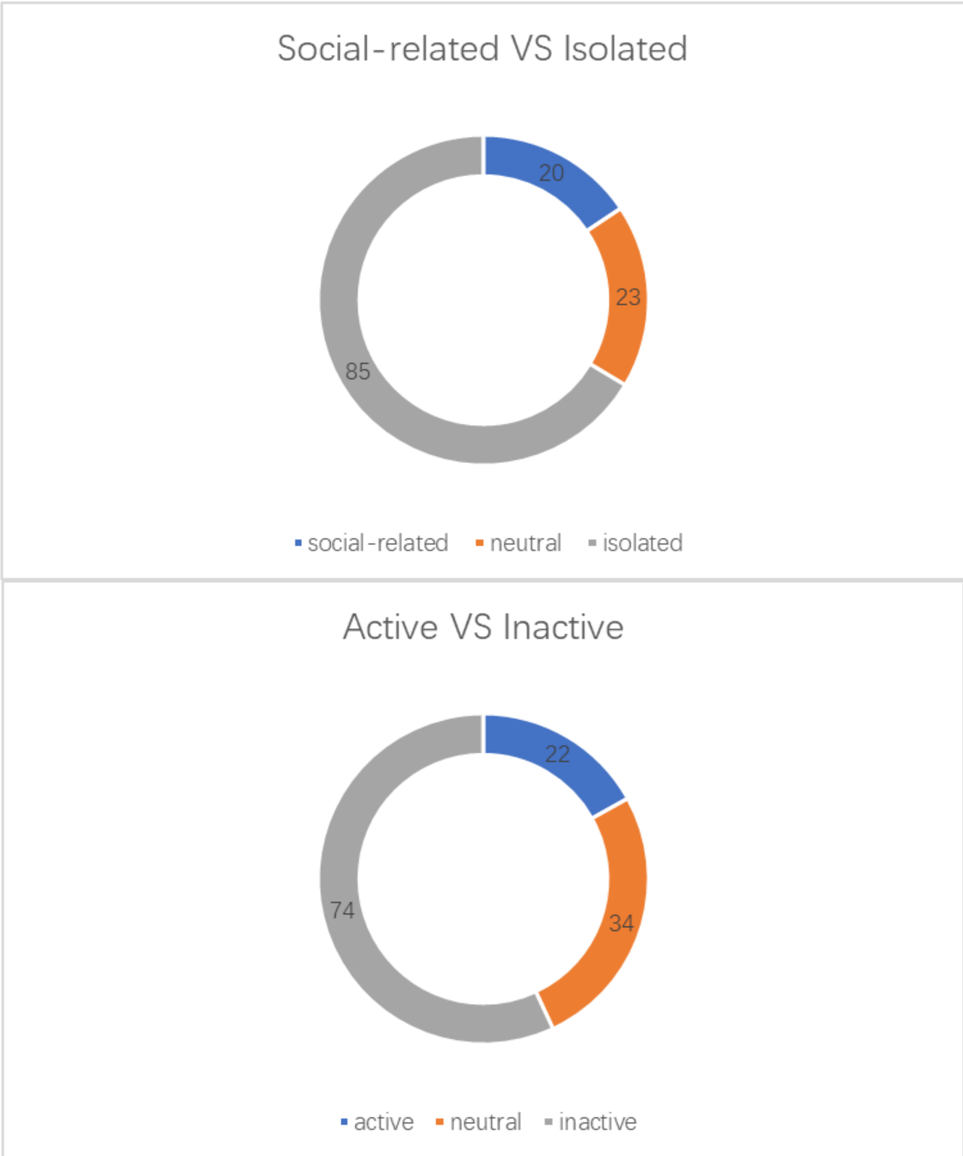

Fig. 4. Number of participants for active vs inactive and social vs isolated (n=128).

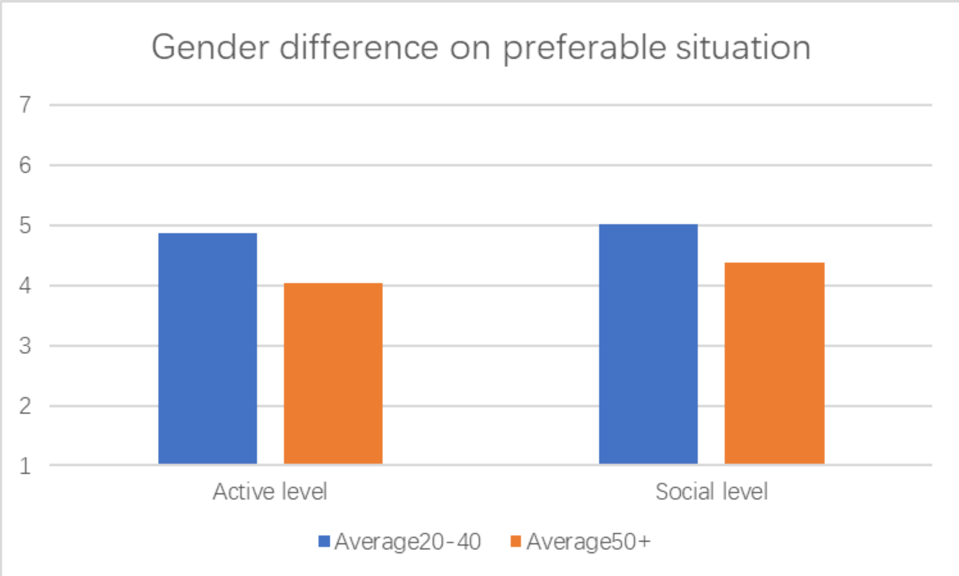

Fig. 5. Different preferences by age (20-40, n=106; 50+, n=21).

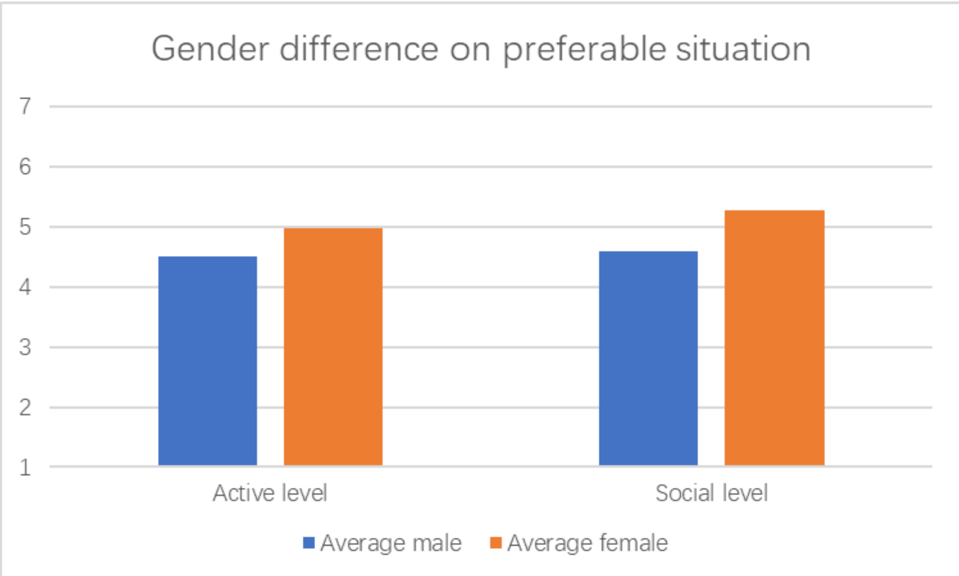

Fig.6. Different preferences by gender (male, n=68; female, n=60).

Table 2. T-Test results on preferable situation.

Preference	*P (different ages)*	*T (different ages)*	*Standard error of deference (different ages)*	*P (different genders)*	*T (different genders)*	*Standard error of deference (different genders)*
Being active.	0.0140	2.4936	0.329	0.0511	1.9691	0.245
Being social.	0.0556	1.9318	0.330	0.0044	2.9005	0.240

4 Discussion

Both the co-creation session and the questionnaire revealed that passengers prefer relaxed activities during the flight as a means to reduce physical discomfort and feelings of boredom. This finding is in agreement with those of other studies. Greghi et al. state that the activity passengers find most difficult is resting/sleeping (76.7% of the 287 participants). In this study, 50% of passengers also experienced difficulties in using the in-flight entertainment [8]. Bouwens et al. showed that the lowest comfort rates were associated with sleeping and feelings of boredom [6]. Our results are also largely in agreement with those of a study by Hiemstra-van Mastrigt et al., which reports that discomfort was significantly lower while passengers were eating, with respondents from their online survey indicating they felt most refreshed after food (34.8%) [9]. Likewise, walking through the plane was also perceived as the most refreshing activity by a majority of long-haul passengers (>6 h) - a result that is in line with our findings – with limited opportunity for physical movement being a cause of discomfort. Our results indicated that the majority of passengers do not desire social interaction and there is no necessity to make the plane into a social space. This is confirmed by Buchholz & Chinlund , who state that solitude is a basic-level human need [10]. In this paper, we mention that eating can help make the passenger experience more interesting. Pine et al. mention that in-flight food could function as a form of entertainment, as is the case in certain theme parks [11]. Meiselman also suggests that experiencing the same food in a different setting offers a different experience, although how this could be integrated into airline dining remains uncertain [12]. Long queues for the toilet can be unpleasant – a finding confirmed by Rarnakar – and certain aircraft have already made changes to the toilet layout to reduce waiting times [13]. However, these redesigns are not yet widely introduced, and there may yet be more effective solutions to this problem. All of these points require further examination.

This study contains certain limitations. In the survey, the age range 40-50 is missing. Genders were also not equally distributed for all ages. Likewise, the co-creation sessions featured a limited age group. These may be the cause of some inaccuracy in the results, especially in the case of the missing age group, as there are clearly some differences to be observed between the different generations. In our study population the young might be overrepresented. However, young people will be the passengers of tomorrow, increasing the relevance of their responses in terms of future aircraft design.

5 Design take-aways

Based on the above results, the following are some suggestions for designers that may help to create a better passenger experience during long-haul flights:

1. More space for passengers to move around.
2. In-flight activities should focus on making people feel relaxed rather than excited. An interior should make it possible to have privacy; however, there should also be some space for passengers who enjoy social interaction. The ideal combination would involve higher levels of privacy.
3. Food service is seen as a relief from boredom. Extending eating times may help to improve the overall experience.
4. Children disturb other passengers. Adding a separate family area could be a solution that may also be appealing for families. Parents could interact with each other while their children play, allowing other child-free passengers to enjoy a more peaceful trip.
5. Toilets are currently used both for bodily functions and as a place for washing hands/faces and changing clothes. Some women also use the mirrors in the toilet to do their makeup. If a separate space could be found for these alternate uses, the waiting line might be shorter.

6 Conclusion

This paper studied the negative and positive experiences of passengers on long-haul flights. Results suggest that physical discomfort and feelings of boredom during the flight are the main causes for concern. Ideally, the future aircraft should be designed in such a way as to contribute to a relaxed, peaceful and pleasant experience. This would require the significant re-design of existing aircraft interiors. While social interaction and privacy should be both possible during a flight, the majority of passengers prefer privacy. Activities such as eating and going to the toilet have a significant impact on the overall experience, and should be taken into consideration in the design process.

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Designing for Different Passenger Experiences: Road, Railway and Aviation Seats

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Abstract Transport products in Road, Railway and Aviation industries have many features in common, however seat design for buses, trains or aircrafts can differ widely across the range of materials, manufacturing processes or safety requirements, while trying to provide the best possible passenger travel experience. Almadesign has worked on seat designs for the three transport areas, developing a cross-knowledge of the requirements, technical processes and passenger needs. In this paper we will to explore the differences and similarities between seat design in road, railway and aviation, using specific design and technical criteria such as Aesthetics, Ergonomics, Maintenance, Weight, Materials and Safety requirements. The broad experience across different industries – from transportation to products and interiors - has led Almadesign to develop design solutions based in cross-pollination strategies, migrating and integrating technologies and manufacturing processes. With a focus on the user-centered experience, we will compare three-seat design case studies based on projects developed by Almadesign over the last ten years for road, railway and aircraft. In the road vehicle industry, we will address the IBUS project: passenger seats developed to maximize the living space using lightweight, eco-efficient composites. In the railway industry, we will focus on the CPA 4000 train refurbishing process, in which the design team tackled the challenges of refurbishing an existing railway seat in order to improve passenger comfort, integrate new technologies and simplify maintenance processes. In the aviation industry, we will address the work developed for TAP Air Portugal fleet retrofit programs and H2020 Project PASSME, on Economy seats.

The discussion will focus on the comparative analysis of the seat designs in the three industries, its similarities and differences, and the role of the design teams in integrating different passenger's needs and expectations. The results will provide an overview in how design can play a key role in articulating different industries and fostering discussion between stakeholders. Seat design analysis and comparison in this three transport industries, will hopefully provide an overview of the role of design in exchanging knowledge, creating synergies and promoting cross-pollination between industries.

Keywords: Seat design, Passenger Experience, Road vehicles, Railway, Aviation, Cross-pollination

1. Introduction

Each transport industry may be different, with various technical needs and constraints, but all have one thing in common: they are centered in people in their role as passengers, regardless of their cultural background, age or experience in travelling. The passenger experience is a key factor in product development, specially the seat design. The concept of "experience" can be analyzed through the point of view of the

“Product Experience” theory - the research area that develops an understanding of users’ experiences that result from interacting with products and interior environment which we can define as follows: “An Experience occurs when services are used as the stage, and goods (used) as props, to engage individual consumers in a way that creates a memorable event” (SCHIFFERSTEIN, 2008) [1]. To create an “enhanced” experience is to engage the passenger at different levels - sensory, social, intellectual and behavioral. Careful attention must be given to the different “touch points” of the travel experience, and the seat is the product in which passengers spend most of their time while being transported.

Designers are able to develop seat design which differ in its functionality, comfort, and aesthetics and also on the different passenger perceptions and experiences. The technical specification of the product imposes certain constraints on shape but within these there is space to change functionality, geometry, surfacing, and materials, modify colors, and add textures…

The passenger experience is influenced by different product features, such as safety, look and feel, ergonomics, features and accessories, etcetera. At the same time, operational needs mean seats must be easy to maintain, durable, easy to clean, etcetera. User safety is also a central issue in transport seats, more importantly in aviation, where safety standards are very demanding. At the same time we know users vary in size, shape and strength. The product should therefore accommodate any person and allow population extremes (e.g. percentiles 5 and 95) to interact in a comfortable and safe mode with the seat. Materials also have an important role in products. The use of highly resistant materials, lightweight solutions or easy to build and to maintain material technologies are examples of requirements of different industries. In this paper we will take a closer look at three transport industries, its need and requirements, and at the different seat features in order to cope with the industry standards and provide the best passenger experience. We will use industry case studies, look at different design requirements and compare product features in order to get a global comparison of the seat design in three industries, its differences and similarities.

2. Case Study I: Road Industry

The IBUS consortium presented a vision for the road transport sector materialized in an eco-efficient, lightweight, comfortable and integrated concept for interior bus coaches. The project aimed to demonstrate the acquisition of new technological skills by a consortium of companies, through the development of integrated, functional and technical solutions. It resulted in a full-scale mock-up (inner and outer cross-section) 2.4 meters long, to visualize, test and validate solutions for future applications in bus coaches, by using innovative solutions inspired by the aeronautical and automotive areas. Two different seats were developed – Raia and Shark, favoring capacity without compromising personal space and user comfort. The Raia is a sleek, lightweight design using natural and composite materials (core cork based thermoplastic composites). The Shark concept combined a unique design with a very comprehensive level of equipment, integrating table, footrest and LCD monitor, favoring the use of lightweight composites. All seats were trimmed in anti-allergenic, chrome free leather, developed for easy cleaning, excellent surface resistance and a high-end look and feel.

Fig. 1,2. I-BUS Seats.

Fig. 3,4. I-BUS Seats.

3. Case Study II: Railway Industry

After 16 years and over 26 million passengers transported, the CPA4000 train series needed a half-life maintenance, and so the opportunity arose to fully refurbish the train interior. Based on the collaboration experience in the INTRAIN project, Almadesign was invited to develop the project together with Portuguese suppliers. The refurbishing process aimed to achieve a new image of the product and associated service, improving passenger comfort, integrating new technologies and simplifying maintenance processes in five main areas: Exterior, Interior, Toilet, Bar and Signage. The seats were fully refurbished, with new foam geometry, new leather trimming, new colors and new materials. The differentiation between the two classes, Tourism and First Class was enhanced in the seat design, color, materials and trim.

The product development process took place over 22 months, from the definition of requirements and specifications, to research on user preferences and operators' needs, to concept generation, product development for prototyping, mock-up build, production and monitoring of industrialization. The new seats designed are now able to accommodate more activities and provide better comfort by including charging sockets, larger head support, revised foam geometry for better ergonomics, leather trim for cleanability and easy maintenance, premium look and feel).

Fig. 5,6. I-BUS Seats.

4. Case Study III: Aviation Industry

The challenge for Almadesign was to refurbish the medium-haul TAP fleet, with A320 and A319 aircraft, seeking to respond to increasing competition and develop a new TAP Portugal experience. Using the same design philosophy that guided the project, the intervention initially focused on business and economic class seats, developed in cooperation with RECARO in which new functionalities for greater connectivity were defined as well as new seat covers and materials.

The new cabin layout and the lighter and thinner seats chosen offer good ergonomics and personal comfort, maximizing seat numbers to make the fleet more efficient. It is worth noting the use of TAP colors to differentiate the economy class - fresh and modern lime green - from the business class - warm and comfortable red - reinforced the company's corporate identity. The laminated leather seat covers provide a high-end look and feel, easy maintenance and durability. The seat features a 4 postions adjustable headrest, tablet supports, and electrical charging points, providing the passenger with the possibility to work, sleep or have fun with more comfort.

This was the first retrofit project totally developed in Portugal with global suppliers, and included the full cabin retrofit carried out in Lisbon by TAP M&E.

Fig. 7,8. TAP A320 Seats.

5. Discussion: Passenger seat feature comparison

While travelling, passengers should be able to seat comfortably and perform different tasks according to different needs (i.e. relax, work, read, play, etc.). Several activities such as reading, sleeping, talking and working on laptop accommodate different body postures and influence passenger experience and seat comfort. Seats are designed for and used by people, and people come in many sizes and have varying physical attributes (DREYFUSS, 1955:26) [2]. A "passenger-centric" mindset adapted to the market trends and new technologies is very important when designing for transports in order to meet passengers' needs and expectations. We will take a look at some of the criteria used at Almadesign to design and develop transport seats.

2.1 Look & Feel

Aesthetics play an important role in the way an object/environment is used, fostering positive attitudes and creating positive relations, which have implications in how effectively people interact. "Aesthetic designs are perceived as easier to use than less-aesthetic designs" (Lidwell, 2003:20) [3]. Both Road seat design, as well as Railway and Aviation design must provide the best aesthetic experience possible for the passenger, enhancing brand loyalty.

Quality perception also enhances brand loyalty and improves the passenger experience by providing a harmony and consistency in the design and assembly of parts, often considered and physical manifestation of precision and quality.

Living space is the space around the passenger during his travel. In industries such as road and aviation, the layout of passenger arrangements aim for maximum capacity (for maximum revenue) turning living space into a very expensive "real estate". Each inch in an aircraft means revenue, which accounts for the compromise between living space and comfort for the passenger, or capacity and revenue for the airline.

2.2 Ergonomics

The physical capabilities of users in relation to the physical qualities of a product are paramount to improve comfort. By undertaking an ergonomic evaluation, the sizes and positions of points of user contact with products can be identified and optimized. This approach enables the physical comfort and ease of use of our products to be improved for all users. The product should therefore accommodate any person within a range of body dimensions and allow population extremes (percentiles 5 and 95) to interact in a comfortable and safe mode. In aviation "Since the 70´s leg room has been reported as the biggest problem for passengers. The thickness of the backrest is very relevant, provides more leg room than a seat at the same pitch with a different thickness of the backrest." (Mastrigt, 2015:138) [4]. To design a thin, lightweight seat is to provide the passenger with more leg room. "Several studies indicate that increasing leg room, knee space, and personal space have a positive effect on the comfort experience. So, leg room and personal space have a have priority in the design and also expectations and preflight experiences." (Vink, Brauer, 201:25) [5].

Seat design must also accommodate different activities, such as eating, sleeping or interacting with digital media. A good headrest with enough neck support will increase comfort by providing a good posture for sleeping: "The presence of a headrest is beneficial for both privacy and variations in posture. It also prevents the head from slipping off to the side." (Vink, 2016) [6].

In longer trips where there is no stopping, such as aircraft long haul flights, seat comfort is very important. In trains passenger can get up and go for a walk or even to a bar carriage. Not on a normal flight, In buses, operators usually stop every three hours in restaurants which have all kinds of services for the passengers,

2.3 Features / Accessories

The seat features play an important role and contribute to an improved passenger experience. Eating/drinking or using a laptop are activities performed by passengers that require a tray table. In the railway industry the tray tables tend to large and very resistant, proving and support to work and eat comfortably. In aviation tables are smaller and more fragile, but also provide and important support to air meals.

In aviation the literature pocket provides space for passengers to keep personal items, promote operators services, provide revenue opportunities. But first and foremost, literature pockets keep safety instructions in front of each passenger.

Nowadays in the digital age passengers expect permanent connectivity so power supplies have become a standard feature in most industries.

2.4 Maintenance

Designers should also give consideration to the durability and the levels of maintenance required to maintain the products. Seats in transportation systems have to be durable, since each seat will carry hundreds of passengers a day. They have to last for years, be easy to clean, and be able to resist to accidents with food and/or liquids and vandalism.

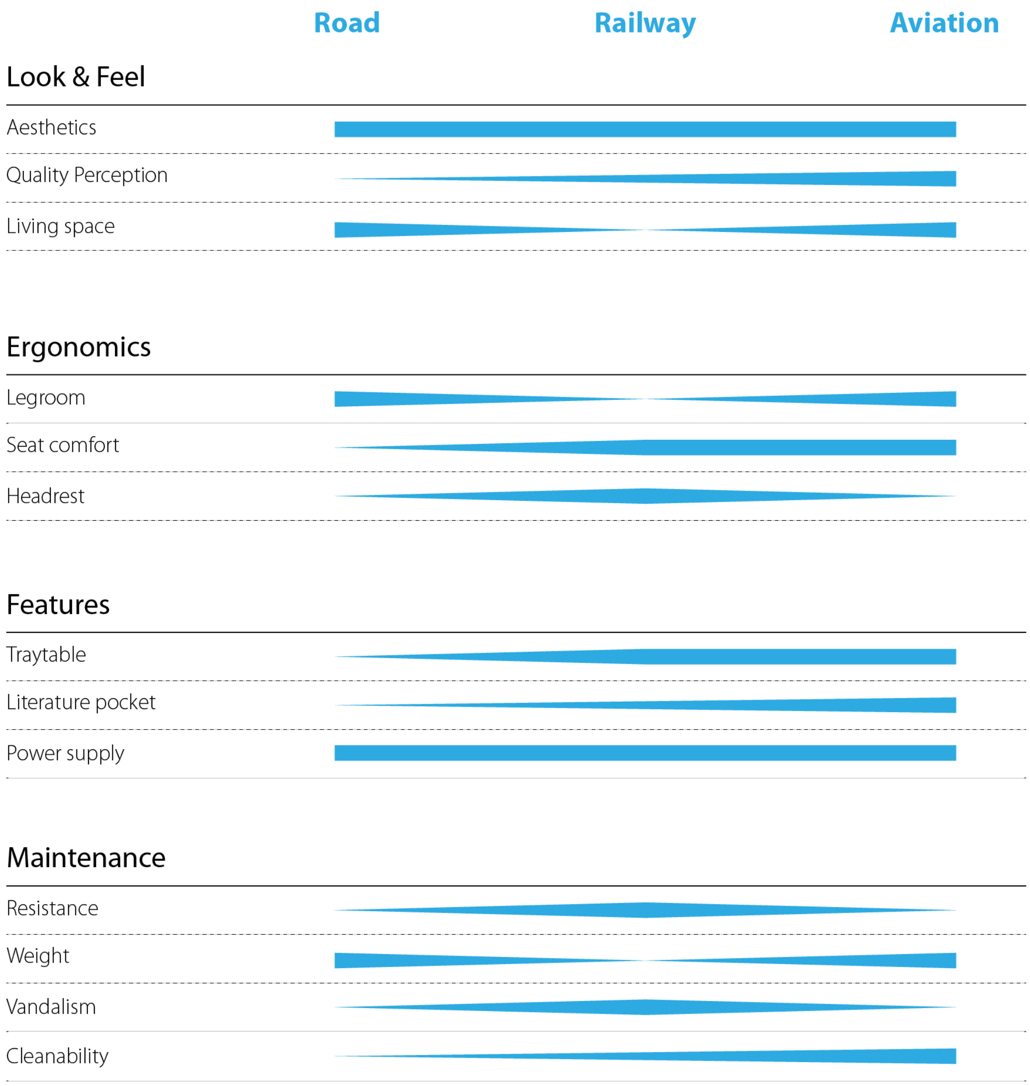
Resistance and cleanability is strongly connected to passenger comfort in public transports, as it is one of the most important aspects in the theory of comfort. Seats in the transport areas, specifically in Railway and Aviation need to comply with strict normatives considering fire and smoke. In the automotive industry and aviation industry crashworthiness is also crucial, with seats being provided with active and passive safety features. Weight saving is crucial in all industries but it is especially important in the aviation industry. The weight savings p/Pax achieved in a high-density layout are the difference between an airline that makes a profit or goes bankrupt. The use of lighter materials, without compromising the load stability, should be possible by the use of the right geometry as well as light metal alloys, polymers and composites that can also improve the living space by reducing volume.

Vandalism is a bigger problem in transports where passengers and not supervised, as in trains or even buses. It is much less important in aviation, where passengers could get arrested for "misbehaving". Railway seats and hence extremely resistant and heavier, as normatives and standards demand very high standards.

6. Conclusions

It is important to analyze design practices and standards in different indsutries in order to get the best out of each practice in a cross pollination approach. We can conclude that transport products in Road, Railway and Aviation industries have many features in common, however seat design can differ widely across the range of materials, manufacturing processes or safety requirements, while trying to provide the best possible passenger experience. Looking in detail on Table 1, we can spot the main differences:

Table 1. Road, Railway and Aviation comparison.



Regarding ‘Look & Feel’, in all three industries, the aesthetic topic is quite important. Quality perception is more relevant in the Aviation industry while the living space in the railway it´s not critical. In both Road and Aviation industry the intensive layouts and tight pitches makes these feature a challenge.

Looking in detail into ‘Ergonomics’ different feature influence these industries. In the Aviation industry the legroom and seat comfort are very important while in the Railway industry the headrest is a critical feature to improve passenger comfort.

Relatively to the features that can improve passenger experience, in the Road industry the tray table and literature pocket are not critical, as power for permanent connectivity are the main point.

Regarding Maintenance in the railway industry the seat must offer more resistance to usage and vandalism. In the aviation industry the presence of a flight attendant can be persuasive to not damage the seat.

The weight is definitely a topic to be addressed in the road and aviation industries, as is connected to performance and efficiency for operators. This paper explores how different seat approaches developed for one industry can benefit successfully other industries, contributing to improvements in passenger experience.

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Comfort driven design of innovative products: the case of the personalized mattress

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Abstract The application of ergonomic principles to the design of processes, workplaces and organizations is not only a way to respond to legal requirements but also an indispensable premise for any company seeking to pursue a business logic. The evolution of Human-centred design brings designers to focus their attention not only to the ergonomic performances of products and processes but, also, to the wellbeing of the customer/worker when interacts with the product. This wellbeing is often translated as the state of perceived (dis)comfort while performing an action. So, in recent years, methods that allow for an objective evaluation of perceived comfort, in terms of postural, physiological, cognitive and environmental comfort, have received a great deal of attention from researchers. The need to have an objective method to evaluate the (dis)comfort perception is definitively due to the will of introducing the comfort evaluation in the early stage of the product development plan, and the necessity to imagine and develop new methods for a preventive evaluation (often made on the digital model of the product) of the future perception of (dis)comfort of the customer. This works deal with the experience of designing an innovative product whose product-development-plan is centred on the customer perceived comfort: a personalized mattress. The mattress is the typical product whose relevance in everyday life of people is under-evaluated. People usually spend from 1/4 to 1/3 of their life on it, but nobody spends more than some minutes for choosing the right one when buying it. Fortunately, this trend is quickly changing and the customer pays more attention and takes information about producers and product characteristics before to buy a product. This trend is more evident in the market of high-performance (that means high price) mattress. Valflex is the luxury brand of Rinaldi Group S.r.l., one of the main player in the world of luxury mattresses' manufacturing companies. This company, together with University of Salerno, has developed methodologies both in terms of preventive comfort evaluation and in comfort-driven design. This work explains the results obtained through the profitable collaboration that allowed to develop two patents and a new reconfigurable mattress, easy to manufacture, whose layout can be tuned on the anthropometric data of the customer to improve the comfort experience during the sleep.

Keywords: Comfort, Mattress, Design

1 Introduction and state of the art

The application of ergonomic principles to the design of processes, workplaces and organizations is not only a way to respond to legal requirements but also an indispensable premise for any company seeking to pursue a business logic. The evolution of Human-centred design brings designers to focus their attention not only to the ergonomic performances of products and processes but, also, to the wellbeing of the customer/worker when

interact with the product. This wellbeing is often translated as the state of perceived (dis)comfort while performing an action. So, in recent years, methods that allow for an objective evaluation of perceived comfort, in terms of postural, physiological, cognitive and environmental comfort, have received a great deal of attention from researchers. The need to have an objective method to evaluate the (dis)comfort perception is definitively due to the will of introducing the comfort evaluation in the early stage of the product development plan, and the necessity to imagine and develop new comfort-driven method for designing new products whose main requirement is the wellbeing of the user. The mattress is one of these products and is the typical product whose relevance in everyday life of people is under-evaluated. One third of human lives are spent in sleep [1] and, in the majority of the world's modern and industrialized countries, this time is spent on a bed-system with a mattress. Sleeping time is very important for the human body to recover from both physical and physiological fatigue suffered throughout the day. Under an engineering point of view, the physical variables associated with sleeping comfort could include spinal alignment [2], contact pressure or weight distribution, interface skin temperature [3], and vapour exchange between the subject and the bedding system. Now, most of the studies and bedding system designs are focused on the measurement of human-back pressure to improve sleep quality and are presented mainly in the way of mattress firmness, but lack of exploring the real relationship between the sleeping postures and mattress design [4].
Going through a bibliographic research over the last 30 years, the first paper dealing with mattress design method is in 1993 [5] in which a pressure pad has been used for measuring the pressure at interface between users and hospital mattresses to develop guidelines for improving mattresses' performances. In recent years, two main approaches have been used to perform studies about the human-mattress interface behaviour; the experimental approach and the simulation approach. Using experimental approach, in 2008, Torres et al [6] have found the strong correlation among pressure variables (in particular pressure variance on buttocks and hands and pressure itself with entire body regions), perceived firmness and perceived comfort. Zhu et al. [7] demonstrated the positive influence of use of foams and latex in mattresses on perceived comfort. Bu et al. [8] demonstrated that the pressure generated through the use of different springs in the mattress frame (different elasticity) has a positive influence on the perceived comfort only in a specific range, thus the mattress needs to be not too firm and not too soft. Shen et al [9] demonstrated that the sleeping quality is correlated to the core material firmness in a three layered mattress (upper, core, bottom). Fang et al. [10] elaborated a simple method to weight the body parts through the pressure distribution on a pressure pad for improving the personalized comfort experience. In [11] Naddeo et al. demonstrated the effect of expectation in performing a mattress evaluation during buying time.
Using the simulation approach, in Ishihara et al [12] a FEM (Finite Element Model) model of soft body on a mattress has been used to evaluate the pressure at interface, with simulation error between 5% and 15%; in Lee et al. [13] a FEM approach has been used with very good correlation results. In Wu et al. [14] a rigid FEM manikin has been positively used to perform a correlation between mattress performances and pressure distribution; Scarfato et al. [15] worked for characterizing the foam mechanical behaviour for realizing really confident simulations.
The conclusion of mentioned papers drives the researcher to develop a method for designing new mattresses that have to be based mainly on the mechanical and the thermal optimization of the interaction between the human body and the mattress. Nevertheless, due to the comfort perception subjectivity, this is also depending from the variability of anthropometric characteristics of users; in Wong et al. [16] the need of customized mattress is highlighted.
In this paper, the problem of developing a new personalized mattress for optimizing the perceived comfort is studied and a practical solution, that have generated two patents, has been explained.

1.1 Aim of the study

The aim of this study was to develop a comfort-driven design method for bring innovation into a market in which it seems very difficult to do that: the mattresses' market.
The first target was to understand what can be the right way to change a standard mattress' configuration to achieve good results in terms of customers satisfaction and, in consequence, in terms of market share. The second target was to develop a new mattress that can be manufactured exactly as the old one, without introducing any kind of complication or new technology in the manufacturing process; the third target was to introduce

a real innovation, not only in the product, but also in the design process, through new methodologies and new instruments.
The case of a personalized mattress seemed to need a big effort and the authors, in cooperation with a mattress company, accepted the challenge.

2 Methods

The first question to which give an answer was: what does a mattress customer, want?
The answer seems obvious: he/she wants to sleep, to sleep well, to feel comfortable and to be refreshed after wake up! But the real behaviour of the customer is completely different: a customer that buy a mattress, in the majority of cases does not test the product or test it just for few seconds [3]; so, what can be done in order to give to customer the feeling of comfort during the first, quick, contact with the product?

Reasoning with these limitations in customer experience, we defined some target to be achieved:

1) The mattress has to be fit to use; in order to achieve this goal, each mattress has to fit to the customers' anthropometric characteristics: height and weight;
2) The sensation and the feeling the customer has during his/her first approach on the mattress, have to persuade him/her that the product fit perfectly with his/her needs.

The second question to which give answers was: what are the factors that influence a mattress' choice and which metric has to be used to measure them?
There are many objective parameters relating to subjective parameter of sleep (dis)comfort. Among various objective parameters, body pressure distribution, temperature and spinal alignment are considered as the critical factors with a substantial impact on sleep comfort and quality. Parameters within the pressure distribution closely correlated to sleep comfort are the maximum pressure, the average pressure [17], the maximum pressure gradient [18], the average pressure gradient, total pressure and total contact area [17] between human body and mattress. In addition, Shelton et al. [19] defined a Pressure Index called "Pindex" to evaluate the homogeneity of pressure distribution across the entire interface area.
On the basis of literature and of mattress company experience, the authors have chosen five parameters to describe the comfort perception, during a quick interaction, by the customer:

1) The average pressure at interface
2) The Variance of the pressure on the surface of mattress
3) The specific pressure distribution on shoulders, along the spine, on pelvis
4) The maximum pressure
5) The sinking into the mattress

The temperature was discarded because, in the buying moment, there is no enough time to reach the temperature equilibrium between mattress and customer laying on. The spinal alignment was discarded because the chosen posture (on the backs with head straight) for the test is the one in which poor sleepers spent more time [10, 15] and poorly affects the spinal alignment.
The analysis was based on a comparison with a reference mattress that was assessed [20] as an acceptable comfortable one, and can be considered as referral values for a used mattress.
All parameters described before were calculated using fully parametrized explicit FE (Finite Element) model that take into account the dynamic interaction between a manikin representing a human with its real joints, and a mattress.
The target of the company was to improve an existing mattress by a Knowledge Based approach for creating a fully configurable personalized mattress. The knowledge-based approach was integrated with the comfort driven analysis and a multiple solution synthesis.
We used a multi-expert system method [21] who recognized the critical factors, gave some guidelines for mattress improvement and evaluated the final solution. Solutions' space was gathered by a technological gate that gave us information about manufacturing feasibility and cost saving.

(1)

3 Comfort driven Innovation

3.1 The starting point

The starting point for new design development was an existing mattress that Rinaldi Group S.r.l. has in its own Commercial Catalogue: the Charlotte mattress, shown in Fig.1.

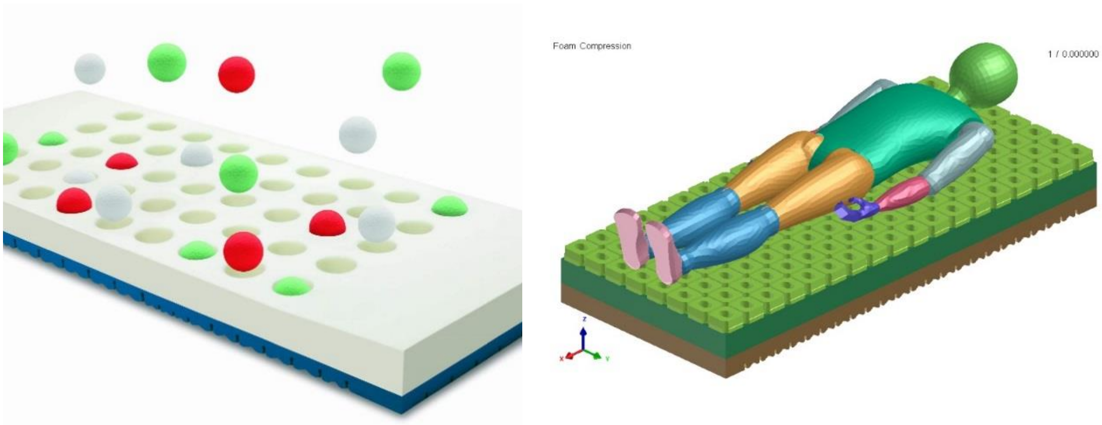

Fig. 1. The Charlotte mattress by Rinaldi Group (Internal part on the left, FEM model on the right).

As shown in the Fig.1, the Charlotte mattress is a three layers mattress made by three different foams: FF60N (High-density memory foam) for the upper part, AP35B (Low-density polyurethane foam) for the intermediate part and Viscopur (Viscoelastic high-density polyurethane foam) for the lower part. In the intermediate part, some balls made by AP35MS (Low-density polyurethane foam) are introduced in cylindrical holes to work as spring. This mattress was the starting point for innovation development.

3.2 Design Constraints

Authors and company engineers were subjected to several design constraints. The most important among them were the following:

1) Materials used for layers have to remain the same and in the same order (Top, Intermediate, Down). Only the content of the cylindrical holes can be changed;
2) The intermediate layer has to be manufactured in the same way (foam extrusion and cutting): the easiest way to respect this constraint is to not change the archetype of the mattress by changing at least the layout, the number and the dimension of the cylindrical holes;
3) The overall dimensions of the mattress have to remain the same due to the use of a textile envelope to wrap the foams layers. The company cannot change the envelope dimensions due to its costs;
4) The gluing systems and the glue type have to remain the same, in order to avoid new certification costs for new materials used in the manufacturing process;
5) New archetype of mattress needs to have the possibility to be personalized in an easy way, without incurring in technological problems or in troubles that might cause a delayed delivery to the customer.

3.2 Technology gate

Rinaldi Group S.r.l. imposed us some technology limitation in order to limit the costs of their innovation. Some technological issues are explained as follows:

1) Technologies used to manufacture the Charlotte mattress have to not be changed;
2) The new cutting systems has to be a cold mechanical cutting one in order to avoid chemical reactions or material's characteristics changes;
3) The mattress assembly operation needs to have the same processing time of the Charlotte one;
4) The assembly operation has to be performed by a robotized system;
5) The increase, in time, of manual operations have to be less than 20%.

On these bases, the new design has been thought.

3.2 The proposed solution

Due to design constraints and technology limitation, the real problem to solve was: what can be used to substitute the foam spheres and what kind of materials can be used to drive the comfort performances?
The basic idea was to fill the cylindrical hole with a special material in order to control the softness and the mechanical behaviour in compression. Material suppliers can offer to the company a wide range of foams from 25 to 65 Kg/m3 having two main behaviour in terms of hysteresis: Elastoplastic and memory foams. The choice was to fill completely the cylindrical hole by inserting a cylindrical-shaped piece of a specific foam among three kind of foams: a softer one, an intermediate one and a harder one. For each kind (soft, intermediate, hard) we had two choices of foam while we had the hypothetical possibility to change the holes diameters as we want. At the end, a unique cylindrical diameter was chosen (as a compromise between the available cutting systems and the workability of cut intermediate layer) and three foams (most performing in terms of durability and costs) were chosen. At this point, the great challenge was to choose the cylinders' layout. In the mattress, 45 cylinders have to be placed; the past knowledge about the mechanical behaviour of the mattresses allow to put some constraints, thus reducing the number of "free cylinders" from 45 to 12.
Due to the hypothesis of Symmetric behaviour of the mattress, the "free cylinders" were reduced to 6; thus, the potential layouts were 3^6 = 729 combinations.
Thanks to the expert consultancy and the previous knowledge about the foam behaviour and its influence on the comfort performances, we were able to drastically reduce the number of models on which perform the sleeping simulation to 15 models. Among 15, three were chosen as best fitting for 3 chosen application: sleeping comfort for a 50% Male with a weight of 60, 70 and 80Kg.

3.3 Technological analysis

The archetype choice allow us to immediately evaluate the changes needed in mattresses' process and the costs/time increase. An evaluation made by process experts bring us to an increase of about 7% of production time and a range of +5/10% in terms of costs.

3.4 Mattress and human modelling and characterization

All materials were physically tested by compression test following the ASTM standards [15] and materials' models were set in order to reach a numerical/experimental correlation of mechanical behaviour with an error always less than 5%, in terms of true-stress-true-strain curve and hysteresis/mechanical parameters.
The Cad model of the new mattress was created in ThinkDesign by Think3® Environment using a hybrid modelling approach (CGS – Constructive Solid Geometry and Surface Modelling). In order to create the model of

the human, we used a still developed MBS model in Solidworks that is fully parametrized in terms of anthropometric measures and human segments dimensions (length, volume, external surface shape) [22]. FEM models were created in VPS© (Virtual Performance Solutions) by ESI® (A dynamic explicit finite element solver) environment and prepared for the run.
Several hypotheses were made in order to simplify the calculations:

- The tests were made in supine position [10, 15] in order to perform a simple/symmetric analysis;
- The manikin was positioned and its joints were blocked in that position.
- All the manikin segments were treated as rigid body connected each other, in order to avoid to calculate flesh deformation during the interaction. This Hypothesis did not affected the calculation and the results because all mattresses were tested in the same conditions and also the referral mattress was tested in the same conditions.
- In order to simulate the body sinking in the mattress, a vertical velocity, from up to down, was imposed to the manikin. The mass distribution was set using the real human mass distribution into segments while the gravity force was neglected due to the use of a constant velocity.
- The equivalent mass of the manikin was calculated by integrating the calculated pressure at interface on the contact surface.
- The lower layer off the mattress was blocked on the ground by a 3DOF clamps (Z direction and rotations off plane)

Materials have been modelled by a nonlinear/viscous material for simulating the mechanical behaviour of foams. The calculation have been performed in order to have the following outputs:

- Map of pressures at interface between human body and mattress;
- Map of pressure at interface between the layers, in order to understand how much each layer works in terms of energy absorption and loads distribution;
- Z displacements of each node in contact with human body;
- Peaks of pressure.

3.5 Solution synthesis

In order to make a comparison between the previous mattress and the one with improvement/innovation, a comfort evaluation criterion was developed.
The comfort formula is protected by NDA (Non-Disclosure Agreement) but the mattress company Valflex permitted us to publish the qualitative information about it. The factors that have been taken into account are the following:

- Ratio between surface in contact with the human body and total surface, in order to take into account the "wrapping" effect;
- Average pressure on Human body that have been compared with the ideal one coming from literature [18,23,24];
- Maximum pressure, that is a good indicator of human body parts that can suffer local discomfort;
- Median Value and Variance of the pressure, that give an idea about the distribution and the difference between the body parts perception;
- Qualitative distribution of the pressure, evaluated by an expert;
- Values and distribution of the pressure in the shoulder/spine area, in order to take into account the discomfort in the body parts that are more sensitive when a person lie down on a mattress [25];
- Qualitative index about the load transfer between the layers, in order to evaluate how each mattress layer works.

All these parameters have been weighted in order to calculate a global comfort index for pressure/postural interaction with a formula like the following:

$$PC = \sum_{i=1}^{n} w_i \times Fc_i + \sum_{j=1}^{m} w_j \times Fs_j$$

In which PC = Perceived Comfort rating, w_i are the weights (relevance) of each evaluated parameter/factor, Fc_j are the n objective factors/parameters calculated by FEM analysis and Fs_j are the m subjective factors evaluated by the experts.
Fortunately, the experience of researchers and experts involved in the process and the limited number of possible layouts due to technological limitation allowed to use a "Trial&Error" method to perform the optimization steps.
The final product coming from this comfort-driven innovation process is shown in Fig.2:

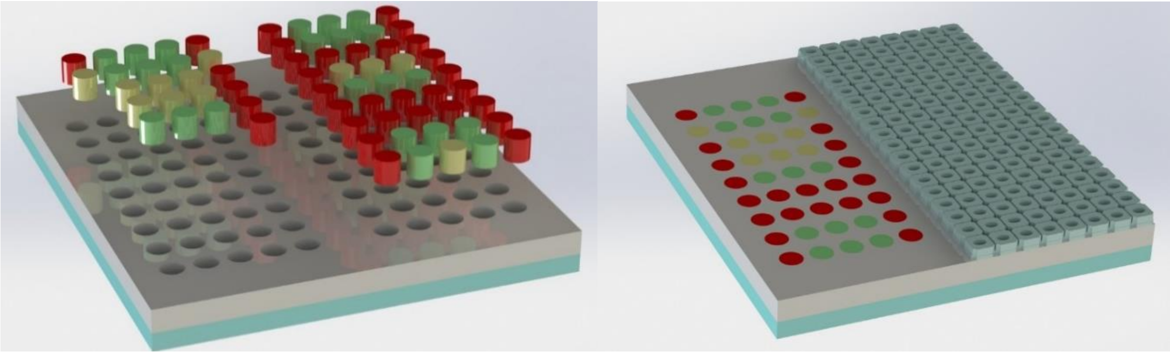

Fig. 2. The New Charlotte archetype.

4 Results

The final result of the innovation and optimization case is showed in Fig. 3-5:

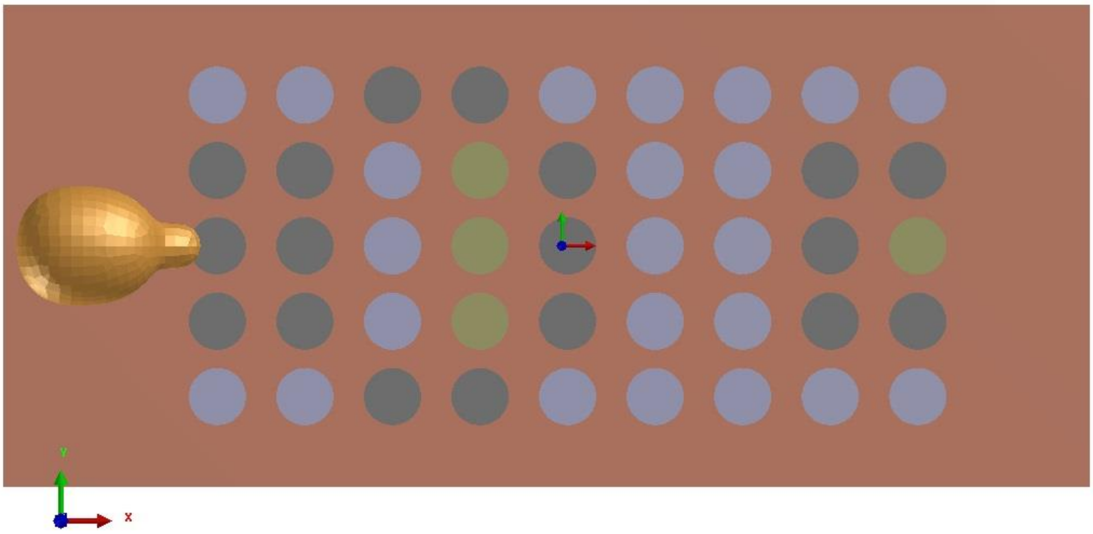

Fig. 3. Layout Charlotte for male 50%, weight 60 Kg

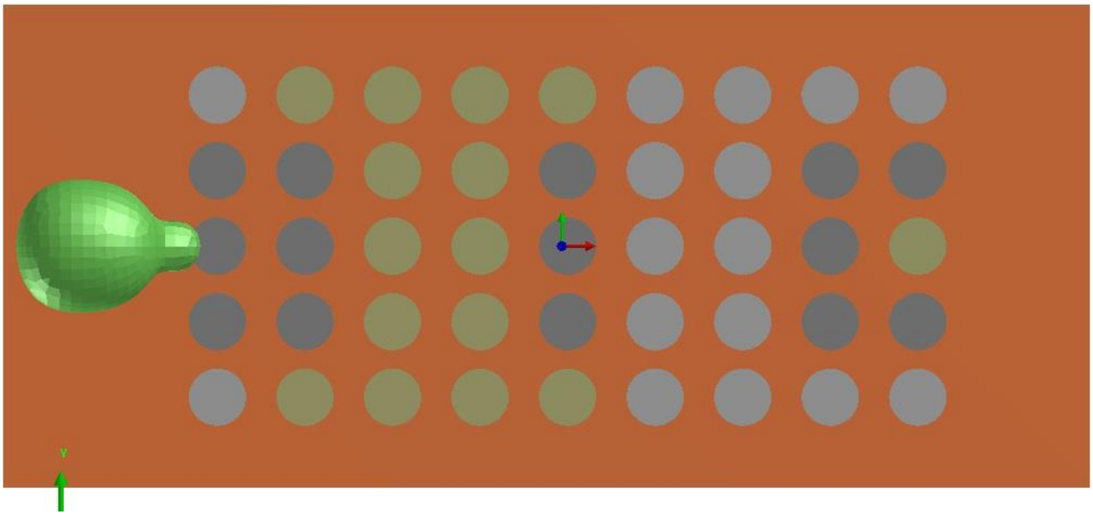

Fig. 4. Layout Charlotte for male 50%, weight 70 Kg

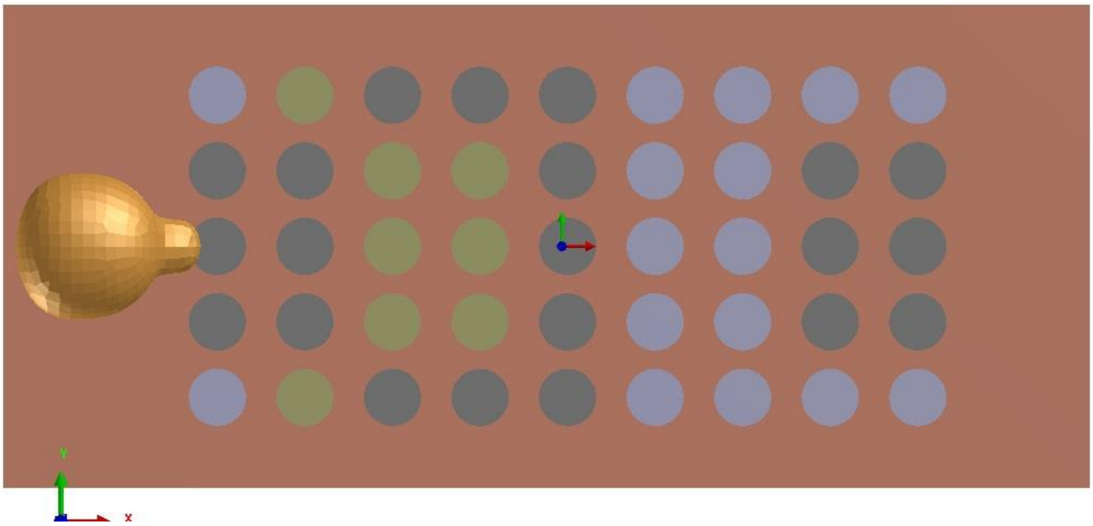

Fig. 5. Layout Charlotte for male 50%, weight 80 Kg

5 Conclusion

The mattress is a typical product whose relevance in everyday life of people is under-evaluated. People usually spend from 1/4 to 1/3 of their life on it, but nobody spend more than some minutes for choosing the right one when buying it. Since several years, the need of customized mattress is highlighted in both scientific literature and market advertisements.

In this paper, a methodological approach has been described to bring innovation by introducing a comfort-driven design method to improve an existing product without changing technologies and costs.

The study has been based on a simulation approach, with a partial correlation between numerical simulation and experiments (made on materials behaviour) that reached high level of precision (under 7% of error on the studied factors).

The new mattress is very easy to be assembled through the gluing of the different layers that constitute the mattress itself.

The comfort-driven design allowed to configure whatever different mattresses we want, and each of them is optimized for a pre-determined users belonging to an anthropometric cluster. The manufacturing cost of personalization is about near zero because the comfort optimization is done simply by adopting an appropriate layout of internal cylinders and using appropriate materials for them. The study was specialized for three different weights of a 50% European Male.
Through the easy personalization of the mattress, the new mattress can fit the customers' needs expressed not only in terms of preferences but also in terms of own anthropometric characteristics like height, weight (i.e. BMI). Therefore, the mattress company organized the new production process in cooperation with their foams' suppliers and had verified that the process times and costs remained almost the same.
Few experiments have been made on the physical prototype of the mattresses, giving very good results in term of perceived comfort. Next steps of this study will be an experimental assessment of the developed mattresses in order to scientifically prove the robustness of the design method.
Finally, this mattress has been introduced in the new Market Catalogue for 2018 and the Marketing&Strategy director of Rinaldi Group made a survey among their distributors and re-sellers and had a very interesting (good) feedback from the pilot customers.
Limitation of the study can be found in the FEM model used and in the wideness of the possible combinations that have been limited by several hypotheses and company's requests. Nevertheless, the study represents a good exercise of developing a comfort driven method with practical outputs.

Acknowledgments We want to thank the Rinaldi Group s.r.l. company, Giffoni Valle Piana (SA) – Italy, for the opportunity to work on a real case and for the competences of the experts they put in the project. It has to be noticed that this study bring the research group to write two patents that are under approval by Italian and European Patent offices.

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Soft Flooring for More Standing Comfort in Trains

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Abstract Standing is a reality in trains worldwide, and at the same time the least preferred travel option for passengers. Swiss Federal Railways undertook initial field research using three types of flooring with different levels of softness. The aim was to identify the potential to increase customer satisfaction when standing. The results clearly indicate that soft flooring can play a key role to improve standing areas on trains. The paper details the findings and puts them into the wider context of ways that aim to increase comfort in standing areas in trains.

Keywords: Standing comfort, soft flooring, public transport, railway.

1 Introduction

During rush hours space on trains becomes scarce. This is particularly true for regional traffic. In spite of reinforcements and expansion of services, standing room cannot always be avoided. The question therefore arises as to how standing space can be made more attractive.

More standing comfort thanks to improved ergonomics.

The awareness for ergonomic workplace design has risen in recent years. Swiss law [1] obliges employers to design and furnish workplaces according to ergonomic criteria. In [2], the Swiss national insurance cover against accidents and occupational diseases *Suva* illustrates that standing work over a longer period of time is easier on the joints and less tiring if the surface is soft. SBB has taken up this idea and implemented it on a trial basis in a regional train.

2 Approach

In a four-carriage FLIRT train of the SBB (RABe 523 068) three existing standing areas were equipped with identical layout as follows:

1. “Normal flooring” marked with a red and white band (control group)
2. "Medium soft mat" (8 mm thick)
3. "Soft mat" (14 mm thick)

From mid-June 2018, the vehicle was in regular service on lines S1 and S3 of the *Regio-S-Bahn Basel* (Switzerland) for around one month. The choice of these two lines ensured that the test took place both in the French and German-speaking regions and that the entire range of possible load factors was mapped.

The selected standing areas are not within sight of each other. As a result, passengers participating in the test were highly likely to have seen only one of the three standing areas.

(a)

(b)

Fig.1. (a) Control group with «normal flooring» (b) Areas with built-in mats "medium soft" (8 mm, left) and "soft" (14 mm)

3 Evaluation

Feedback was obtained in three ways: (1) passenger survey, (2) expert inspection, (3) observation of passenger behaviour in trains.

The "passenger survey" was carried out via an online survey of the entire standing area, in which participants could participate via the QR code or link displayed on the train. The equipment of the three standing areas with different QR codes allowed a simple assignment of the answers. Only one question specifically related to the satisfaction with the standing area. A total of exactly 50 persons took part. Although the results are not representative, they can form a component of the SBB's core question: Does a further deepening of the topic appear to be appropriate?

The "expert inspection" took place as part of a ride in a test vehicle with SBB rolling stock specialists. The "observation of passenger behaviour in the train" was carried out onboard the test train during several hours over the entire test period.

4 Results

The softer, the longer satisfied.

The topic of "soft standing surfaces" is clearly worth further investigation. All three feedback channels have provided this answer.

The "passenger survey" showed the expected effect in its results to be interpreted as impact direction: the softer the standing surface, the higher the satisfaction. The increase between the normal floor and the soft standing surface is impressively above 40% (from 4.79 to 6.78 points, see figure on the left). Since no passenger comments were received on the vehicle floor, it is reasonable to assume that the soft floors were perceived rather unconsciously. The next step would be to find out at which mat thickness the highest satisfaction is achieved. The comfort should stagnate or decrease at a certain point.

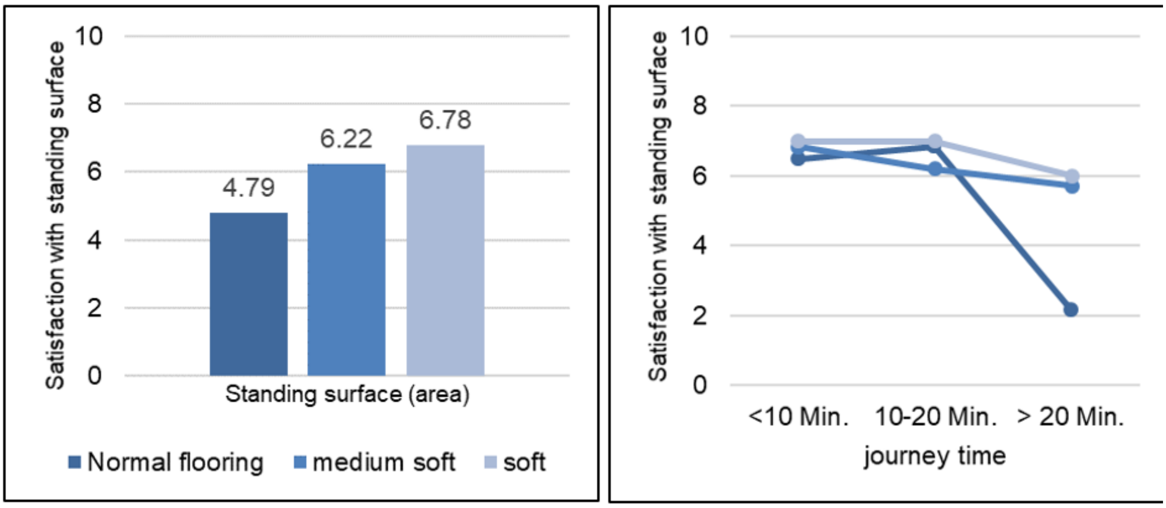

Fig. 2

A second result of the "passenger survey": The comfort gain seems to be most obvious with a standing time of 20 minutes or longer (cf. right figure). Due to the small number of cases, this tendency must be intensified in following studies.

The "expert inspection" revealed further positive aspects. Standing in the direction of travel and leaning back, the soft floor supports the necessary power movement during braking and improves stability. The increase in comfort is noticeable even on short distances.

The "observation of passenger behaviour in trains" showed that a certain number of passengers use the standing areas for shorter distances despite free seats. Other features of the standing area, such as the spatial design, the holding options or the perceived personal safety, also appear to be just as relevant from the customer's point of view. The feedback from the “passenger survey”, in which the desire for comfortable leaning aids for all body sizes and more space between clearly defined standing areas was expressed, is related to this.

5 Discussion

If so, then with soft standing surfaces.

The results show that a deepening of the impact direction "soft standing surfaces" makes sense in the overall context of a more attractive design of standing areas in new vehicles.

In addition to the floor condition, further components need to be optimised. Strict user orientation is required as a conceptual approach for the design of "standing landscapes" in trains. As a consequence, for example, reclining options need to be made even more ergonomic or further support options need to be specified for all body sizes. Small storage facilities or a power supply could create additional benefits.

How and when comprehensive innovations will be implemented will be decided in due course. SBB's goal remains unchanged: to offer the highest possible number of high-quality seats. Where standing room is unavoidable, it should also be of high quality.

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Overcoming Interior Design Challenges to Improve the Comfort of Future Vehicles

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Abstract The automotive industry is experiencing a major transformation driven by societal and environmental trends leading to an acceleration of autonomous driving, electrification and new mobility solutions. Therefore, car manufacturers and OEMs are facing new challenges to make vehicles more comfortable and personalized. Indeed, they need to provide solutions for vehicle of the future respecting standards and certifications without physical prototypes while optimizing time and costs development.

The main purpose of ESI interior solution is to use virtual prototypes based on a single core model enabling to test static, thermal and acoustic comfort of passengers in any position inside the cabin while minimizing energy consumption of vehicle and this at the early stage of interior and seat development process. This paper presents the approach that is used to virtually test new innovative equipment inside a vehicle interior.

1 Introduction

Mobility is fast evolving. In recent years, we have rethought car usage to fit multiple usages supporting environmental and societal welfare, from car sharing to electric, hybrid vehicles and autonomous cars. Automotive interior engineers must reinvent cabin design, without ever compromising occupant comfort.

Different use cases are emerging to allow both driver and passengers to interact differently, which can greatly impact the interior layout. Interior design and engineering teams must deliver new and innovative cabin designs and control their impact on various in-car systems. Teams need to iterate quickly and work towards optimum solutions on several scenarios without impacting the final delivery schedule.

With the prohibitive cost of hardware prototyping and associated delays, simulation is the key to help engineering teams face these new challenges. To meet expectations, ESI proposes a Virtual prototyping solution for seats and interiors applicable from the early stage of the development cycle. Engineering teams test occupant static, dynamic, thermal, and acoustic comfort.

2 Static Comfort of Car Occupants

Many challenges dealing with the advent of autonomous vehicles concern static comfort of passengers. Lots of automotive manufacturers and suppliers will integrate seats enabling to change inclination. This option will permit to switch from a usual to a lying position. Moreover, the interior layout could be changed during journey. It will be possible to be face to face or to be in a classical disposition. Finally, with the democratization of car sharing, comfort must be more and more individualized.

Usually, companies use human volunteers and analyze pressure map distribution to test and certify all parameters linked to static comfort. However, these technics have several drawbacks. Indeed, seats must be adapted to several anthropometries. Moreover, results depend also on the volunteer’s mood. Finally, it is necessary to build a seat model. As it comes late in the development process, if seat does not deliver right performances, modifying design at this stage could require costly countermeasures and associated delays.

1.1 Lying position

1.1.1 Pressure map distribution

Using a set of scalable comfort human models, included in Interior Solution, makes it possible to estimate the seat comfort performance through pressure mapping with integrated and customizable comfort criteria. Discomfort can thus be evaluated for several anthropometries and variants of seats can be easily compared.

We have done a static comfort test with a dummy in a lying position (Figure 1). The aim of this study was to compare influence of inclination on static comfort.

Fig. 1. Lying Position

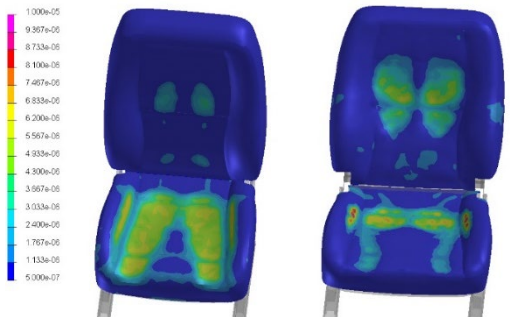

Fig. 2. Pressure map distribution. On the left in usual position, On the right in lying position

We can observe (Figure 2) that there are two pressure pics on backrest in lying position. Engineers have new issues on backrest and must reinforce backrest.

1.1.2 Virtual Seat Model

To ensure a right level of static comfort, it is necessary to create a very realistic seat model, as it interacts directly with the occupant, representing a behavior close to a real one: it contains all the seat components: frame, suspensions, foam blocks, heating pads, cover and padding with related attachment systems. The frame is considered as rigid since the model will be used only for seating and thermal simulations, but all other components are deformable and connected with each other through joints and contacts. This modelling method has been extensively validated through comparison between simulations and real tests regarding pressure distribution measurements. [1] [2] [3]

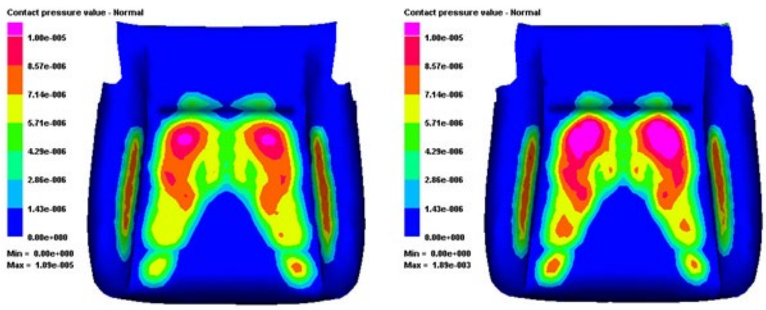

Fig. 3. Pressure map distribution. On the left without manufacturing effects, On the right with manufacturing effects

1.1 Individualized Comfort

1.1.3 Human Model

To deliver accurate results and enable individualized comfort, ESI has a complete library of humans developed specifically for comfort evaluation. They have deformable flesh and are fully articulated, and they correspond to real people that have been scanned. Several anthropometries are available and also overweight, elderly and disable population.

Fig. 4. ESI's human models library

1.1.4 Optimal Seating Experience

Lots of companies want to design an innovative seat concept maximizing comfort and reduce muscular fatigue, while improving the posture of the occupant. To create such new concept, including an innovative air bladders system used to promote good posture for each occupant morphology, it is necessary to use innovative simulation tools. They have created a system controlled by an app enabling auto adjustment of the bladders in the seat based on sensor data and personal settings. They used Interior Solution to model the inflation of the bladders and predicted how the bladders affect the posture of the occupant. By simulating the inflation of the bladders and the impact on the occupant's posture, Lear was able to optimize their seat concept. [4]

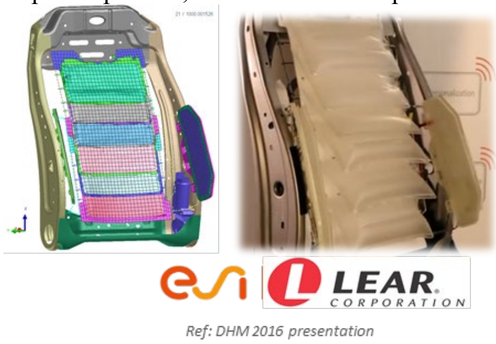

Fig. 5. LEAR Seat Prototype

2 Thermal Comfort

Many changes concern also the thermal management. Indeed, because of seat's orientation, the usual climate system as well as some thermal equipment will be not able to provide a right level of thermal comfort. Moreover, with the advent of electric vehicles, it is necessary to reduce energy consumption of thermal system to improve autonomy.

2.1 Individualized Comfort

2.1.1 Virtual Seat Model

As conduction depends on several mechanical phenomena, it is important for having accurate prediction of the thermal exchange, to consider all these phenomena during simulation. First the conduction between the seat and the occupant depends on the surface of contact between the human and the seat, but also on the distance between the human and the seat. The conductivity is also dependent on the strain conditions. So, to obtain accurate results through simulation, it is very important to perform a good seating simulation which will correctly predict the contact area between seat and human, the seat deformation and the associated mechanical interaction between the seat and the occupant.

The model includes heating pads on the seat which is deformable and connected to the other components. A thermostat rules has been integrated to on/off heating pads and fans to reproduce several scenarios. [5]

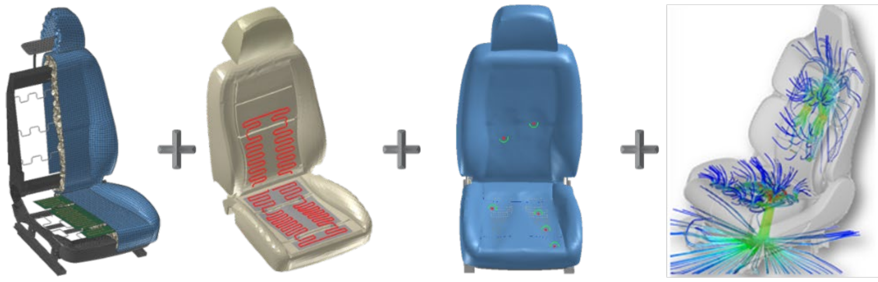

Fig. 6. ESI's seat model

2.1.2 Human Models

The human body can be considered as the combination of 2 thermal systems: A passive system and an active system. The active system models the conduction, blood circulation convection and radiation with the environment. The thermoregulation reflects the thermal response of the human body.

Thanks to these detailed models, we can have access to data that can give us at the end the levels of thermal sensation and comfort. The sensation range between -4 and +4 from a very cold to a very hot temperature. [6]

Fig. 7. Thermal score

2.2 Manage different positions of the seat

In real conditions, air blows, air temperature and thermal management can fluctuate. For this reason, air dynamics are simulated using CFD techniques. It enables to make sure that the exchanges between air and human, or between air and seat are accurate. This resolution is transient, and computes simultaneously heat exchanges within and between all domains, making results more accurate.

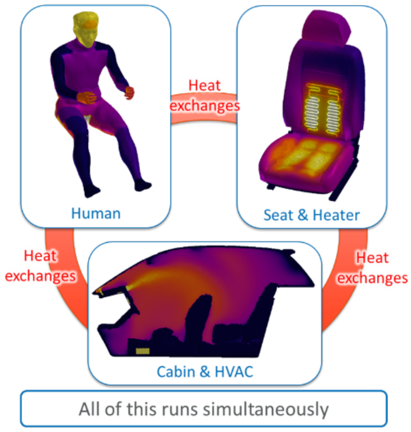

Fig. 8. Coupling Process

2.3 Energy consumption

To minimize HVAC energy consumption in cold weather, it is possible to decrease the global car cabin temperature and add a seat heating system to compensate and maintain the thermal comfort of the occupant. Simulation can be used to test such scenario and find an optimum thermal management system.

An active heating seat could contribute in keeping the same level of comfort for the occupant without having to increase the overall car cabin temperature. A study was focused on the improvement of local thermal comfort in the lower abdomen area, by activating a heating pad system in the virtual seat prototype. The heating pad was piloted by a thermostat, used to control heating cycles (the on/off status) and maintained the temperature between two limit values. The heating pad staid ON until the seat has reached the maximum prescribed temperature and it was then turned off until the seat temperature was lower than the minimum temperature limit.

The use of virtual seat prototyping with digital human model helps finding the solution to reduce the cabin temperature (in this case of 3°C), without decreasing thermal comfort of the occupant. Such solution will contribute to reduce the car energy consumption and thus the range of electric car vehicle. Applied on a car such as the Nissan Leaf, it can be calculated that:

- In cold weather, by activating the HVAC to maintain the car cabin temperature, the EV car loses more than 40 % of its autonomy, which is equivalent to 1 kWh.
- On the other hand, a standard heating pad with electric power of 40 W will consume 80 Wh in 2 hours, thus much less than the saving performed with the cabin global temperature diminution.

This means that the car energy consumption by the HVAC system in electrical vehicles can be reduced and the vehicle range increased, all this without any thermal discomfort.

3 Acoustic Comfort

Problematic: Electric vehicle noise +Sound Zone

Audio personalized space is becoming more and more important in modern vehicles representing new challenges for acoustic designers. Car sharing, for example, contributes to reduced air pollution by optimizing the number of rides and results in strangers sharing the same space, with a clear need to preserve privacy. Soon the deployment of the autonomous car will become increasingly popular, approved by governments and accepted by drivers. In this context the driver will not be fully focused on driving the vehicle, resulting in perceived noise previously largely ignored becoming more annoying. Another important consideration is that customized audio and video streaming will become more accessible, making online services available from personal or car devices available during the journey. Classic noise reduction techniques that rely mainly on passive systems, such as noise control treatments or structural countermeasures to control noise sources are not suitable to create a personalized sound area for each car occupant. Active Noise Cancellation systems (ANC) have been widely studied and developed in the last two decades to generate anti-noise from speaker locations to ensure the minimum noise level for vehicle occupants. Simulation can help in the design and validation process of an ANC reducing the number of protypes and complementing the testing phase.

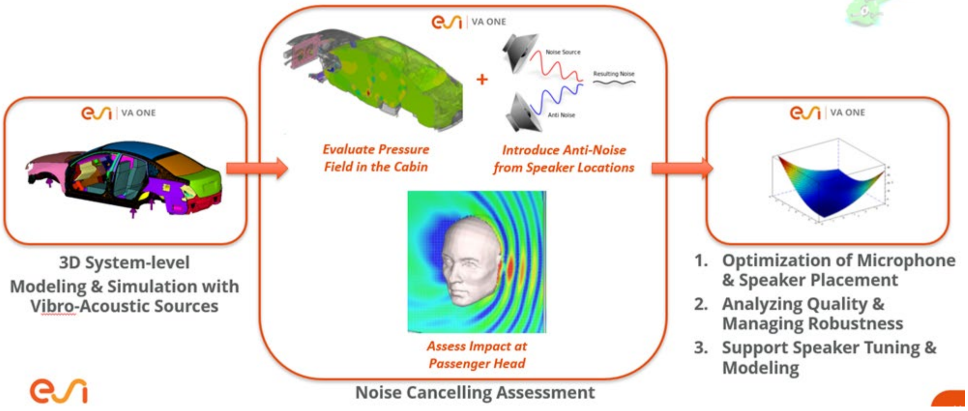

Fig. 9. Noise cancelling Assessment

In the ANC simulation process a full frequency 3D car model is developed using different techniques depending on the frequency range of interest (FE, BE, Ray-tracing). The sound pressure level in the cabin is predicted and combined with the effect of placing anti-noise speakers that minimize noise at the passenger headspace. An optimization process is used to evaluate optimal control microphones positions and speaker locations.A typical outcome of an ANC simulation process using realistic noise sources is a prediction of the expected noise reduction within a designated ‘Sound Bubble’. This can present some concerns, as adjacent passengers can be subject to unwanted anti-noise.

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