Digitalization of posture-based Seat Design
Developing car interiors by involving user demands and activities

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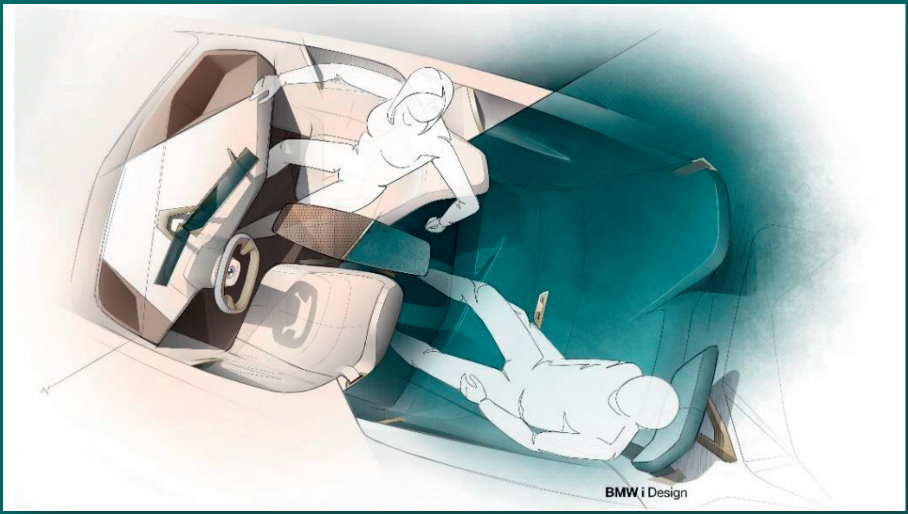

Ümit Kılınçsoy

Digitalization of posture-based Seat Design

Developing car interiors by involving user demands and activities

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, Prof. dr.ir. T.H.J.J. van der Hagen,
chair of the Board for Doctorates
to be defended publicly on
Thursday 17 January 2019 at 12:30 o'clock

by
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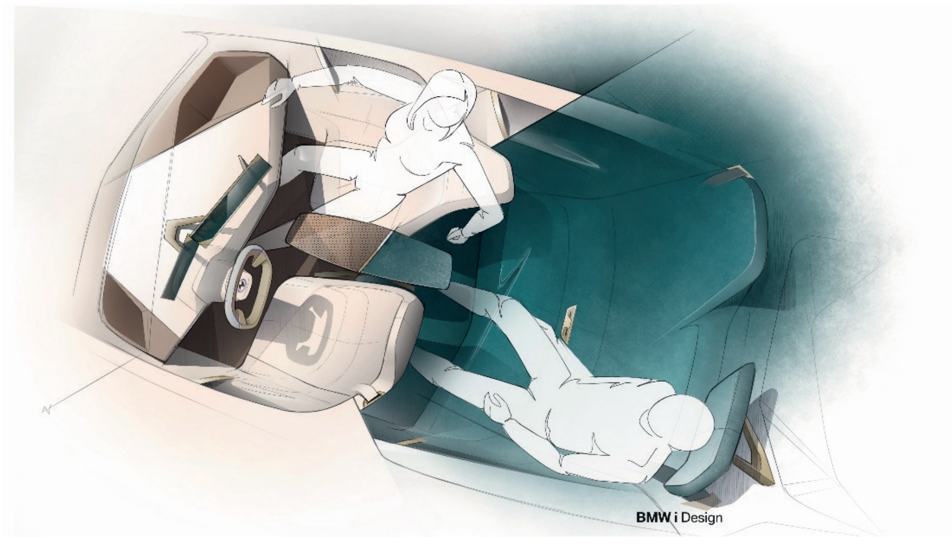

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1. THEORETICAL FRAMEWORK AND DEVELOPMENT OF A SEAT BASED ON HUMAN BODY CONTOUR AND SITTING POSTURES

1.1 Introduction

Almost everyone in the industrial nations uses car seats. Today's traffic situations show a diversified use of cars. Cars are mostly used for work and leisure activities. The number of passengers in a car can vary massively dependent on the type of car varying from a very small one to a van. However, compacts, station wagons, and sedans are the most frequent seen car concepts (Kilincsoy et al, 2014). Often research activities focus on the driver's seat (eg. Zenk, 2004; Hartung, 2005; Franz, 2011; Mergl, 2006; Sammonds et al. 2017). In this PhD the focus is on the rear seats. This focus on the rear seat can be transferred in future to the front seat, because of the introduction of autonomous driving, or Adaptive Cruise Control (ACC). In both situations the user is enabled to move his legs and, in some cases, also do other activities, thus making the driver's seat more similar to the rear seat. The design of a rear seat is part of the complete design process of a car, which will be described in the next paragraph.

1.2 Car design approaches change

The conventional development of a new vehicle starts with a first proportional model. In this model, the exterior geometry of a car can be distinguished into vehicle category (i.e. upper, middle, and lower class), engine and drive train portfolio (i.e. front-, rear-, and all-wheel drive), market requests, legal and consumer protective requirements, and design target (Hofmann, 2018). The interior design results from the proportional model with specific characteristics, such as spaciousness, control and display concept and ergonomic requirements. For instance, the posture of the occupant is defined by how a car user has to position the eyes to watch outside, can reach the pedals, steering wheel, arm rest, and controls. Since the exterior design represents the first appeal for a potential customer, cars are designed and developed from outside to inside. During the automobile history, the interior became more important for engineers in relation to the simultaneous changes in digital services and infotainment (Hofmann, 2018). The car emerged from the sole purpose of transportation with driver orientation into a vacation or commuter experience of all users by a broad spectrum of comfort- and infotainment features. This is sustained by emerging mobility concepts like autonomous car concepts. In order to consider this change in mobility concepts, consumer habits and mobility behavior of users, the interior design becomes more important, which creates the frame within which this PhD is written. This PhD thesis focuses designing car interiors from the inside to the outside by involving users. An essential part within the interior is the seat. According to Hiemstra-van Mastrigt (2015) the activities of the users and user requirements should be determined first to develop a seat and this approach is followed in this PhD (see Figure 1).

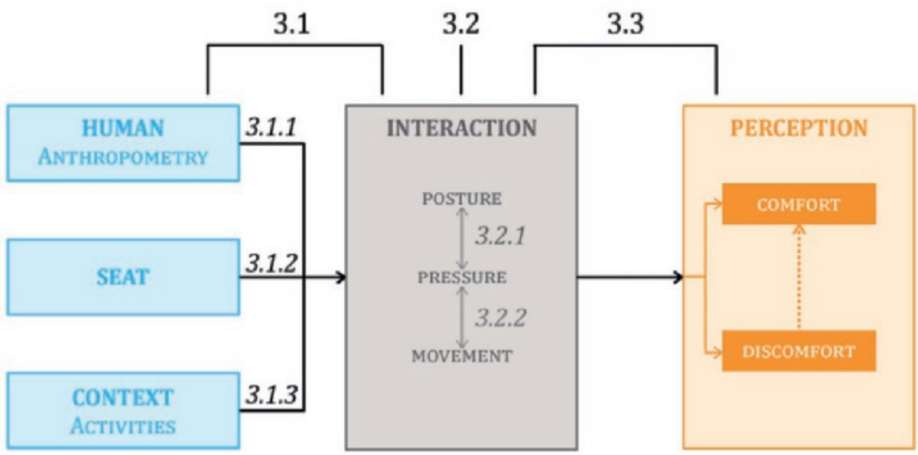

Figure 1: The model of Hiemstra-van Mastrigt to design a comfortable vehicle seat (Hiemstra-van Mastrigt, 2015).

Based on activities occupants perform in their vehicle and other user requirements like those based on anthropometrics, rear seat requirements are developed that are applicable to current car models.

The research question in this PhD is: What are the requirements for a rear seat starting with the activities and user demands fitting within the car design process without drastic changes in the exterior design.

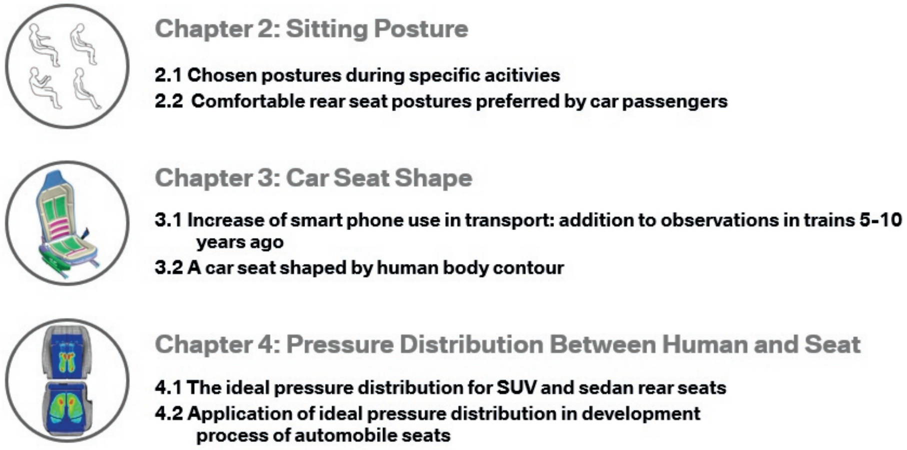

Figure 2: Graphical outline of the thesis.

As not all aspects of comfort and interior design can be studied a selection is made by subdividing the general research question into the aspects: sitting posture, car seat shape and pressure distribution between human and seat in order to establish seat design guidelines (cf. Figure 2).

The second chapter of this PhD investigates the activities of users during transportation independent from the purpose of the trip (i.e. commuting, vacation etc.) and postures found during the activities. In chapter 2.1, postures of users in trains and public spaces (e.g. benches at the airport) are observed and analyzed. An important aspect of this field study is the environment where the people are observed. The environment influences the human behavior (Bazley, 2015). In a train, travelers have freedom of movement and have no driving tasks, which is assumed to be closer to the activities in the rear seat or autonomous driving seat. In a laboratory environment the constraints or the fact that participants know that they are observed may influence the behavior of travelers. Hence, the preferred activities while seated were identified in a natural environment. These findings served as input for a mock-up, which is investigated in chapter 2.2. The most observed activities and corresponding postures of chapter 2.1 that are possible within the space of a car were again tested in the context of the automobile interior. By the identification and digitalization of the corresponding postures inside a car, a probability-based posture model for automobile passengers could be developed. This model can be used to estimate joint angles in for instance the 3D-simulation software RAMSIS (Seidl, 1997). Consequently, this implemented posture model for car passengers can be used for the development of future interiors.

The activities and postures of passengers are dependent from the spaciousness and the seat itself. Therefore, seat dimensions and seat design have an impact on the user's posture. Especially, aspects such as height, length and width of the seat and backrest, as well as the angle of seat and backrest affect the posture of users. Also, the passenger space for legs, arms and head have an impact on the postures. It is impossible to study all car interiors. Therefore, a limitation had to be set. In our study we used an interior of the BMW 7Series. Chapter 3 focuses on seat design. The study concerns the development of guidelines for seat contour design with the purpose to reduce weight. The conducted study questions design guidelines which facilitate comfort for passengers with an adequate level of space and lightweight design simultaneously. Regarding emission targets, regulatory requirements increase constantly. Thus, weight reduction poses a challenge for automotive manufacturers, because consistent lightweight design helps reducing consumption and emissions (Vink et al., 2012). Simultaneously, rigorous consumer protection requirements and laws entail airbags, trim reinforcement, advanced driver assistance systems, and systems for accident avoidance, which cause additional weight in cars. Hence, a lightweight human body contour-based seat was developed with a group of engineers, designers and a physiotherapist at BMW. This seat followed the human contour to increase comfort and a minimum of upholstery and cushion was used to reduce weight.

A further important aspect of developing a comfortable seat is the interface between seating surface and the human anatomy, i.e. the pressure distribution. Mergl (2006) and Zenk (2008) showed the importance of the pressure distribution for the design of seat parameters like height, length, width, and angle of seat and backrest. Furthermore, the consistency and density of the upholstery play an important role. Mergl (2006) and Zenk (2008) defined an assumed ideal pressure distribution between human and seat. However, this respective pressure distribution was established for the driver's seat with the task-orientation and the corresponding posture determined by the connection to the steering wheel and pedals. Chapter 4.1 concerns a study which evaluates whether this ideal pressure distribution can be transferred to non-driving activities, or if adaptation is necessary. This chapter combines the findings of chapter 2 and 3, in order to analyze the pressure distribution of passengers. A study was conducted in a lab environment with an authentic mock-up and seat pressure mats to quantify the feeling of comfort by a direct measurement technique. These results were compared to the results of questionnaires of the sample as an indirect measurement technique. The implications were compared to the findings of Mergl (2006) and Zenk (2008) in order to deduce concrete seat design guidelines. For application of this knowledge, software was developed, which is described in chapter 4.2. By using pressure mats, this software is able to identify the pressure distribution in real-time, while the cushion and upholstery can be optimized to create an ideal comfort experience.

1.3 Seat design

The seat is an important interface between driver and car along with control design (Braess & Seiffert, 2011) and there are many users varying in size. This is why car engineering focuses on facilitating a range of users between small female (e.g. 5-percentile) and a tall male (95-perenctile) (Braess & Seiffert, 2011). The adjustment possibilities of the seat are focused on this variation in body size and at the same time supporting the ideal driver's position. Digital models of humans in CAD systems (digital human models) support the complex task of designing and engineering the car interior today (Franz et al., 2011). Many digital human models are available like Jack and RAMSIS, but also other factors play a role in and also for these areas digital human models are available like for crash simulations, supporting seat design and engineering. To add knowledge for rear seat and autonomous driving seat design background information is gathered in this PhD and translated into digital human models. The current digital models are based on the driver's seat, which might not be sufficient for optimal rear seat development.

1.4 Comfort Experience and Comfort Models

In the literature there are many definitions of comfort and discomfort (Vink & Hallbeck, 2012). Some definitions focus on the wellbeing aspect of comfort between a user and his environment (Slater, 1985; Richards, 1980). De Looze et al. (2003) complement this definition by the influence of physical, physiological, and psychological factors on discomfort, and establishes discomfort as a reaction to the environment. Another model, which is often referred to in the literature, was the comfort model of Zhang (1996). This model shows that comfort and discomfort can happen simultaneously and do not necessarily exclude each other.

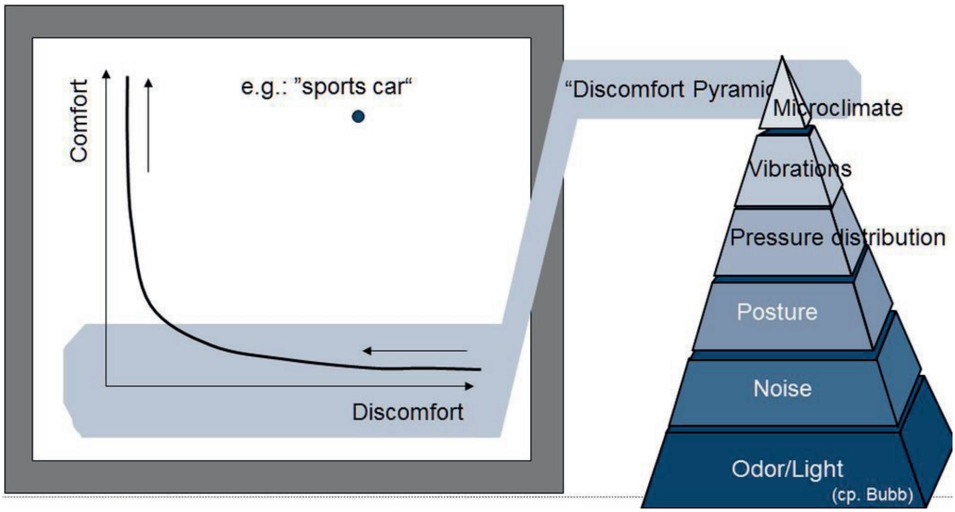

Figure 1: Comfort Model of Zhang (1996) (left) and Discomfort Pyramid of Bubb (2003) (right).

Figure 3 illustrates this phenomenon by the example of a sports car. An enthusiastic driver of a sports car (e.g. Ferrari, Porsche, and Lamborghini) can experience a drive as comfortable, even if the seats are sporty, stiff, and may even result in a cramped position, complemented by a stiff suspension of chassis and drive train. The overall experience of the driving pleasure, luxurious materials, design, and brand attribution also creates value (Wiegandt, 2009) which can result in a comfortable ride in a seat which creates discomfort. Additionally, expectation plays a role. Naddeo et al. 2015 demonstrated that an increase of the expected comfort implied an increase of the perceived discomfort, and a decrease of the expected comfort implied a decrease of the perceived discomfort.

Herzberg (1972) argues whether comfort is the absence of discomfort. According to Bubb (2003) a comfort experience is dependent upon individual expectations and thus it is not quantitative measurable. Many authors agree that comfort is assumed to be a subjective phenomenon (Vink et al., 2005). Discomfort is related to “suffering” and can occur simultaneously to or separately from comfort (Zhang, 1996).

There is no unambiguous definition for comfort, as this experience is influenced by the expectations of users as well. Humans get used to comfort and the more they are used to it, the higher the expectations (Vink et al., 2005). This means that satisfying the comfort is more complex as now the needs are often regarded as standard and users will not notice those anymore.

Often in the literature, comfort is recorded by analyzing discomfort. For discomfort there are many measurement methods and it is therefore easier to record. The literature shows that posture influences comfort and discomfort (e.g. Sammonds et al., 2017) However, for car seats, pressure distribution influences seating comfort and discomfort as well (Mergl, 2006; Zenk, 2008), (see chapter 2.2). Seating comfort can be subdivided in three periods: the first contact of seat and human in the very first instance, short-term comfort of about 30 minutes, and long-term comfort of more than 30 minutes (see Figure 4) (Mergl, 2006). For instance, aspects of discomfort and comfort during long-term flights can be distinguished in thermal, acoustics, visual, and physical aspects of comfort as well as vibration or even shocks (Vink et al., 2005).

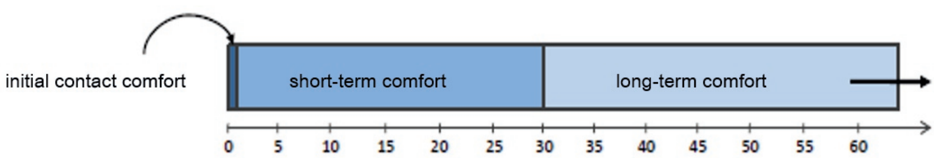

Figure 4: Chronological Classification of static seating comfort (Mergl, 2006)

A study of Reed et al. (1991) shows that the evaluation of short-term comfort is not identical to the evaluation of long-term comfort (Reed, Lee, Saito, Kakishima, & Schneider, 1991). Consequently, experiments gathering results on short-term comfort cannot be one-to-one transferred to representative conclusions for long-term comfort.

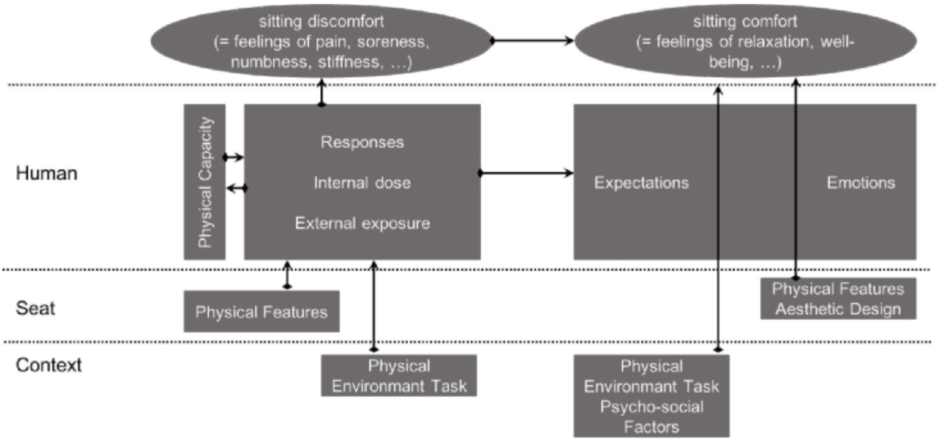

Figure 5: The comfort model for sitting described by de Looze (2003).

Based on the findings of Zhang et al. (2003) in the theoretical comfort Model for sitting of De Looze (2003) the underlying factors are translated from a general approach to seating comfort. Zhang (1996) clustered characteristics such as fatigue, restlessness, pain/biomechanics, strain, and circulation. In De Looze's model (2003) discomfort and comfort are independent characteristics. The part of the model describing sitting discomfort (see Figure 5) describes the human-seat interaction in a specified context. For instance, the human characterized by his individual capacity and physical processes is influenced by the seat during the initial contact, short- and long-term comfort and the physical capabilities of the seat (e.g. upholstery, materials, cushion, and foam), but also by the context (e.g. environmental conditions, commuting, travelling, or the driving task per se). De Looze (2003) describes an exposure of loading factors on seated persons resulting from pressure of the seat onto the body and joint angles such as muscle activation, internal force, intradiscal pressure, nerve and circulation inclusion among further chemical, physiological and biomechanical responses. The other major part of De

Looze's model (2003) describes the sitting comfort by feelings of relaxation and wellbeing, which includes psychological and psychosocial factors. The user's emotions and expectations manipulate the comfort experience. For instance, culturally imprinted favors of colors of sofas and furniture influence also the color preferences of car interiors that leads to a favor of brown and beige (Wagner et al., 2018).

1.5 Characteristics of seating comfort

Mergl (2006) describes the dimensions of seating comfort in the comfort of posture, the first feeling to be seated, micro climate, vibration comfort, capabilities of lateral support, and long-term comfort.

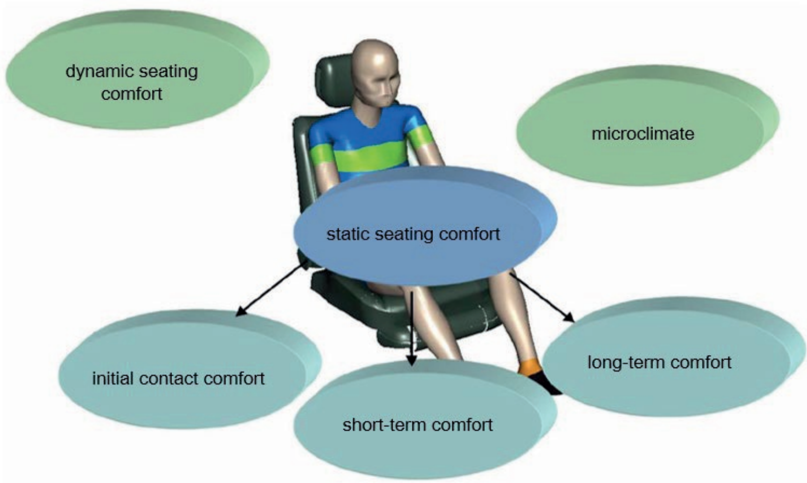

Figure 6: Dimensions of seating comfort (Bubb, 2007 – RAMSIS User Conference).

In relation to the discomfort pyramid (Bubb, 2003) the dimensions of seating comfort can be established (Bubb, 2007) that have an immediate influence (cf. Figure 6). Two basic elements of seating comfort are the comfort of microclimate and vibration, but this is not the focus of this PhD and the background knowledge is not so much dependent on whether you drive or are passive in the car. This PhD focuses merely on the static aspects of seating comfort, i.e. the first impression of comfort (e.g. in a showroom), short-term, and long-term seating comfort.

Hartung (2005) also categorizes seating comfort into the first impression (few seconds after being seated), short-term comfort (from 15 to 30 minutes after being seated), and long-term comfort (more than 30 minutes after being seated). These categories are also relevant for this PhD thesis and used in the studies. Furthermore, there is agreement in the literature that the only one who decides on comfort is the end-user. Therefore, in this PhD the ratings of the end-user's comfort play a central role and the focus will be on comfort (and not discomfort) in alignment with the work of Hartung, Mergl and Zenk.

1.6 Digitalization of human models by RAMSIS

There are many human digital models, like Anybody, Jack, RAMSIS, and Safework, which can be used designing a car interior. In this PhD there was access to the RAMSIS model, which made it logical to choose this software as a bases. RAMSIS is a digital 3-D human model, which was developed by the chair of ergonomics of the Munich University of Technology in collaboration with the VDA (Verband der Deutschen Automobilindustrie). The term RAMSIS is an acronym of "Rechnergestütztes Anthropometrisch-Mathematischer System zur Insassen-Simulation" (i.e. software-based anthropometric-mathematical system for driver and passenger simulation). RAMSIS can be used for ergonomic analysis and designing of working spaces and products in that working space on the basis of CAD (Computer Aided Design). This human model consists of 3D-components to evaluate the interface between the product and a human. By varying the anthropometrics and gender of digital human in RAMSIS, needs and reachability of various interior characteristics can be observed and analyzed. This simulation technique is applied in the aviation, construction machinery, and automobile industry for the design of products and working spaces. The major field of application is the analysis of car interiors.

RAMSIS consists of a model, which can move in the joints and in the joints different angles can be chosen (cf. Figure 7). It also consists of a driver posture model that specifically simulates the posture of humans during a driving task and comfort aspects can be evaluated. Hence, RAMSIS enables the analysis of different aspects that can be predicted such as position, reachability, operating space, and visibility.

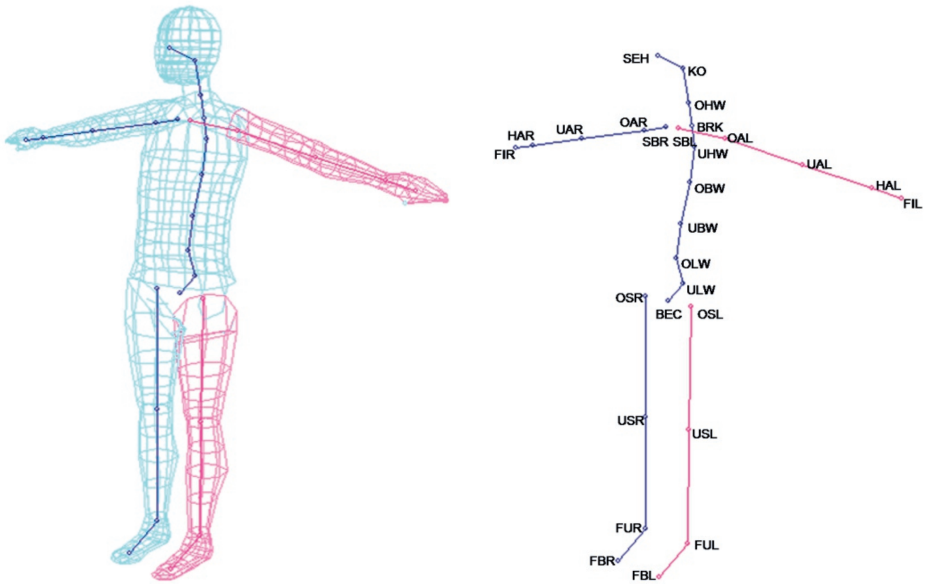

Figure 7: Human Model and definition of joint angles of the software RAMSIS (chair for ergonomics, Munich University of Technology, 2007).

This model exists only for the driver of a car, truck, and motorcycle, but not for the passengers. The driver's posture cannot easily be transferred to the posture of rear seat passengers due to the lacking driving task, and the increasing variety of possible postures. Thus, the implementation of a model for comfortable postures of passengers considering this variety is important and the background information for the rear seat will be studied in this PhD.

1.7 Pressure Distribution and Seating Comfort

In many studies, a relationship between discomfort and pressure distribution is established (Goosens et al. 1998, 2002; Looze et al., 2003). De Looze (2003) found out that the uniformity of pressure distribution on backrest and seat pan contributes to reducing discomfort. By this method, a subjective evaluation of discomfort can be objectified by the use of pressure mats. The feeling of discomfort differs among various body parts. Hence, any discomfort evaluation has to consider this by differentiating those various body parts. Hartung (2005) developed a body map (see Figure 8) for the human back and buttocks and distinguishes 17 body zones. This body map also facilitates the discomfort ratings for subjects during experiments, because each zone is defined and can be evaluated explicitly. The subjects' physique might have an influence on the pressure reception and discomfort. For instance, an increasing ratio of adipose increases a cushioning effect and makes the pressure distribution different.

In an extensive study of Mergl (2006) on the ideal pressure distribution it was established what distribution offers a best fit of seating comfort. This ideal pressure distribution can be defined by three parameters, i.e. maximal pressure, pressure gradient, and pressure distribution. This last parameter proved to be the most valid.

The critical values of the pressure distribution ranges from a maximum of 29% for the zones 10 and 11 (see Figure 8), to 12% of the middle area of the thighs (zone 13, and 14), and to a maximum of 4% of the knee area of the thighs (zone 16, 17). Concerning the spine, valid critical values could only be found for the zones 4, 6, 7, 8, and 9. However in the areas of scapulae, and backrest lateral foam parts no unambiguous relationship could be established as those areas are influenced by users' preferences, experiences, and expectations.

Figure 8 summarizes the findings of Mergl (2006) and Zenk (2004). A body map is projected onto a seat with the pressure distribution of the best fit of humans regardless of height and weight.

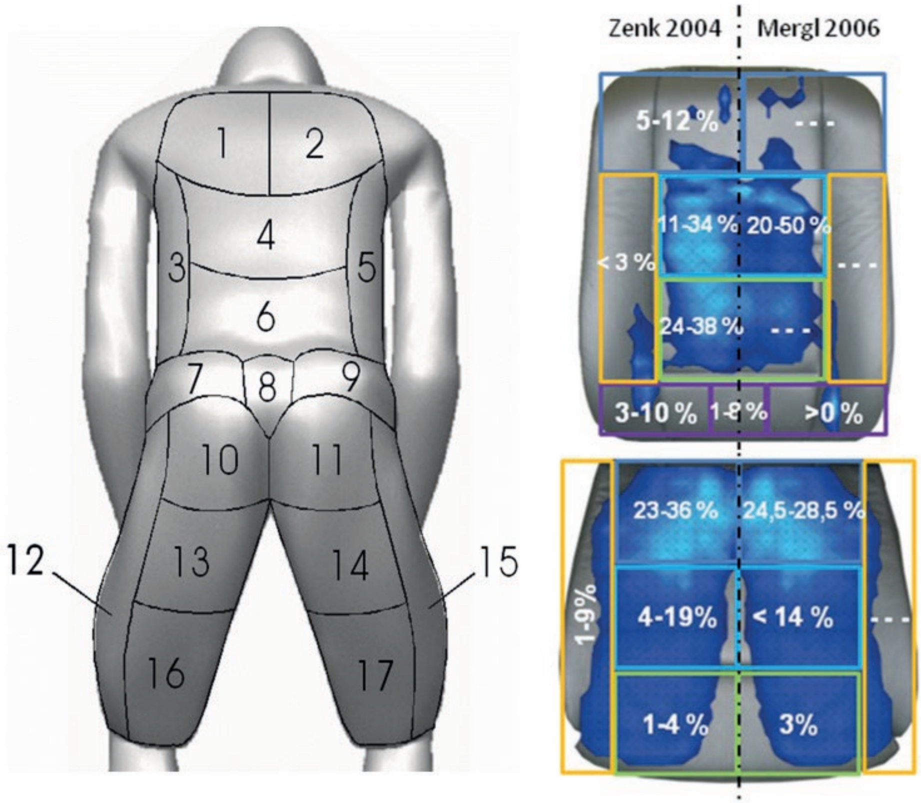

Figure 8: Left: body map (Hartung, 2005), Right: ideal pressure distribution considering the body map (Zenk, 2004; Mergl, 2006).

Despite the previously described fact that there is a difference in comfort experience between short-term and long term sitting, Mergl proved in field tests that the short-term ideal pressure distribution is valid also for the long-term sitting.

1.8 Conclusion

For designing a car seat much knowledge is available in digital models on the drivers' seat. Knowledge for the rear seat is missing and is gathered in this PhD. This knowledge can be applied in the future in the front seats as well for autonomous driving cars. In studying the requirements for a rear seat design, it is good to start with the activities and postures of the occupants in a natural setting and translate these into postures possible in the car seat. There is much discussion on comfort and discomfort, but most studies agree that it is a subjective phenomenon, which entails that experiments with real subjects will be needed to study comfort. A relationship between comfort on the one hand and posture and pressure distribution on the other hand is found, indicating that these aspects should be recorded. It is important to make a distinction between initial comfort experience, short term and long-term experience. However, the short-term ideal pressure distribution seems to resemble the long term and can be used for interior design.

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2 SITTING POSTURE (WITHOUT DRIVING TASK)

Kamp, I., Kilincsoy, Ü., & Vink, P. (2011). Chosen postures during specific sitting activities. Ergonomics, 54(11), 1029-1042

2.1 Chosen postures during specific sitting activities

Abstract

The technological developments of the last decades enable to work in bed with our laptop, watch movies while commuting and plan a new route into our navigation system while we are driving. Because of the increased mobility and flexibility, a new seat design is desirable. This is an opportunity for the car industry. Additionally, the new power supplies make changes in the car package and thereby the interior possible. These changes are opportunities for more flexible and comfortable seats that allow car passengers to do what they want to do in the limited space.

This research is focused on the relationship between chosen activities of people in public spaces and during transport and the corresponding postures they appear to have while doing these activities. Besides the relationship between activities and postures, there is a special interest in the way (small) mobile devices are used by travelers, because they could influence the posture and in literature little can be found on this topic.

It turned out that after analyzing the recordings made in German trains and photographs made in Dutch (semi) public spaces, especially in dynamic situations there is a significant relationship between most activities and the position of head, trunk and arms. In static situations this relationship was less obvious probably due to the differences in available seatings. Remarkable was that when using small electronic devices, there was no significant relationship to be found with the position of head, trunk, arms nor legs.

Key words: Postures, Activities, Seating, Comfort, Transport

Introduction

At the beginning of the nineties, developments in information technology speeded up which had a high impact on the accessibility of information and people as well. Twenty years ago, a common upgrade to laptops was a color screen [1] and in 1992 the first Smartphone was introduced by IBM; 'Simon' [2]. Also, it is the era of the big breakthrough of the World Wide Web. Since then, people became more mobile and accessible than ever. Now you can manage your business calendar on a terrace, working on a text file while waiting at an airport or playing digital games (in color!) while commuting. And the development continues to go on, with increasing sales figures of mobile phones as well as smart phones, notebooks and other mobile devices such as I-Pads [3]. With these technological developments the borders of previously strictly defined spaces are fading. E.g. the office does not have to be in an office building; you can work at home and while travelling. The same goes for watching a television program or a movie; nowadays you are not restricted to your living room or the cinema; you can watch everything you want, wherever you want. This means that the demand for more flexible and comfortable seating possibilities will be influenced.

This is relevant for travel seats and for seats in public spaces. It is also of importance for the car industry. Especially, in combination with the introduction of different car power supplies, there is an opportunity to change the car package. By adapting the interior to these changes and enabling a comfortable and flexible use of these devices a competitive advantage can be achieved. To design the ideal interior, it is essential to know what the natural behavior of human beings. This could be an opportunity to increase the experience and comfort for car passengers. However, the natural behavior is unknown and research is needed to define what activities people want do and want to do and what the corresponding postures are. The purpose of this study is to discover more on what activities people *want* to do when travelling from A to B and *how* they prefer to sit during this activity.

In the past, research was focused on postures and the effect of these postures during specific activities. Andersson (1974) investigated the disc pressure and back muscle activity during sitting. Grandjean et al. (1983) conducted a field study to assess the preferences of VDT operators. Fujimaki and Mitsuya (2005) studied the seated posture for VDT work as well but focused on the advantages of a reclining, ‘slumped’, posture. There have also been observations on people’s postures while watching television (Van Rosmalen et al., 2009). Kolich (2003) investigated the differences between car occupant preferences and anthropometric accommodation. Whereas Parkin et al (1995) observed how drivers were sitting during driving tasks.

Seat design for specific tasks is studied as well. Groenesteijn et al. (2009) focused for example on office chair controls and design in relation to office tasks. And when redesigning a new train seat, Bronkhorst et al. (2005) observed the posture and activities of 1700 passengers in a commuter train. Already in 1967 Branton et al. (1967) evaluated train seats and investigated whether people would sit differently due to the variation in seat design. Harrisson et al. (2000) reviewed the literature to determine an optimal automobile seat and spinal model of a driver. In the literature review of Reed (1994) several seat characteristics like the vertical position of the lumbar support and its prominence are summarized.

Unfortunately, these researches are either dated (Branton et al. published their study in 1967), especially when the technological development in the field of small electronic devices are considered, or they take place in a private and rather unlimited space, like the research of Van Rosmalen et al (2009), which is not realistic for public spaces as you do not have so much privacy, nor for (public) transport situations as there is not an unlimited space. There is also hardly research that focuses on the *relationship* between posture and activity; in most research one of the two is taken as a given fact. Many researchers investigate the sitting postures and comfort experience of someone with a specific task. Like in the car industry were comfort research is done for driver seats and postures (e.g. Parkin et al, 1995). The driver of a car has a dedicated task (driving the car) and his posture is therefore derived from this activity. Unfortunately, the car passengers were never really primarily subject of research and their postures and activities are mostly dictated by their seats and the limited space they have.

This research focuses on postures of people during activities they choose themselves. This means that people were observed during situations where they had some freedom of choosing their activities: during train travels, waiting for public transport, having a drink on a terrace and so on. They had some freedom in how to sit as well, of course within the limitations of the available seating options in the environment. These situations in semi-public spaces have some resemblance with sitting in a car. The differences are important as well (the height of the seats, the available space, the dynamic character of a car travel), but in both situations people are visible to others. Also, in both situations people have to be rather flexible and creative in what they do and how they sit while doing it; they are not at home or in an office where they have all their desired utensils at their disposal.

Research questions:

1. What are the primary activities of people on train journeys and in semi-public places/leisure situations and what is the chosen posture during these primary activities?
2. Is there a difference between activities and postures in dynamic versus static situations?
3. When people use mobile devices, what is the most frequently observed posture?
4. How can the results of this study contribute to the design of future car interiors?

1. Methods

1.1. Definitions

1.1.1. Postures

Before the actual observations took place, the postures were defined and classified in order to record these quickly and easily during the research. For this purpose, the rapid coding technique based on the coding technique of Branton used in his "Evaluation of train seats by observation of sitting behavior" was used. Each posture was represented by a set of four figures. The first figure refers to the position of the head, the second to the trunk, the third to the arms and the fourth to the legs. The denotation of the positions, which are listed in Table 1, is slightly different from Branton because his seat design was different from ours regarding available support and shape of seat cushion, back- and headrest.

Table 1: Denotation of positions.

	Description	Nr.
Head	Free of support	1
	Against headrest	2
	Supported by hands	3
Trunk	Free from backrest	1
	Against backrest	2
	Lounging (slumped back)	3
Arms	Free from armrest	1
	Upon armrest	2
	Only elbow	3
Legs	Free, both feet on floor	1
	Crossed	2
	Other	3

1.1.2. Activities

To define the activities, first a pilot was done. For this pilot the researchers walked through train carriages writing down the observed activities and the frequency of these activities. During the real test, the most observed activities were on a tally sheet (see Table 2). In order to analyze the data, we grouped the activities in low level, medium level and high-level activities. Low level included sleeping, relaxing, watching / observing. Medium level included reading, talking / discussing and eating / drinking. Using small electronic devices and working / using larger electronic devices were defined as high level activities.

Table 2: Activity and observed individuals during train journeys and leisure situations.

Activity	Train	Leisure
Sleeping	78	0
Relaxing	133	39
Watching / observing	49	36
Reading	112	10
Talking / discussing	134	35
Using small electronic devices (e.g. smart phones)	22	11
Eating / drinking	18	32
Working / Using larger electronic devices (e.g. Laptop)	22	12
Total	**568**	**175**

1.2. Samples & recording

To estimate the characteristics of the human sitting postures in relation to their activities, the sitting behavior of 743 different people (adults and children) were recorded by two techniques. First, 568 sitting individuals were video recorded during train journeys in Germany. Second, photographs were taken in the Netherlands of 175 individuals in different sitting situations by a student of the graphic academy who had the assignment to make pictures of people in waiting and leisure areas. The only requirement for selecting the sitting situations were that they should not be at home in a private atmosphere. Both the camera recordings and photographs were made unobtrusively as not to influence the individuals.

This technique of observation was chosen because the assumption is that humans tend not to actively seek discomfort. They will make it themselves as comfortable as possible in a given situation, depending on the environment, available seating and desired activity. A pilot run during a train journey was done to define the activities and to confirm if the method proposed would work well. In Table 2 the activities (based on the pilot run) and the number of observed individuals is listed.

1.3. Data analysis

The recordings and pictures were afterwards analyzed using the tally sheet. On the left side of the sheet the postures per body part were printed, on the top of the list the activities were mentioned (see Table 3). The observers had to observe every individual and mark the corresponding cell. So, for every individual four checks under the observed activity were needed (e.g. a person reading a book while leaning with his head against the headrest, his back against the backrest, using the armrests and his feet crossed received checks in the column 'reading' and in the cells 2222). The photographs were analyzed using the same tally sheet; therefore, it was possible to compare the results of the two techniques.

After analysing the recordings with the tally sheet, the data were entered into SPSS (version 17.0.0, 2008). The chi-squared test was used to find significant relationships between the activities and postures ($p < 0.05$), because the level of measurement consists of categorical and nominal variables (individuals are divided into distinct categories and there are more than two categories).

Table 3: Example of tally sheet used in analyzing train recordings.

POSTURES	laptop - passive	laptop - active	reading	listening to music	working	phoning	playing	talking/ discussing	sleeping/ dozing	relaxing	eating/ drinking	other	remarks
													
													
													
													
													
													

2. Results

2.1. Activities

2.1.1. Most observed activities during train journeys

Table 4 gives an overview of the observed activities during train journeys. Talking and discussing were most often observed (23,6%) closely followed by relaxing (23,4%) and reading (19,7%).

Table 4: The most observed activities during the train journey.

	talking/discussing	relaxing	reading	sleeping	watching	using small elec. devices	working – using larger elec. devices	eating/drinking
%	23.6	23.4	19.7	13.7	8.6	3.9	3.9	3.2

2.1.2. Most observed activities during leisure situations

Table 5 gives an overview of observed activities during leisure situations. This table shows that sleeping was not observed at all. Relaxing was the most often observed activity (22.3%) followed by watching (20.6%) and talking / discussing (20,0%).

Table 5: The most observed activities during semi-public/leisure situations.

	relaxing	watching	talking/discussing	eating/drinking	working – using larger elec. devices	using small elec. devices	reading	sleeping
%	22.3	20.6	20.0	18.3	6.9	6.3	5.7	0.0

2.1.3. Comparison of activities during train journeys and leisure situations

The most striking difference between the train journeys and semi-public/leisure spaces is that sleeping was not observed during semi-public/leisure situations. Talking/discussing activities were commonly observed during both train journeys and semi-public/leisure situations. This activity was primary (23.6%) for train journeys, yet third in frequency (20.0%) during semi-public/leisure situations. During train journeys, relaxing was second (23.4%), although it was primary (22.3%) during semi-public/ leisure situations. Watching was second in semi-public/leisure situations but not one of the top three activities during train journeys. Instead of watching, reading was one of the top three activities during train journeys. However, reading did not appear in the top three for semi-public/leisure situations.

Chi-squared tests of the raw data for the observed activities showed that the differences between travelling by train and semi-public/leisure situations were significant in some cases. Sleeping, as already mentioned, was not observed during semi-public/leisure situations. During train journeys, 78 individuals were observed sleeping. The fact that no one sleeps in semi-public/leisure situations is highly significant ($p < 0.001$), and, for train journeys, the chance that someone does sleep is significant ($p < 0.05$). In semi-public/leisure situations, it can be expected that people are just watching ($p < 0.001$). Watching is not to be expected by people travelling by train ($p < 0.05$). Reading is positively significant for train travelers ($p < 0.05$) however, negatively significant for semi-public/leisure situations ($p < 0.001$). There is also a substantial correlation for eating and/or drinking during train journeys and in semi-public/leisure situations. However, during train journeys, a negative significant relationship was found. It is expected that individuals will not eat and/or drink on a train ($p < 0.001$), whereas, in semi-public/leisure situations, people are expected to eat and/or drink ($p < 0.001$). Relaxing, talking/discussing, working/using larger electronic devices and using small electronic devices did not have a significant relationship in either train journeys or semi-public/leisure situations. There is a significant relationship between the situation (train journeys or semi-public/leisure situations) and the activity. However, there is a medium association between the situation and the performed activity (Cramer’s V = 0.38).

2.2. Postures

2.2.1. Most observed postures during train journeys

Table 6 gives an overview of the observed postures during train journeys. As can be seen from this table, posture 1211 (Figure 9) was observed most with 40%, followed by 2321 (15.1%) and 1212 (12.5%).

Table 6: Overview of percentages of the ten observed postures during train journey.

	1211	2321	1212	2221	2231	3333	1111	1112	2313	1233
%	40.0	15.1	12.5	10.9	8.3	6.5	5.1	0.5	0.7	0.4

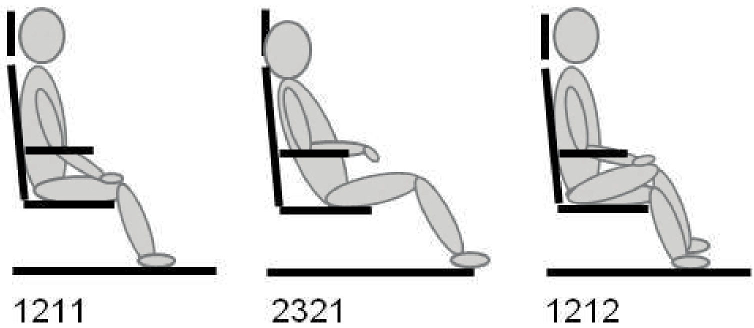

Figure 9: The three most observed postures during train journeys.

2.2.2. Most observed postures during leisure situations

Table 7 shows the postures observed in semi-public/leisure situations. The first remarkable fact is that there are more different postures observed; during train journeys of all theoretical possible postures (64), only 10 were observed; however, during semi-public leisure situations, 16 different postures were observed. The most frequently observed postures were 1111, head free of support, trunk free from backrest, arms free from armrest and legs free with both feet on the floor (32.0%), followed by 1211, head free of support, trunk against the backrest, arms free from armrest and legs free with both feet on the floor (19.4%), and

1212, head free of support, trunk against the backrest, arms free from armrest and legs crossed (15.4%), see Figure 10.

Table 7: Overview of percentages of the observed postures during leisure situations

	1111	1211	1212	12222	1232	1332	1121	1221	1233	3333	2332	1322	1323	1331	1333	3332
%	32.0	19.4	15.4	9.1	8.0	6.3	1.7	1.7	1.1	1.1	1.1	0.6	0.6	0.6	0.6	0.6

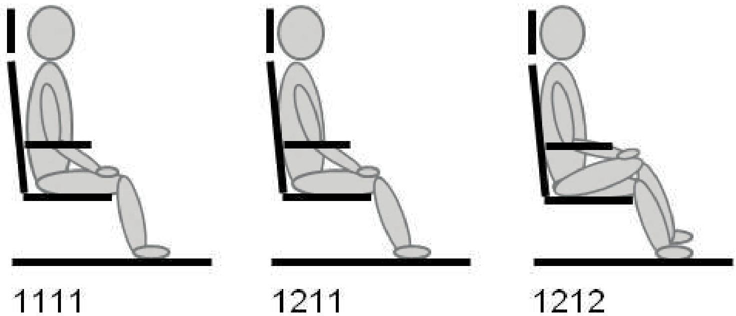

Figure 10. The three most observed postures during semi-public/ leisure situations.

2.2.3. Comparison of postures during train journeys and leisure situations

Table 8 is an overview (in percentages) of the observed posture of head, trunk, arms and legs for both the train journey and the semi-public/leisure situations. Included in this overview is the level of significance.

Table 8: Overview of observed head, trunk, arm and leg postures in percentage of the total during train journeys and semi-public/leisure situations.
* = positive sign. $p > 0.05$; ** = positive sign. $p > 0.01$; *** = positive sign. $p > 0.001$;
-* = negative sign. $p > 0.05$; -** = negative sign. $p > 0.01$; -*** = negative sign. $p > 0.001$

		Train (%)	**Leisure (%)**	**Total (%)**
Head	1	58.5^{-**}	97.1^{***}	67.6
	2	35.0^{***}	1.1^{-***}	27.1
	3	6.5	1.7^{-*}	5.4
Trunk	1	5.6^{-***}	35.4^{***}	12.7
	2	72.0	53.1^{-*}	67.6
	3	22.4	11.4^{-*}	19.8
Arms	1	58.8	65.1	60.3
	2	26.1	15.4^{-*}	23.6
	3	15.1	19.4	16.2
Legs	1	79.4	54.9^{-**}	73.6
	2	13.0^{-***}	41.7^{***}	19.8
	3	7.6	3.4	6.6

During train journeys, the head is most likely supported ($p < 0.01$), against the headrest ($p < 0.001$), the trunk is against the backrest ($p < 0.001$) and the legs are most likely not crossed ($p < 0.001$). During leisure situations, the head is free from support ($p < 0.001$) and not leaning against a headrest ($p < 0.001$) or is supported by the hands ($p < 0.05$). The trunk is free from support during leisure situations ($p < 0.001$), and it is not expected that the trunk is leaning against a backrest or is slumped. In this study, in the leisure situations, there was no backrest available most of the time; therefore, people were bent forward or sitting with the back straight and upright ($p < 0.05$). The arms are not supported by armrests ($p < 0.05$), the legs are most likely to be crossed ($p < 0.001$), and both feet are not on the floor ($p < 0.01$). Overall, the position of the head in relation to the situation is significant; however, there is a moderate association between the situation and the position of the head (Cramer's V = 0.352). The trunk position and the leg position both depend significantly on the situation; again, there is a medium association, Cramer's V = 0.383 and 0.307, respectively.

2.3. Postures in relation to activities

2.3.1. Train journeys

The relationship between postures and activities for the train observations are represented in Figure 11. The light shading indicates a rather low activity level (activities like sleeping, relaxing, watching), the darker shading represents medium activity levels (activities like talking / discussing and eating / drinking) the darkest shade presents high activity levels (activities like using small and larger electronic devices).

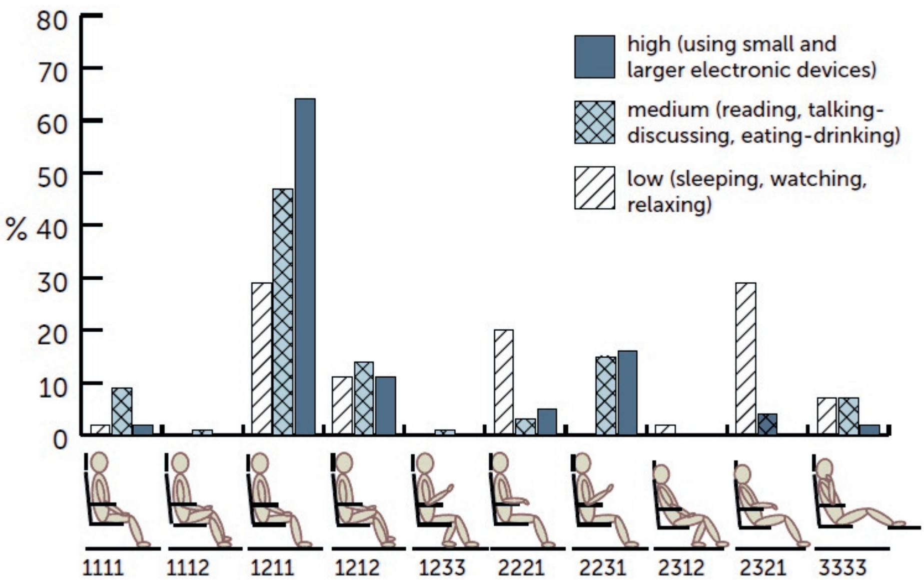

Figure 11: Graph representing postures and activities during train journeys.

Figure 11 shows that postures 2321 (29.2% of all individuals who were doing a low-level activity), 1211 (28.8% of all individuals who were doing a low-level activity) and 2221 (20.0% of all individuals who were doing a low-level activity) were observed when people did activities at a low level. For medium-level activities, the most observed posture was 1211 (47.0% of all individuals who were doing a medium-level activity), followed by

2231 (14.8% of all individuals who were doing a medium-level activity) and 1212 (14.0% of all individuals who were doing a medium-level activity). The high-level activities were mostly carried out in posture 1211 (63.6% of all individuals who were doing a high-level activity), 2231 (15.9% of all individuals who were doing a high-level activity) and 1212 (11.4% of all individuals who were doing a high-level activity).

2.3.2. Leisure situations

Figure 12 represents the relationship between postures and activities during leisure situations. The shading in Figure 12 is kept the same as in Figure 11.

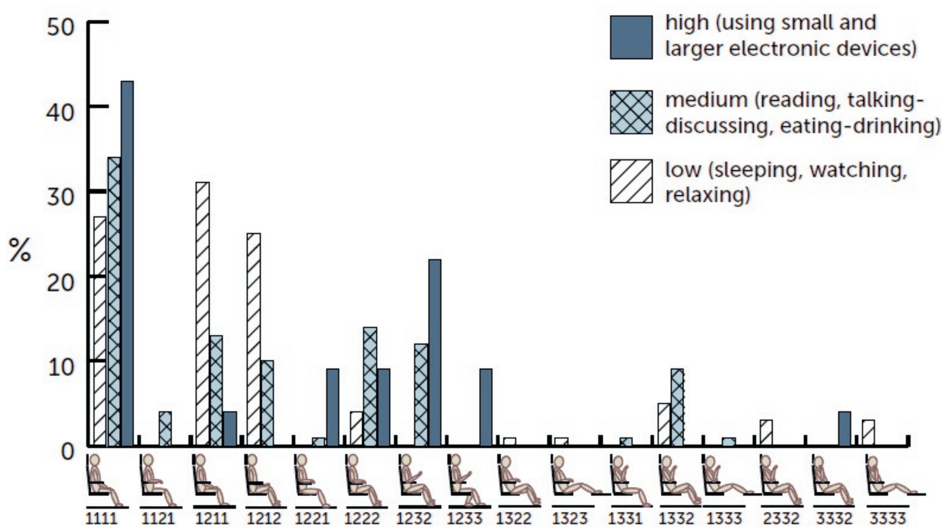

Figure 12: A graph representing postures and activities during semi-public/leisure situations.

Figure 12 shows that postures 1211 (30.7%), 1111 (26.7%) and 1212 (25.3%) were observed among all individuals doing a low-level activity. Among all individuals who did medium-level activities, the most observed postures were 1111 (33.8%), 1222 (14.3%) and 1211 (13.0%). The high-level activities were mostly carried out in postures 1111 (43.5% of all individuals who were doing a high-level activity), 1232 (21.7% of all individuals who were doing a high-level activity), 1221 and 1222 (both 8.7% of all individuals who were doing a high-level activity).

2.3.3. *Travel and leisure combined*

When the train journey and the semi-public/leisure situations are combined and the counts below 5 are omitted, the postures during low, medium and high activities become clearer (see Table 9 for the values and Figure 13 for the graphical representation).

Table 9. An overview of the observed postures and low, medium and high levels of activity in percentages.

Posture	**Low (%)**	**Medium (%)**	**High (%)**
1111	7.5	14.4	16.4
1211	29.3	39.3	43.3
1212	14.3	13.2	7.5
1222	0.9	3.2	3.0
1232	0.0	2.6	7.5
1332	1.2	2.1	0.0
2221	15.5	2.3	3.0
2231	0.3	11.4	10.4
2321	22.7	2.9	0.0
3333	6.0	5.3	1.5

Overall, it can be said that posture 1211 (head free of support, trunk against the backrest, arms free from armrest and legs free with both feet on the floor) is seen when people are involved in high- and medium-level activities. For low-level activities, postures 1211 (head free of support, trunk against the backrest, arms free from armrest and legs free with both feet on the floor) and 2321 (head against headrest, back in a slumped position, arms upon the armrest and legs free with both feet on the floor) are preferred.

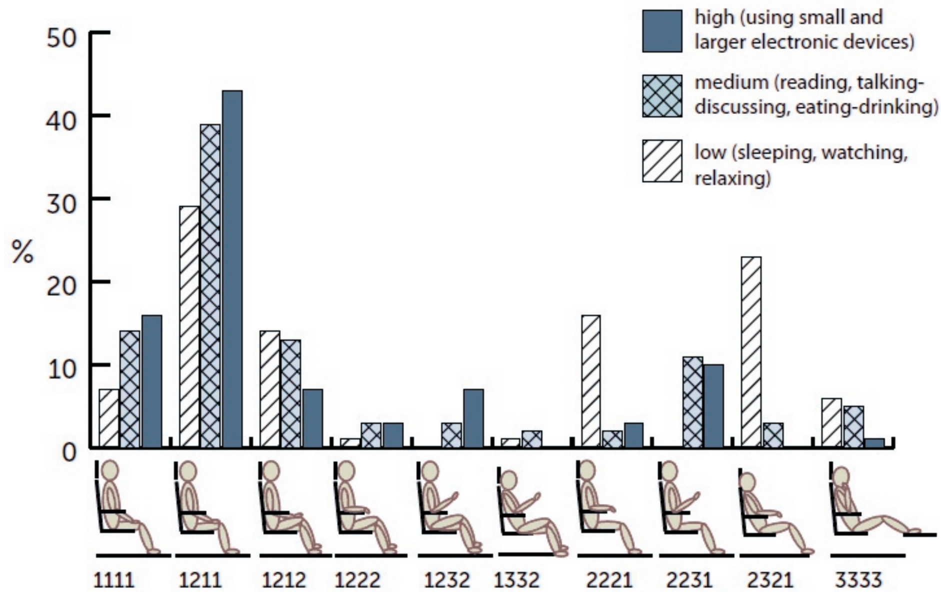

Figure 13: A graph representing postures and activities during semi-public and train journey situations.

2.4. Significance between Postures and Activities

2.4.1. Train journeys

With the chi-squared tests, some postures are highly significant coupled with activities (negative, e.g. the specific posture is not to be expected with the specific activity or positive, e.g. the posture is to be expected while doing the specific activity). In Table 10 all significant relationships are presented for the observations during the train journeys. Table 10 shows that the leg position varied most among the train travelers. Also, when using small electronic devices, no significance in posture was found. For sleeping, relaxing, talking/discussing and working with larger electronically devices, at least five aspects of the postures were significant.

Overall, it can be said that there is a moderate/relatively strong association between the activity performed and position of the head (Cramer's V = 0.37), the trunk (Cramer's V = 0.37) and the arm (Cramer's

V = 0.49). The position of the feet does not have a significant relationship with the activity.

Table 10: An overview of significant relationships between postures and activities for train journeys only (-- = no significance; * = negative relationship).

LEVEL		LOW			MEDIUM			HIGH	
		Sleeping	Relaxing	Watching	Reading	Talking/ discussing	Eating/ drinking	Using small elec. Dev.	Working – using larger elec. Dev.
Head	1	0.001*	0.001*	--	--	0.001	--	--	0.05
	2	0.001	0.001	--	--	0.001*	--	--	0.05*
	3	--	--	--	--	--	0.01	--	--
Trunk	1	0.05*	0.01*	--	--	0.001	0.01	--	--
	2	0.01*	--	--	0.05	--	--	--	--
	3	0.001	0.001	0.01*	0.001*	0.05*	--	--	0.05*
Arms	1	0.001*	0.01*	0.1	--	0.001	--	--	0.05
	2	0.001	0.001	0.01*	0.001*	0.001*	--	--	0.05*
	3	0.05*	--	0.05*	0.001	0.05*	--	--	--
Legs	1	--	--	--	--	--	--	--	--
	2	--	--	--	--	--	--	--	--
	3	--	--	--	--	--	0.05	--	--

2.4.2. Leisure situations

Table 11 shows all the significant relationships for the observations during the leisure situations. Table 11 shows the less significant relationships applied when looking at the train journeys. One significant relationship was found for relaxing, watching, using small electronically devices and eating/drinking.

Table 11: Overview of significance postures and activities for semi-public/leisure situations only (-- = no significance; * = negative relationship).

LEVEL		LOW			MEDIUM			HIGH	
		Sleeping	Relaxing	Watching	Reading	Talking/ discussing	Eating/ drinking	Using small elec. Dev.	Working – using larger elec. Dev.
Head	1		--	--	--	--	--	--	--
	2		0.05	--	--	--	--	--	--
	3		--	--	--	--	--	--	--
Trunk	1		0.001*	0.01	--	--	0.05	--	--
	2		--	--	--	--	--	--	--
	3		0.05	--	--	--	--	--	--
Arms	1		--	--	--	--	--	--	--
	2		--	--	--	--	--	--	--
	3		--	0.01*	--	--	--	0.05	--
Legs	1		--	--	--	--	--	--	--
	2		--	--	--	--	--	--	--
	3		--	--	--	--	--	0.01	--

2.4.3. Travel & Leisure combined

When combining the raw data of the train journeys and the leisure situations, also significant relationships were found (see Table 12). Remarkably, the position of the legs is the least significant with different activities. Sleeping, relaxing, watching and reading have at least five significant relationships with the postures.

In this case, it can be said that there is a moderate/relatively strong association between the activity performed and position of the head (Cramer's V = 0.37), the trunk (Cramer's V = 0.40) and the arm (Cramer's V = 0.425). The position of the feet does not have a significant relationship with the activity.

Table 12: An overview of significance postures and activities for train journeys and semi-public/leisure situation (-- = no significance; * = negative relationship).

LEVEL		LOW			MEDIUM			HIGH	
		Sleeping	Relaxing	Watching	Reading	Talking/ discussing	Eating/ drinking	Using small elec. Dev.	Working – using larger elec. Dev.
Head	1	0.001*	0.01*	0.01	--	0.01	--	--	--
	2	0.001	0.001	0.001*	--	0.001*	0.01*	--	0.05*
	3	--	0.05	0.05*	--	--	--	--	--
Trunk	1	0.01*	0.001*	0.001	0.01*	--	0.001	--	--
	2	0.05*	--	--	0.01	--	0.05*	--	--
	3	0.001	0.001	0.001*	0.001*	--	--	0.05*	0.05*
Arms	1	0.001*	0.05*	0.001	--	0.001	--	--	--
	2	0.001	0.001	0.01*	0.001*	0.001*	--	0.05*	--
	3	0.05*	--	0.001*	0.001	--	--	0.05	--
Legs	1	--	--	--	--	--	--	--	--
	2	0.01*	--	--	--	--	--	--	--
	3	--	0.05	--	--	--	--	--	--

3. Discussion

3.1. Research questions

3.1.1. What are the primary activities of people on train journeys and in semi-public places/leisure situations and what is the chosen posture during these primary activities?

This research study was conducted to provide input for car interior design. For this purpose, the first question to be answered is what activities do people want to carry out when they are travelling by train and in semi-public/leisure spaces? As described in the introduction, car interior seating is comparable to semi-public/leisure space seating in terms of visibility to other people (inside, as well as outside the car), flexibility and improvisation that is asked of people in both sitting situations. For this study, the most observed activities for train journeys and semi-public/leisure situations overall are watching, talking/discussing and reading (see Figure 14). In looking at the activities performed during train travel only, the most observed activity was talking and discussing, closely followed by relaxing and reading. In their research, Khan & Sundström (2007) asked train passengers what kind of activities they preferred and how long did it take to do those preferred activities. The results showed the average journey took 72 minutes and 42 passengers spent an average of 44 minutes on sleeping/napping.

Additionally, 263 passengers spent 40 minutes reading and 79 passengers spent 35 minutes of their time chatting with other passengers. Although this article had a different research approach, both studies found similar results: talking/discussing, reading and relaxing were the most observed activities during train journeys. The research of Krishna Kant (2007) showed that the top three activities on trains in India were talking to fellow passengers, no particular activity (interpreted as relaxing) and reading. Remarkably, sleeping/napping was not one of the three most observed activities in their study, surprising with the average train journey taking 107.6 minutes.

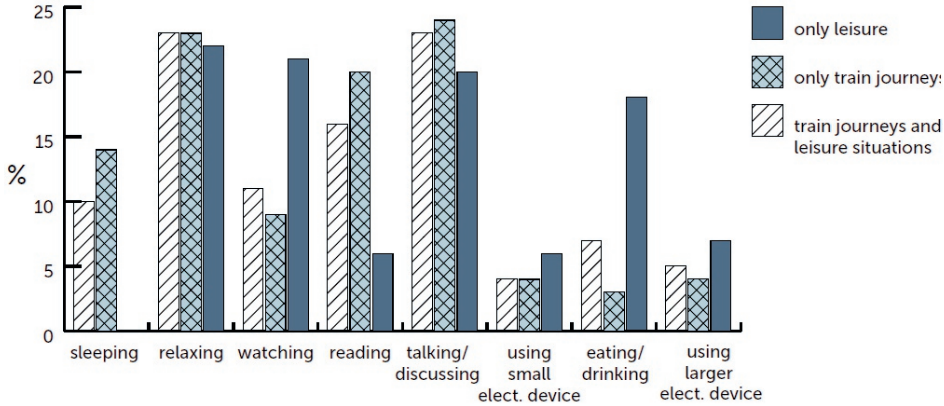

Figure 14: An overview of the most observed activities during train journeys and semi-public/leisure situations, only train journeys and only semi-public/leisure situations.

For this study, the most observed corresponding postures while watching are (see Figure 15) 1211, 2321 and 2221. For talking/discussing, the top three is 1211, 1111 and 1211. Finally, for reading, the results are 1211, 2231 and 1212. There are few studies on the relationship between postures and activities, although Van Rosmalen et al. (2009) researched and tested a new lounge chair concept. The activities during the research are comparable to the low activity level activities in this article. In the Van Rosmalen study, the concept seat supported head, back, arms and feet. This compares with the results on the postures in this article that the most observed postures during low-level activities are 1211, 2321 and 2221. Apart from 1211 (where only the back is supported), the other two postures indicate that the observant preferred as much support as possible (headrest, back support and armrests). Bronkhorst & Krause (2005) observed the postures of passengers riding on commuter trains but did not link postures with activities. When the results of this article are compared with the most observed postures of Bronkhorst & Krause (2005), it is clear that train passengers prefer to be supported by the backrest in both studies. Branton & Grayson (1967) observed the postures as well (again, not in relationship with the activities). The most observed postures in the Branton & Grayson study were the head was free from support, the trunk was supported, the arms supported and the legs free or crossed. The results in this article are comparable to the Branton & Grayson study, in that most of the postures existed of the head free from support, the back supported and the feet 'free'; in this study, most individuals did not support their arms with the armrests. For the design of car interiors, it is interesting to know the most observed postures, overall. Thus, independent of the activities, the most observed postures of people during train journeys and semi-public/leisure situations combined can be seen in Table 13 and Figures 9 and 10.

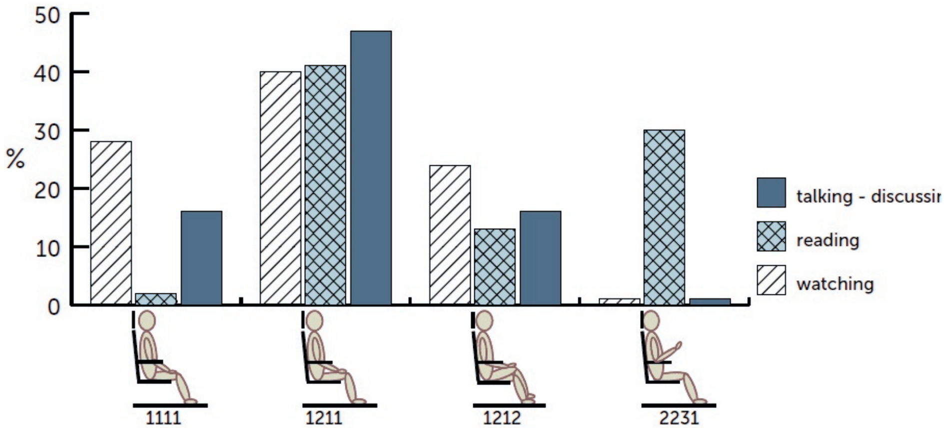

Figure 15: An overview of the most observed corresponding postures for watching, reading and talking/discussing.

Table 13: An overview of most observed postures and percentages.

Postures	Percentages
1211	35.1%
1212	13.2%
2321	11.6%

3.1.2. Is there a difference between activities and postures in dynamic versus static situations?

The observations for this article were conducted in two different situations. The first group of observed individuals were video recorded on regional trains in Germany, and the second group of observed people were photographed while sitting in semi-public/leisure spaces and situations in the Netherlands.

Train travel is a dynamic experience whereas semi-public/leisure situations are static. It is interesting for automotive industry to examine the difference and similarities between the dynamic and the static presented in the two observations. Car travel is similar to train travel especially for a car passenger as it is a dynamic situation; therefore, the activities and postures of train travel are interesting to the automotive industry as well. During semi-public/leisure activities, however, people choose activities where they have relatively more freedom of movement than is possible on a train journey or in a car. There are space- and movement limitations for car interior design, and people are – most of the time – in a dynamic situation. However, with the possibility of changing the car packaging options, it is interesting to look at a broader spectrum of postures and to later specify what activities and postures are possible for future car interiors. Therefore, the differences between both situations, the dynamic and the static, are summarized here.

While travelling by train, sleeping and reading were found significantly more often than during semi-public/leisure situations. Train travelers are not expected to just watch or eat and drink. The fact that people on trains are not just watching could be explained by the movement and constant rhythm of the train that often makes travelers sleepy. From this observation, the activity category sleeping was identified for the study. Additionally, the outside views may be uninteresting and/or fast changing and people are unlikely to observe the outside landscape. The category for this observation is considered relaxing for this study. It may be an unexpected finding that eating and drinking is not a likely activity for train travelers. This can be explained by the fact that the observations were done for a very brief moment in time; the observers walked through the train aisles and recorded 'on the go'. Khan & Sundström (2007) found in their study that eating and drinking was mentioned by 103 participants, but over a relatively short period of time in comparison with other mentioned activities. Therefore, people who take a sip out of a bottle or eat a candy bar are often not recorded in this study. Thus, eating and drinking over a longer period of time is not likely for commuters and train travelers on rather short trips. It is possible that people are not eating and drinking due to the dynamic character of the train travel; Corbridge & Griffin (1991) found that the chance for spilling drinks or food is higher in a dynamic situation especially the sinusoidal component with duration of 10 s, with frequencies in the range 3.15–5.0 Hz. The fact that the space is shared with strangers results in a limited amount of personal space and may also contribute to a limited amount of people eating in a train; or they may not eat and drink as not to disturb others with the smell of food or possible drink spillage. When people are in confined space, coughs and sneezes of strangers do not encourage people to eat or drink. This is partly in line with the activities (sleeping/napping, listening to music/talking/staring, reading a newspaper, reading a book or magazine and writing/typing). Bronkhorst & Krause (2005) found in their observation of activities on commuter trains. Eating and drinking was not found at all in that study.

In a static, semi-public/leisure situation, people tend not to sleep, which is sensible because sleeping is considered a private activity. Besides, most of the available seats found in the semi-public/leisure situations are not appropriate for a comfortable sleeping posture. During semi-public/leisure activities, a substantial amount of time was spent just watching. These findings are consistent, in that users would sometimes sleep on the train, but not in semi-public/leisure spaces. Users of semi-public/leisure environments are also considerably less prone to read. This could be explained by the expected duration of a train journey versus the unexpected character of a semi-public/leisure activity. When travelling by train, the duration of the journey is generally known ahead of time. However, in a static situation or semi-public/leisure activity, time cannot be as easily determined. There may be an unexpected delay, e.g. waiting for a bus or a social appointment. A cultural factor could prevent a person from reading as well, e.g. when joining a good friend sitting on a terrace, a person probably will not start reading a book. On the other hand, eating and drinking is an expected semi-public/leisure activity. In both the train journey and the semi-public/leisure situations, the observations were captured over a short period of time. Although the observation time was short, people in the semi-public/leisure situations were observed to sit down and eat a sandwich or have a drink.

When looking at the relationship between activities and postures during static semi-public/leisure situations, there is little significance for the position of head, trunk, arms and legs. This may be due to the various seating possibilities while observing the semi-public/leisure situations. The seats were all the same in the trains; each had a headrest, backrest and armrest. Also, the height of the seat and the length of the backrest were equal. For the semi-public/leisure situations, this was not the case; the seating was varied and different. People were observed sitting on benches and on other seats that did not have a headrest or armrests and so on. Not all people could sit the same way because the seats were not the same, and, therefore, their postures were varied and differed.

3.1.3. When people use mobile devices what is the most frequently observed posture?

When people were using mobile devices the most observed posture was 1211 (43.3%, see Figure 9). A remarkable observation occurred during the analysis for the train journeys. There was some significant relationship between activity and posture for most activities. However, this was not the case for the use of small electronic devices. This is an important conclusion because it was expected that the use of small to medium mobile devices would be one of the higher activities performed in these situations. The future forecasts a higher usage of these devices when looking at the increasing sales figures of smartphones, pads, notebooks and so on. Further research is needed to evaluate the relationship between sitting postures while using these devices and discomfort. The primary focus should be whether posture matter or not when using small electronic devices and if there are different activities that call for different postures. For this research instead of low-, medium- and high-level activities, the classification of McLeod & Griffin (1986) would be more useful. McLeod & Griffin (1986) distinctly classify three types of tasks as well; however, the tasks are divided as follows: Type A tasks, in which the ‘subject controls the hand freely in space: examples include reaching and pointing. In some Type A tasks, the hand may hold an object which will itself be affected by motion, such as fluid in a cup’. Type B tasks, in which the ‘subject’s hand manipulates a control at a fixed position attached to the vibrating structure: examples include the operation of joysticks and knobs’. And, finally, Type C tasks, in which the 'subject performs a single, discrete operation, such as changing a switch setting or pressing a button'. This type of task may often be preceded by a Type A task, in which the hand moves through space in order to locate the control (e.g. Type A/low level; reading an electronic book, Type B/middle-level activity; playing a game and Type C/high-level activity; typing/working). For medium mobile devices, the trunk was in a slumped position. This corresponds with the research of Khan & Sundström (2007), stating that people put their books, writing materials and portable computers on their laps while using them due to vibrations during train transport. Bhiwapurkar et al. (2010) found that when using the laptop in a train on a table, typing was more difficult than when the laptop was placed on a person's actual lap. However, this does not automatically mean a comfortable posture; several researchers discovered that laptop computer usage (Moffet et al. 2002; Seghers et al. 2003; Asundi et al. 2010) and small mobile device usage (Gold et al. 2012b) increases downwards head tilt which increases the subjective-reported discomfort during whole body vibrations (Rahmatalla & Deshaw 2011).

3.2. Recommendations for further research

Because of practical reasons, a few important issues were not considered in this study. These issues include the influence of the duration of time, the gender and age of the observed test subjects and the influence of the time of day. The goal of this study is to give direction and guidelines for car interiors on a group level. However, the specific differences between human characteristics and conditions often influence the design. Reitenbach et al. (2009) showed, for instance, that smaller people do not like a standard office seat. The seat pan is often too deep and the large area influences the way they sit on the seat. The relationship between human characteristics, test conditions and posture is an interesting subject for further research that could lead to guidelines for adjustability features.

4. Conclusion

This research was a first approach to discover the interaction between desired activities and chosen postures in train transportation and semi-public/ leisure spaces. Important issues that were not considered in this study include the interactions between the duration of activities, the gender and age of the observed subjects and the influence of the time of day. These specific issues call for additional research. In order to translate these activities and related postures into car interiors, some additional research has to be done. The vibrations and sometimes unexpected movements influence the possible activities in a car. As several researchers have shown (Corbridge & Griffin, 1991; Khan & Sundström, 2004, 2007, Krishna Kant, 2007; Bhiwapurkar et al. 2010), a dynamic situation often influences the chosen activities. A specific example of an activity for car travel is reading. This activity may cause nausea in some people, because linear acceleration and deceleration without the appropriate view of the road ahead cause car sickness (Probst et al. 1982). Besides vibration and movement, there is a limited amount of space available. The seating situation in a car is different than in a train. On a train, most of the seating is similar throughout the entire train, as opposed to a car; front seat versus back seats and the difference in car types, e.g. a micro car, luxurious limousine or sport utility vehicle (SUV). The most observed postures are important when considering a new car interior and are important to the design for usability and comfort. Further research is necessary to analyse car interior specific details. Additional research should be conducted on how to integrate a comfortable seat, additional storage, adapters and/or small (folding) tables in car interiors to provide for additional space to accommodate the number of possible and desired activities people want to do in a car. This research should include passenger range of motion and reach ranges so that it is possible to operate their small mobile devices and do their desired activities while travelling. Overall, it can be said that, due to the technological developments of mobile devices, it is necessary to investigate if the seating now used in cars still meets the requirements and demands of the people and their desired activities. This study is advantageous for the automotive industry but is also informative for the train, bus and aircraft industries, as well as all semi-public/leisure spaces where seating is available.

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Kilincsoy, Ü., Wagner, A., Bengler, C., Bubb, H., & Vink, P. (2014). Comfortable Rear Seat Postures Preferred by Car Passengers. Paper presented at the 5th International Conference on Applied Human Factors and Ergonomics

2.2 Comfortable Rear Seat Postures Preferred by Car Passengers

Abstract

The joint angles of three most common postures of passengers sitting in the rear seats (sleeping, standard, upright) were recorded to develop an ideal posture model for rear seat passengers within a car. The passengers were positioned in a realistic mock-up of a whole car interior with a fully adjustable back seat and postures recorded. The results showed that the upright and standard postures have similarities to the postures of the driver's seat in the literature. The relaxed posture showed a higher angle between trunk and thigh compared with the driving position and the variation in leg postures was much larger, which can be explained by the fact that the legs have more freedom in the rear seat than in the driving position.

Keywords:

rear seat, posture, RAMSIS, comfort.

Introduction

Today's traffic situations show a diversified use of cars differentiating in two typical ones: commuting and vacation. The number of passengers can vary massively regarding to the various situations with compacts, station wagons and sedans as the most frequently seen car concepts (see Figure 16). Even if the number of SUVs would increase and new car concepts emerge like rear passenger focused ones, in commuting and vacation those three car types remain the most frequent ones for a while. Interestingly, a traffic observation showed that those car concepts also proved to be the ones that are most flexible as they can be used for both use scenarios (see Figure 16).

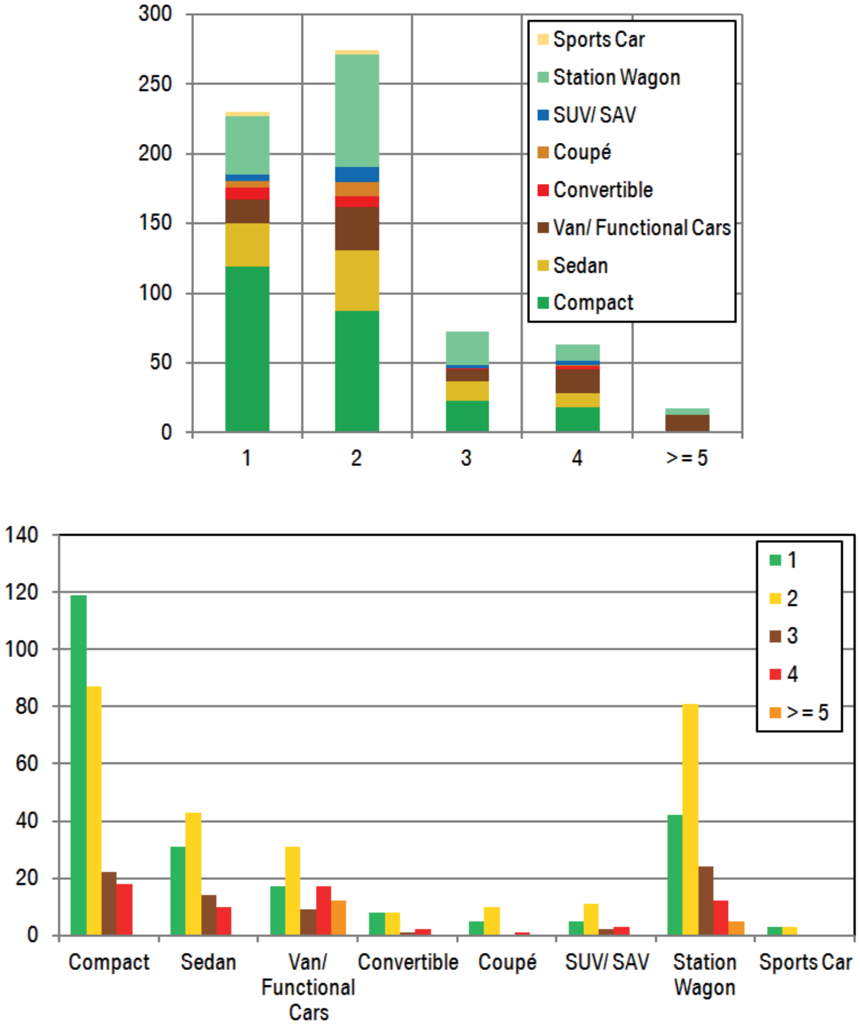


Figure 16: Traffic analysis (trip from Munich to Delft on a Sunday: 850 km/530 miles on a highway). In the upper picture the frequency distribution of passenger numbers in different car types is shown, the lower picture illustrates the car types with the related passenger numbers.

Especially for long travels comfort plays an important role. However, there are not many rear seat comfort models. Whereas a lot of research exists about the comfort of the driving seat e.g. by seating pressure distribution (Mergl, 2006; Zenk, 2008), comfort angles (De Looze et al., 2003) and seating design (Franz, 2010), only little knowledge exists about the rear seat. In spite of the forced posture of the driver resulting from the maneuvering of the car (reaching the pedals, steering wheel, changing gears, view up forwards and backwards), the back seat passenger lacks a concrete task. Therefore, an indefinite number of possible postures unfolds only restricted by the cabin and design of the back seats.

From a prior train passenger observation and analysis (Kamp et al., 2011) three typical sitting postures were seen most often. These positions are chosen for further study in the rear seats. It is important to select these three positions as the number of postures is indefinite. The examination of comfort angles in relation to those sitting postures is of importance in designing back seats as it can be assumed that the often chosen postures in trains, where there is also much freedom of posture choice could be transferred to the rear seats.

Thus, for an insight in passenger habits and postures in passive driving situations the train study on 580 travelers was used (Kamp et al., 2011). The train movement was evaluated to be more comparable to a car's movement, because of the similar impact on passengers regarding longitudinal and lateral acceleration, as well as decelerating. Therefore, the activities can be transferred to those rear seat passengers would conduct in various travel situations (commuting, vacation, etc.).

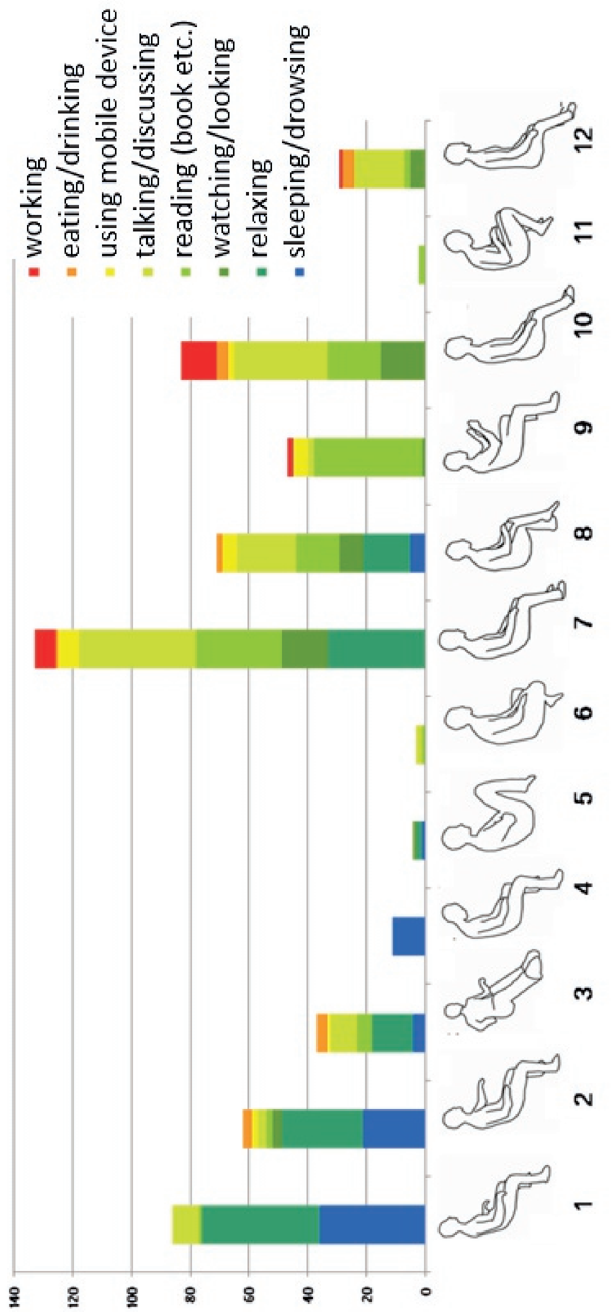


Figure 17: Research of typical activities of train passengers and the resulting postures.

In Figure 17 on the left, postures for relaxing and sleeping activities are shown and in the middle the tasks are reading, watching and talking. These activities show a more upright posture. On the right side, postures seen for activities like working, eating, drinking and using mobile gadgets are illustrated. Based on these 12 postures, which were observed during travelling, a selection was made for the rear seat of a car. Most of these postures are not applicable for the rear seating of a car, because of safety requirements and physical constraints due to the car's package. For instance, there is a shaft tunnel in the middle between the seats which limits space for your feet and lower legs. However, three positions out of the 12 observed postures are possible and most observed (Kamp et al., 2011). Figure 18 represents those possible three postures a back seat passenger could choose.

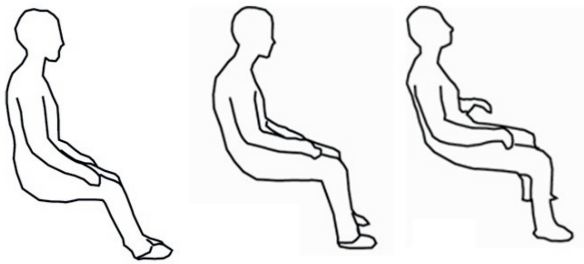


Figure 18: Resulting 3 possible postures applicable for back seat passengers after a selection from the 12 observed postures.

The left posture represents an upright position for short term travelling, watching the surrounding, using your mobile phone, talking to other front seat car passengers and eating. Additionally, Kamp et al. (2011) illustrated that this posture could be the most frequent one for diverse activities with high, medium and low activity levels in trains which is a comparable travel situation to the rear seats. In the middle the posture would need more space for a slightly relaxed seating, still awake and typically performing activities like listening to music. The right one is a special position for bigger cars and long term travelling with relaxing, maybe sleeping and drowsiness as major characteristics. This position maybe even more important for long term travelling (Khan & Sundström, 2007). For car manufacturers it is also important to consider these three postures, because in smaller cars only the upright position is possible and larger cars allow the relaxed position to be possible. Also, for software (like RAMSIS) it is important to further specify the posture for the different body parts. Therefore, it is interesting to have a closer look on these postures and analyse these more deeply.

The research question for this study is:

What are the angles in space with respect to a reference position of the different human body parts while sitting in the three described positions in a sedan?

Methods

To answer the research question first the previously defined three typical postures derived from the study of Kamp et al. (2011) were more precisely analyzed. For this purpose, 20 subjects were positioned in these three postures in a mock-up of a car interior which had the same size as a real car: a luxury limousine with adjustable back seats (see Figure 19). Posture and comfort were recorded for all subjects sitting in this mockup. The measurement of the posture was done by using PC-Man, which is a software for measuring anthropometry based on stereo photography.

Figure 19: The typical PC-man net of a subject sitting in a sleeping position in the mock-up.

The experiment started with collecting anthropometric data of each subject like age, body height, sitting height, leg length. A total of 20 subjects took part in the experiment (11 male and 9 female). The subjects were between 21-36 years old and with body height from 1.58-1.97 meters. According to Seidl (1994) the comfort angles do not necessarily depend on the body height which means that we can hypothesize that the same comfort angles will be obtained for everyone.

The comfort was checked by using a questionnaire and the posture was recorded by taking pictures for the stereo photography right after the position (see Figure 19). The stereo photogrammetry delivered data on complete body segments and for comparing the joint angles to the literature. The joint angles in the sagittal plane were calculated with the support of RAMSIS.

The backseat itself was fully adjustable, including angle of seat pan, backrest and upper lumbar rest (see Figure 20). Also, the height of armrest (left hand side and right hand side) and headrest were variable which is important to enable a good position in order to achieve a high comfort situation (= posture).

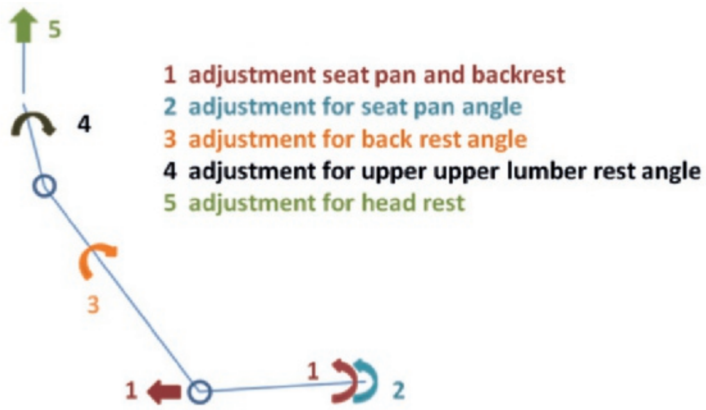


Figure 20: Fully adjustable mock-up seat. Overview of the adjustment possibilities.

Protocol

The experiment started by putting a subject in the initial situation. In this initial situation: the seat was adjusted in a very uncomfortable position in order to ensure that subject has to adjust the entire seat according to the own preferences and not just take over the predefined settings of previous subjects. For each subject the following sequence was defined:

1) Fasten the seat belt (a lap belt for more realistic rear seat posture, important for pelvis position in relation to the seat pan).
2) Adjust seat for standard posture.
3) Adjust seat for a relaxed posture.
4) Adjust seat for the upright posture.

All three postures were recorded via stereo photography, after the subject reported that the position is taken and after each posture a questionnaire was completed. The intention of using this sequence was to avoid that the subject uses same posture for upright and standard position. It was assumed that the upright position was also seen as the ideal one for the last sequence for answering the questionnaire using a blotting pad.

Results

All of the subjects declared that they feel like sitting in the backseat of a real car. For this reason, the mockup was considered as suitable for the test series. As planned the subjects did indeed adjust their seat to another position in all three situations. In Table 14 the measured joint angles for the three passenger postures are compared with the driver posture. The thigh angles are comparable between driving posture, the upright and standard posture. Only the relaxed posture differs as the subjects show a larger angle of the trunk, because the subjects were stretching their legs: z = 61.1°instead of 82.1°of the driving posture.

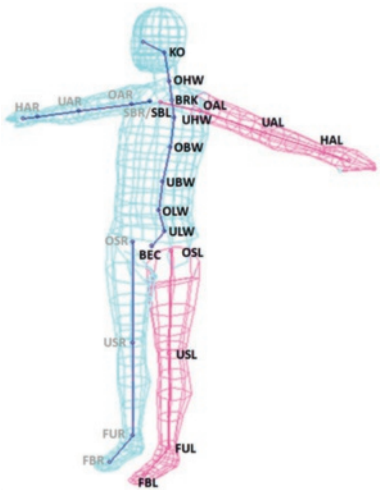
Noticeably, in the upright position the thighs are closer with y = 5.5° than 11.1° which can be explained by using the thighs as support for notebooks, books, etc. The foot opening angle of the driving posture (z

= 72.0°) is bigger than the one of the passenger model (z = 59.0°), because of the missing pedals. Therefore, the foot can be kept relaxed.

The whole chain of arm, elbow and shoulder of the relaxed passengers' position differs intensively from the driving posture as the arms lack a concrete task and consequently can rest in a relaxed but manifold position.

Table 14: Average of measured joint angles for 20 subjects in three different postures with standard deviation (SD).

RAMSIS



RAMSIS Joint	RAMSIS driver posture angels [°]			passenger upright posture [°] (SD)			passenger standard posture [°] (SD)			passenger relaxed posture [°] (SD)		
	x	y	z	x	y	z	x	y	z	x	y	z
BEC	0	0	-26.9	0	0	-17.2 (9.3)	0	0	-16.7 (9.5)	0	0	-31.4 (8.2)
ULW	0	0	-14.7	0	0	-5.0 (7.9)	0	0	-5.9 (7.0)	0	0	0.9 (4.9)
OLW	0	0	16.6	0	0	6.9 (4.4)	0	0	5.9 (5.0)	0	0	5.5 (3.3)
UBW	0	0	7.9	0	0	2.8 (3.4)	0	0	3.2 (4.0)	0	0	2.3 (2.9)
OBW	0	0	9.6	0	0	13.5 (7.6)	0	0	10.2 (4.7)	0	0	6.9 (3.9)
UHW	0	0	12.5	0	0	9.9 (5.6)	0	0	7.5 (4.4)	0	0	6.8 (5.4)
OHW	0	0	-5.7	0	0	9.5 (6.3)	0	0	-0.9 (6.9)	0	0	0.2 (8.6)
KO	0	0	-1.4	0	0	4.8 (4.7)	0	0	-1.0 (3.8)	0	0	0.1 (4.2)
OSL	-12.4	11.1	82.1	-5.7 (8.2)	5.5 (5.4)	76.2 (9.5)	-7.4 (7.5)	9.0 (7.3)	79.1 (9.4)	-9.1 (9.7)	10.7 (7.5)	61.6 (12.6)
USL	0	63.1	0	0	76.8 (11.6)	0	0	80.8 (7.6)	0	0	76.3 (10.1)	0
FUL	0	0	72.0	0	0	61.4 (5.3)	0	0	62.5 (4.4)	0	0	59.0 (5.6)
SBL	0	-7.8	5.7	0.1 (0.8)	1.7 (6.1)	-0.9 (5.6)	0.1 (0.8)	-0.6 (6.8)	0.4 (6.6)	0.2 (0.8)	3.1 (7.7)	-3.7 (5.5)
OAL	-66.9	-33.0	75.6	-14.3 (21.6)	-52.6 (14.8)	46.9 (11.7)	-12.4 (17.3)	-53.6 (12.4)	45.3 (19.7)	2.3 (16.5)	-57.2 (11.5)	42.1 (13.0)
UAL	4.6	-54.0	0	3.9 (13.4)	-84.5 (12.0)	0	4.8 (17.2)	-62.5 (13.8)	0	6.9 (17.7)	-56.6 (13.1)	0
HAL	0	6.6	8.5	0	-2.1 (5.4)	0.8 (3.8)	0	-4.2 (11.3)	0.0 (0.0)	0	-2.1 (14.9)	-0.3 (1.3)

The visualization of the three different postures in RAMSIS can be seen in Figure 21 with presenting the mean values for each joint angle.

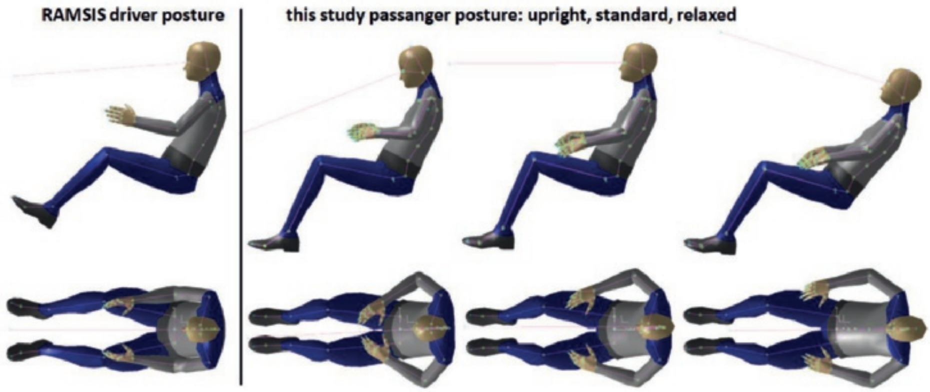


Figure 21: Visualization of the results in RAMSIS: upright posture (left), standard posture (middle), relaxed posture (right).

In order to highlight the differences and to compare the findings of the study to the established values of the literature, the 3D angles were projected on a 2D surface (see Figure 22):

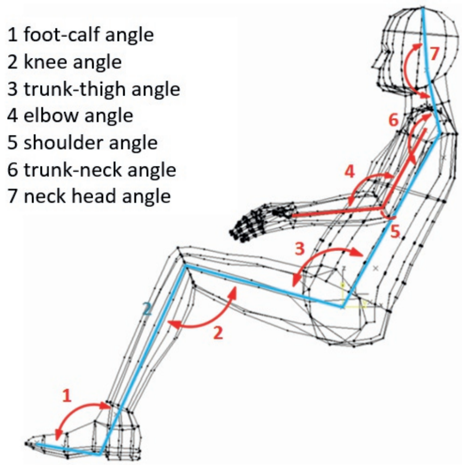


Figure 22: Projection of RAMSIS manikin in 2D-plane showing the measured joint angles.

A comparison of the three different passenger positions is shown in Table 15. The average angles with the standard deviation (SD) the subjects took in the comfortable position are shown in Table 15. The difference between the upright and standard position was not that large. The only significant difference can be seen in the shoulder angle which has an average value of 32.4° for the upright position and 0.6° for the standard posture. This is obvious because subjects were using their hands for doing tasks like filling out the questionnaire (representing tasks like using a mobile device, eating, reading in a magazine etc.). The difference in the sagittal plane was largest between relaxed and the other two (see Table 15), while the trunk-thigh angle is 104.2° for the standard posture the relaxed position showed here 118.9° because subjects sit more relaxed. Accordingly, the elbow angle in the relaxed position is 139.9° compared with 128.5° for standard position. Also, foot-calf angle and trunk-neck angle show a slightly more open angle. The questionnaires showed that the majority of the subjects could take their ideal position.

Table 15: Average of measured joint angles for 20 subjects projected on the sagittal plane.

Classification	Passenger Sitting Posture		
	Upright (SD)	Standard (SD)	Relaxed (SD)
Trunk-thigh angle	105.5 (5.5)	104.2 (7.6)	118.9 (10.5)
Knee angle	103.4 (12.5)	99.5 (9.9)	104.9 (11.9)
Elbow angle	113.1 (11.7)	128.5 (14.1)	139.9 (11.8)
Foot-calf angle	104.9 (5.8)	104.7 (4.6)	107.9 (8.2)
Shoulder angle	32.4 (13.3)	0.6 (12.6)	1.0 (11.8)
Trunk-neck angle	130.3 (3.5)	139.5 (0.7)	142.7 (2.1)
Neck-head angle	177.5 (4.6)	187.2 (3.9)	185.3 (4.3)

Discussion and Conclusion

Regarding the research question this study shows that it was possible to detect differences in postures. The three positions found in the study of Kamp et al. (2011) did show different angles in space in a sedan mock-up. Analogous to Kamp’s study, the armrests were excluded, as even in passenger trains the support was seldom used.

The differences were largest between the relaxed and both other positions (upright and standard). In Table 16 a comparison with the literature is shown. Most values are comparable with the literature and fall within the range that is described in the literature. Differences are especially found in the relaxed position. The trunk-thigh angle in the relaxed position is close to the highest recorded in the literature. In the literature sometimes this trunk angle is also compared to the horizontal and the upper leg is usually not equal to the horizontal, enforcing the difference to the literature. This difference is easy to explain as in the literature the driving position is taken. Probably the head position in our study is also more backwards than in the driving position.

So for the rear seat it is important to use somewhat different guidelines than often used for the driver's seat, as there are also advantages of a reclined and slumped posture (Fujikmaki & Mitsuya, 2002). Important differences are the lacking driving tasks and therefore the increase probability of posture variation. The standard deviation was also high in some recordings like for the lower leg and upper leg which can also be explained by the fact that the driving task is missing. Because of this variation it is perhaps wise to further investigate the findings with more subjects or even in different cultures in order to identify the influence of cultural differences.

In the market there is a growing popularity of SUVs and new vehicles possible due to the electric cars. Therefore, in a new study the advice is also to pay attention to the posture in a SUV. And for instance, pressure mat data are missing. As Mergl (2006) and Zenk (2008) identified the ideal pressure distributions for the position in the driver's seat. Further research is needed also to identify long term effects of comfortable postures in the rear seats. So this study should integrate pressure distribution data in order to be able to design the ideal rear seat.

Table 16: Comparison of measured joint angles of this study with the angles measured in the literature.

Classification	**Rebiffe** (1969)	**Grand-jean** (1980)	**Porter and Gyi** (1998)	**Park et al.** (2000) mean (SD) Range	**this study** mean (SD)		
					upright	standard	relaxed
Trunk-thigh angle	95-120	100-120	90-115	117.4 (7.71) 103-131	105.5 (5.5)	104.2 (7.6)	118.9 (10.5)
Knee angle	95-135	110-130	99-138	133.7 (8.53)	103.4 (12.5)	99.5 (9.9)	104.9 (11.9)
Elbow angle	80-120	-	86-164	113.0 (14.01) 86-144	113.1 (11.7)	128.5 (14.1)	139.9 (11.8)
Foot-calf angle	90-110	90-110	80-113	100.8 (8.61) 82-124	104.9 (5.8)	104.7 (4.6)	107.9 (8.2)
Shoulder angle	-	-	-	19.5 (6.38) 7-37	32.4 (13.3)	0.6 (12.6)	1.0 (11.8)
Trunk-neck angle	-	-	-	-	130.3 (3.5)	139.5 (0.7)	142.7 (2.1)
Neck-head angle	-	-	-	-	177.5 (4.6)	187.2 (3.9)	185.3 (4.3)

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3 SEAT

Kilincsoy, Ü., Vink, P. (2018), TU-Delft. The impact of increased smart phone use in trains. Tijdschrift voor Human Factors, 43(4), 16-18.

3.1 The impact of increased smart phone use in trains

Abstract

Activities of 354 1st and 2nd class train passengers were observed. Previous research has shown that train passengers spend their time mostly on reading, relaxing (i.e., staring or sleeping), conversing and working on laptop. The increased use of smart phone past years may affect train passengers' pass time. However, data are not available. To validate this assumption, recordings were made of activities in trains in 2017 and 2018. Results show that 43% of the passengers use their smart phone in the train. This implies that the need for new guidelines for train interior design and other vehicle interior design.

Keywords**:**

train passenger comfort; activities; smart phone use; seat design

Introduction

According to studies, the use of the smartphone has become more and more intrusive to privacy and everyday life (e.g., Lee et al., 2015). To operate a smartphone, the user must place the smartphone in his primary viewing area and use it either with one or two hands. The resulting posture might increase head or neck flexion, and accumulation of neck flexion devices could increase discomfort in the arm. Therefore, the influence of this trend on the design of interiors should be explored deeper in order to derive possible design guidelines. Many studies report the increase in smart phone use (e.g., Lee et al., 2015). According to International Data Corporation (IDC), one of the premier global market intelligence firms, the worldwide number of smart phones shipments increased from 300 Million in 2010 to 1.5 Billion in 2016 (IDC, 2018). In 2017, the number of shipments was also 1.5 Billion. This increase in smart phone use could influence the activities humans perform as it offers completely new application and support options in many areas of everyday life. Groenesteijn et al. (2014) and Kamp et al. (2011) published data on the observed activities train passengers perform. This was based on observations done in 2011 and earlier. The question is how much did the smart phone use increase as pass time in train passengers seven years after previous studies?

Methods

To study the effect of the increase in smart phones on the type activities performed by passengers in the train, the same observation method of Groenesteijn et al. (2014) and Kamp et al. (2011) was applied. In our study we observed activities of 354 train passengers (252 2nd class and 102 1st class). The following main activities (one per subjects) were recorded by taking notes of the sitting posture while passing the passengers: working on laptop, listening to music, reading from paper, talking, writing, using PDA, making a call (using a smart phone), staring or sleeping, eating or drinking and ‘other activity’. In a pilot study observing 40 passengers, we found it was hard to observe what type of activity the passengers did on their smart phone. In the observations of Groenesteijn et al. (2014), a distinction could be made between phoning and PDA use. In the pilot observations, it was often not clear whether passengers were phoning, reading from the smart phone or listening to music. Therefore, it was decided to make one category ‘smart phone use’, which is a combination of the PDA use and phoning of the Groenesteijn et. (2014) method. When subjects made a rhythmic movement, it was categorized as ‘music/smart phone’. The recordings (observations) were made between April 2017 and March 2018 in 1st class and 2nd class on the NS intercity train from Leiden to The Hague Central (14 minutes) and TGV from Schiphol to Rotterdam (20 minutes). The sum of the observed activities was calculated and the percentage of the sum as well.

Results

In Figure 23 the results of this study are shown in comparison with the observed data by Groenesteijn et al. (2014).

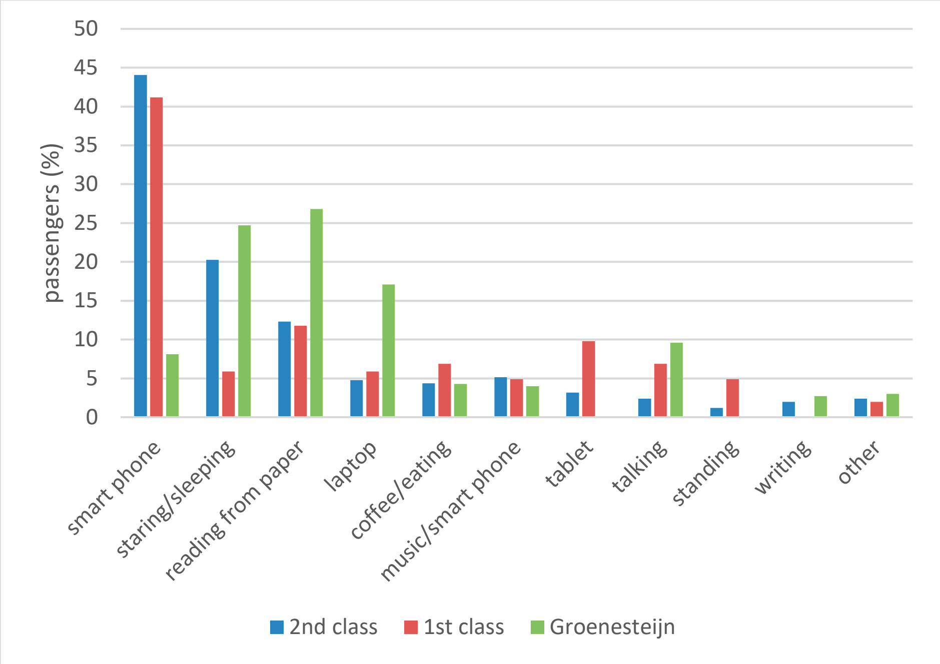

Figure 23: The results of the 2017/2018 observations compared with the observations of Groenesteijn et al. (2014).

Reading from paper and using a laptop was reduced in the new observations compared with the Groenesteijn et al. (2014) observations. As is stated a rhythmic movement of the passenger made us categorize it as ‘music/smart phone’. However, it could be that more passengers did listen to music as earphones were used more often, but could also be used in combination with a movie or phoning and some forms of music will not give a rhythmic movement. If we combine all smart phone use, it is 48.3% in 2017/2018 and 12.1% in 2011 by Groenesteijn et al. (2014) and 3.8% in the study by Kamp et al. (2011).

Discussion

Since previous study on train passengers' pass time in 2011, the smart phone use in the train increased by 36% (from 12 to 48%). Although it is the question whether it is exactly 36% as the times of observation could be different and the location is also not exactly the same, we observe a considerable increase in smart phone use. Moreover, IATA (2017) presented that 82% of the travelers on airports would like to have their information digital at their smart phones, which means that the majority of travelers has a smart phone.

The method used in this study and the study of Groenesteijn et al. (2014) and Kamp et al. (2011) is identical. However, this study was performed in the Netherlands, while the 'Groenesteijn data' were gathered in France, Belgium and the Netherlands and the 'Kamp data' were gathered around Munich. The activities observed most by Groenesteijn et al. (2014) (i.e., reading, staring/sleeping, talking and working on laptop) were also observed in this study, but the smart phone is now the most frequent observed activity.

Using a smart phone is usually observed in an upright position (Groenesteijn et al. (2013). It might increase the head flexion, which could cause neck discomfort and lifting the device to avoid neck flexion might increase the discomfort in the arm. Perhaps an addition to the requirements for train seat design should a support for the smart phone as described by Veen et al. (2014).

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3.2 A car seat shaped by human body contour

1. Introduction

In car manufacturing mostly, data are used for the construction of car seats based on experience of engineers and 3D digital models (e.g., Jack and RAMSIS). Additionally, several studies are available providing information for designing and constructing comfortable car and office seats (Vink, 2017). In the study of Helander and Zhang (1997) general aspects of sitting comfort and discomfort were found, which can be used. Based on questionnaires, they found that discomfort is more related to physical characteristics of the environment such as posture, stiffness and fatigue. Comfort is more related to subjective factors such as luxury, relaxation, etc.

Information on the seating position and pressure distribution can be found as well in literature and are described in other chapters of this PhD. For example, the optimal seat angle was found by Harrisson et al. (2000). Wilke et al. (1999) proposed that a reduced pressure in the intervertebral discs is achieved through a backward leaning position. Also, Zenk (2008) found in his research that a relaxed, well supported position results in a low pressure in the spinal discs. Mergl (2006) defined the ideal pressure distribution for car seats and showed that the comfort is rated high when there is an ideal pressure distribution under the legs and buttock. De Looze et al. (2003b) showed in his literature review that there are several studies indicating that a good pressure distribution in the seat cushion is related to the comfort experience.

Dieën et al. (2001) found that a seat should not enable one ideal sitting position but stimulate variation in posture. Lueder (2004) also mentions the importance of chairs that enable users to shift dynamically between ranges of stable and healthy postures, in a review on the ergonomics of seating. For office chairs the effects of systems that give active movement have been described (Van Deursen et al., 2001) and studied (Ellegast et al., 2012) and show that variation in the task is important to stimulate variation in posture. Andreoni et al. (2002) analysed pressure and comfort in a larger number of seats with different shapes and foam stiffness, and defined correlations with the shape of the human body at the interface measured by the imprinted surface. Using this method, it was possible to find an optimum for the foam.

There are indications that a better fit to the contour of the body leads to more comfort (Friehmelt, 2009; Nijholt et al., 2016). A shell following the body contour and using a minimum of upholstery material could also be a solution for creating a light weight and comfortable car seat. However, data on the anatomical human contour of a group of people in a position described in literature and facilitating some change in posture are not available yet.

The purpose of this study is therefore to define a contour of the back of the human body in the driving position described by Zenk (2008), Mergl (2006) and Harrison et al. (2000) in order to design a seat shell which follows closely this body contour. Therefore, the research question of this study is:

What is the form of a seat based on the human body contour in a driving position?

2. Methodology

To answer the research question several steps were taken. Firstly, a laboratory research was done to find the optimal contour of the back, buttocks and thighs contacting the seat while the participants performed driving tasks. Secondly, these data were scanned and transferred to a computer aided design (CAD) software (CATIA V5, R15). A seat was designed and manufactured based on these results. Thirdly, a re-test was performed to analyse and compare the results from part one with the new body contoured light weight seat. Lastly, the new seat was compared with a standard BMW seat in a user test.

2.1. Laboratory test

In total 25 participants took part in this research: 15 men and ten women aged between 20 and 40 years (mean age: 30 years) from 5th percentile women to 95th percentile men (mean height: 176.6 cm, mean weight:

77 kg). All participants had driver experience and were instructed to sit in a research mock up with a vacuum mattress (see Figure 24).

Figure 24: Frame with vacuum mattress after imprinting in the lab.

The subjects were instructed to perform some driving tasks such as moving a steering wheel, using the gear, look in the mirror and pressing the pedals (clutch, brake, and accelerator). The objective was to push the body into the rescue mattress as to create a contour specifically optimal for these driving tasks. After performing the driving tasks and finding their own optimal position, the test subjects had to rate their sitting position and comfort feeling via a questionnaire. Additionally, the Emocards method developed by Desmet et al. (2001) was used. The Emocards used in this research consisted of 2 × 8 different faces (male as well as female) expressing different emotions.

The first step was to rate the first emotional impression about the tactile experience of their own sitting position by choosing the Emocard that comes closest to their emotional experience.

The second step was to rate their sitting position using prescribed words. With the assistance of a semantic differential, a clear connection between a linguistic answer and a psychological correspondence to the Emocard was established (see Table 17 for the semantic differential). Positive and negative attributes were not automatically listed in this way on the semantic differential, they were deliberately mixed. The main purpose of this element was to evaluate how the subjects felt in the seat and their first impressions.

Table 17: Semantic differential used to rate the sitting position.

restricted	□ □ □ □ □ □ □	unrestrained
cosy	□ □ □ □ □ □ □	unpleasant
enfolding	□ □ □ □ □ □ □	off putting
insecure	□ □ □ □ □ □ □	secure
inviting	□ □ □ □ □ □ □	unwelcoming
protected	□ □ □ □ □ □ □	unprotected
heavy	□ □ □ □ □ □ □	exhilarating

The third step was to complete a questionnaire in which the ability to find a comfortable sitting position and the ability to do a long drive in that position were questioned. The goal of the questionnaire was to find out what body postures were important for a comfortable sitting experience in a car seat and what aspects could cause discomfort according to the participants. In the questionnaire, space was available for comments to discover what people said and thought (tacit knowledge), and also what they knew, felt and experienced.

After performing the driving tasks, rating the emotions and completing the questionnaire, the air was removed out of the mattress. This way the rescue mattress was fixed and the exact same contour was kept. The test subject had to leave the now the vacuumed mattress in the research seat and a picture was taken with a digital camera and each individual imprint of the subject in the mattress was scanned with a 3D laser scanner (Steinbichler Optoscan T-scan 2).

2.2. Seat development process

In order to combine the shapes derived from all the individual scanned contours, a three-step process was carried out: At first all the scanning data were arranged in a certain position, approaching the scatter plots of the scans as close as possible to each other, using a best-fit algorithm.

This was realized with 3D modelling software, which can handle scanned scatter plots and perform shape design. Because of the major divergence of each individual shape, based on the body height and the proportions, it was necessary to prioritized particular scanned areas. Based on seating comfort literature (e.g., Mergl, 2006; De Looze et al., 2003b) the buttocks and lower back area were in this case prioritized for the best-fit algorithm. As a result, bigger variations in the shoulder and the front thighs were allowed (however the aim was to have as less variation as possible). Next, an arithmetic averaging of the resulting scatter plot was performed, by creating one new shape which fits best to all the initial scanned body contours. The disadvantage of this averaged contour is that it does not suit tall people any more. In order to overcome this obstacle, finally a last step is necessary. For this reason, the contour was enlarged by defining a uniformly continuous offset of the surface in the positive direction. Finally, a new shape was created, which fits closely each individual person regardless of height or proportion.

Based on these contour data a seat shell prototype was built of glass fiber laminate, fitting the extreme (largest) subjects. Inflatable cushions were put in the shell, which could be adapted in such a way that all 25 scanned subjects would fit by relating it to the CATIA data. On top of the inflatable cushions a 30 mm light weight 3 mesh spacer fabric (1) was used to enable airflow between the human body and seat and then the upholstery fabric was placed on the surface. The seat shell was built on a standard car seat frame. The backrest was adjustable, as was the angle of the seat cushion.

2.3. Comparison new seat with mattress

With this new seat, the same evaluation was done as with the rescue mattress. The same participants as in the laboratory test participated (three participants could not take part in this second test). They had to sit in the new seat, performing driving tasks, rate their emotional experience and finally answer the questions on the experienced comfort in the questionnaire. The tasks and questions were identical with the ones during the laboratory research described in part 2.1. To compare both situations, a paired t-test was done.

2.4. Comparison new seat with a current BMW seat

In order to get a feeling on the comfort experience and the light weight aspect of the newly developed seat, a comparison to a current BMW seat was made. Both seats were weighed on a scale. The comfort rating of the 7 series seat was done in a past experiment (with 40 participants). The same test conditions were applied in this study: the same questionnaires, frames and seat positions were used.

3. Results

3.1. Laboratory test

Most participants (44%) rated the tactile input of their own sitting position in the vacuum mattress with a neutral, slightly positive emotion (see Figure 25).

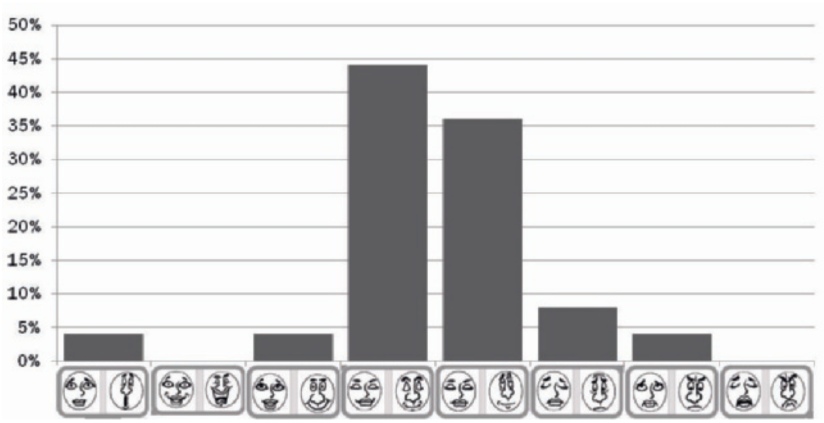

Figure 25: Emocard rating of the imprinted mat.

The results of the semantic differential showed this neutral feeling as well; participants rated all semantic differentials neutral or slightly more positive, except for ‘restricted’ (see Figure 26).

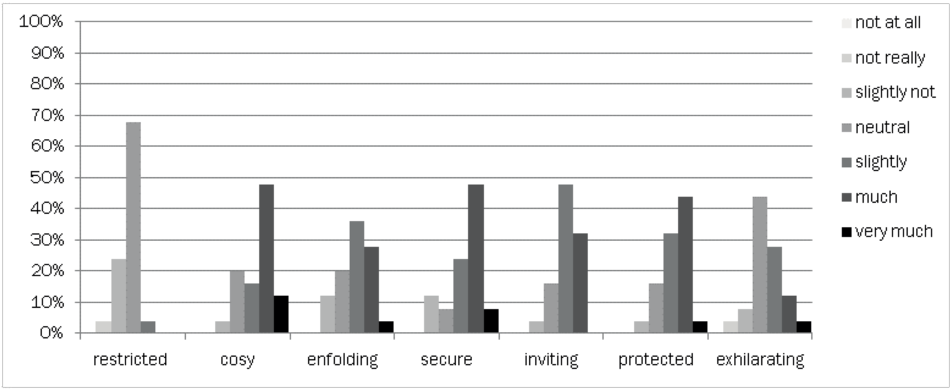

Figure 26: Semantic differential rating of the imprinted mat.

All subjects confirmed that they could find a comfortable sitting position in the mattress. Of all participants 88% believed that they could drive for a long time in this position. Three subjects (12%) disagreed because they expected to need rest breaks in this position.

3.2. Seat development process

After all mattress imprints were photographed and scanned, the data was converted to the CAD software CATIA v5. The general seat shell was created by using the 'best fit' of all superimposed scans to find the final, ideal seat shape (see also Section 2.2). Using Polyworks software, the discrepancies between the superimposed scans appeared to be less than 3 mm. Three millimeters was the maximum difference in the outer areas. The outer form was taken (see Figure 27) as the bases for the shell as for the smaller subjects the inner form could be filled by pumping up the aircushions.

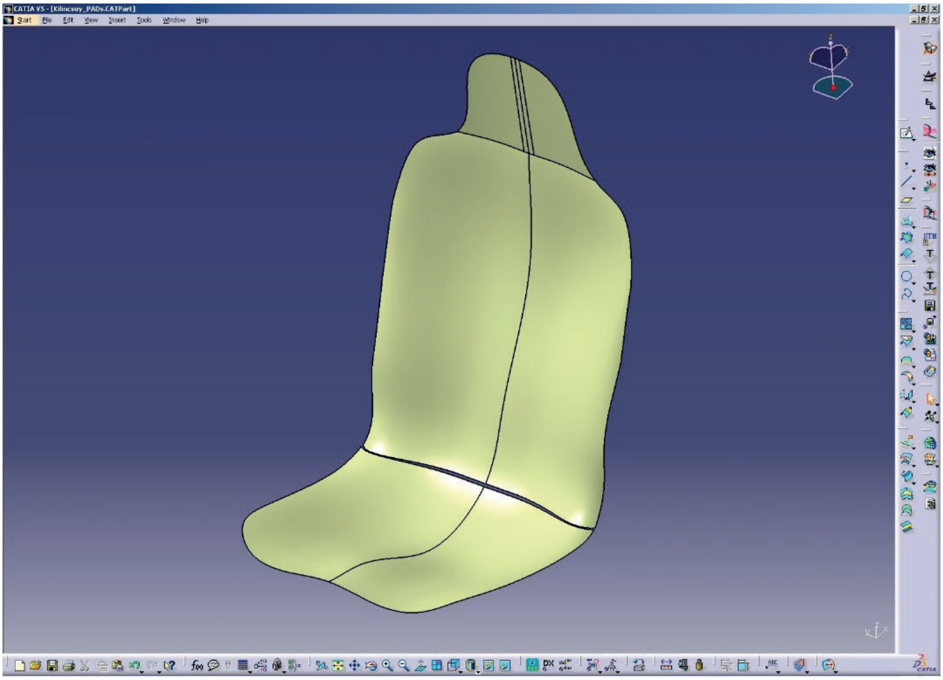

Figure 27: Seat Shell in CAD software.

A new glass-fiber seat shell was built following the CATIA design. Initially inflatable cushions which could be inflated up to 3 mm were put in the shell, to make sure the seat could be adjusted to the 5th percentile women as well as the 95th percentile man. After a pre-test with seat experts, a decision was made to have the cushions more inflatable, because the seat felt too hard. Based on the experts experience an arbitrary decision was made to increase it to 15 mm also to enable variation in posture needed for the various driving tasks. This seat shell was built on a metal car seat frame and the backrest and seat position could be adjusted (see Figure 28).

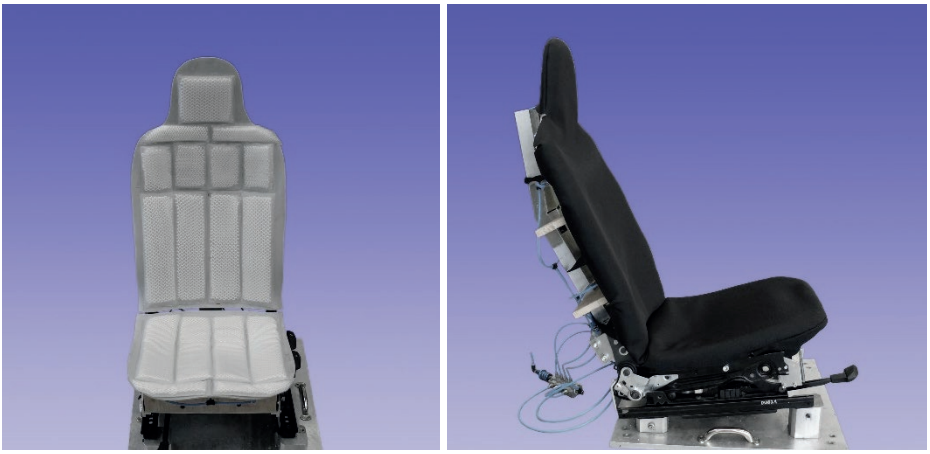

Figure 28: Prototype of the light weight body contoured seat. Left: the inflatable cushions.

3.3. Comparison new seat with mattress

In the re-test the tactile input of the sitting position in the body contoured seat shell was rated slightly positive, to neutral (Figure 29). When compared with the semantic differential questionnaire, the results of the laboratory test show a similarity to the semantic differential of the retest with the seat shell (Figure 30). The overall results look similar when the mean scores of the new seat concept are compared to the mattress (see Figure 31 and Table 18). In Table 18 the mean, standard deviation and P values for the paired t-test can be found. No significant relationships were discovered. Both seats are a bit less rated on the restricted aspect and all the other descriptive words are rated neutral or slightly more applicable. A closer look at this graph shows minor differences between both set-ups; the mattress was experienced a bit more cosy, inviting and protected and less restricting. Whereas the seat shell concept was rated on average more enfolding, secure and exhilarating. However, as the differences were not significant no conclusions can be drawn.

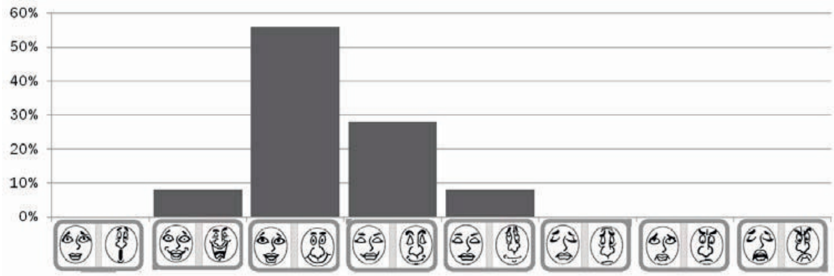

Figure 29: Emocard rating of new seat concept.

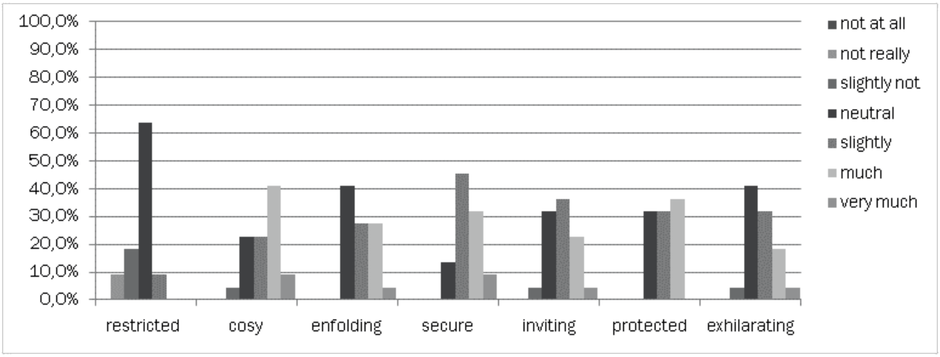

Figure 30: Semantic differential rating of the new seat concept.

All test subjects confirmed that they could find a comfortable sitting position in the body contoured light weight seat shell and mentioned that they could drive for a long time in this position, which was better than for the mattress (there 12% doubted that they could drive for a longer period of time).

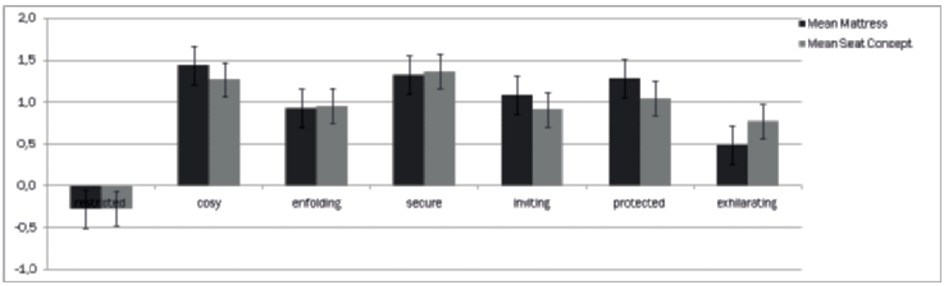

Figure 31: Average values for the new seat concept vs. the rescue mattress (on the vertical axis the scale is shown: -3, -2, -1, 0, 1, 2, 3 where 3 is very much and -3 not at all. Zero is neutral and the negative scores mean that the descriptive words are less applicable to the test seat.)

Table 18: Overview of mean and standard deviation for the mattress research and the new seat concept.

Descriptive words	Mean Mattress	StDev Mattress	Mean Seat Concept	StDev Seat Concept	Matress vs Seat Concept (P)
cosy	-0.3	0.6	-0.3	0.8	0.833
enfolding	1.4	1.1	1.3	1.1	0.6419
secure	0.9	1.1	1.0	1.0	0.5894
inviting	1.3	1.1	1.4	0.8	0.8739
protected	1.1	0.8	0.9	1.0	0.4238
exhilarating	1.3	0.9	1.0	0.8	0.3145
restricted	0.5	1.1	0.8	1.0	0.3652

3.4. Comparison the mattress, the new seat concept and a current BMW seat

Figure 32 shows the comparison between the mattress, body contoured seat and a BMW standard seat. The body contoured seat and also the mattress, is in all categories better than the BMW standard seat, except for the category restricted-unrestraint. The standard seat does not fit all body regions to the anatomical curves. The most frequently mentioned area, where the new seat follows the body better was the lumbar/lower back region.

When the weight of the standard BMW seat is compared to the new body contoured seat shell, it turns out that the new concept is almost 50 % lighter.

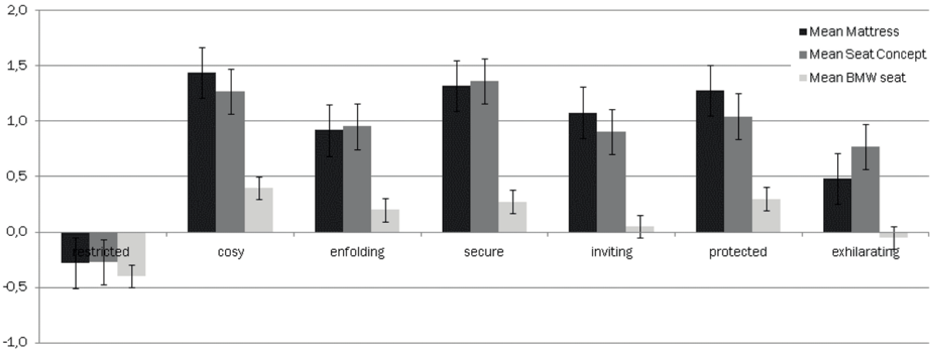

Figure 32: Comparison between the mattress, body contoured seat and a BMW standard seat (mean and standard deviation).

4. Discussion

4.1. Answering the research question

Firstly, this study showed that it is possible to define a body contour. It was interesting to observe that we could find a contour in the software with the maximum variation between the subjects of only 3 mm, even though a 5th percentile woman and 95th percentile man was among the subjects. Smulders et al. (2017) used another procedure for scanning and finding the optimal curve, by using a grid. Points on this grid were projected on a mesh of the seat surface, resulting in height maps (Z-coordinate for each XY-coordinate on the grid) for alignment of all scans.

Hiemstra-van Mastrigt (2016) also used a rescue mattress in scanning the human contour, but defined a fixed point and translated and rotated all other scans around this point to find an optimum. This resulted in much variation under the front of the thighs. It is not clear which method is best for combining scans, but our method resulted variations of 3 mm which is acceptable in seat design.

Secondly, this study indicates that a seat based on the body contour of 25 subjects is comparable to a standard BMW seat. The contour felt better in the lumbar region in the contour seat and many descriptive words given to the seat come close to the standard seat. However, the category restricted-unrestraint might need some attention.

Thirdly, the body contoured seat weighs almost 50% less than a conventional BMW seat. However, this was only the prototype compared to a fully functional BMW seat. When the seat is further developed, extra weight can be expected due to safety measurements and crash regulations.

4.2. Reflection of the survey methods

In the process of designing a comfortable body contoured car seat it appeared that the questionnaires and Emocards were useful. It gave insight into the experiences of the user when they were able to verbalise and visualise their (tacit) needs and wishes. These needs and wishes were stated directly by the participants, minimising interpretation by the researcher. In this way the subjects were able to choose their most preferred position more consciously and this position was scanned. Using tacit knowledge in seat design is not new for instance Van Rosmalen et al. (2009) used this in designing a lounge seat. The seat experiment is an example of research that provides more information that can be incorporated in the design of a comfortable car seat. It is acknowledged, that the testing time in the lab test and also the retest was based on a short term evaluation. It would also be interesting to do a retest under real driving conditions for a longer time. More research is needed to specify the long term comfort of the seat concept. Another issue which could disturb the outcomes is the fact that the method is not sensible enough to measure differences. The methods have been used before in various studies. De Looze et al. (2003a) did find significant differences between office seats with Emocards and this method and Franz (2010) also found differences using the method with car seats. However, these were all short term tests, which support the need for a long term test as well.

In conclusion, the used research methods provided useful information for the design of a comfortable seat giving a good seating experience. The studies complement each other and are valuable for the creation of a new seat and provide the opportunity to understand the anatomy and the user’s needs. For more detailed design requirements additional research is needed, e.g., comparison to other car seats, different contours and their emotional perception and long term tests.

4.3. Surface material for the body contoured seat

The new body contoured seat shell combines all of the imprinted contours of the subjects. Each individual contour can be found in this (digital) seat shell. This means however, that for some individuals, the body contour shape is not an exact fit. For this reason, a specific surface material is needed to cover these contour differences. Pre-tests have shown that regular foam material works very well to eliminate these differences. However, the more light weight solution of inflatable cushions (air does not increase the weight) also seems promising. This inflatable cushion allowing some variation is also important to be able to have another posture. It is important to allow these changes in the seat position as van Dieën et al. (2001) and Lueder (2004) have also shown that being able to vary the posture, reduces local perceived discomfort.

The contour and the development process of the body contoured light weight seat is patented PA2009016051 DE.

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4 PRESSURE DISTRIBUTION

Ü. Kilincsoy, A. Wagner, P. Vink, H. Bubb; The ideal pressure distribution for SUV and sedan rear seats (submitted for publication in Applied Ergonomics)

4.1 The Ideal Pressure Distribution for SUV and Sedan Rear Seats

Abstract

The ideal pressure distribution for rear seats of a sedan and an SUV was determined using a mockup. Pressure distribution was recorded using 50 participants in a comfortable relaxed and comfortable upright posture.

It appeared that for an ideal seat tested in a static situation most pressure should be in the back of the seat: 27-30% in the left as well as the right buttock area. For the front of the seat a pressure between 2-4% for one leg is advised. But for relaxed positions pressures could go up to 5% for one leg in the front of the seat pan

Regardless of the type of car e.g. sedan or SUV (different H30 values) an ideal pressure distribution was found for two different postures which are the most common ones of the rear seats. This ideal pressure distribution found in front seats resembled the rear seats as well with the limitation of the chosen posture: the slouched position proved to slightly deviate from the pressure distribution of the upright position.

Keywords:

comfort, pressure distribution, car seat, rear seat, SUV, sedan, posture

1. Introduction

In designing a car seat, the contact between the human and the seat is an essential element as it is the largest contact area between the human and the car.

Various studies analyzed this contact area for the driver's seat and suggestions for the ideal pressure distribution between the human and the seat are proposed (e.g. Zenk et al., 2012, Franz et al, 2012). Though, only little information is available about the rear seats. As a compromise the knowledge of the driver's seat is often used in designing the passenger and the rear seat. However, the activities and postures of rear seat passengers differ because there is no driving task. This study tries to add knowledge to the contact area in the rear seat. The knowledge on the rear seat could also be relevant for the front seat because of driving assistant systems like Adaptive Cruise Control (ACC) offering the driver freedom of movement of the legs and because in the future autonomous driving will grow. The postures using driver assistance resemble the posture of rear seat passengers more than the position taken during the driving task. In the future, autonomous driving cars can make use of understanding how passengers behave in the rear seats and impact the interior design.

Groenesteijn et al. (2009) showed that seat forms should be influenced by activities and should vary in order to facilitate different activities. Also, Hiemstra-van Mastrigt (2015) advised to start with the activities in seat design. Therefore, in this study different activities are considered and studied to identify whether an adaptation of the seat to these activities is preferred. To design rear seats first activities and postures were observed in an environment where there is more freedom of choice and less restrictions in space: the train and semi-public spaces. Overall 743 subjects were observed and three postures were often found in the train (Kamp et al, 2011), (see Figure 33).

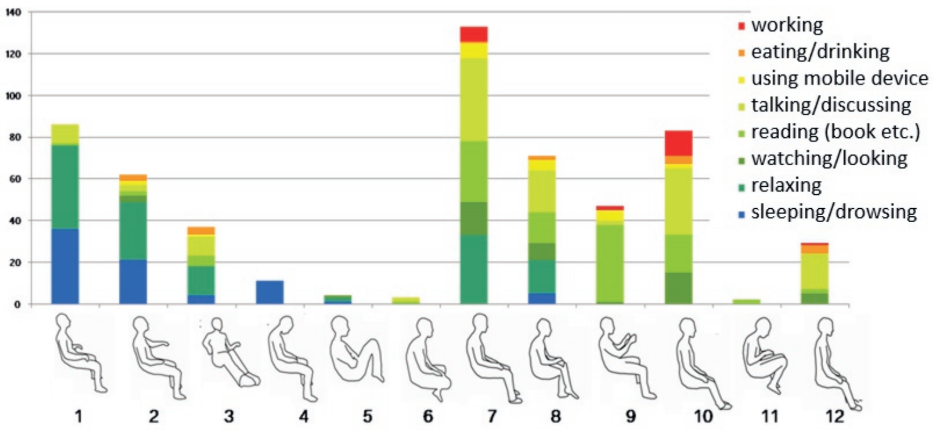

Figure 33: Research of typical activities of train passengers and the resulting postures.

Two positions are selected from the 12 observed postures from the train study. As selection criteria two conditions were regarded as mandatory:

1) The posture should be possible in the rear seat of a car.
2) The posture should be frequently observed.

The two chosen postures are the rather relaxed posture (no 1 and 7 in Figure 33) and the upright posture (no 12). Posture number 1 and 7 are the positions with a high percentage of relaxing (cosy seating, not busy) and simultaneously most frequent seen among the observed train travelers. And number 12 is the upright posture which is assumed often to be seen in cars, the only difference could be the restricted knee space in the car interior compared with the train interior.

Many papers describe the relationship between comfort and seating (e.g. Lueder 2004; De Looze et al. 2003; Franz 2010; Mansfield et al., 2015; Sammonds et al., 2017). The study of Paul et al. (2012) described, for instance, a correlation between anthropometrics and pressure distribution. This means that in this study a large variety of subject sizes is preferable. In a literature review De Looze et al. (2003) identified the pressure distribution as the most distinct objective measurement method linked to discomfort. On the other hand, in a specific study of Porter (2004) no clear relationship has been found between interface pressure data and reported discomfort. There is limited literature on postures and the corresponding ideal pressure distribution for car seats.

Mergl (2006), Zenk (2008) and Hartung (2006) describe the ideal pressure distribution for a drivers' seat and showed that the seat adjustment that facilitates this ideal pressure distribution leads to more comfort on a more than 2 hours' drive than self-chosen seat adjustments (Zenk, 2008). Even the pressure in the lumbar intervertebral disc is low in the position with the ideal pressure distribution (Zenk et al., 2012). These studies are mainly written in German language, which limits the accessibility for a large scientific audience. This paper contributes also to reduce this lack of information on ideal pressure distribution. The three German studies available on ideal pressure distribution focus on the driver's seat, while this study concentrates on the rear seat. The question is whether the ideal postures and ideal pressure distribution of the rear seat differ from the ones of the front seats. Also, there is a distinct trend that aside from sedans SUVs become more attractive to customers which is also proven by the traffic observation study by Kilincsoy et al. (2014) and a notification of registrations of new cars by the German Federal Office for Motor Traffic (KBA, 2016) that shows that SUV sales have increased relative to sedans in recent years. It is assumed that the posture is different in the two models. Therefore, the question is whether the ideal posture and pressure distribution differs in these models as well.

Research question:

Is the ideal pressure distribution found in the drivers' seat also applicable for two chosen postures in the rear seats of sedans and SUVs?

2. Methods

2.1 Participant selection

A sample of 50 passengers, 30 males and 20 females (21 to 53 years old), was selected including a wide range of body sizes (stature from 140cm to 200cm). Consequently, the body height percentiles could be investigated from 0.1 to 99.5 percentile (see Figure 34) of the German population of 2004 as described in the RAMSIS software. 2004 may seem old, but a study of Molenbroek et al. (2017) showed that in 30 years not much anthropometrical values change except for the hip width.

The classification of corpulence was done by visual inspection of the researchers. The subjects were classified in slim, normal and corpulent regardless of measured weight, or calculated BMI.

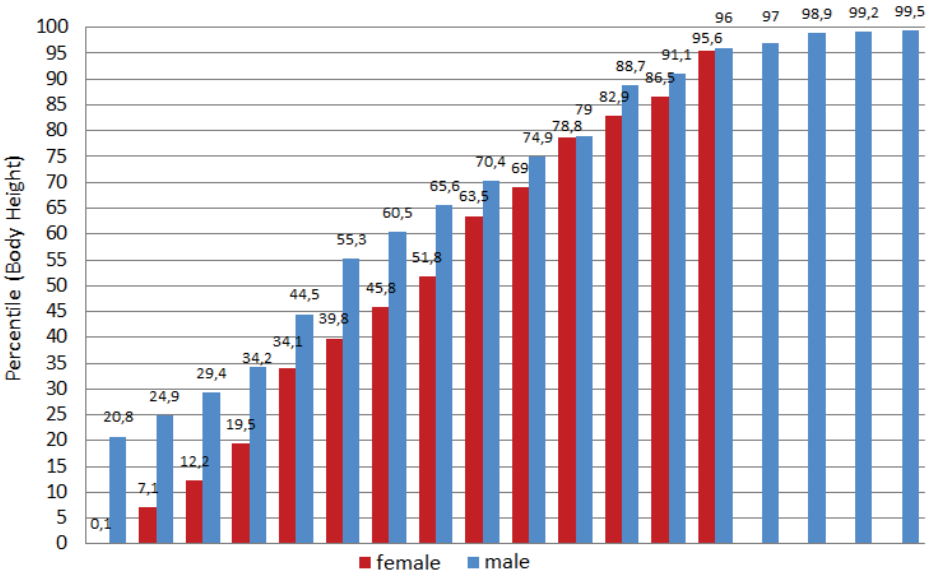

Figure 34: Overview of subject's body height percentile.

In addition to the subjects' height, the buttock-popliteal depth and the shoulder height sitting of each subject were recorded while sitting on a table in an upright position (see Figure 35).

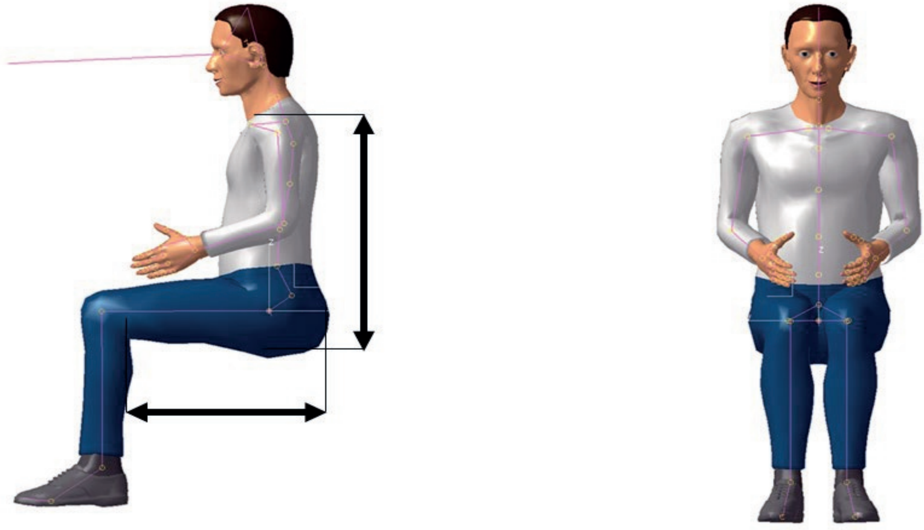

Figure 35: Measurement of buttock-popliteal depth and shoulder height sitting.

2.2 The Mockup

The mockup (see Figure 36) was built using interior parts and the interior package of the BMW 7series. The BMW 7series represents the upper car class of sedans providing maximum space and comfort because of its large dimensions. Due to the fact that the back seats are fully adjustable (also in the height) also the configuration of an SUV (dimensions of the BMW X5) could be simulated with this mockup. The dimensions of the seat are: seat panel length 500 mm, seat panel width 500 mm, backrest height 600 mm. The horizontal distance measured from front of the backrest of rear seat to the back panel of the front seat is 770mm for the sedan and 740 for the SUV. And the sitting height (vertical distance between seating reference point to point of heel) of the sedan was 290 mm. In comparison, the sitting height of the SUV was 315 mm.

For seat pressure mapping the XSensor LX100 sensor was used (see Figure 36). This is a capacitive pressure imaging sensor that can measure a pressure range from 0.1-3.87 psi (0.07-2.7N/cm2) and comes with a spatial resolution from 0.5” (12.7mm). It has an accuracy with +/-10% full scale and a sampling Rate with 39 frames/s. The LX100 sensors have low hysteresis, minimal creep characteristics and is calibrated once a year. One of the main reasons why this pressure mat was chosen for this study is its very thin appearance: thickness in sensing area is 0.024” (0.06cm). This is important due to the fact that the participant is required to sit on the mat.

Zhang et al. (1996) suggested that pressure mats can heavily influence the perceptions of a seat simply by altering the aesthetics and furthermore presence of the mat may alter some of the other static factors of the seat such as breathability, stiffness and style.

Figure 36: Mockup used for the experiment is built of parts from the BMW 7series.

The rear seat itself was fully adjustable, including angle of the seat pan, backrest and above lumbar rest (see Figure 37). Also the height of armrest (left hand side and right hand side) and headrest could be modified which is relevant to support a good suitable position for the individual and consequently to achieve a high comfort situation (= posture).

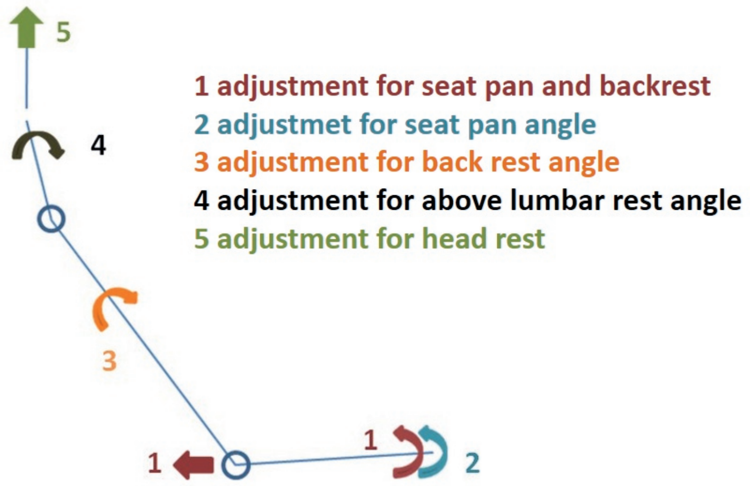

Figure 37: Fully adjustable mock-up seat. Overview of the adjustment possibilities.

2.3 Mockup trials

The mockup trials involved two seats (sedan and SUV) in two postures. Six measurements were taken in each posture and each seat (see Figure 38).

First the anthropometric data of each subject were gathered. Then, six measurements of the pressure distribution for each package (SUV, sedan) were recorded. The first recording was made after the subjects took their preferred posture (PREF1), with the instruction of the researcher: “take a position for an average ride of half an hour”. This position resembled the upright posture (no 12 in Figure 33). In order to prevent the subjects using any pre-adjusted position, the seat was adjusted in a very uncomfortable position. So the subjects were forced to adjust the seat and used most of the controls. The subjects did not complete the questionnaire by themselves, the researcher did and asked the questions while the occupant was in the seat. The comfort was measured after each condition on a five-point Likert scale for each body region. This was done to avoid any disturbance of the posture. The researchers conducted also a structured interview of a comfort questionnaire. Afterwards, the leading edge of the seat cushion was lifted in order to increase the pressure between front thigh and seat cushion to more than six percent (MAX). The third measurement was done after the seat was adjusted in a position that results in the ideal pressure distribution (IDEAL) according to Zenk et al. (2012).

In the fourth measurement, the leading edge of the seat cushion was lowered to reduce the pressure under the front part of the seat to less than six percent (MIN) and to increase the pressure in the buttock region. In the fifth measurement, the subjects again could adapt the seat to their preferred posture (PREF2). This was the preferred position that was recorded approximately 40 minutes after the test start. In comparison to the first preferred position which was measured at the very beginning. In the 2nd preferred position participants are more used to adapting the seat and have some habituation to sitting and are better equipped to adapt the seat to their preferred comfort experience. Additionally, the researchers aimed for long term comfort ratings in the study, emerging only after a time span of 30 minutes in seat comfort measurements. Porter et al. (2003) found that some seats are considered uncomfortable after 15 minutes of driving, others that are initially considered to be comfortable become uncomfortable after about one hour. By comparison Mansfield et al. (2015) only found differences between seat foam configurations after 40 minutes. Furthermore, Gyi & Porter (1999) suggested a minimum of 2 hours testing. But this would take too much time with 50 subjects in different conditions which was not possible in this study.

The sixth position was also the preferred position of the subjects, but now the instruction was to take the ideal sleeping position. This position resembles the relaxed posture (no 1 in Figure 33).

This procedure was followed for the sedan as well as for the SUV.

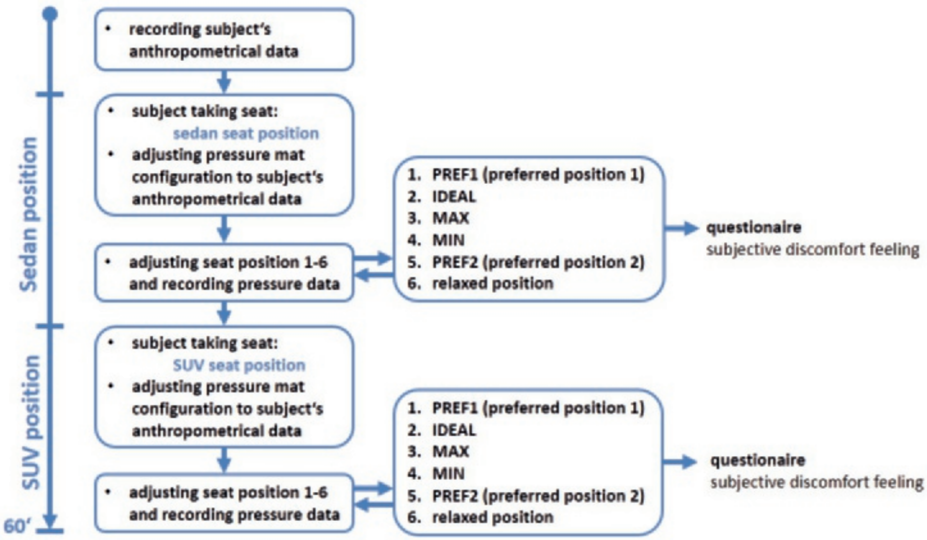

Figure 38: Protocol followed for each of the 50 test subjects.

2.4 Collection of pressure data and comparison to subjective discomfort by questionnaires

For each seat setting ("MAX", "IDEAL" and "MIN") the pressure distribution and subjective comfort sensation of the subjects were recorded. The selection for this MAX, IDEAL and MIN was inspired by Zenk et al. (2012). In this study of Zenk et al. (2012) the IDEAL setting can be described as: 54.0% of the weight being allocated on the buttocks and 6.4% upon the front of the thighs. In contrast to this "IDEAL" seat setting, two other settings were generated. One is the setting "MAX" which can be characterized by a maximal support of the frontal thighs (10.6%) and consequently a smaller load on the buttocks (47.6%). Therefore, the seat cushion front was titled upwards and the seat cushion's depth was extended. The other setting was called "MIN": in this case there was a minimal support of the area close to the knees (0.4%) and consequently more load on the buttocks (66.5%). Apart from the three postures MAX, IDEAL and MIN subjects could also define a preferred position before and after the three prescribed postures (PREF1 and PREF2). Pressure was recorded by the software XSensor AutoSeat (see Figure 39; Kilincsoy et al., 2016) in order to collect the objective comfort measurements. After experiencing the sitting configuration (lead time about ten minutes) each subject was interviewed in the seat about the resulting comfort sensation and the researchers documented the answers in questionnaires in order to evaluate the subjective discomfort. Additionally, the questions focused on the specific comfort of different body parts in the body map as described by Hartung (2006). To have some a kind of check on the influence of the mockup the subjects were asked for a statement whether the mockup is comparable to the real car interior situation.

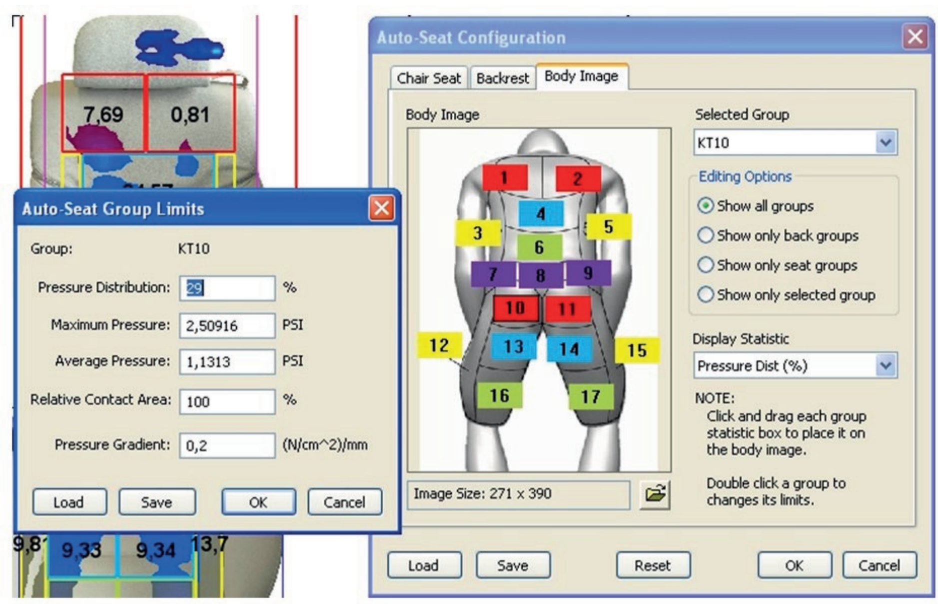

Figure 39: XSensor Auto-Seat showing body regions according to Hartung's body map.

2.5 Data analysis

The pressure distribution data were averaged for each area of the body map. The sum of all individual pressure percentages of the body parts was set at 100 percent and then the average per body area was calculated giving each individual a comparable influence on the total. For each of the five conditions (PREF1, MAX, IDEAL, MIN, PREF2) this score was calculated for each of the packages (SUV, sedan) as well as for each of the areas of figure 7 (body regions from 1 to 17). Differences between the five conditions were tested using one-way ANOVA with Turkey-Analysis ($p < 0.05$).

Descriptive statistics like mean and standard deviation are used and compared to the comfort scores of each of the five conditions in order to identify the pressure of the most appreciated condition regarding comfort.

3. Results

3.1 Reported Subjective Discomfort

Figure 40 illustrates that the start position (PREF1) and end position (PREF2) show the lowest discomfort ratings in sedan and SUV as well as in the upright and sleeping position.

This was the self-adjusted position with least discomfort after experiencing the pre-set standard position of the researchers. The ideal position also scores rather good in the discomfort ratings, whereas either the MIN or MAX position result in higher discomfort ratings. However, a large similarity of the discomfort scores can be noticed for both packages of SUV (see Figure 41) and sedan.

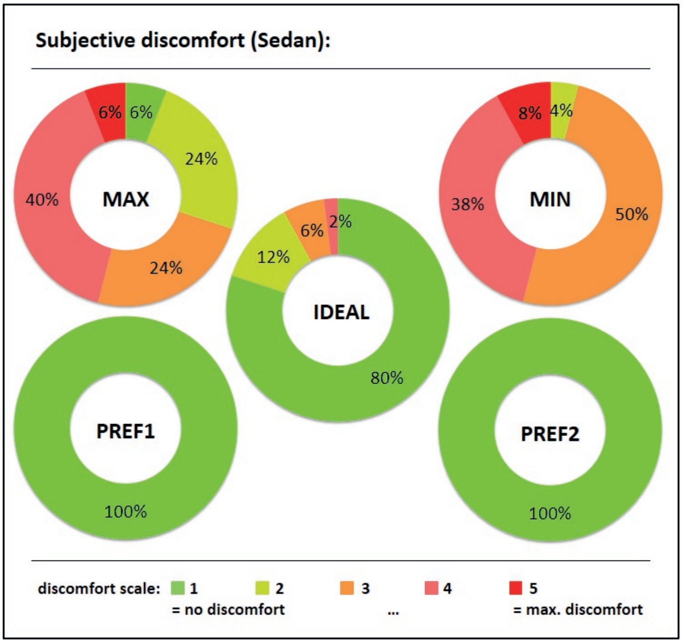

Figure 40: The discomfort of the first five measurements in the sedan (green = no discomfort; red = maximum discomfort)

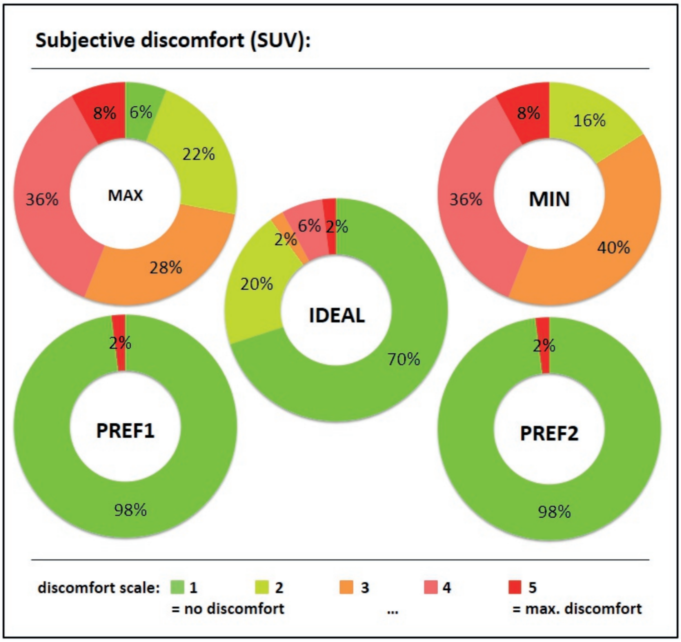

Figure 41: The discomfort of the first five measurements in the SUV sedan (green = no discomfort; red = maximum discomfort).

In Table 19 and Table 20 it is shown that the ideal and first preferred positions do not differ significantly but the MIN and MAX positions differ significantly from the IDEAL position, the preferred positions and the sleeping position for the seating in a sedan as well as in an SUV.

Table 19: Results of the Turkey-Analysis (PREF1) for the sedan and SUV.

Variable comparison	p-value (Sedan)	p-value (SUV)
PREF1 vs MAX	.000	.000
PREF1 vs IDEAL	.265	.093
PREF1 vs MIN	.000	.000
PREF1 vs PREF2	1.000	1.000
PREF1 vs sleeping	1.000	1.000

By analyzing the second preferred position, the findings of the first preferred position can be validated: again, the preferred position does not differ significantly from the ideal position whereas MIN and MAX differ significantly from PREF2 and IDEAL. The analysis of the SUV data lead to the comparable results. By analyzing the second preferred position, the findings of the first preferred position can be compared: again, the preferred position does not differ significantly from the ideal position whereas MIN and MAX differ significantly from PREF2 and IDEAL. An analysis of the SUV data leads to the comparable results.

Table 20: Results of the Turkey-Analysis (PREF2) for the sedan and SUV.

Variable comparison	p-value (Sedan)	p-value (SUV)
PREF2 vs MAX	.000	.000
PREF2 vs IDEAL	.265	.093
PREF2 vs MIN	.000	.000
PREF2 vs PREF1	1.000	1.000
PREF2 vs sleeping	1.000	1.000

A cross-check to the ideal pressure distribution of Mergl (2006) and Zenk (2008) also shows that the ideal and base position only differ significantly from the MIN and MAX (see Table 21).

Table 21: Results of the Turkey-Analysis for the sedan and SUV.

Variable comparison	p-value (Sedan)	p-value (SUV)
IDEAL vs PREF1	.265	.093
IDEAL vs MAX	.000	.000
IDEAL vs MIN	.000	.000
IDEAL vs PREF2	.265	.093
IDEAL vs sleeping	.265	.015

3.2 Interface pressure data for measuring objective comfort

The preferred position as the most comfortable self-adjusted position of each of the 50 subjects can be characterized as follows:

For the seat pan the mean pressure distribution of an upright as well as a relaxed posture in the sedan and SUV reached 27% to 30% for the area closest to the backrest (see Figure 42). The middle area in the seat pan showed around 10% of the overall load. And the pressure in the front of the seat pan scored between 2% to 5%. In the relaxed position the pressure increased in the front area compared to the upright position (see Figure 42).

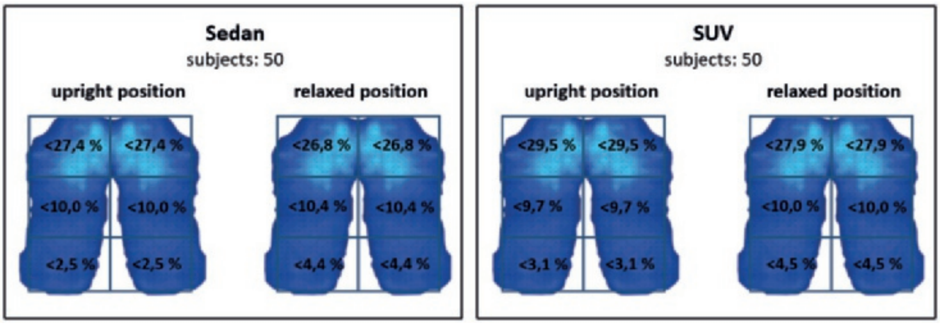

Figure 42: Results of the characteristic mean pressure distribution of upright and relaxed position in a sedan and SUV of all 50 subjects.

No distinct pattern of the pressure distribution of the backrest could be detected regarding the ideal posture. This finding is not surprising, as

Mergl (2006) investigated the pressure distribution upon the backrest in detail and did not find significant correlations. Only weak relationships could be discovered between subjective discomfort and objective parameters regarding the area of the back. A possible explanation of the fact of the absence of less significant findings in the backrest compared to the seat pan is the load distribution of a human in a seat. About 70% of the body mass is carried by the seat pan, while only 11% is supported by the back (cf. Stumbaum, 1983). The resulting 19% of the body mass is carried by hands and feet. Additionally, any discomfort in the back can be potentially diminished by modifications of the posture. This is less the fact in the buttock and resitting would only marginally affect the occurrence of discomfort caused by the seat pan (Mergl, 2006).

4. Discussion

A comparison of the findings of the study to the findings in the literature will answer the research question whether the ideal pressure distribution found in the driver seat is also applicable for the chosen two postures, upright and relaxed, in the rear seats of sedans and SUVs. Figure 43 summarizes this comparison to the ideal pressure distribution of Mergl's (2006) and Zenk's (2004) driving seat. The difference is less than expected, while the posture is less dictated by the driver task. The ideal pressure distribution of the upright posture of the rear seats showed similarities to both studies focusing on front seats. In order to generate a comfortable feeling, more pressure is needed in the back of the seat pan. For the driving task Zenk (2004) postulated a pressure range from 23% to 36% load at the back of the seat. Mergl (2006) established 28.5%. In addition, this study indicates 27.4% pressure load for the comfortable upright posture in a sedan and 29.5% in a SUV which is not much different from the data of Zenk and Mergl. Zenk's study was merely focused on comfort in dynamic situations as he measured while driving 2.5 hours resulting in larger value variations of the pressure distribution. Mergl was more precise in giving one concrete value of the pressure distribution which is close to our findings in the sedan and also in the SUV setting. Regarding the front part of the seat, the results were also comparable except for the relaxed position. This makes sense, because the thighs will get more pressure in a relaxed than in an upright posture by bringing the knees more lateral or by stretching the legs. A possible explanation could be that in this relaxed posture humans need an increased surface in order to relax because of lower muscle activities, which is described by Zenk et al. (2012) as well.

The subjective comfort ratings of the preferred position were higher than the evaluation of the ideal position. This can be explained by the fact that the ideal pressure distribution is deduced from the driving posture (Zenk et al., 2012), while in our case the rear seat posture was taken without a concrete task or prescribed activity. Additionally, the subjective comfort might be influenced by the fact, that the preferred posture was chosen by each subject individually; whereas the ideal pressure distribution was determined by a posture set by the researchers. This phenomenon that your own choice is preferred above the one prescribed by others has been described before. For instance, Bordass & Leaman (1997) also described that office workers that could choose their own comfortable inner climate were more satisfied than employees where it was decided for them.

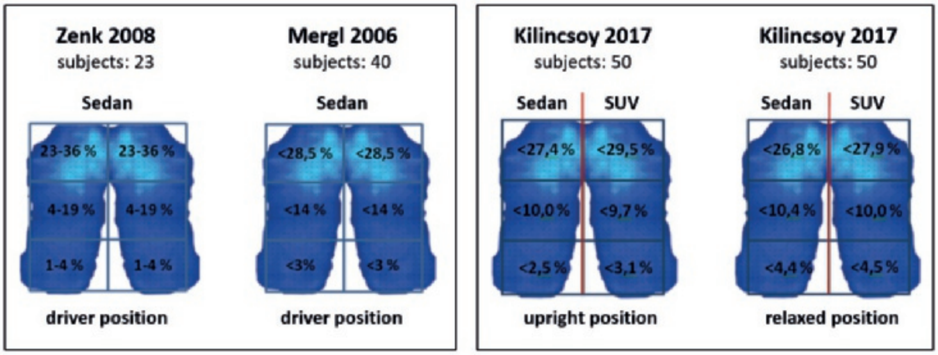

Figure 43: Results compared to Zenk (2008) and Mergl (2006).

This study also has some limitations. A static test in a mockup in a lab is not the naturalistic setting. On the other hand, the conditions of this experiment can be repeated precisely. The question is, whether this approach is transferable to real driving situations. Zenk (2008) showed during his real driving experiments that the results of Mergl (2006) based on a study in a mockup in a lab were affirmed, which might indicate that current values are valid as well for real driving situations. Another drawback could be, that the interior of a BMW 7series was used and the question is if this is 1:1 comparable to other sedans and SUVs because of the form and sizes of the interior components. In smaller cars there might be more limitations of choosing the postures which influences the evaluation of subjective comfort due to the resulting package. Li et al. (2017) clearly showed that in a limited space comfort reduces and discomfort increases. If the same pressure distribution is valid for other situations it can be an interesting consideration as perhaps these data are valid for other vehicle seats as well. Further research is needed to affirm this hypothesis. In order to prevent a limitation of the study caused by age and body sizes of the subjects, a large variation in size was selected to enable generalization to a large group. Another aspect important for generalization is the duration of the experiments that were chosen for the seating experience in this study: 40 minutes was the compromise chosen and Zenk (2008) showed that the 2.5 hour drive condition is comparable, but Sammonds et al. (2017) and Smulders et al. (2016) clearly show that in time discomfort increases.

Today’s creation of seat design is often done by testing an appropriate number of subjects without any objective measurements. The findings of the study can be useful in generating objective tests of seats at an early design stage and looking for possibilities to improve seats. Testing different seats and checking which pressure distribution comes closest to the ones described here are now an additional option. Of course, the pressure distribution is not the only determinant of the seat design. Aspects like for instance anthropometrics and posture (Kilincsoy et al., 2014), form and color (Wagner et al. 2014) and variation of posture (Veen & Vink, 2016) are important as well.

5. Conclusion

The ideal pressure distribution in the rear seat shows large similarities to the driving situation in the front seat. For the ideal seat (experienced most comfortable) tested in a static situation most pressure should be in the back of the seat: 27-30% under each buttock. For the front of the seat a pressure between 2-4% per leg is advised. But for relaxed positions pressures could go up to 5% for one leg in the front of the seat pan.

The independence from the car package, either sedan or SUV, might indicate a broader application of objective comfort measurement techniques in the seat design process.

Further research in limited space and with longer duration is needed in order to check the effects in real driving situations and deduce a possible application of this method to different types of seats like smaller cars, aircraft seats, train seats or office seats.

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4.2 Application of Ideal Pressure Distribution in Development Process of Automobile Seats

Abstract

In designing a car seat, the ideal pressure distribution is important as it is the largest contact surface between the human and the car. Because of obstacles hindering a more general application of the ideal pressure distribution in seating design, multidimensional measuring techniques are necessary with extensive user tests.

The objective of this study is to apply and integrate the knowledge about the ideal pressure distribution in the seat design process for a car manufacturer in an efficient way.

Ideal pressure distribution was combined with pressure measurement, in this case pressure mats. In order to integrate this theoretical knowledge of seating comfort in the seat development process for a car manufacturer a special user interface was defined and developed.

The mapping of the measured pressure distribution in real-time scaled to actual seats during test setups directly lead to design implications for seat design even during the test situation. Detailed analysis of the subject's feedback was correlated with objective measurements of the subject's pressure distribution in real time. Therefore, existing seating characteristics were taken into account as well.

A user interface can incorporate theoretical and validated 'state of the art' models of comfort. Consequently, this information can reduce extensive testing and lead to more detailed results in a shorter time period.

Keywords: Automobile seats, pressure distribution, pressure mat, passenger comfort

1. Introduction

Megatrend studies indicate a change in the mobility behavior separating consumer groups between people's perception of mobility as a means to get from A to B, and people experiencing pleasure driving and owning a car (Winterhoff et al., 2009). Design and Comfort are important customer relevant criteria in the development process which appeals to both consumer groups (Teske & Goßmann, 2011). De Looze (2003) discloses a relationship between an optimal pressure distribution in the seat and the comfort experience indicated by several studies (Ebe & Griffin, 2000; Ebe & Griffin, 2001; Kamijo et al., 1982; Park & Kim, 1997; Vergara & Page, 2002).

Designing a car seat with the ideal pressure distribution is important as it is the largest contact surface between the human and the car. Extensive research in this contact area primarily focuses on the driver's seat (e.g. Zenk et al., 2012; Franz et al., 2012). Knowledge of the seat development stages for car manufacturers is not established in each case. Obstacles hindering a more general application of the ideal pressure distribution in seating design require multidimensional measuring techniques with extensive user tests. Tests are necessary in order to obtain user information, because they deliver subjective information about the seating comfort and implications for design. Pressure mats can serve as an additional test. However, the existing user interfaces offer no sufficient reliance to the ideal pressure distribution today. In order to guarantee conclusive results both test methods should be conducted in comparable situations or even be combined.

Extensive research on comfort and seating (De Looze et al., 2003; Lueder, 2004; Franz, 2010) exists concerning the relationship between anthropometry and posture (Reed et al., 2000; Reed et al., 2002). The study of Paul (2012) described correlations between anthropometrics and pressure distribution of rear seat measurements in different seats. However, Paul noted that seams, leather wrinkles or unevenness can result in pressure peaks and thus discomfort was not derived from an anthropological approach only. The studies of Gyi and Porter (1999) did not show a precise relationship between reported subjective discomfort from questionnaires and pressure data in lab tests as well as road trials. Pressure measurements need to be evaluated in form of the distribution instead of absolute values. Therefore, the studies of Mergl (2006), Zenk

(2008) and Hartung (2006) established an ideal pressure distribution. Those studies were partially written in German and the accessibility was therefore limited for international audiences. These papers contributed to a better understanding of the relationship of ideal postures, ideal pressure distribution and comfort of seat design.

This leads to a core question how this knowledge regarding the ideal pressure distribution can be applied and integrated in the seat design process for a car manufacturer in an efficient way.

2. Methodology

2.1 Literature review

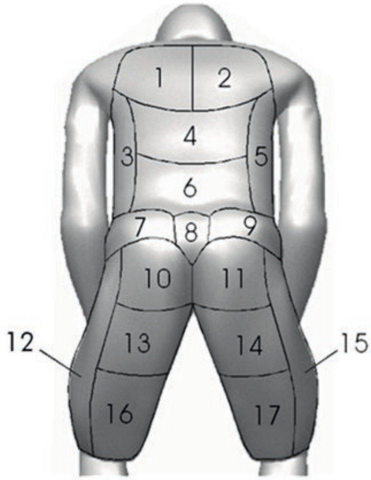
A literature analysis on comfort models focusing on pressure distribution was conducted. Mergl (2006) developed a method for optimizing the comfort of driver seats. After a RAMSIS (computational anthropometrical-mathematical system for passenger simulation) investigation and a Finite Element model, the results of both were integrated into the design of a prototype seat which optimized the pressure distribution. Additionally, a dummy model was used for first loop. The main optimization will be completed after tests with a statistically appropriate number of subjects. Zenk (2004) described the projection of the body map (Hartung, 2006) on a pressure mat covering the thigh and spine length of the subject. Zenk (2004) used an Excel-based calculation system in order to imprint the subject's anatomy to the body map. But yet, there is no known user interface for pressure mat systems applying this theoretical knowledge so far.

2.2 Identification of input parameters for a user interface

Defining the user interface for such a measurement system with input parameters is defined as: the body map, pressure distribution, maximum pressure, average pressure, gradient and relative contact area.

2.2.1 Body map and subject's thigh length/spine length

Thigh length and spine length of the subject were measured (using the www.DINED.nl method) in order to adjust the body map correctly onto the pressure mat (see Figure 44). As a result, the buttock-popliteal depth was deduced.



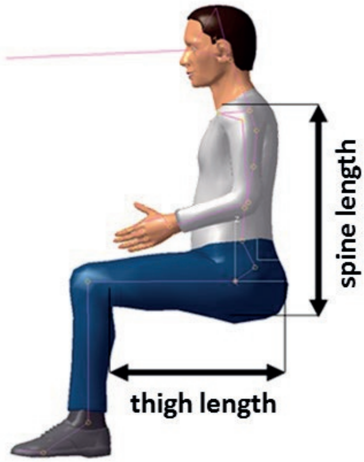


Figure 44: Body map (Hartung, 2006) and definition of thigh length/spine length in this study.

2.2.2 Pressure distribution

The pressure distribution ratio of the total body load in each body part on the seat was measured in percentage. This ratio indicated how the total load (100%) was split between the individual body parts (KT1-KT9 for the backrest and KT10-17 for the seat cushion). This parameter was a key feature of this methodology. Figure 45 illustrates the ideal pressure distribution of Mergl (2006) and Zenk (2004).

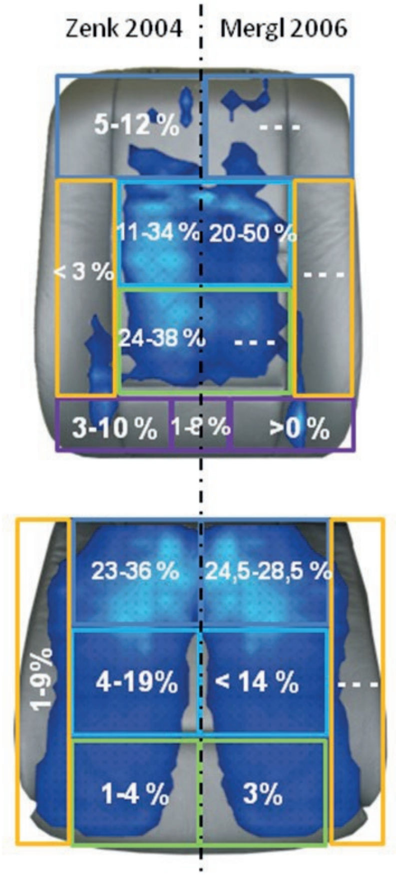


Figure 45: Marginal percentages of the ideal load distribution according to the body map (Mergl, 2006; Zenk, 2004).

Although a generalization of the evaluation of short-term comfort to long-term comfort may be limited, Mergl proved that short term comfort assessments were valid in field tests. Consequently, a transfer of the short-term comfort model of the ideal pressure distribution to the long-term perspective was possible.

2.2.3 Maximum pressure

The maximum pressure [N/cm2] was defined as the value of the highest measured pressure point of a particular body part. This parameter shows whether there was, for example, a seam, wrinkles or unevenness in the area of seat in relation to the body part. For example: time-averaged peak pressure at which no discomfort-induced fidgeting occurred was measured by Jackson (2009) for airplane pilot seats.

2.2.4 Average pressure

The average pressure [N/cm2] was calculated by dividing the sum of all pressure points (sensors) within a body part by the number of sensors per body part (KT). This parameter was related to load balance between the body parts according to the body map and also reflected the relative values of the individual body parts. There are other ways to record this like the method described by Naddeo et al. (2018). We chose for the Zenk (2012) method to make comparison to his study possible.

2.2.5 Gradient

The pressure gradient described the pressure differences along the sensor lines running left to right horizontally. The pressure values of a horizontal line of sensors were added, sensor cell by sensor cell, and the resulting sum of the pressures linked to the adjacent horizontal line of sensors. This gradient may be regarded as the first derivative of the pressure distribution and was therefore regarded as the slope of the accumulated curve. Consequently, the harmoniousness of the seat's support was estimated along the buttock-popliteal line.

Mergl investigated the resulting 2-dimensional curves of the seat (see Figure 46) for all body areas (KT10/11, KT13/14 and KT16/17). Neither the right nor the left side of the body was different. For certain body parts such as the lateral spine (3 and 5) and tailbone (8), the gradient was not calculated.

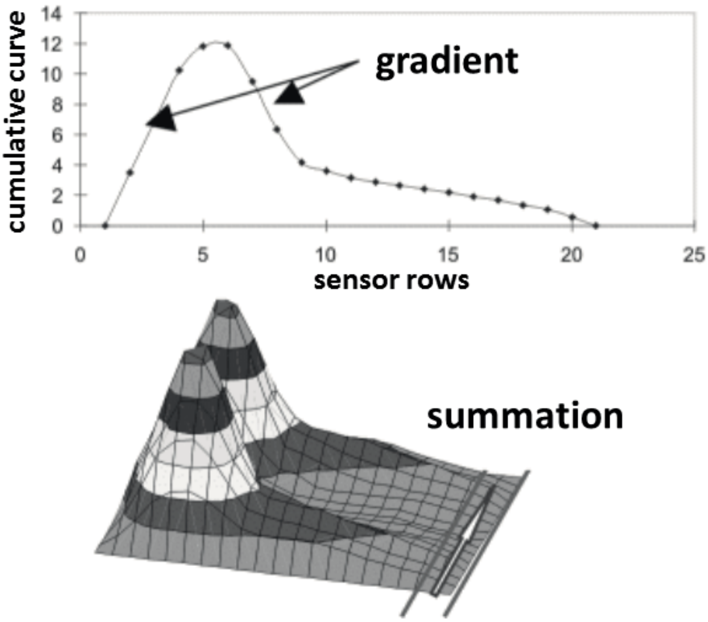


Figure 46: Resulting 2-dimensional curves along the seat for the body areas KT10-KT17 (Mergl, 2006).

2.2.6 Relative contact area

For instance, if 40 sensors detect contact pressure in one body part (KT), which has a number of 42 sensors, the results of the relative contact area would be 95%. This calculation indicated the relationship between the subject’s body surface and seat surface (contact surface). The number of sensors on a body part which measured pressures higher than zero were multiplied with the sensor surface. Zenk’s research (Zenk, 2004) indicated decreasing discomfort with increasing contact surfaces. An extensive support of the body should be pursued in seat design. However, there is a limited number of significant findings regarding this parameter.

2.3 Selection of pressure mats and user interfaces

The next step identified a suitable pressure mat system. There were several commercial products available in the market. The following pressure mat systems were analyzed: RS Scan, X-Sensor and Tekscan. All those systems came with a very specific user interface, where different images could be operated in real time. However, intense preparations were necessary for aligning the sensor cells in defined boxes according to the body map in order to consider the theoretical knowledge of the ideal pressure distribution. One of the primary disadvantages for investigated pressure mat systems, except XSensor, was the manual pre-calibration of the pressure mats followed by maintenance cycles. The system needed to be calibrated every few hours with a determined cycle of once a week. As a result, the X-Sensor system was identified as adequate for answering the research question because of its ready-to-use calibrated pressure mat system. Additionally, the option to create a customized user interface offered further advantages. By programming a tool considering body mapping, pressure distribution, maximum pressure, average pressure, gradient and relative contact area, the theoretical knowledge could be analyzed almost instantaneously along with a subject's feedback and the possibility of immediate implications for seat design. The user interface was defined and programmed by X-Sensor.

3 Results

The customized user interface was based on the XSENSOR X3 Pro v.6.0 software which delivered, by default the pressure mat measure system. For the seat pan the XSENSOR Technology Corporation pressure mat X3 Seat Sensor Pad PX100 : 40.40.02 was used and for the backrest PX100 : 0.64.02 was used. Because the original software was not sufficient for the planned measuring purposes, various functionalities were added. The composition and implementation of those functionalities as well as the design of the program surface was conducted in collaboration with the programming department of XSENSOR Technology Corporation. The algorithms were added for calculating the pressure distribution within the body areas, maximum pressure, average pressure, and gradient. The relative contact area provided the required additional functionalities of the customized software version.

3.1 Step No. 1: Selection of pressure mats and upload of photograph of seat and backrest

The described software functionalities were stored in the option "Auto-Seat Mode" (see Figure 47). In this mode the respective sensor was selected for the considered areas "Chair Seat" or "Backrest". By rotating in 90-degree-steps, the adequate orientation of the pressure mats was achieved. Furthermore, the surfaces of seat and backrest were uploaded as pictures in order to be scaled in size and position of the pressure mats. The software the measured values were projected semi-transparently onto the photo of seat and backrest. Consequently, the software user deduced pressure peaks upon the seat and backrest with an accuracy of +/– 10mm i.e. the positioning tolerance. This illustration provided engineers a precise allocation of pressure points on the seat pan, which has not yet been achieved by comparable applications.

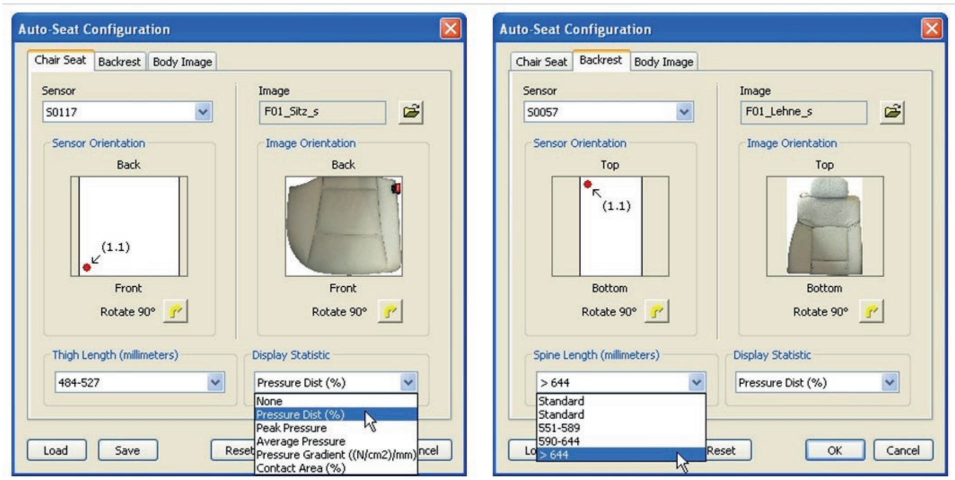


Figure 47: The "Auto-Seat Configuration" user interface.

3.2 Step No. 2: input of anthropometric values and adjustment of the body map

Based on the input of thigh and spine length the software configured automatically the adequate proportion of the boxes (see Figure 48) which represented the 17 body zones. The definition of each the classification of the lengths of body zones was described by Zenk (2004) as shown in Table 22:

Table 22: Classification of the lengths of body zones depending on thigh and spine length.

thigh length [mm]	**KT 10/11**	**KT 13/14**	**KT 16/17**
<484	41%	30%	29%
484-527	39%	28%	33%
528-543	38%	31%	31%
544-565	35%	30%	35%
>565	33,3%	33,3%	33,3%

spine length [mm]	**KT 1/2**	**KT 4**	**KT 6**	**KT 7/8/9**
551-590	38%	25%	25%	12%
590-644	33%	33%	22%	12%
>=644	27%	27%	27%	19%

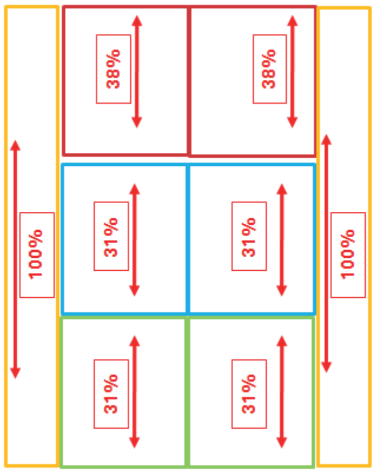


Figure 48: Example for configuration of the body zones for the seat pan for thigh length from 528-543 mm.

The classification can be explained by the following observations: the shorter measurement of the subject's thigh length resulted in a higher relative percentage of the buttocks (KT 10/11) in the body map. A shorter spine length caused a higher length percentage of the neck shoulder area (KT1/2) through transference to the spine or upper acromioscapular region.

3.3 Step No. 3: selection of the displayed measurements

The display of the measurement's unity was defined by a drop-down menu (Figure 49) within the main window of the boxes according to pressure distribution (%), peak pressure, and average pressure, pressure gradient and contact area.

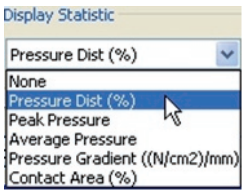


Figure 49: Selection of the measurement's unity via drop-down menu.

The use of the parameters and their relevance regarding the application of the ideal pressure distribution is illustrated by Table 23.

Table 23: Parameters and their relevance regarding the application of the ideal pressure distribution.

	BodyMap	pressure distribution [%]	maximum pressure [N/cm2]	average pressure [N/cm2]	pressure gradient [(N/cm2)/mm]	relative contact area [%]
Spine	**KT 1/2**	5.5-12.1	0.25-0.67	0.04-0.07	0.01-0.04	46-81
	KT 3/5	0-3	0.03	0.01-0.03	-	13-93
	KT 4	11-33.5	0.21-0.78	0.06-0.34	0.01-0.03	85-100
	KT 6	24-41	0.41-0.82	0.14-0.29	-	80-100
	KT 7/9	3-10	0.10-0.47	0.04-0.15	0-0.05	15-56
	KT 8	1-8	0.04-0.49	0.03-0.24	0-0.03	-
Thigh	**KT 10/11**	23-36	0.76-1.73	0.38-0.78	0.04-0.20	92-100
	KT 12/15	1-9	0.12-0.97	0.05-0.36	-	24-63
	KT 13/14	4-19	0.30-1.10	0.12-0.55	0.05-0.32	60-95
	KT 16/16	1-4	0.11-0.62	0.01-0.07	0.03-0.15	7-35

Additionally, information of the “Chair Seat” and “Backrest” within the window “Auto-Seat Configuration” a third tab “Body Image” offered the possibility to input the five parameters for each individual body area by choosing the colored boxes by double clicks. The following example (Figure 50) shows the limits of all five parameters for KT 10 which are identical to KT11 because of the symmetry of the body.

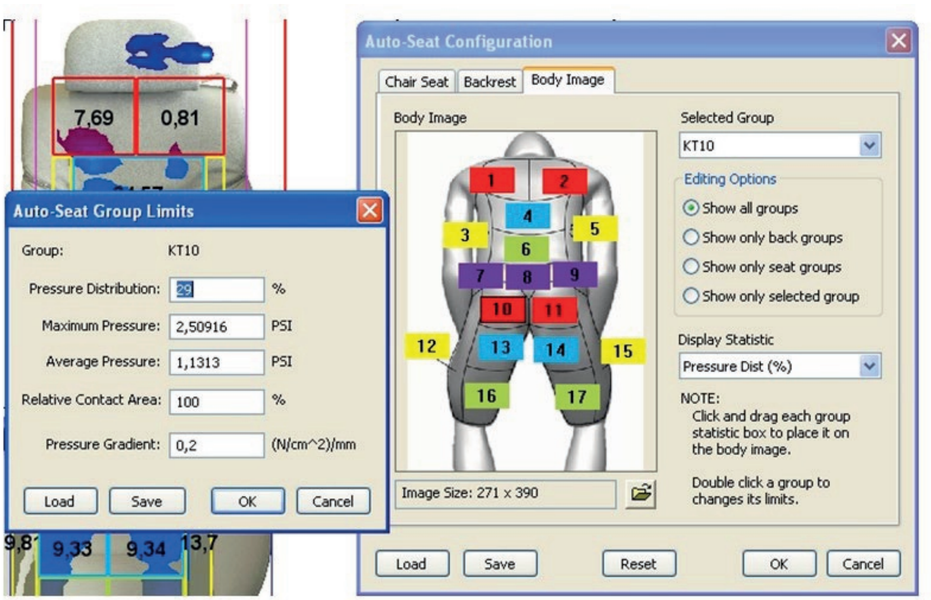


Figure 50: Configuration of limits by definition of the five parameters.

With the command “Display Statistic” the units could be selected and displayed directly onto the body map. If the measured value exceeded the defined limit of the five parameters, the box immediately turned into a red color. In the case of measurements close to the ideal pressure distribution, this box turns green. In order to use the system for comfort of trials of seats, the automatically generated body zone boxes (cf. left window in Figure 51) needed adjustment for each subject. Therefore, the subject was positioned in the test seat and slightly shifted his or her legs so that the pressure peaks resulting from the ischial tuberosity of the buttocks could be distinguished in the pressure measurement image. Afterwards, the “Sensor Groups” were positioned by manipulating the crosslines “Position” so that the pressure peaks laid concentrically in the boxes 10 and 11. The next adjustment for the subject was to apply popliteal force upon the mat in order to deduce the absolute length of the “Sensor Groups” by the adjusting the arrows “Group Length”. The width of the boxes was manually varied by “Group Width” so that the noticeable pressure frames of the thighs of boxes 12 and 15 were included.

Adjustment of the boxes for the spine began with the detection of the lower back followed by the acromioclavicular ligament by each subject's weight load upon the pressure mat. Subsequently, the sensor groups were altered for as long as the upper frame touched the pressure peak. The underlying seat photos were only used for illustration purposes and did not have any negative effects upon the measurements.

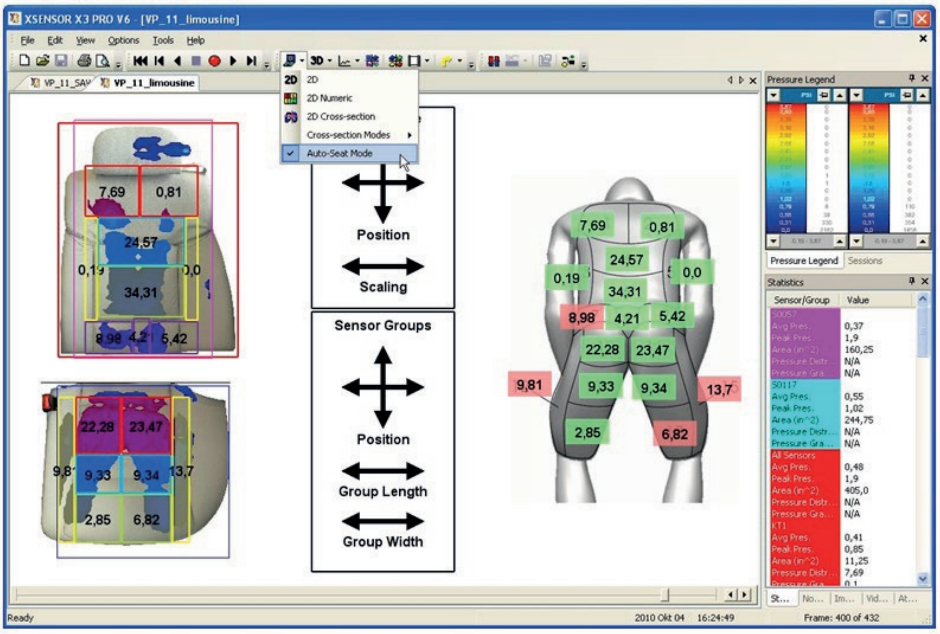


Figure 51: Implemented "Auto-Seat Mode" Option in the XSensor user interface.

4. Discussion and Conclusion

The seat represents the major interface between human and automobile and is thus an important element of the comfort experience. The anthropometric framework varies according to age, cultures and gender, but different sitting behaviors also influence this experience. Therefore, car manufacturers should focus on the ideal matching of seat frame, springs, foam and upholstery to achieve an overall impression of comfort. Surprisingly, subjects did not necessarily guess the ideal pressure distribution as discussed in the research study of Franz and Zenk (Zenk et al., 2012). In this case of Franz and Zenk (Zenk et al., 2012) a subject underwent surgery on his intervertebral disk and was voluntarily implanted with a pressure sensor to detect the local pressure directly upon the disk. During the study the subject evaluated the experienced comfort of the automatically adjusted ideal pressure distribution as opposed to the pressure distribution from his/her own seat adjustments. The subject concluded that for him, the automatic pressure distribution adjustment was more comfortable than the self-adjustment settings.

Although the study was a unique experiment with only one subject, it served as an indication for the need of objective testing focusing on the comfort of car seats. The results should encourage engineers in future seat design. The examples of objective evaluation approaches in seat comfort are many in the literature. The question is if this theoretical knowledge can be applied by an efficient tool. Such a tool should be integrated into the standard serial development stages of seat design in order to allow engineers an early user feedback for their design proposals.

The research question for this paper was how the theoretical knowledge about the ideal pressure distribution can be integrated in the seat development process for car manufacturers efficiently. State of the art procedures use pressure mats in order to evaluate comfort at an early stage in the development process which can contribute efficiently by the specific customization of the user interface. The pre-measured anthropometric data of the subjects served as input parameters for the analysis tool and guaranteed the correct allocation of the body map onto the pressure mat. This alleviates extensive and time-consuming manual adjustments, interpretation of data and further editing in Excel by engineers. In between analysis steps are not necessary, as those steps occur automatically and in real-time analysis. Thus, repeatable and reliable results with minimized user interference are available for final outcome. Consequently, reliable and reproducible series of measurements without specialized and skilled employees is possible. The accuracy of positioning the pressure mat upon the seat varies between +/– 10mm and can be carried out quickly by a three point adjustment system. Mergl’s and Zenk’s approaches used Excel tools in which the pressure peaks of the ischial tuberosity served as a rough orientation. Also, the customized user interface allows an identification of suddenly occurring discomfort in real-time when the boxes of respective body zones turn red. The allocation of the area causing discomfort can be done quickly and precisely because of the uploaded photograph of the seat. Thus, implications for seat design offer engineers the possibility of incremental improvements during the development process. Furthermore, a precise identification of the area of discomfort is extended by additional information such as seat frame images in CAD which can lead to a deeper understanding of the causes of discomfort. If a spring is not constructed properly or a crossbar is located near-by, this additional information can be identified as a potential cause for pressure peaks and therefore altered immediately (see Figure 52).

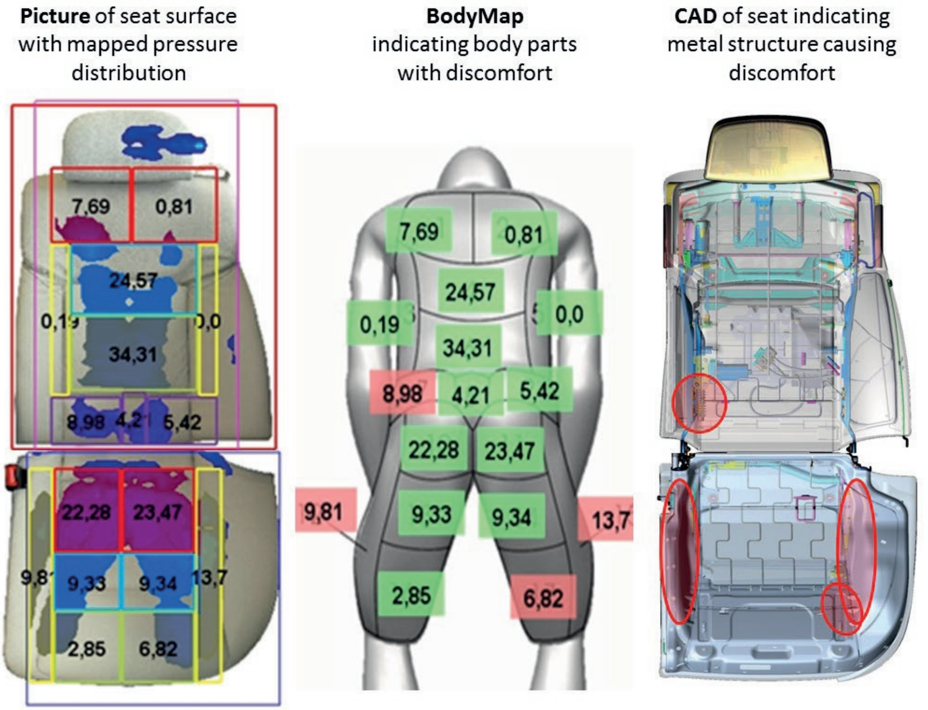


Figure 52: Identification of pressure peaks on the seat surface and in the seat structure.

This paper focused mainly on the research of Hartung, Mergl and Zenk. The literature analysis showed differing classifications of the body map e.g. Na (2005). In this study the seat and backrest surfaces were divided in only four body zones. The concentration on the theoretical knowledge of Zenk and Mergl were explained by the intensive measurements with large heterogeneous samples but also by the validation of the theory both in static and dynamic environments.

Additionally, the detailed definition of the limits of the five parameters supported the decision for this theoretical framework of the customized user interface. Upcoming theories should consider freely programmable limits of the five parameters. Those limits indicate discomfort ratings by turning from green to red in respective body zones, thus allowing adjustment to those parameters by implementing new insights if necessary.

Despite the accurate positioning of body zones on the seat surface, there are limitations to this approach in relation to the contour of the seat surface which disclosed higher variance than estimated. Laurent (2014) indicated a certain unpredictability of human inter-tissue stress which limited the applicability of pressure distribution to evaluate seat comfort. During the experimental stage of the subjects sitting down misinterpretations in the positioning procedure occurred. Thus Laurent (2014) suggests a virtual determination of the pressure distribution and developed a FEM-model. However, the virtual validation was challenged by a realistically derived replication and reference to the characteristics of human tissue. Because of the intense procedure process, only 50 percent models were used and sometimes supplemented by the percentile ranges from 5 to 95. A validation by testing prototypes must continue to use mock-ups with subjects representing a heterogeneous group of common users.

The theoretical framework of the customized user interface was based on validated measurements of the driver’s seat. Car manufacturers also focus on the back seats, which can be deduced from rear seat oriented car concepts such as the BMW 5 and 3 Series GT. During the 1950s back seats strongly resembled couch cushions. However, the driver orientation has become the main focus in the automotive market in the subsequent years (cf. Figure 53).

Figure 53: Comparison of the interior design of a BMW501 first upper class BMW and predecessor of today’s BMW 7 Series to the driver orientation and the interior of a M3 Sports Evolution with a distinct driver orientation of the dashboard.

The comfort model of the ideal pressure distribution needs to be investigated and validated for the efficient development of rear seats. Therefore, further research is necessary (a forthcoming paper will address this topic). The customized user interface for rear seats must be tested with a large variety of subjects in order to prove the applicability and flexibility of the system. Regardless of the heterogeneity of the sample a fast adjustment of the body zones to the pressure mat should be possible.

The application of this research could result in a customized user interface which is based on a theoretical framework of the comfort model of the ideal pressure distribution. The model could provide incremental seat development process. This add-on has already been integrated into the version 7.0’s “AutoSeatMode” by the company XSensor with a few optimizations of the user interface and is accessible in the market (see Figure 54).

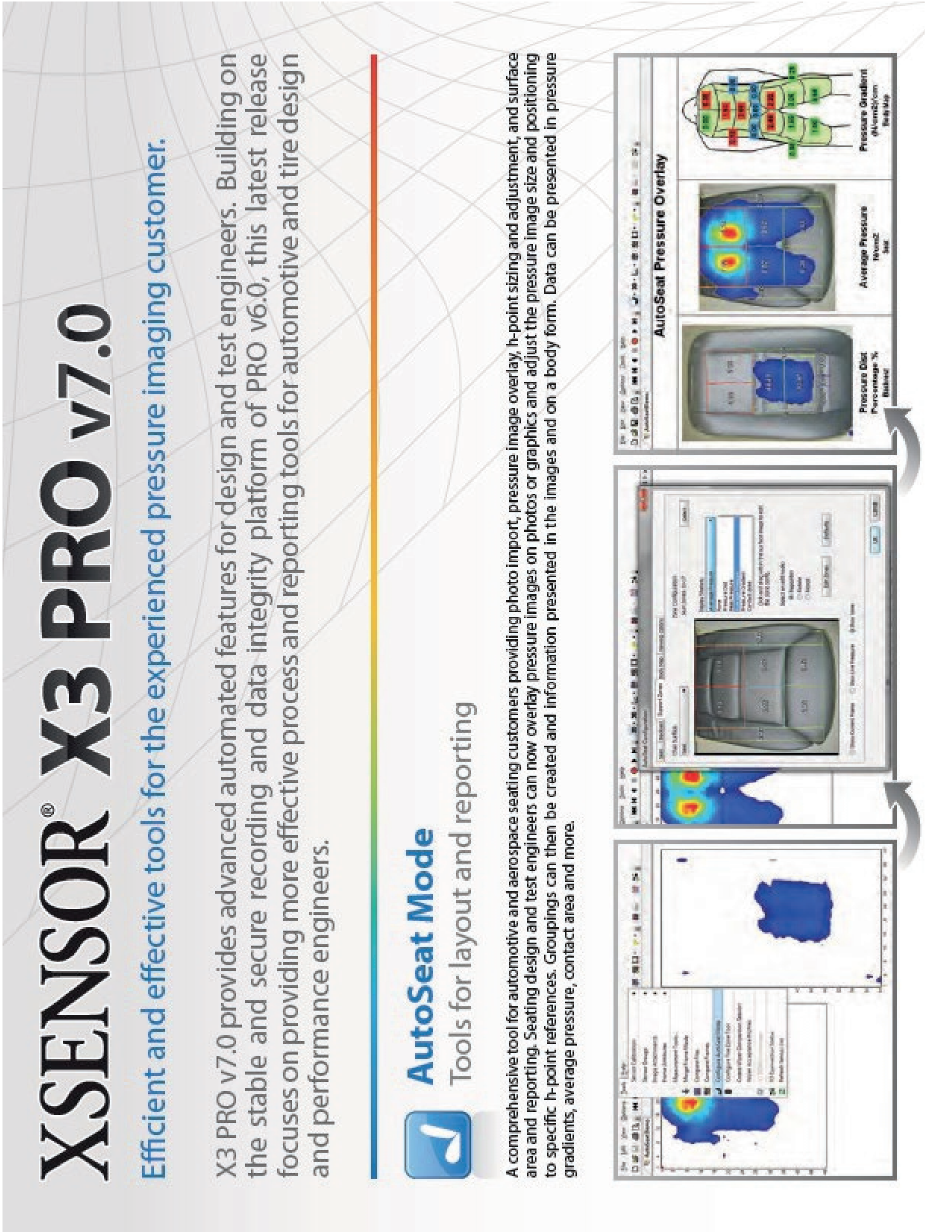


Figure 54: The results of this study are implemented in XSensor X3 Pro v7.0.

The transfer from theoretical knowledge about discomfort will lead to useful results for application-oriented cases in the automotive industry, consequently, other software solutions will follow. New programs should emerge with a specific focus on ease of use and ready to use.

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5 EPILOGUE

The objective of this PhD was to propose design guidelines for comfortable car interiors that are designed from the inside to the outside by user-involvement. An approach, which is becoming more popular in automotive design according to Hofmann (2018) and is called 'Inside-out". "Inside-out" means that the occupant is the starting point of the design. The comfort of the occupant is therefore getting more attention. A part of that is approach is focusing on the comfort of the occupants' seat. As described, there is knowledge available on the drivers' seat comfort, but the passengers' seat was the central theme of this PhD to support inside out design.

In chapter 2.1, a study was conducted to observe the postures and activities in passenger environments where humans were free to choose their posture (i.e. traveling by train and waiting at the airport) and had no driving task. To gather information on postures that could be seen in future driving situations, the observations were done at semi-public spaces related to travelling. Although different methods were used (observing in the train and pictures studying the postures in leisure situations) in both cases the most frequent seen postures could be established. The most frequent activities during train rides and seated waiting situations were: observing (23.1%), talking (22.7%), and reading (16.4%). In the train study relaxing (23.4%) also appears and in a later study smart phoning was dominant. A further finding was the particular posture people did take when there is no head rests, and arm rests, while leaning to the backrest. Remarkable was the diversity of the postures of upper and lower legs. There was more variation then observed in the driving task, which is logical as there is no driving task. Also, a difference between dynamic and static situations could be observed. For instance, during the train study sleeping and reading were more frequently seen than in static leisure situations (e.g. waiting at the airport), probably because of the constant speed and dynamic characteristics in a driving train. In static situations, there were no significant findings for the relationship between activity and posture regarding position of the head, trunk, arms and legs due to the diversity of seats. In the train study this was different, as the seats are comparable in their parts, height, size, shape, form, and design influencing the subjects and their postures as the only independent variables.

In Chapter 2.2, the corresponding postures of the train study with diverse activities like reading, observing, talking, or sleeping were classified in 12 postures (Kamp et al., 2011). Based on these 12 postures, a selection was made for the rear seat of a car. This selection was limited as for most of these postures safety requirements and physical constraints hinder the application for the rear seats of a car. The car package is a further limitation as there is a shaft tunnel in the middle between the seats, which limits space for your feet and lower legs. Two postures (sleeping/relaxed and upright) were investigated further in a lab experiment with a mock-up. Chapter 2 showed the importance of the upright posture in a more recent study as in using the smart phone this posture was also often seen. The activity 'using the smart phone' in a train increased significantly in 6 years. The angles of the upright posture (104.2° backrest angle) and the relaxed posture differed (118.9°). This can also be transferred to the angles of the elbow (139.9° vs. 128.5°) and to the degree of stretched legs. The upright, standard and relaxed posture were digitalized for the software package RAMSIS to establish a probability-based comfort model in 3D for each joint angle which supports designers in inside-out design and facilitates interior design starting from the user perspective of passengers.

Apart from supporting body angles, it is also important to support the form of the human body. Therefore, an additional procedure was developed to establish the human contour while sitting. This procedure was useful and has been applied later in other studies (Hiemstra-van Mastrigt, 2015; Smulders et., 2016). In chapter 3.2, a human contour based seat was developed. The imprints of spine, buttocks, and thighs of 25 seated subjects were scanned and digitalized to create a seating contour based on a best-fit algorithm. This fit was found despite the large variation between the subjects (5-percentile female to 95-percentile male). The resulting seat design was compared with an established seat design regarding comfort experience. Subjects mentioned a better support of the lumbar region with the new seat design, while the weight of the seat could be reduced about 50% simultaneously. In order to expand the seat design of a contour seat, specific upholsteries are needed to cover the contour differences. Pre-tests showed that conventional foam materials are able to eliminate the differences of the diversely imprinted contour. To heighten the lightweight design of the seat, inflatable cushions can be used to gain additional value through posture variation (van Dieën et al., 2001; Lueder, 2004). The contour and the development process of the body contoured light weight seat is patented PA2009016051 DE.

Apart from the ideal body angles and a seat contour fitting to the contour of the human body, the pressure distribution has often been described as a parameter linked to discomfort (Looze et al., 2003; Zenk et al., 2012). This is not yet studied for the rear seat and described in this PhD. The ideal pressure distribution found in the drivers' seat has large similarities to the chosen two postures, upright and relaxed, in the rear seats of sedans and SUVs (chapter 4.1). The term ideal is in this case relative as it was the position with most comfort for this environment: the rear seat. It could be that laying flat for instance shows higher comfort scores. The real comfort score on a scale 1-10 is unknown as the goal was to find the optimum in current situation.

In order to generate a comfortable feeling, more pressure is needed in the back of the seat pan. Zenk (2004) postulated a pressure range from 23% to 36% load at the back of the seat in relation to the driving task. Mergl (2006) established 28.5%. Regarding passenger rear seats, the study of chapter 4.1 shows a 27.4% pressure load for the upright posture in a sedan and a 29.5% in a SUV which is close to the results of Zenk and Mergl. The relaxed position proved to be different, which makes sense, because the thighs get more pressure in a relaxed than in an upright posture. The knees can be more lateral or legs could be stretched. The resulting posture is characterized by an increased contact surface, which could have a relaxing effect because of lower muscle activities as postulated by Zenk et al. (2012). The subjective comfort ratings of the preferred position were higher than the evaluation of the upright position. The pressure of 2-4% of the total per leg was found in the driver's seats and in our study in the rear seat, but for relaxed positions pressures could go up to 5% for one leg in the front of the seat pan. Also, this study showed an independence from the car package (sedan or SUV), that might indicate a broader application of designing seats as these values in various seats are close to each other.

The findings of chapter 4.1 were summarized in a software tool for designing car seats (see chapter 4.2) which can be applied in various development stages of seat design. Also in the early stages engineers can check their design with this software. The software uses the results of pressure mats with a graphical user interface and CAD data for simultaneous measuring and fully automated analysis of the pressure distribution based on the body map of Hartung (2005). The findings of chapter 4.1 are displayed in real-time and projected on the CAD data of the seat, which means an instant digitalization of pressure peaks of a seat such as internal seat frame structures.

The application of this research could help creating a customized seat which results in a user interface based on a theoretical framework of the comfort model of the ideal pressure distribution. This model could support an incremental seat development process. This software has already been integrated into the version 7.0's "AutoSeatMode" by the company XSensor with a few optimizations of the user interface and is accessible in the market (see chapter 4.2, Figure 54).

5.1 Design Guidelines for car interiors from the inside to the outside

The consistent implementation of comfort relevant aspects in the seat design process is very complex. The car development process is neither a linear, nor sequential process, but an iterative one with itemization and improvement (Hofmann, 2018). As shown in this PhD thesis and in scientific literature, the human varies much regarding its anatomy (Molenbroek et al., 2017), habits (Hofmann, 2018), and preferences (Hiemstra et al., 2017). On the other hand, humans are very flexible and have the ability to adapt to the environment and to the products of everyday use. Thus, it is not easy to determine the user needs and requirements and to quantify these and translate these into digital seat design. In this PhD, observations of the human in a travel environment where they were free to choose their postures was important to link to the human natural behavior while seated in a vehicle. A lab test might influence subjects negatively and bias the results. This is why a combination of research methods was chosen with observations during travelling and precise measurements in a controlled lab environment. The findings about the activities and corresponding postures of users were transferred to the automotive interior. During this deduction, the variety of observed activities and postures was reduced and specified into three most seen postures that are possible in a car as the car limits this diversity due to regulations, space, and package. In future autonomous driving electric cars there could be much more freedom of movement (Hofmann, 2018), which asks for new research as the data in this PhD are not covering all of these new future postures. For the current cars the data of this PhD are still useful as most cars still have a front and rear seat configuration. After this deduction, the findings could be digitalized and retested by a mock-up in a lab test in order to transfer this knowledge to a digitalized model for posture-based seat design. The Internet of Things opens new possibilities. Future research might make use of big data gathered while driving, which can be translated into digital models. Now future interior concepts and seat designs can be tested for comfort with the digitalized model based on the research in this PhD and thus support the early stages of car development.

Consequently, geometrical targets can be defined, that enable comfortable seat designs.

A further step of this digitalized model is the actual design of a seat considering comfort and lightweight aspects as discussed by Vink et al. (2012). Franz (2010) showed a method to develop human body contoured seats by the digitalization of body scans, and a best-fit geometry which enables higher comfort due to ergonomic design. A further possibility for comfortable car seat designs is to reduce cushion, foam and thus weight, by using the individual body contour of passengers in real-time. Hence, the seat is able to adjust to passengers instantly by pneumatic elements that measure and analyze the pressure distribution of its users.

Activities, postures, and seat geometry influence the pressure distribution between passengers and the seat pan (Hiemstra-van Mastrigt, 2015). This PhD establishes parameters for the ideal pressure distribution of passengers in relation to their postures and compares these findings to the ideal pressure distribution of the driver by Mergl and Zenk. Hence, the iterative circle of seat design suggested in this PhD closes by further detailing and evolutionary improvement (cf. Figure 55).

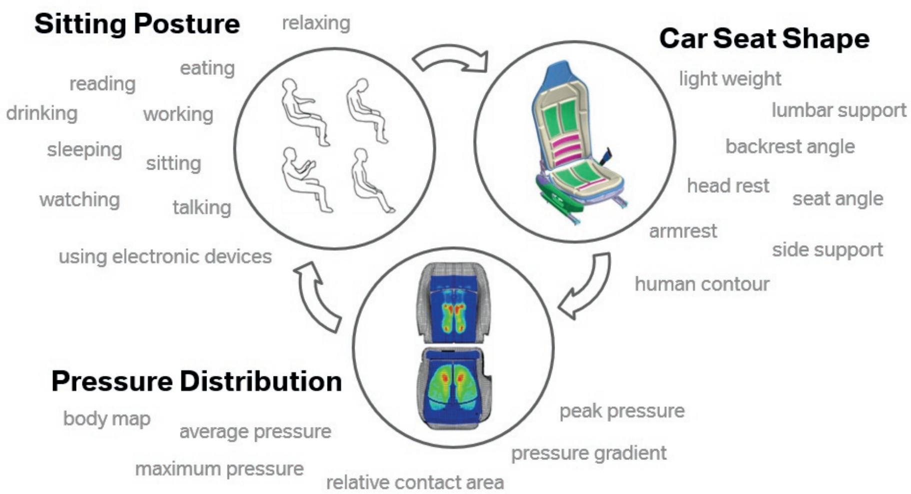

Figure 55: Iterative model for digitalization of posture and comfort-based seat design from inside-out.

5.2 *Reflections on methodology and design concepts and suggestions for future research*

Future trends show an increase in the use of CE (consumer electronic) devices as is shown in chapter 3. The studies of Kamp et al., (2011) and Groenesteijn et al. (2014) suggest that often the upright posture is seen using smart phones. However, Van Veen (2016) shows that for smart phones and tablets special features in the interior is preferable to support the arms and prevent the neck bending while using these devices. Further research about the observed posture of users of CE (consumer electronic) devices like a smartphone or tablet, might be interesting. This special focus might require different classification theories (McLeod and Griffin, 1986) than the one used in this PhD (low, medium and high-level activities). Bhiwapurkar et al. (2010) investigated use case scenarios of laptops on a table during train rides. As a result, typing was more difficult on a table than placed on the lap. For larger electronic devices, the trunk of users was in a slumped position. This corresponds to the research of Khan and Sundström (2004), who proved that people put their books, writing materials, and portable computers on their laps during use due to vibrations.

To translate these activities and related postures into car interiors, some additional research has to be done. The vibrations and sometimes unexpected movements will probably influence the possible activities in a car. As several researchers have shown (Bhiwapurkar et al., 2010; Corbrige and Griffin, 1991; Kant, 2007; Khan and Sundström, 2004), a dynamic situation influences the chosen activities. So, further studies might include dynamic situations as well.

Besides vibrations and movements, there is only limited space in car interiors available. The spaciousness also differs from travelling by train, or upper-class cars to smaller cars (a micro car offers a different space compared to a luxurious limousine, or SUV). The most observed postures are important for considering a new car interior, but additional research to design can interiors and find space in cars to support the activities and postures in smaller cars is still necessary.

Additionally, most of the lab tests focused on short-term comfort. Especially, the prototype of the lightweight contour seat would be interesting to test in a field study for long-term comfort.

The study of the ideal pressure distribution also has some limitations. The mockup in a lab leads to a static test situation, which has the advantage that the conditions can be repeated precisely. The question is, whether this approach is transferable to real driving situations. Zenk (2008) showed during his real driving situations that the results of Mergl (2006) also gathered in a mockup in a lab were comparable, which is promising. Another drawback is that only the ideal static posture is studied in the PhD, while nowadays more studies show the importance of variation in posture (Bouwens et al., 2018). Variation of posture means that the seat design should be made in such a way that various postures can be taken, which is still possible using the current software. It means that not only the ideal posture should be supported by the seat, but a variety of postures, which makes seat design in a limited space challenging.

The observed postures were based on the train study and static situations of semi-public spaces in waiting areas of airports. This is only a small part of the daily routine of users and thus excludes some activities and the corresponding postures. Further research should consider observations of sitting behaviors of humans in private areas like living rooms like the study of Rosmalen et al. (2009), or in the cinema, or on long-term flights. These aspects might be interesting, due to the growing trend of autonomous driving. Hence the driver tasks change more to the passenger tasks. These might include slouched postures (e.g. Rosmalen et al., 2009). Slouched postures pose new challenges for passive and active car restraint systems.

5.3 *Conclusion*

In this PhD, seating concepts were investigated with the current state of art and conventional seats and materials. To reduce weight, new materials for seat frame, cushion, parts, and upholstery might influence the human-seat interface, as well as the microclimate and the pressure distribution. This leads to new parameters for posture, pressure distribution, and seat design which have to be included in the iterative model for digitalization of posture-based seat design and comfort-based seat design from inside-out in the future.

However, based on observation in trains and public spaces related to travelling, frequently seen postures could be discovered. A selection of these postures is possible in a car. This selection was studied in a laboratory, to make the study reproducible. In the lab data on postures and pressure distribution were gathered and put into a digital human model, which can be used in designing car seats. The ideal position could be established and it was comparable to other studies making the outcome one that really can be used in designing seats. Also testing the comfort can now be done with an objective method. The pressure distribution between an occupant and a concept seat can be recorded and indicate whether the seat and the chosen posture is comfortable.

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SUMMARY

The aim of this dissertation is the development of a tool for designing a comfortable automotive interior starting by the human (inside-out) with a focus on seating comfort of the rear seat.

For this purpose, in the first chapter of this thesis, relevant research results for the content of this research in the literature were determined and described. The literature is mainly focused on the comfort of the drivers' seat and the rear seat gets little attention. The rear seat is the focus of this PhD and tries to fill this gap. The literature also shows that in the last years there is more focus on designing starting from the inside of the car, which ask for knowledge on the interior including rear seats. The information gathered on rear seat design in this PhD might be relevant for the front seat as well as autonomous driving will be introduced.

In Chapter 2 the relevant activities while sitting in environments related to travelling with more freedom of movement than in the car were observed. In order to identify the most realistic behavior and postures, people were observed in their natural environment. The observation was performed related to transport in order not to lose the technical connection to the automobile and the travel context. For this purpose, 568 persons in a regional train and 175 persons in public spaces at airports were observed and classified with regard to their activities and the corresponding postures.

Three typical postures were identified for the automotive context: upright, standard, and relaxed. While the upright position has been observed for activities such as eating, drinking, using a smart phone or working, the standard position represents the typical sitting posture for looking out or being entertained. The relaxed position is preferred for activities like relaxing, dozing and sleeping.

In an additional more recent observation of 354 train travelers it appeared that the use of the smart phone was increased. Almost half of the travelers were using their smart phone. According to the study of

Groenesteijn the smart phone use often happens in the upright posture, which shows the importance of having this posture in the next studies.

Based on this data collection, a mock-up was created to digitize the previously identified and car-relevant postures and to implement them in the form of a probability-based posture model in the CAD tool RAMSIS. By this the comfortable position of different body parts could be determined for different body sizes. For this purpose, comfort angles were recorded and digitally imaged for each individual body joint in all three dimensions. Thus, it is possible to convert the determined joint angle data into a RAMSIS software model for seats with primarily non-driver-active purpose. Finally, a posture model has been developed for each of the three typical postures: upright, standard and relaxed.

The ideal seat pressure distribution was developed as part of a test subject study on the basis of previously determined specifications for the driver's seat in Chapter 4. In their study, Mergl and Zenk had developed specifications for an ideal pressure distribution for a driver's seat, taking account of driving-specific postures. This ideal seat pressure distribution has been validated and developed in this PhD thesis for the postures classified in Chapter 2 in the rear seat. Participants in the test (n=50) were asked to take the three positions and for each position they had to adjust the seat to make it as comfortable as possible. Basically, the values of Mergl and Zenk were comparable to the upright and standard posture of this study. This means that probably the values could be applied in other areas as well. However, more research is needed to affirm this statement. The relaxed position results in slightly different values in the area of the ischial tuberosity (more relief) and front thigh area (more support).

In designing a seat these values could be of help. The seat pressure distribution can be determined in a seat and compared to the values found in this study. This way an estimation of the expected comfort can be made.

This PhD thesis delivers background information for CAD rear seat design to make seats with a higher chance of being comfortable.

A disadvantage of this study might be that the data collection of activities and corresponding postures was based on: passenger train and public space observations. These reflect only a part of the human sitting habits. Studies in other areas of life, like in living rooms or theaters the sitting behavior could probably more broadly be captured and result in other postures. However, the now most observed postures are in this study and the data in this PhD thesis are at least to some extent useful.

In addition, new infotainment options and electronic gadgets will influence people's activities and their respective sitting posture. In order to meet this aspect in the design of comfortable interiors, further research activities are required. On the other hand, these developments also make it possible to gather data from many sensors and create big data sets, which can be used as well to find the ideal postures and often seen activities.

But for now, this PhD thesis generated data which make it possible for designers to create in the digital car more comfortable seats. Additionally, the data can be used to test with pressure mats whether the prototype is close to the ideal pressure distribution.

SAMENVATTING

Het doel van dit proefschrift is het ontwikkelen van een hulpmiddel om een comfortabel auto interieur te ontwerpen (van binnen naar buiten) waarbij het startpunt de passagiersstoel is. Het eerste hoofdstuk van dit proefschrift behandelt de literatuur gerelateerd aan dit onderwerp. In de literatuur is de focus voornamelijk op de bestuurdersstoel en de achterbank krijgt nauwelijks aandacht. De achterbank krijgt meer aandacht in dit proefschrift. De literatuur laat ook zien dat er meer aandacht komt voor het van binnen naar buiten ontwerpen van een auto. Ook autonoom rijden krijgt meer aandacht. In dat kader is kennis over de achterbank ook interessant omdat die kennis relevant wordt voor de voorstoelen wanneer er autonoom gereden wordt en de taak de houding minder dwingt.

In hoofdstuk 2 zijn mensen geobserveerd in treinen en in publieke plaatsen op een vliegveld. Hierdoor is informatie verkregen over wat mensen doen (activiteiten) en welke houdingen daarbij worden aangenomen zonder dat de bewegingen beperkt worden door het frame van de auto. In de trein zijn 568 mensen geobserveerd en 175 op openbare ruimtes. De activiteiten zijn bepaald en de bijbehorende houdingen. Hieruit zijn drie typische houdingen gedestilleerd, die veel voorkomen en in de context van een auto mogelijk zijn: het ‘gewoon zitten’, meer rechtop zitten en ontspannen zitten. Rechtop zitten komt voor bij eten, drinken, gebruiken mobiele telefoon of werken. Het gewoon zitten komt meer voor bij voor je uitkijken bezig gehouden worden en de ontspannen positie komt voor bij rusten, dommelen of slapen.

Uit een meer recente observatie in de trein (hoofdstuk 3) bij 354 reizigers bleek dat ten opzichte van 2011 het mobiele telefoongebruik veel toegenomen te zijn. Ongeveer 50% van de geobserveerde reizigers gebruikte de mobiele telefoon. In andere studies werd aangetoond dat mobiel telefoongebruik veel in de rechtop houding plaatsvind, wat het belang van de rechtop houding onderstreept.

Gebaseerd op de observatie data is een proefopstelling gebouwd waarin deze houdingen aangenomen konden worden. Het doel was om deze houdingen in een auto aan te nemen en op basis daarvan de hoeken van de verschillende ledematen te bepalen voor mensen met verschillende lengtes. Dit is gebruikt om een CAD model te maken dat in de software RAMSIS is ingebouwd. Hierbij kan een ontwerper de meest comfortabele houding bepalen voor drie houdingen: rechtop, gewoon en ontspannen zitten.

In hoofdstuk 4 is de ideale drukverdeling bepaalt voor de drie houdingen. Mergl en Zenk hadden in hun proefschrift al de ideale drukverdeling voor de bestuurdersstoel bepaald voor de houdingen die voorkomen achter het stuur. In dit proefschrift zijn de drie andere houdingen genomen waar bijvoorbeeld meer vrijheid voor de positie van de benen is op de achterbank. Proefpersonen (n=50) moesten in de drie houdingen zitten in de stoel en de stoel zo instellen dat de houding comfortabel was. De waarden van de comfortabele houdingen waren goed vergelijkbaar met die van Zenk en Mergl, wat betekent dat wellicht de waarden breder toepasbaar zijn, zoals in trein en vliegtuigstoelen. Maar hier moet nog nader onderzoek naar worden gedaan. Alleen de ontspannen positie gaf meer druk op de voorkant van de stoel en minder aan de achterkant onder de zitbeenderen.

Bij het ontwerpen van een stoel kan deze waarde van belang zijn. Door de drukverdeling vast te stellen in een stoel en te vergelijken met de ‘ideale’ drukverdeling kan een inschatting van het verwachte comfort worden gemaakt.

Dit proefschrift levert dus achtergrond informatie voor CAD stoel ontwerpen op basis waarvan achterbank stoelen kunnen worden gemaakt die een grotere kans hebben om als comfortabel te worden ervaren.

Een nadeel van deze studie kan zijn dat de observatie alleen treinreizigers en reizigers op publieke plaatsen is. Hier worden niet alle activiteiten uitgevoerd. Observaties thuis of in theaters kunnen bijvoorbeeld nieuwe activiteiten en houdingen naar voren brengen. Aan de andere kant de houdingen, die geobserveerd zijn komen wel veel voor en daarom zijn de data in dit proefschrift in ieder geval voor een deel nuttig. Daarnaast zullen zich weer nieuwe taken voordoen. Infotainment en elektronische gadgets zullen ons gedrag gaan beïnvloeden en wellicht weer tot andere houdingen leiden. Dit zal in de toekomst verder onderzocht moeten worden. Overigens is de toename van sensors en opslag van data ook weer een mogelijkheid om op andere wijzen gegevens over activiteiten en houdingen te kunnen registreren. Ook iets wat verder verkend dient te worden. Maar voorlopig bevat dit proefschrift data op basis waarvan ontwerpers in een digitale omgeving een meer comfortabel stoel kunnen ontwikkelen en waarmee tests met drukmatten kunnen worden vergeleken om tot de ideale drukverdeling te komen.

ABOUT THE AUTHOR

Ümit Kilincsoy was born October 18, 1979 in Parsberg and studied Mechanical Engineering with a special focus on automotive technology and production management at the Technische Universität München in Garching. He achieved his degree September 30, 2007. During his study he gained 18 weeks of practical experience at BMW. After his master degree he worked at BMW as PhD student to develop an ergonomic posture model for rear seats combined with an ideal pressure distribution. With train observations, realistic mock-ups, fully adjustable seats and broad samples he studied the human behavior during static and dynamic travel situations disclosing insights in the research of rear seat passengers in order to establish design guidelines for automotive rear seats.

He worked in different departments of research and development in lighting engineering and geometrical design at the BMW Group.

His current task at BMW Group is the geometrical design, starting from the first vehicle proportions to the complete vehicle geometry for series. He is responsible for the implementation of geometric property profiles such as comfort-relevant dimensions in the interior and legal dimensions in the exterior. In this sense, his PhD project has a high relevance for his current area of responsibility.

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Patent

Process for producing a supporting shell for a seat, M. Franz, D. Alexander, Ü. Kilincsoy, P. Vink; US Patent 8,733,843

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The conventional development of a new automobile starts with a first proportional model. In this model, the exterior geometry of a car can be distinguished into vehicle, power train portfolio, market requests, safety requirements, and design target. The interior design results from the proportional model with specific characteristics, such as spaciousness, control and display concept, and ergonomic requirements. The automobile emerged from the sole purpose of transportation with driver orientation into a vacation or commuter experience of all users by a broad spectrum of comfort- and infotainment features. This is sustained by emerging mobility concepts like autonomous car concepts. In order to consider this change in mobility concepts, consumer habits and mobility behavior of users, the interior design becomes more important, which creates the frame for this PhD project. An essential part of the interior is the seat. This PhD thesis focuses on designing car interiors from the inside to the outside by user involvement.