COMFORTABLE PASSENGER SEATS

Recommendations for design and research

Suzanne Hiemstra-van Mastrigt

COMFORTABLE PASSENGER SEATS

RECOMMENDATIONS FOR DESIGN AND RESEARCH

Proefschrift

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TAKE-OFF

Chapter 1

General introduction

1.1 BACKGROUND

"Beam me up, Scotty" Although the teleportation of Star Trek is likely the most widely-recognized fictional teleportation, the concept of teleportation is well used by other TV series and movies. And even though researchers have recently proven that it is possible to teleport information between two points three meters apart (Pfaff et al. 2014), it will certainly be far, far in the future – if ever – before it will be possible to teleport humans. So, unfortunately, until teleportation becomes reality, people depend on other ways of transportation from one place to another, such as aircraft, trains, and cars.

The numbers of passenger transport are increasing. For example, in 2013, over 3 billion passengers were carried by the world's airlines (ATAG 2014), and numbers are growing. According to the global market forecast by Airbus, air traffic will double in the next 15 years, showing 4.7% annual growth between 2013 and 2033 (Airbus 2014). Air traffic has proven to be resilient to external shocks, as it has shown 73% growth through multiple crises over the last ten years (e.g., SARS, financial crisis). Similarly, the sales volume of automobiles shows continuous growth. For example, car sales volumes of the BMW Group almost doubled the past 5 years, delivering almost 2 million vehicles in 2014.

1.2 CHANGING PASSENGER POPULATION

Next to an increase in the number of air passengers, the diversity of air passengers increases as well. Air transport growth is highest in emerging regions such as India, Africa and Eastern Europe. For example, the expected 20-year growth is largest for the Middle East (7.1% a year) and Asia-Pasific (5.7%). The growth in emerging regions is also seen for the automotive industry. Although it is expected to slow down to an average of 8% a year between 2011 and 2020, China's automotive sector grew at an average rate of 24% a year between 2005 and 2011 (McKinsey & Co. 2012). Hence, also in the automotive industry, the diversity in drivers and passengers increases. The same development is seen for train passengers. As a result of innovations in railway, trains are becoming a competitive alternative for air travel. Compared to short and medium distance flights, train journeys could be faster, in particular for high-speed lines covering distances up to 800 km (European High Speed Rail – An Easy Way to Connect 2009). While trains have traditionally transported passengers more or less in the same area, due to longer distances covered by high-speed lines, the diversity of train passengers will increase as well.

Besides this cultural diversity of passengers, the world population in itself is changing as well. Although the trend of increasing height has been gradually slowing or stopping in many populations (Godina 2008), there is a strong tendency towards increasing weight and obesity in many European countries and the USA (Komlos and Baur 2004). In the last twenty years, the number of people in the USA who are considered "obese" has doubled. Another trend is the ageing of the population: the proportion of people 60 years and over is predicted to increase to as much as 21% by 2050 (Ilmarinen 2005). In the UK, 80% of the disposable income is with people of 50 years and older. Older people are willing to fly and can afford time and money.

1.3 Changing technologies

Furthermore, a revolution in ICT devices, applications and networks also introduces a larger variation in activities that passengers perform while traveling. It is expected that the use of small handheld devices, such as PDAs, smart phones, e-readers and tablet PCs, will continue to increase, thereby increasing the number of passengers that use these devices.

Another development is that of autonomous driving cars. Currently, active safety features such as lane change warning, autonomous cruise control, and collision avoidance increasingly find their way into passenger cars (Litman 2015). Additionally, many major automotive manufacturers, including Volkswagen, BMW, Volvo, Toyota and Mercedes Benz, are testing driverless car systems as of 2013. The *XchangE* concept by Rinspeed, presented at the Geneva Motor Show in 2014, shows how the interior of an autonomous vehicle could be designed (see Figure 1.1). In a self-driving car, the driver becomes a passenger and as a result, is able to perform other activities while being driven towards the destination. Current vehicle interiors do not facilitate this yet and thus, this could be an opportunity for car manufacturers.

***Figure 1.1** XchangE vehicle concept (Rinspeed 2014)*

1.4 CHANGING ACTIVITIES

In addition, these modern technologies and the shift towards a service and knowledge driven economy allow people to work while travelling. In London, 20% of commuters spend more than two hours a day travelling to and from work, adding up to one working day a week (Transport for London 2009). Supported by these new technologies, knowledge workers are able to work anywhere, at any time, thus allowing passengers to use their travel time for work activities. Results from a survey performed in the USA in 2008, for example, show that 21% of respondents conducted work activities while on an aeroplane, train or subway (WorldatWork 2009).

1.5 INTERIOR DESIGN CHALLENGES

Thus, although the first studies on passenger seat comfort and activities appeared already 40 years ago (Oborne 1975; Branton and Grayson 1976) the passenger population, technological developments and travel habits have changed, resulting in other activities and a different context. Unfortunately for the passenger, not much has changed in seat design in the past 40 years: although the comfort of new planes is rated higher than old ones, knee space is still one of the major problems (Vink et al. 2012), as it was in 1977 (Richards and Jacobson 1977). Airlines are even pushing seat capacity to the limits of the airplane design: single-aisle airliners such as the Airbus A321 already have more seats than a much larger twin-aisle airplane such as the Boeing 767-200[1], limiting passenger space even more.

To attract passengers, seats could take into account the cultural diversity of passengers, the change in demographics and the activities that they want to perform during travel. By 2033, there will be a demand for 30,600 new passenger aircrafts (Airbus 2014). With an average of 250 seats per aircraft, this means almost 8 million new aircraft seats – and that is for aviation only. These and other passenger seats should allow passengers to feel fit after a few hours traveling without experiencing discomfort. Discomfort is a predictor of musculoskeletal pain (Hamberg-van Reenen et al. 2008), and also seems inversely related to productivity (e.g., Hozeski and Rohles 1987). However, every year, passengers are traveling in restricted postures, not being able to perform the activities they want and risking health problems such as back pain (Helander and Quance 1990; Burdorf et al. 1993) and neck pain (Ariëns et al. 2000; 2001).

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[1] *For example, the A321 from Monarch has 214 seats (seatplans.com), while the B767-200 from AeroMexico has 174 seats (SeatGuru.com)*

1.6 DESIGN FOR COMFORT

Comfortable seats can attract passengers. Depending on the length of the flight, 20-40% of air passengers name the cabin environment as the most important factor in their choice of an airline (Brauer 2006). Vink et al. (2012) also found a strong correlation (r=0.73) between aircraft interior comfort and "*fly again with the same airline*". The seat is an important feature of every vehicle interior, as it is the interface with the passenger for (almost) the whole journey.

According to Zhang et al. (1996), comfort and discomfort are two independent factors associated with different underlying factors. Discomfort is associated with feelings of pain, soreness, numbness and stiffness, and is caused by physical constraints in the design. On the other hand, comfort is associated with feelings of relaxation and well-being, and can be influenced by, for example, the aesthetic impression. Thus, reducing discomfort will not necessarily increase comfort, but in order to accomplish a high level of comfort, the level of discomfort should be low (Helander and Zhang 1997).

Building on the model by Helander and Zhang (1997), the theoretical model of comfort and discomfort and its underlying factors by De Looze et al. (2003) distinguishes three levels: human, seat and context level. For instance, at context level, the physical environment has an influence on sitting discomfort, whereas at seat level, aesthetic design can influence sitting comfort. At human level, physical capacity as well as expectations and emotions play a role in the perception of sitting discomfort and comfort, respectively.

However, little is known yet about the influence of passengers' anthropometry, the activities they perform, and the properties of the seat, on the comfort and discomfort perception of passengers. Also, it is unclear how this knowledge can be incorporated into the design process of seats.

1.7 HOLISTIC APPROACH NEEDED

Although numerous studies have been performed on sitting comfort, most of these studies focus on office seats (e.g. Bendix et al. 1985; Van Dieën et al. 2001; Groenesteijn et al. 2009) or driver seats (e.g. Franz 2010; Mergl 2006; Zenk 2008). Unfortunately, the results from these studies cannot be applied one-to-one to passenger seats, due to different restrictions of the activity and different body postures. Scientific papers on passenger seats in public transport are much less common (e.g. Jung et al. 1998; Lee et al. 2000; Park et al. 2014).

In addition, most of these studies investigated the effect on pressure variables, such as mean and peak pressure (e.g. Hostens et al. 2001; Moes 2007), contact area (e.g. Paul et al. 2012; Kyung and Nussbaum 2008; Vos et al. 2006) and pressure distribution (e.g. Mergl 2006; Zenk 2008). Mergl (2006) and Zenk (2008), for example, defined an ideal pressure distribution for a car driver. Even though pressure distribution seems to be the best objective measure for discomfort (De Looze et al. 2003), it is influenced by other variables such as posture and movement, which are not taken into account in most of these studies.

Until now, aspects concerning sitting comfort and/or discomfort are only considered in separate studies and their interdependencies and interactions are little known, let alone their effect on comfort and discomfort. Hence, the exact relationships between human, seat and context variables remain unclear. A more holistic approach is needed to gain insight into the relationships between passengers' anthropometry, the activities they perform and the design of seats on comfort and discomfort perception of passengers.

1.8 AIM OF THIS THESIS

The aim of this thesis is to provide knowledge on how to design comfortable passenger seats, taking into account the diversity of passengers' anthropometry and variety in activities they perform. The goal is to provide recommendations for the seat, as well as guidelines for the design process. Researchers and seat designers will benefit from this knowledge, as well as purchasers and manufacturers of vehicles and vehicle interiors.

In order to accomplish this goal, first, a literature review has been conducted on the current state of knowledge, to investigate whether it is possible to predict passenger comfort and discomfort on the basis of human, seat and context characteristics. Next, several experiments have been performed on aircraft seats, train seats and the backseat of a car. Finally, the results of these experiments are translated into recommendations for passenger seat design and research.

1.9 OUTLINE OF THIS THESIS

The literature review in **Chapter 2** provides an overview of the relationships between passengers' anthropometry, their performed activities, and seat design, and their influence on passengers' perceived comfort and discomfort. It also presents a new conceptual model on how human, seat and context characteristics are influencing passenger comfort.

Corresponding with the conceptual model on passenger comfort presented in Chapter 2, this thesis is then divided into three parts: Context, Human, and Seat (see visual outline in Figure 1.2). The chapters in these parts (Chapters 3 to 9) describe experiment results from train seats (🚆), car seats (🚗), and aeroplane seats (✈), as indicated by the corresponding icons.

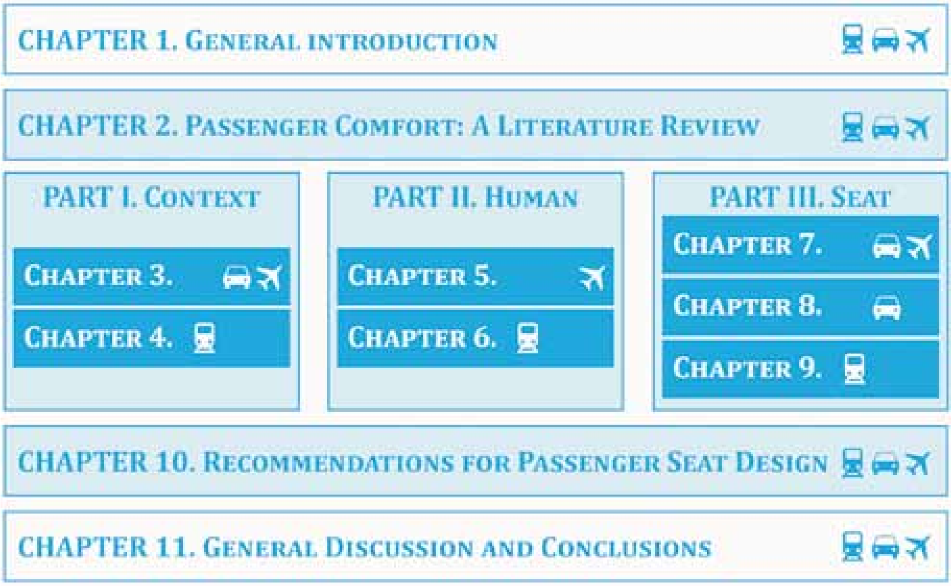

***Figure 1.2** Visual outline of this thesis (blue chapters describe experiment results)*

The first part, "**CONTEXT**", studies the influence of context characteristics on comfort and discomfort perception, in particular passengers' performed activities and duration of the journey. In **Chapter 3,** it is investigated how these performed activities influence body posture and discomfort development in time, while in **Chapter 4**, most observed activities and corresponding postures of train passengers are defined.

The second part, "**HUMAN**", investigates the influence of human characteristics on comfort and discomfort perception, in particular passengers' body sizes (anthropometry). In **Chapter 5**, the influence of human characteristics is investigated and illustrated by two case studies. First, anthropometric characteristics are compared with aircraft seat dimensions and second, correlations between anthropometry and posture are investigated. In **Chapter 6**, the effects of activities and anthropometry on comfort of a train seat is studied by means of an experimental set-up in which train seat parameters could be adjusted.

The third and last part, “**SEAT**”, studies the influence of seat design on passengers’ comfort and discomfort perception. In **Chapter 7**, the influence of seat characteristics is investigated and illustrated by two case studies. The first case study shows how the design of innovative armrests can improve car passengers’ comfort and experience by supporting the use of handheld devices. The second case study describes a method to develop an ideal seat contour for an aircraft seat. **Chapter 8** evaluates the effect of an active seating system on the perceived comfort and activity levels of car passengers. In **Chapter 9**, the effect of seat cushion material on the perceived comfort and discomfort of a train seat is studied.

Based on aforementioned studies, **Chapter 10** then presents the recommendations for specific elements of a comfortable passenger seat, such as a back rest and a seat pan, as well as more general guidelines on the design process of passenger seats. Finally, **Chapter 11** contains a general discussion and conclusions on the design of comfortable passenger seats, including a reflection and recommendations for future research.

Table 1.1 *Overview of publications part of this thesis (asterisk * means second author)*

Chapter	Article title	Journal	Status
2	Predicting passenger comfort and discomfort on the basis of human, seat and context characteristics: a literature review	Ergonomics	Under review
3	Requirements for the back seat of a car for working while travelling *	*Conference paper* AHFE 2012	Published
3	The influence of activities and duration on discomfort development in time of aircraft passengers	Work	Accepted for publication
4	Activities, postures and comfort perception of train passengers as input for train seat design *	Ergonomics	Published
5	Effects of anthropometry and tasks on posture and discomfort in an aircraft seat	International Journal of Human Factors and Ergonomics	*Submitted*
6	Designing comfortable train seats: the influence of activities, postures and anthropometry of passengers	Applied Ergonomics	*Submitted*
7	The design of innovative armrests to support handheld device use *	Work	Published
8	The influence of active seating on car passengers' perceived comfort and activity levels	Applied Ergonomics	Published
9	Effects of seat cushion material and aging on the perceived comfort and discomfort of a train seat	International Journal of Industrial Ergonomics	*Submitted*

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CHAPTER 2

PASSENGER COMFORT: A NEW CONCEPTUAL MODEL

The aim of this thesis is to provide knowledge on how to design comfortable passenger seats, taking into account the diversity of passengers' anthropometry and variety in the activities that they perform. First, existing literature on this topic is studied to provide an overview of the current state of knowledge. Furthermore, this chapter investigates whether it is possible to predict passenger comfort and discomfort on the basis of characteristics at human (anthropometry), seat and context (activities) level.

A new conceptual model has been constructed to serve as a framework for the literature review; both are explained in Section 2.2. In the results section (2.3), the relationships within the model are addressed one by one: between human, seat and context characteristics and interaction variables (posture, interface pressure, movement) on the one hand, and between interaction variables and comfort and discomfort perception on the other hand. This section concludes with a completed model that shows the gaps in current knowledge. Section 2.4 then discusses both the results of the literature review itself as well as the model, and in Section 2.5 it is concluded that the majority of studies found focus on pressure measures, whereas other factors play an important role as well.

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2.1 INTRODUCTION

Job characteristics in western societies are changing. In the past, most people worked in either the agricultural or the industrial sector. However, the modern economy is changing into a service and knowledge-driven economy (Drucker 1999). Within these developments, creativity and knowledge are recognised as the drivers of productivity and economic growth. The number of people who work in the knowledge-intensive service sector is growing (OECD 1996). In the EU in 2011, almost 70% of the employed worked in the service sector (Eurostat 2012). These knowledge workers are supported by a revolution in ICT devices, applications and networks. Because of these developments in technology, knowledge workers are able to work anywhere, at any time. Borders between work and leisure have become fuzzy since people are more often using their travel time for work activities. Results from a survey performed in the USA in 2008, for example, show that 21% of respondents conducted work activities while on an aeroplane, train or subway (WorldatWork 2009). These developments are seen not only in western societies. The new economies of China, India and Brazil have shown an increase in the number of flights, as flying becomes possible for more people. This leads to a greater diversity of people who are travelling – diversity in the sense not only of anthropometry, but also of cultural backgrounds and habits.

Over the past few decades, many studies have focused on optimising office workplaces for workers, in order to optimise human well-being and overall system performance (e.g. Hedge and Sakr 2005; Lee and Brand 2005). These studies concerned for example work devices (e.g. laptop stands, mice and keyboards) (Asundi et al. 2012; De Kraker et al. 2008), work stations and seats (Robertson et al. 2007; Zhu and Shin 2012; Groenesteijn et al. 2012), and the effects of office concepts (De Croon et al. 2005; Banburry and Berry 2005). More recently, the focus has shifted from preventing health problems to providing comfort (Makhsous et al. 2012; Zhang et al. 1996), resulting in many studies and theories on comfort and discomfort in sitting (among them De Looze et al. 2003; Vink and Hallbeck 2012; Helander 2003). These focused not only on office seats (Helander and Zhang 1997; Groenesteijn et al. 2009), but also on seats in heavy machinery (Kuijt-Evers et al. 2003) and passenger seats (Bronkhorst and Krause 2005).

Comfort is seen as one of the major factors that determine, for instance, workers' job satisfaction, but also passengers' flight experience. The importance of comfort in flying is mentioned by Vink et al. (2012), who state that comfort can increase passenger repeat purchase. On the other hand, discomfort is seen as a major source of dissatisfaction and it has a negative effect on human well-being and human performance. That is why seat design is focused on preventing discomfort and providing comfort to the user (Vink et al. 2005).

Comfort exists only in the interaction between a human and a product within a context (Vink and Hallbeck 2012; De Looze et al. 2003). This means that the characteristics of the potential user population, the activities they perform and the physical context in which they are seated should be taken into account when designing a seat. The activities people perform while travelling by public transport have been studied by several researchers (Bronkhorst and Krause 2005; Jung et al. 1998). Kamp et al. (2011) recently studied the relationship between activities and postures during a train journey and in semi-public situations. They distinguished three categories of activities: high level (using electronic devices), medium level (eating, talking) and low level (sleeping, relaxing, watching). For train journeys, they found a relationship between the activity level and the posture. This means that the most common posture can be predicted based on the level of activity people perform while travelling by train. Still, these studies do not take into account the personal characteristics of passengers, such as anthropometry. Leg length, hip width and other body dimensions also affect the ease with which passengers can adopt a comfortable posture when changing their posture. Especially when the space is limited, like in aeroplanes, the adopted posture will greatly depend on the passenger's anthropometry in relation to the physical environment (Kremser et al. 2012). Hence, the effect of anthropometry on the relationship between activities and body postures is unknown. Furthermore, it is unknown how this is related to comfort and discomfort, and how seat design can influence this. Interface pressure may play a role, as the pressure distribution differs between different sitting postures (e.g. Tessendorf et al. 2009) and the physique of the person (e.g. Hostens et al. 2001). Furthermore, pressure distribution seems to be the best objective measure of discomfort (De Looze et al. 2003). This is, for example, illustrated in a study by Mergl (2006), who established the ideal pressure distribution (i.e. the pressure distribution that shows the lowest discomfort ratings) for one type of car seat.

The abovementioned developments, namely the increase in passenger diversity, the increase in passengers' activities (such as working with several devices in a healthy and effective way), and the importance of comfort and the passengers' experience, have made designing an optimal passenger seat more complex. Therefore, it would be helpful for designers and purchasers to have an insight into the interactions between anthropometric characteristics, the activities that people perform and working postures on the one hand, and seat design and perceived comfort and/or discomfort on the other hand. Until now, these aspects concerning sitting comfort and/or discomfort have only been considered in separate studies and little is known about their interdependencies and interactions, let alone their effect on comfort and discomfort.

The underlying factors for comfort and discomfort in sitting have been studied by Helander and Zhang (1997), who concluded that comfort and discomfort are separate entities with different underlying factors. Based on these findings, they presented a conceptual model in which they showed that comfort ratings can hardly be predicted from low discomfort ratings, and that low comfort ratings can be accompanied by either high or low discomfort ratings. When either discomfort ratings or comfort ratings are high, however, the other entity will be low (Helander and Zhang 1997). These findings are useful in clarifying the interaction between comfort and discomfort. De Looze et al. (2003) extended this model by illustrating the human–seat–context interaction. Both models contribute to the understanding of the difficulties of the concepts 'comfort' and 'discomfort', but neither can predict either comfort or discomfort. However, in an ideal situation, designers would be able to predict and quantify the perceived comfort and/or discomfort and compare different ideas for seat design by making use of mathematical models that are based on human characteristics (e.g. anthropometry), contextual characteristics (e.g. seat pitch) and seat characteristics (e.g. dimensions, material). For purchasers such as airlines, it would be of interest to compare different seats by quantifying the expected perception of comfort and discomfort, by using specific passenger characteristics and context characteristics.

The aim of this study was to examine the possibility of predicting passenger comfort and discomfort on the basis of human characteristics (i.e. anthropometric variables), context characteristics (i.e. performed activities) and seat characteristics. Therefore, a conceptual model was constructed to serve as a basis for the literature review, in order to investigate the following relationships:

1. *The effects of anthropometrics (human level), seat characteristics (seat level), and the activities of passengers (contextual level) on interaction variables (sitting posture, interface pressure and movement);*
2. *The interdependencies between the interaction variables (sitting posture, interface pressure and movement);*
3. *The effects of interaction variables (sitting posture, interface pressure and movement) on the comfort and discomfort perception of passengers.*

The results of this study will be applied in future studies to build a predictive model that can be used to indicate comfort and discomfort based on human, contextual and seat characteristics.

2.2 METHODS

2.2.1 LITERATURE REVIEW

The literature review focused on the relationships between the activities of passengers, sitting posture, anthropometrics, interface pressure, comfort and discomfort. The studies for the literature review were retrieved through a search in Scopus. The following text words or combination of these words were searched for in article title, key words and abstract: ‘sitting comfort’, ‘sitting discomfort’, ‘anthropometrics’, ‘weight’, ‘height’, ‘BMI’, ‘pressure distribution’, ‘pressure’, ‘maximum pressure’, ‘pressure gradient’, ‘activity’, ‘activities’, ‘task’, ‘posture’, ‘passenger comfort’, ‘cushion’, ‘material’. Furthermore, relevant references from the selected articles were also checked. Articles were included in this review only if they met all three of the following criteria:

1. The paper describes an experiment or a literature review related to comfort and/or discomfort measurements in sitting/while seated in combination with measurements of anthropometry and/or pressure measurements;
2. The paper describes studies with healthy subjects in standard sitting situations; that is, studies regarding decubitus and with a focus on sitting in wheelchairs were excluded;
3. The paper is available and published in English and was published after 2003 (except for reviews and high-impact papers).

2.2.2 CONCEPTUAL MODEL

First, a conceptual model was built in order to illustrate the hypotheses about the relationships between the variables that affect discomfort and comfort. The comfort model of sitting developed by De Looze et al. (2003), which is based on the interaction between the seat and the human within a certain context, was used as a starting point. Their model is based on the theory of Helander and Zhang (1997), who consider discomfort and comfort as two separate entities, with discomfort having a dominant effect. The conceptual model building on these models is shown in Figure 2.1.

The underlying factors of sitting comfort and discomfort exist on the human, seat and context levels (De Looze et al. 2003). These levels are therefore illustrated

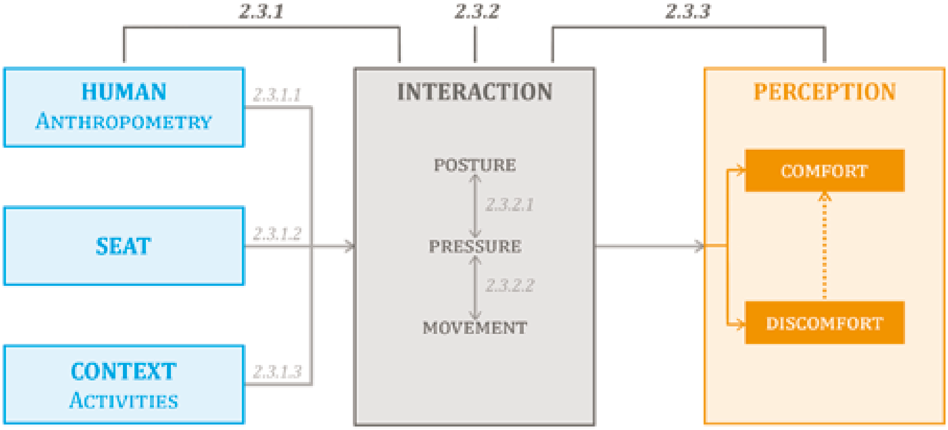

Figure 2.1 *Conceptual model with numbers referring to subsections in this chapter*

in three separate boxes on the left-hand side of the model. However, perception of comfort and discomfort only occurs through the interaction between the seat and the human, within a certain context. This interaction is illustrated by the box in the centre of the model. Such interactions result in feelings of comfort and discomfort. The dominant effect of discomfort is indicated by the arrow pointing from discomfort towards comfort in the box on the right-hand side of the model.

As stated in the research questions, the relationships will be investigated between anthropometry and performed activities on sitting posture, movement and interface pressure and feelings of comfort and discomfort. The underlying factors of sitting comfort and discomfort that will be the focus in this review, are anthropometry and activities. These are mentioned in the boxes at the left side of the model. The interaction between anthropometric variables and activities results in a set of body postures and interface pressures. However, body posture and interface pressure are also affected by other factors, such as characteristics of the seat and the environment (context). These interactions result in feelings of comfort or discomfort. For seat designers, it is interesting to know how seat characteristics affect this interaction and thus how they can design for comfort.

2.3 RESULTS

In this section, the results of the literature review are described. After reading their abstracts, 86 studies were selected. A reading of the articles themselves showed that 28 studies met the selection criteria. After checking relevant references, an additional 13 studies were included. All of these studies described an experiment in which sitting discomfort and/or sitting comfort, context and/or seat and/or one of the interaction variables were measured. In 11 studies, correlations were calculated between some or all of the variables. Almost none of the studies reported effect sizes.

The model presented in Figure 2.1 is the framework in which the findings from the literature are presented in this paper. Human, seat and context characteristics and their influence on the interaction variables (posture, movement, interface pressure) are described first. The associations between the interaction variables posture, movement and interface pressure are then elaborated. After that, the relationships between the interaction variables (posture, movement, interface pressure) and comfort and discomfort are described. Finally, the direct influence of context variables on comfort and discomfort experience is explained.

2.3.1 EFFECTS OF HUMAN, SEAT AND CONTEXT CHARACTERISTICS ON INTERACTION VARIABLES

2.3.1.1 Human characteristics and their effects on interaction variables

Human characteristics in this paper are limited to anthropometric variables, such as stature, weight, somatotype, and body mass index (BMI) or reciprocal ponderal index (RPI). This section describes the associations between anthropometry and the interaction variables posture, movement, and interface pressure.

Effects of anthropometry on posture and movement

Only a few studies report about body postures in relation to anthropometric variables in the context of seating. Branton and Grayson (1967) observed train passengers and were the first to report that tall people sat in postures with knees crossed for longer periods than short people, particularly when slumped. Compared to the tall people, the short people sat more often with both feet on the floor. In research about home furniture, Teraoka et al. (1994) also found differences between tall and short people: in comparison with tall people, short people had less foot contact with the floor, or less contact with the backrest in combination with a slumped posture. Ciaccia and Sznelwar (2012) concluded that the participants in their study adopted very similar postures for both reading and resting in order to avoid discomfort, despite having different anthropometric characteristics. However, this was based on an observational study with only five participants (Ciaccia and Sznelwar 2012). In a driving simulation experiment, Park et al. (2013) found a relationship between upper-body posture and gender; most of the female drivers preferred a slouched or erect posture, while most of the male drivers preferred a slouched or reclined posture. In a study on car driver seats, Kyung and Nussbaum

(2013) found that older drivers preferred a higher and more upright driving posture (SUV seat configuration), while younger drivers preferred a more reclined posture (sedan seat configuration).

In summary, five studies reported that different body postures were associated with anthropometric characteristics (stature, gender and age). No studies were found in which correlations were reported between anthropometry and movement.

Effects of anthropometry on interface pressure

Six studies reported a correlation between anthropometry and pressure. Different variables of pressure were studied, such as contact area, sitting force, mean pressure, peak pressure, pressure factor (the combination of peak and mean pressure), and pressure gradient. Anthropometric variables were stature, weight, gender, age, BMI, RPI, percentage of subcutaneous fat, and ectomorphic index. Below, the correlations are described for each pressure variable. Table 2.1 gives an overview of these correlations.

Six studies found effects of anthropometric variables on contact area. For vehicle occupant seats, Paul et al. (2012) found a correlation between weight and contact area on the seat pan (r ranges from r=0.432 to r=0.845), and between weight and contact area on the backrest (r=0.432 to r=0.741) for different car seats. Differences between car seats were explained by different body postures. According to Paul et al. (2012), body mass and hip circumference were the best anthropometric indicators for the seat pan contact area. Kyung and Nussbaum (2008) also found effects of stature on pressure variables related to the contact area in the driver's seat of cars. The contact area at the right thigh (because of the asymmetric driving posture) and that at the upper back were significantly larger for taller persons. Vos et al. (2006) found correlations between several anthropometric variables and the seat pan contact area in office chairs: BMI and contact area (r=0.62), weight and contact area (r=0.61), RPI and contact area (r=0.50) and stature and contact area (r=0.48). According to Moes (2007), who studied pressure in upright sitting without back support, there is also a correlation between the percentage of subcutaneous fat and the contact area of the seat pan. Vincent et al. (2012) found that the contact area in different seat regions (e.g. front half of the seat pan) could be predicted relatively well on the basis of cushion hardness and hip width, gender, weight and stature. When comparing older and younger drivers, Kyung and Nussbaum (2013) found that the average contact area at the right buttock was larger for the older drivers, which were explained by different driving postures. To summarize, the highest

Table 2.1 *Overview of studies in which some measures for anthropometry and some pressure variables were obtained. The conclusions regarding the relationships between these variables are described in the last column.*

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Vos et al. 2006	BMI (kg/m^2)	Contact area (active cell count)	r=.62	N=24 (12 males; 12 females) participants compared 12 different office chairs	Moderate significant correlations were observed between active cell counts and BMI, mass, RPI and stature.
	Mass	Contact area (active cell count)	r=.61		
	RPI (kg/m^3)	Contact area (active cell count)	r=.50		
	Stature	Contact area (active cell count)	r=.48		
	Mass	Pressure factor	r=.42		Pressure factor (combination of peak and average pressure) was moderately correlated with mass and stature, with weak but significant correlations observed for BMI and RPI.
	Stature	Pressure factor	r=.38		
	BMI (kg/m^2)	Pressure factor	r=.33		
	RPI (kg/m^3)	Pressure factor	r=-.21		
	Gender	Pressure factor	?		Females experienced lower pressure factor values than males.
Hostens et al. 2001	BMI	Mean pressure	R^2=.8881	4 foam and 1 air-based agricultural machinery seats N=10 males 4x2 min. sitting per seat with 2–min. breaks, with feet hanging free	Almost linear relationship between mean pressure and BMI.
		Peak pressure	No significant correlations		No significant correlation of BMI with peak pressure.

(Table continued on next page)

Table 2.1 *(continued)*

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Jackson et al. 2009	BMI	Peak pressure	No significant correlations	5 different glider seat cushions N=35 (15+20) male glider pilots <1.85m 1.5 h simulated flight	No significant correlations found between BMI, stature, mass and mean peak pressure.
	Stature				
	Mass				
Kyung and Nussbaum 2008	Body stature (short/medium/ tall)	Average contact area right buttock	Tall group had larger contact area at right thigh	Car driver's seats N=27 (12 male; 15 female) 6 driving sessions, 15-20 min each 2x2x2 design (seat x vehicle class x driving venue)	Significant (p<.046) stature effects were found only on the three pressure variables that were related to average contact areas and ratio.
		Average contact area upper back	Tall group has larger contact area at upper back		
		Average contact area ratio (upper back/sum)	Tall group had larger contact area ratios at upper back		
Paul et al. 2012	Body mass	Total contact area seat	Significant correlations for 3 cars; range r=.413-.856	N= 64 participants were randomly assigned to 1 of 3 vehicles for pressure measurements	Body mass and hip circumference were the best indicators for cushion contact area and for cushion front and rear force. Body mass and shoulder breadth were the best indicators for seat back contact area and upper seat back contact area.
		Total contact area rear cushion	Significant correlations for 3 cars; range r=.432-.741		
		Total force rear cushion	Significant correlations for 3 cars; range r=.452-.605		
		Total force front cushion	Significant correlations for 3 cars; range r=.589-.666		
		Total contact area seat back	Significant correlations for 3 cars; range r=.611-.895		
		Total contact area lower seat back	Significant correlations for 2 cars; range r=.568-.832		
		Total contact area upper seat back	Significant correlations for 3 cars; range r=.440-.688		

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Paul et al. 2012 *(continued)*	Hip circumference	Total contact area seat	Significant correlations for 3 cars; range r=.494-.866	N= 64 participants were randomly assigned to 1 of 3 vehicles for pressure measurements	Body mass and hip circumference were the best indicators for cushion contact area and for cushion front and rear force. Body mass and shoulder breadth were the best indicators for seat back contact area and upper seat back contact area.
		Total contact area rear cushion	Significant correlations for 3 cars; range r=.546-.592		
		Total force rear cushion	Significant correlations for 2 cars; range r=.479-.501		
		Total force front cushion	Significant correlations for 3 cars; range r=.446-.694		
	Hip breadth	Total contact area seat	Significant correlations for 2 cars; range r=.734-.847		
		Total contact area rear cushion	Significant correlations for 2 cars; range r=.638-.640		
		Total force rear cushion	Significant correlations for 2 cars; range r=.452-.467		
		Total force front cushion	Significant correlations for 3 cars; range r=.477-.580		
	Sitting knee height	Total contact area seat	Significant correlations for 1 car; r=.498		
		Total contact area rear cushion	Significant correlations for 2 cars; range r=.406-.463		
		Total force rear cushion	No significant correlations		
		Total force front cushion	Significant correlations for 1 car: r=.481		

(Table continued on next page)

Table 2.1 *(continued)*

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Paul et al. 2012 *(continued)*	Buttock-knee length	Total contact area seat	Significant correlations for 2 cars; range r=.399-.533 Significant correlations for 1 car: r=.452	N= 64 participants were randomly assigned to 1 of 3 vehicles for pressure measurements	Body mass and hip circumference were the best indicators for cushion contact area and for cushion front and rear force. Body mass and shoulder breadth were the best indicators for seat back contact area and upper seat back contact area.
		Total force rear cushion	Significant correlations for 1 car: r=.432		
		Total force front cushion	Significant correlations for 1 car: r=.408		
	Sitting height	Total contact area seat back	No significant correlations		
		Total contact area lower seat back	Significant correlations for 1 car: r=.396		
		Total contact area upper seat back	No significant correlations		
	Shoulder breadth	Total contact area seat back	Significant correlations for 3 cars; range r=.536-.806		
		Total contact area lower seat back	Significant correlations for 2 cars; range r=.598-.749		
		Total contact area upper seat back	Significant correlations for 3 cars; range r=.365-.621		
	Sitting shoulder height	Total contact area seat back	Significant correlations for 1 car: r=.552		
		Total contact area lower seat back	Significant correlations for 1 car: r=.514		
		Total contact area upper seat back	Significant correlations for 3 cars in the range r=.424		

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Moes 2007	Somatotype, subcutaneous fat, stature, body mass, thigh depth at level buttock fold, distance between SIPS (breadth)	Transverse pressure gradient (discerns between medial and lateral components)	Transverse pressure gradient is predicted by ectomorphic index and stature (mult. r=.80)	N=20 Laboratory flat measuring seat without back support. The influence of pelvic rotation and anthropometric variables on pressure variables was analysed through multiple regression analysis.	Influence of somatotype on max. pressure was found, as well as stature on pressure gradient. Ectomorphy rating explains transverse pressure gradient and max. pressure; ectomorphy rating and stature explain circular pressure gradient. Several pressure variables can be predicted by different anthropometric variables or a combination thereof. It is remarkable that average pressure is predicted only by gender. This implies that average pressure is mainly dependent on gender.
		Maximum pressure	Maximum pressure predicted by ectomorphic index (mult. r=.73)		
		Circular pressure gradient	Circular pressure gradient predicted by the ectomorphic index and stature (mult. r=.90)		
		Size of contact area	Distance between SIPS and subcutaneous fat (mult. r=.81)		
		Sitting force	Sitting force predicted only by mass (r=.91)		
		Average pressure	Average pressure predicted only by gender (mult. r=.75)		

(Table continued on next page)

Table 2.1 *(continued)*

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Gyi and Porter 1999	Gender, hip breadth, weight, RPI	Mean pressure for different areas	Hip breadth and gender were selected as best predictors of mean pressure under IT in multiple regressions (mult r not reported). Buttock discomfort, sitting height and hip breadth explained 99% (mult r=.99) of the variance in mean IT area pressure. The highest average IT pressures were found for tall and thin males (with highest RPI). Positive correlations were found between weight and thigh pressure.	Experiment 1: N=14 participants (representing a wide range of statures) sat on their most preferred and least preferred car seat (out of 7 seats) for a 2.5–hour static drive Experiment 2: N=12 participants (representing a wide range of statures) sat on the most overall preferred seat from experiment 1 for a 2.5–hour static drive	Gender and hip breadth are the best predictors of mean IT pressure; thinner subjects (lower RPI) had higher IT pressures.
		Average seat ratio (ratio between seat mean and back mean)			No associations reported
		Maximum pressure for different areas			No associations reported
		Standard deviation of the mean pressure for different areas			No associations reported
		Pressure area for different areas			No associations reported
Park et al. 2013	Gender	Seating pressure ratio (in %) of 17 body parts (9 for seat back and 8 for seat pan pressure)	No significant effect	N=40 (20 male, 20 female) car drivers in driving simulation experiment	No significant correlations between gender and seating pressure

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Kyung and Nussbaum 2013	Age	Mean contact area and ratio (local measure relative to sum) for 6 body parts: left/right thigh, left/right buttock, lower/upper back	Older drivers had a 12.9% higher value for mean contact area at the right buttock Younger drivers had a 7.3% higher value for contact area ratio at left thigh	N=22 car drivers, divided into 2 age groups: older (≥60 years, N=11) and younger (20-35 years, N=11)(6 male, 5 female per group) 6 driving sessions: combination of vehicle class (SUV/sedan), driving venue (lab/field), and seat (high/low comfort score)	A significant effect of age was found for 4 of 36 pressure measures; different loadings were due to postural differences between older and younger drivers
		Mean contact pressure and ratio (local measure relative to sum) for 6 body parts	Younger drivers had a 30.8% higher value for mean contact pressure at lower back		
		Mean peak pressure and ratio (local measure relative to sum) for 6 body parts	Younger drivers had a 13.9% higher value for peak pressure ratio at upper back		

correlation coefficients were found, in more than one study, for body mass with contact area, followed by stature with contact area. Furthermore, correlations were found for hip breadth, hip circumference, BMI and percentage of subcutaneous fat with contact area.

Three studies investigated effects of anthropometric variables on mean pressure (Hostens et al. 2001; Gyi and Porter 1999; Vincent et al. 2012). For agricultural machinery, Hostens et al. (2001) found a linear increase in mean pressure with BMI (r=0.88) for sitting on seats with the feet unsupported. Gyi and Porter (1999) studied the correlation between anthropometry and pressure variables while driving a car. They found that the highest average pressure was in thin and tall males (with highest RPI), and found a positive correlation between weight and thigh pressure (no correlation coefficients reported). Furthermore, hip breadth was one of the independent variables that explains mean pressure in a multiple regression (Gyi and Porter 1999). Vincent et al. (2012) found that weight, stature and buttock-popliteal length were the best predictors of average pressures. Additionally, Moes (2007) found that gender was the best predictor of average pressure (mult. r=0.75), with the average pressure being lower for females than for males, and explains this by the lower mass in combination with a larger contact area for women. Lower mass, in turn, is correlated with a lower sitting force (Moes 2007; Paul et al. 2012). Furthermore, Kyung and Nussbaum (2013) found that the average contact pressure at the lower back was higher for younger drivers compared to older drivers.

The effect of anthropometric variables on peak or maximum pressure was described in four studies (Hostens et al. 2001; Jackson et al. 2009; Moes 2007; Vincent et al. 2012). Hostens et al. (2001) found no correlation between BMI and maximum pressure. The same result was obtained by Jackson et al. (2009), who studied the effects of anthropometric variables on peak pressure of glider pilot seats. They did not find a relationship between weight, stature or BMI and peak pressure. This can be explained by the small variation in anthropometrics of the subjects, all of whom were UK glider pilots (Jackston et al. 2009). Moes (2007) found that the ectomorphic index (which is one of the indexes of the somatotype classification) was the only explaining variable of maximum pressure (mult. r=0.73). In the prediction of maximum pressures, Vincent et al. (2012) found that weight, stature and buttock-popliteal length were the best predictors. In addition, Kyung and Nussbaum (2013) found significant effects of age on average peak pressure ratio at the upper back, which was higher for younger drivers.

A number of studies included less common pressure variables, such as circular pressure gradient, transverse pressure gradient (Moes 2007) and pressure factor (a combination of pressure variables, derived from a principle compound analysis) (Vos et al. 2006). Moes (2007) found that the ectomorphic index and stature were the explaining variables for the transverse pressure gradient (mult. r=0.90) and that the ectomorphic index was the only explaining variable for the circular pressure gradient (mult. r=0.80). Vos et al. (2006) found correlations between BMI and pressure factor (r=0.31), weight and pressure factor (r=0.44), and stature and pressure factor (r=0.38). Park et al. (2013) did not find significant effects of car driver's gender on pressure distribution of upper-body parts (i.e. back and lumbar).

In conclusion, several studies report correlations between anthropometric variables and different variables of pressure. Age was found to influence posture and therefore pressure distribution. Contact area, average pressure and peak pressure are the most common pressure variables studied. A larger contact area can be explained by greater weight and greater stature. A higher average pressure can be explained by a greater weight. However, gender affects this relationship as the contact area for women is larger (due to larger hip breadth). Besides weight and stature, buttock-popliteal length was found to be a predictor of average and maximum pressures. Peak pressure is best explained by the score on the ectomorphic index of the somatotype classification.

2.3.1.2 Seat characteristics and their influence on interaction variables

Seat characteristics can be divided into seat dimensions, shape of the seat and material of the seat cushions. Their associations with the interaction variables are described below.

Effects of seat characteristics on posture and movement

Various seat characteristics can affect body posture and movement whilst sitting. Of course, the angles of the backrest and the seat pan determine the overall body posture, such as the trunk–upper leg angle. However, some seat characteristics have a more subtle effect.

Telfer et al. (2009) used an activity monitor to measure the movements of 12 participants who were sitting on four different seats. Although they found a significant difference between the four seats for postural changes, it remained unclear which of the seat characteristics were responsible for these differences as the seats differed in dimensions, as well as in materials and shape.

The effect of seat shape on body posture was studied by Noro et al. (2012). In their study on surgical seats, they found that the seat shape following the contour of the buttock and providing sacral support led to more pelvic tilt compared to a seat without sacral support. Park et al. (2013) observed that the sitting strategy adopted for lower-body was influenced by car driver's seat height (determined by occupant package layout). The posture with knees bent predominantly occurred in the SUV condition, but hardly occurred in the coupe condition, whereas the posture with the knee extended hardly occurred in the SUV condition, but did appear in the coupe and sedan conditions. In a study on supporting the use of a tablet device, Van Veen et al. (2014) showed that the neck flexion angle of passengers could be significantly reduced when using specially designed armrests, thereby increasing the ratings for overall comfort, and comfort ratings for the neck region specifically.

Van Deursen et al. (2000) developed a special seat that induced passive motion of the spine whilst sitting. This special seat feature caused passive movements of the body that lengthened the spine in order to reduce discomfort in sitting.

These studies show that seat characteristics affect body posture and movement. As all seats will cause discomfort over time, it is important that the seat should provide the possibility to adopt different body postures in order to reduce discomfort (Van Rosmalen et al. 2009).

Effects of seat characteristics on interface pressure

Eight out of nine studies discovered associations between seat dimensions or seat shape and interface pressure. No studies were found that reported a correlation between the material of the seat cushions and interface pressure.

Five studies reported associations between seat dimensions and interface pressure. Kyung and Nussbaum (2008) found significant effects of different seats on pressure variables, such as average pressure on buttock and thigh, peak pressure on buttock and thigh, and contact area on buttock and thigh. This may be due to the different dimensions of the tested seats, but may also be caused by different shapes and cushion materials. According to Reed et al. (2000), cushion length is an important determinant of thigh support. A cushion that is too long can put pressure on the posterior portion of the occupant's legs near the knee. Pressure in this area will lead to local discomfort and restrict blood flow to the legs. This is supported by Mergl (2006), who defined the ideal pressure distribution for car driver's seats. He showed that comfort is rated high when there is an ideal pressure distribution under the legs and buttocks, namely 24.5-28.5% of the total load for both left and right buttock, less than 14% of the total load for the thighs and less than 3% of the total load for the front of the thighs. The shape of the seat pan can contribute to this ideal pressure distribution. Additionally, Hostens et al. (2001) found that a smaller backrest inclination angle leads to higher sub-maximum pressures on the seat pan and smaller sub-maximum pressures on the backrest. However, Park et al. (2013) did not find significant effects of car driver's seat height (determined by occupant package layout) on pressure distribution of lower-body parts (i.e. buttock and thighs).

Another four studies reported associations between the shape of the seat and interface pressure. According to Chen et al. (2007), different shapes of cushions lead to different pressure distributions. Carcone and Keir (2007) studied the effects of anthropometry (individual size and stature) on backrest preference, but found no significant effects. 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 shape and stiffness of the foam. Noro et al. (2012) found a larger contact area and lower average pressure for a prototype of surgical seat that followed the buttock–sacral contour of the human body compared to a conventional surgical seat.

Although none of the studies calculated correlations between seat characteristics and interface pressure, the results do show associations between seat dimensions, seat shape, seat material and interface pressure; however, the exact relationships are unclear.

2.3.1.3 Context characteristics and their influence on interaction variables

The context characteristic in our research was the activity that passengers perform and its effect on body posture, movement and interface pressure. These associations are described in this section.

Effect of performed activities on posture and movement

Different sitting postures are associated with different tasks and activities. An overview of the relationships between tasks and activities and the corresponding postures and/or posture shifts is presented in Table 2.2. According to three studies, in which activities and tasks performed in offices, in semi-public situations and on trains were observed (Ellegast et al. 2012; Kamp et al. 2011; Groenesteijn et al. 2014), different activities or tasks have related sitting postures that are significantly

Table 2.2 *Overview of studies found in which people performed different activities and some observations or measures of sitting body posture were obtained. The conclusions regarding the relationships between these variables are described in the last column.*

Reference	Activity variables	Posture variables	Study design	Conclusions
Kamp et al. 2011	Sleeping	Head, trunk, arms, legs	Momentary observations N=743 on trains and in semi-public situations	Significantly different posture of head against headrest; trunk slumped and arms upon armrest and uncrossed feet
	Relaxing			Significantly different posture of head against headrest or supported by hands; trunk slumped and arms upon armrest
	Watching			Significantly different posture of head unsupported; trunk free or against backrest and arms free from armrest
	Reading			Significantly different posture of trunk against backrest and arms free from armrest
	Talking			Significantly different posture of head free of support and arms free from armrest
	Using small electronic devices			Significantly different posture of head free or against backrest and arms free from armrest
	Eating/drinking			Significantly different posture of head unsupported; trunk free from backrest or slumped
	Working; using larger electronic devices			Significantly different posture of head unsupported and trunk free or against backrest
Graf et al. 1995	Computer programming vs. general office work	Variation in postures	Postures at 5 workplaces	Computer programming workers have less variability in postures in comparison to general office workers

Reference	Activity variables	Posture variables	Study design	Conclusions
Lueder 2004	Use of screen and input devices	Sitting postures	Office chairs ergonomic review study	Visual demands of the task and the reach distance can play a role in leaning forward
Ellegast et al. 2012	7 standardized office tasks	Postures/joint angles	Office chairs N=10	Many significant effects of performed tasks on postures and joint angles
Groenesteijn et al. 2014	Staring/sleeping	Body part positions of head, trunk and seat contact and comfort score in relation to activity on 10–point scale	Top 4 of most observed activities during momentary observations N=786 and journey observations N=30 on trains	Tendency highest comfort score with posture: head straight up, trunk straight and up and full seat contact
	Reading			Tendency highest comfort score with posture: head straight up, trunk backwards and full seat contact
	Talking			Tendency highest comfort score with posture: head sideward, trunk backwards and full seat contact
	Working			Tendency highest comfort score with posture: head forward, trunk straight and up and full seat contact
Babski-Reeves et al. 2005	Standard data entry (typing task)	Posture shifts	Office work station N=8	Significantly larger number of neck posture shifts with data entry task compared to math task
	Simple math calculations			Significantly larger number of feet posture shifts with math task compared to data entry task
	Task repetition (*set of times each task was completed within each session)*			Significant increase in posture shifts across task repetitions

(Table continued on next page)

Table 2.2 *(continued)*

Reference	Activity variables	Posture variables	Study design	Conclusions
Groenesteijn et al. 2012	Computer work	Postures/joint angles, physical activity of body parts	Office chairs field study; N=12	Lowest physical activity in all body parts, together with upright trunk, upright head position and low backrest inclination
	Telephoning			Medium physical activity and the highest kyphosis
	Conversation			Highest activity of head and legs, and the highest cervical spine extension
	Desk work			The second lowest activity; most cervical spine flexion

different from each other. Additionally, there is a tendency for typical activity-related postures to be chosen in relation to the perceived comfort (Groenesteijn et al. 2012) and due to the task demands (Lueder 2004). Temporal variations like posture shifts or movements also depend on the task or activity performed as reflected in the significant differences between tasks and activities (Graf et al. 1995; Babski-Reeves et al. 2005; Commissaris and Reijneveld 2005; Groenesteijn et al. 2012). Hence, tasks or activities determine both postures and posture shifts.

Several studies investigated which postures are seen in public transport regarding the tasks people perform in that situation. Kamp et al. (2011) studied the interaction between body postures and activities in semi-public situations and during a train journey. They found a significant relationship between most activities and the position of the head, trunk and arms during transport: in low-level activities (sleeping, relaxing, watching), the head was supported in 49% of the observed situations, whereas in medium-level activities (reading, talking, eating/drinking) and high activity levels (using small or larger electronic devices), this was only in 39% and 36% of the observed situations, respectively. The trunk position varied mostly in the low-level activities (free of support, against backrest or lounging); however, in the medium-level and high-level activities, it was mostly straight against the backrest. Except for just the elbow on the armrest, which was not observed in low-level activities, differences in using the armrest were less clear between the activity levels.

Groenesteijn et al. (2014) found that the posture with the highest comfort ratings was a slumped posture, with the head against the headrest. This posture was observed in all activities: reading, staring/sleeping, talking and working on a laptop. The next most common posture was straight up, with the back against the backrest and the head against the headrest (observed in reading, staring/sleeping and working on a laptop). For reading and working on a laptop, the same position for the back was observed in combination with a bent neck (Groenesteijn et al. 2014). For watching television (comparable to watching in-flight entertainment), it has been shown that a more backward rotated backrest is preferable (Van Rosmalen et al. 2009). Additionally, if we follow the approach of Goossens and Snijders (1995) that shear forces should be prevented, a tilted seat with the front of the seat upwards is a consequence of this posture. Gscheidle et al. (2004) describe a variation in observed backrest angles of between 20 and 40 degrees backwards for one task (office work), while Park et al. (2000) describe a variation of between 103 and 131 degrees in observed trunk–thigh angle of Koreans while driving a car.

It can be concluded from these studies that the task or activity that people perform affects their posture. However, due to the nature of the measurements (often observational studies), no quantitative relationships can be described.

Effect of performed activities on interface pressure

No studies were found that describe the direct association between performed activities and interface pressure. Earlier it was concluded that posture is dependent on the task or activity, and that posture is associated with interface pressure. This is probably why no studies were found that described a relationship between activities and interface pressure directly.

2.3.2 INTERDEPENDENCIES OF THE INTERACTION VARIABLES

The interaction variables posture, movement and interface pressure, and their influence on each other are described in this section.

2.3.2.1 Interdependencies between interface pressure and posture

Nine studies measured the relationship between posture and interface pressure. Vos et al. (2006) studied the effect of personal factors, posture and seat design on interface pressure in ergonomic office chairs. They found that an increased trunk–thigh angle reduced the pressure factor values (i.e. a combination of peak pressure and average pressure). Moes (2007) found that pelvis rotation affects the contact area and the average pressure in upright sitting without a backrest. The relationship between pelvis rotation and contact area is affected by anthropometric characteristics, such as subcutaneous fat and endomorphic index (Moes 2007).

Tessendorf et al. (2009) employed pressure distribution patterns acquired from a pressure mat to generate 16 prototype sitting postures which they then used to classify incoming pressure data. In this way, the sitting posture could be predicted in real time from pressure data. The classification performance was studied and, on average, the assignment of a posture to a prototype sitting posture was achieved in 91% of the cases. In 86% of the cases, an unambiguous assignment of a posture to a prototype sitting posture was achieved (Tessendorf et al. 2009). Likewise, Xu et al. (2012) developed a method to recognize nine different seating postures on the basis of binary pressure distribution data. They achieved an accuracy of 82.3% by using 64 pressure sensors (6*8 sensors for the seat pan and 2*8 sensors for the backrest) with a threshold of 3 N.

Zhiping and Jian (2011) studied three sitting postures induced by three inclination angles of the backrest of an office seat. They found significant effects of different postures on six pressure variables (average seat pan pressure, peak seat pan pressure, average backrest pressure, peak backrest pressure, back contact area and back load). In a study by Oyama et al. (2003), an upright sitting posture was compared to a reclined sitting posture for a 20–minute typing task. They also found significant differences for the mean seat pan pressure (which was lower in the reclining group) and mean backrest pressure (which was higher in the reclining group), and showed that there is a relationship between the pelvic angle and the seat pressure pattern. In a study by Kyung and Nussbaum (2013), postural differences in car driver seats also led to differences in pressure measures. For example, peak pressure ratio at the upper back was higher in a SUV seat configuration, indicating that a more upright posture provided more support for the upper back than a more reclined posture (sedan seat configuration). This seems to be in contrast with Chen et al. (2013), who found that increasing the back rest angle increases pressure values at the back rest and reduces pressure values of the seat pan due to the shifting of body weight (centre of gravity) towards the back rest. On the other hand, Park et al. (2013) analysed the relative pressure ratio of 17 body parts, and found no relationship between driving posture and seating pressure.

These studies show that interface pressure is correlated with body posture. However, effect sizes were not reported in any of the studies.

2.3.2.2 Interdependencies between interface pressure and movement

Change in interface pressure is also used as an indicator of change in body posture, namely movement. Wang et al. (2011) studied the effect of movements on pressure variables in car seats. The aim of their study was to distinguish between movements that drivers make in order to drive a car and those that they make to reduce discomfort over time. Their study proved that the seat pressure variables are sensitive to driving movements. Ciaccia and Sznelwar (2012) studied the postures and interface pressure of two activities (resting and reading) in an aeroplane in only five subjects. The combination of a pressure map and its corresponding posture (the postures had been visually recorded) gave an insight into the alterations of body postures over time for each activity. The study by Ciaccia and Sznelwar (2012) presents only qualitative observations, but the study by Na et al. (2005) provides the scientific support. The latter used body pressure change variables – which count the number of large changes in body pressure – as indicators of movement. They found that, when the driving period increased, the body pressure change variables increased along with the ratings of discomfort.

It can be concluded from these studies that interface pressure can be an indication of alterations of body postures and thus of movement.

2.3.3 Effects of interaction variables on comfort and discomfort

This section describes the influence of the interaction variables posture, movement and interface pressure on passengers' perception of comfort and discomfort.

Effects of posture and movement on comfort and discomfort

Six studies indicated that the human body seems to compensate for discomfort by changing body posture or making postural movements. Body pressure change variables and subjective discomfort ratings were found to increase when the driving period increased. This implies that the driver tends to move more frequently when he feels discomfort (Na et al. 2005). Similarly, when measuring pressure distribution of two automotive seats, Le et al. (2014) noticed that discomfort led to movement. For glider pilots, Jackson (2009) found that, after about 40 minutes, pilots began to make large fidgeting movements to relieve buttock pressure. In another study by Sember (1994), it was found that it took at least 30 minutes for discomfort to become sufficient for a behavioural response to occur. Movements are therefore also used as an indication of discomfort. Telfer et al. (2009) concluded that postural movement explained 29.7% of the variance in discomfort, and Søndergaard et al. (2010) reported that the standard deviation of the movement of the centre of pressure is correlated to discomfort.

On the other hand, movements could also be used to prevent discomfort over time and to create comfort. Both active and passive motion during sitting have been shown to have a positive effect on comfort and to decrease discomfort (Hiemstra-van Mastrigt et al. 2015; Van Dieën et al. 2001; Van Deursen et al. 2000; Franz et al. 2012). Discomfort in sitting occurs due to prolonged and monotonous low-level mechanical load imposed by a seated posture (Van Dieën et al. 2001). Several studies have shown that passive motion has positive effects on preventing discomfort in office seats (Van Deursen et al. 2000) and driver's seats (Reinecke et al. 1994). Franz et al. (2012) showed that comfort was higher and the muscle activity of the trapezius area was significantly lower when driving with a massage system. Other studies focused on active dynamic sitting in office chairs (Van Dieën et al. 2001) and the rear seat of a car (Hiemstra-van Mastrigt et al. 2015). For example, car passengers felt more refreshed, more challenged and more fit after a drive if they had played a video game during the drive that requires players to move their upper bodies (Hiemstra-van Mastrigt et al. 2015). Further, several studies show the importance of alternating seated postures (e.g. Lueder 2004; Nordin 2004). Van Rosmalen et al. (2009) showed that a seat supporting a variety of postures when watching television is experienced as comfortable.

Hence, the relationship between movement and comfort and discomfort is twofold. On the one hand, several studies show that micro–movements and fidgeting are an appropriate measure for discomfort, even before the person is aware of discomfort. On the other hand, active seating can reduce discomfort and improve comfort.

Effect of interface pressure on comfort and discomfort

An overview of studies on the correlation between interface pressure and comfort and discomfort is presented in Table 2.3. Different variables were used to indicate the interface pressure on seat pan and backrest, such as contact area, average pressure, peak pressure, pressure gradient and pressure change. Furthermore, six studies divided the interface area into different parts, for instance, front thigh, middle thigh and buttocks (Porter et al. 2003; Mergl 2006; Na et al. 2005; Gyi and Porter 1999; Noro et al. 2012; Kyung and Nussbaum 2008). The effects on comfort and discomfort were measured by different methods, such as discomfort and/or comfort ratings per body region, the number of discomfort-induced fidgeting movements, and ranking between seats on comfort. The correlations found in the studies between interface pressure variables and comfort and discomfort are described below.

For *seat pan comfort*, Carcone and Keir (2007) found a tendency for larger contact areas to be associated with a higher ranking on comfort. For average and peak pressure, no significant relationship with comfort in lumbar, hip and thigh regions was found in interaction with car seats (Porter et al. 2003). For seat pan discomfort, Noro et al. (2012) showed that lower average pressure is accompanied by less discomfort. Body pressure change variables increase along with whole body discomfort and local body part discomfort (including lumbar, hip and thigh) (Na et al. 2005). For glider pilots, Jackson et al. (2009) determined a mean peak pressure threshold of 8.8 kPa: below this pressure, no discomfort will occur. According to Chen et al. (2007), pressure should be highest underneath the central sitting bones (ischial tuberosity) and should dissipate towards the thighs and sides. Mergl (2006) found that the shape of the relationship between mean pressure and seat pan discomfort differs for different areas of the buttocks and upper legs. He found a quadratic relationship between the mean pressure and discomfort for the buttocks, and a linear relationship for the middle thigh and frontal thigh. The quadratic relationship implies that when the mean pressure under the buttocks is either too low or too high, discomfort occurs. This means that an optimum of mean pressure values for the buttocks does exist. For the middle and the front thigh, the relationship is linear, which means that when the mean pressure increases, the discomfort perception increases. Significant correlations between pressure and subjective ratings for car driver seats were reported by Kyung and Nussbaum (2013) for 22 of 36 pressure measures; the largest positive correlation (ρ=.31) was found between the contact pressure at the right buttock and discomfort ratings.

For *backrest comfort*, Carcone and Keir (2007) found a tendency for the mean contact area of the backrest and average backrest pressure to be lowest for backrests that were preferred. Contrarily, Porter et al. (2003) reported no significant relation for average pressure and comfort in the backrest area for car seats. Furthermore, they found no relationship between peak pressure and comfort in lumbar, hip and thigh regions. For *lower back discomfort*, Zhiping and Jian (2011) found a significant positive correlation with contact area of the backrest (high discomfort with large contact area), as well as a marginally positive correlation with backrest peak pressure load (high discomfort with high pressure). In addition, Mergl (2006) points out that the pressure distribution on the back side of the seat pan had an influence on perceived discomfort in the lower back. He found that the material under the ischial tuberosity should be harder in order to prevent discomfort in the lower back.

For *neck and head pressure*, Franz et al. (2012) showed that the preferred pressure on the neck is much lower than that on the back of the head. However, the positions of the back of the head with respect to the shoulders vary greatly between people, which makes a proper design of a neck/head rest even more complex.

In their literature review, De Looze et al. (2003) concluded that pressure distribution appears to be the objective measure with the clearest association with subjective ratings of comfort and discomfort compared to other measures (such as measurements of body movements, estimations of muscle activation and muscle fatigue by electromyography, and measurements of stature loss (spinal shrinkage) and foot/leg volume changes). Of the seven studies found by De Looze et al. (2003), three reported significant correlations between pressure and comfort or discomfort, and two reported associations. Vincent et al. (2012) measured pressure distribution of four different cushions in an office armchair while subjects obtained automotive driving postures. They found significant but weak (correlation coefficients between 0.1 and 0.38) negative correlations between pressure and overall seat comfort

Table 2.3 *Overview of studies in which some measures of pressure and measures of comfort and discomfort were obtained. The conclusions regarding the relationships between these variables are described in the last column.*

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Mergl 2006	Percentage of load of buttocks, middle thighs, front thighs and side thighs	Discomfort measurements by body map of seat pan (regions 10-17) with a CP50 scale	*Buttock:* Quadratic relationship; ≥15% and ≤25% of subjects had a significant relationship *Middle of thigh*: Linear relationship; ≥50% of the subjects had a correlation coefficient r≥.81 *Front of thigh:* Linear relationship; ≥50% of the subjects had a correlation coefficient r≥.81 *Side of thighs:* Linear relationship; ≤15% of the subjects had a correlation coefficient r≥.81	N=10 Six different settings of automobile seats were evaluated on pressure variables and discomfort.	Depending on the body part region and the pressure variable, the relationship between interface pressure variables and body part discomfort can be either quadratic or linear. For some body parts (middle of thigh) and some pressure variables (percentage of load, mean pressure, maximum pressure) more evidence for a relationship was found than for others.
	Maximum pressure of buttocks, middle thighs, front thighs and side thighs	Discomfort measurements by body map of seat pan (regions 10-17) with a CP50 scale	*Buttock:* Linear relationship; ≥25% and ≤50% of the subjects had a correlation coefficient r≥.81 *Middle of thigh*: Linear relationship; ≥50% of the subjects had a correlation coefficient r≥.81 *Front of thigh*: Linear relationship; ≤15% of the subjects had a correlation coefficient r≥.81 *Side of thighs*: Linear relationship; ≤15% of the subjects had a correlation coefficient r≥0.81		

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Table 2.3 *(continued)*

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Mergl 2006 *(continued)*	Mean pressure of buttocks, middle thighs, front thighs and side thighs	Discomfort measurements by body map of seat pan (regions 10-17) with a CP50 scale	*Buttocks*: Quadratic relationship; ≥25% and ≤50% of the subjects had a significant correlation *Middle of thigh*: Linear relationship; ≥50% of the subjects had a correlation coefficient r≥.81 *Front of thigh*: Linear relationship; ≥15% and ≤25% of subjects had a significant relationship *Side of thighs*: No relationship found	N=10 Six different settings of automobile seats were evaluated on pressure variables and discomfort.	Depending on the body part region and the pressure variable, the relationship between interface pressure variables and body part discomfort can be either quadratic or linear. For some body parts (middle of thigh) and some pressure variables (percentage of load, mean pressure, maximum pressure) more evidence for a relationship was found than for others.
	Pressure gradient of buttocks, middle thighs, front thighs and side thighs	Discomfort measurements by body map of seat pan (regions 10-17) with a CP50 scale	*Buttocks*: Linear relationship; ≥15% and ≤25% of subjects had a significant relationship *Middle of thigh*: Linear relationship; ≥25% and ≤50% of the subjects had a correlation coefficient r≥.81 *Front of thigh*: Linear relationship ≥15% and ≤25% of subjects had a correlation coefficient r≥.81		

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Carcone and Keir 2007	Mean peak backrest pressure	Comfort ranking of backrests	Lower peak backrest pressure was associated with higher ranked backrests	N=30 Participants were seated at a computer workstation in 5 backrest conditions: chair only, chair with backrest, chair with backrest with three different lumbar pad thicknesses.	No correlations calculated. Only qualitative associations were described of some pressure variables and ranking of backrests.
	Backrest contact area		Smaller backrest contact area was associated with higher ranked backrests		
	Seat pan contact area		Greater seat pan contact area was associated with higher ranked backrests		
Noro et al. 2012	Peak pressure and pressure area of 6 body parts: sacral area, ischial area, left and right lateral area of buttocks, left and right thigh	Senses of comfort of body parts on a 5–point scale of sacral, ischial and thigh body parts and other items, like sliding	No correlations between pressure variables and subjective measures available	N=11 participants sat on two different surgical seats during surgical operations: a conventional seat and a prototype of a new seat	The average pressure on the seat pan was lower for the preferred seat.

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Table 2.3 *(continued)*

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Na et al. 2005	Body pressure ratio (sum of body pressures per region divided by sum of body pressures of lumbar and buttocks region). Body pressure change variables (number of pressure changes exceeding 15 % of the average total pressure for the back and 5% of the seat pan) indicating the number of subject's movements.	Body part discomfort ratings of neck, shoulder, back, lumbar, hip and thigh on a 7-point scale	Body pressure change increased as the driving period increased. The same tendency was found in whole body part discomfort level. Furthermore, the same interaction effect was found of stature group and lumbar support for both body pressure change variables and body part discomfort.	N=16 subjects sat on a seat of a mid-size sedan in Korean automobile market in a seating buck, driving a simulated track course consisting of 15 laps of 3 mins per lap.	No correlations were calculated. A tendency for association was found between body pressure change and body part discomfort.

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Kyung and Nussbaum 2008	Average contact areas of different regions (upper back, lower back, right buttock, left buttock, right thigh, left thigh) and ratios of a specific region divided by the total contact area	Overall ratings of comfort and discomfort on VAS scale with discomfort and comfort as extremes; separate whole body comfort and 6 local body parts (left/right thighs, left/right buttocks, upper/lower back) and discomfort rating of the 6 local body parts on a scale ranging from 0 to 10 for comfort and from 0 to -10 for discomfort.	*Overall comfort and discomfort rating:* Significant correlations were found between the average contact area ratio of the right thigh with the overall comfort and discomfort rating (r=.16). *Whole body comfort rating:* Significant correlations were found between average contact area of the left thigh with whole body comfort rating (r=-.20), for the ratio of the left thigh and the whole body comfort rating (r=-.20). *Whole body discomfort rating:* No correlations were found	N=27 participants completed 6 short (25–20 mins) driving sessions.	Correlations were found between several pressure variables and ratios and overall comfort and discomfort rating and with whole body comfort rating. No correlations were found between pressure variables and local body part discomfort rating.

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Table 2.3 *(continued)*

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Kyung and Nussbaum 2008 *(continued)*	Average contact pressures of different regions (upper back, lower back, right buttock, left buttock, right thigh, left thigh) and ratios of the average contact pressure of a specific region divided by the average contact pressure of the total area	Overall ratings of comfort and discomfort on VAS scale with discomfort and comfort as extremes; separate whole body comfort and 6 local body parts (left/right thighs, left/right buttocks, upper/ lower back) and discomfort rating of the 6 local body parts on a scale ranging from 0 to 10 and 0 to -10 for comfort and discomfort respectively.	*Overall comfort and discomfort rating:* Significant correlations were found for the Buttock left (r=-30), buttock right (r=-.28) and for the ratio of the left buttock (r=-.23) and ratio of the right buttock (r=-.22), and the ratio of the lower back (r=.16) and the ratio of the upper back (r=.18). *Whole body comfort rating:* Significant correlations were found for the left thigh (r=-.18), right thigh (r=-.25), left buttock (r=-.20), right buttock (r=-.21) and upper back (r=-.19) and the ratio of the lower back (r=.28). *Whole body discomfort rating:* No correlations were found	N=27 participants completed 6 short (25–20 mins) driving sessions.	Correlations were found between several pressure variables and ratios and overall comfort and discomfort rating and with whole body comfort rating. No correlations were found between pressure variables and local body part discomfort rating.

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Kyung and Nussbaum 2008 (*continued*)	Average peak pressures of different regions (upper back, lower back, right buttock, left buttock, right thigh, left thigh) and ratios of a specific region divided by the peak pressure of the total area.		*Overall comfort and discomfort rating:* Significant correlations were for the right thigh (r=-0.18), left buttock (r=-0.41), right buttock (r=-0.29), upper back (r=-0.28), the ratio of the left thigh (r=0.19), ratio of the left buttock (r=-0.19), ratio of the right buttock (r=-0.16).For the other regions, no correlations were found. *Whole body comfort rating:* Significant correlations were found for the right thigh (r=-0.16), left buttock (r=-0.24), right buttock (r=-0.17), upper back (r=-0.25), ratio of lower back (r=0.160)For the other regions no correlations were found. *Whole body discomfort rating:* No correlations were found		

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Table 2.3 *(continued)*

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Porter et al. 2003	Mean pressure of 6 regions: left and right ischial tuberosity, left and right thighs, upper back and lower back.	Seat feature checklist and body part comfort scale of buttocks, thighs and lower back on a 7–point scale (ranging from very comfortable to very uncomfortable)	Car A: *Right thigh* and thigh comfort rating r=.52 (average over 3 measurement moments) Car B: *Upper back* and upper back comfort rating r=.61 (after a 135–min drive) and r=.58 (average over 3 measurement moments). For the other cars and variables no significant correlations were found.	N=18 participants participated in road trials and drove in 3 cars for 2.5 hours. Measurements after 15 and 135 mins.	No clear relationship was found between interface pressure data and reported comfort/discomfort. Five out of the six significant Spearman rank order correlation coefficients were from one car.
	Maximum pressure of 6 regions: left and right ischial tuberosity, left and right thighs, upper back and lower back.		Car B: *Right thigh* and thigh comfort rating r= .57 (after 15 min drive) and r=.47 (average over 3 measurement moments) For the other cars and variables no significant correlations were found.		
Chen et al. 2007	Qualitative description of pressure distribution based on 3D pressure distribution images compared to the body pressure distribution rule	Subjective evaluation of 3 items: buttock comfort, thigh comfort, overall comfort on a 10–point scale (ranging from very uncomfortable to very comfortable)	When the pressure distribution is more like the body pressure distribution rule, the comfort score is higher.	N=20 participants sitting on three different shaped seat cushions	No correlations were calculated

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Zhiping and Jian 2011	Average seat pan pressure, peak seat pan pressure, seat pan contact area, average back rest pressure, peak backrest pressure, back contact area.	Body-part discomfort of neck, shoulder, back, low back, hip and thigh on a 5–point scale (ranging from very strong to no discomfort) and overall discomfort (2 points: comfort or discomfort)	Lower back discomfort was significantly correlated with back contact area (r=.297), with peak backrest pressure (r=.235), and with backrest load (.281).	N=10 participants sat on 2 office chairs with the backrest in 3 inclination positions (90°, 110° and 130°)	Backrest pressure variables were correlated with lower back discomfort, however correlation coefficients were low.
Søndergaard et al. 2010	Mean centre of pressure (COP) displacement (anterior-posterior; medial-lateral) over time	BPD index, i.e. sum of body part discomfort ratings on a 6–point scale ranging from 0 to 5 (no discomfort to worst imaginable discomfort)	No correlations between mean COP_{A-P} and COP_{M-L} with BPD	N=9 participants watched a movie whilst sitting on a force platform with no back- or foot support, no armrest and no cushions for 90 mins.	Correlations were found between centre of pressure displacement and discomfort, which indicates when discomfort increases, the sitting movement patterns became larger and more regular.
	Standard deviation of centre of pressure (COP) displacement (anterior-posterior; medial-lateral) over time		Standard deviation of COP_{A-P} is correlated with BPD (r=.273) Standard deviation of COP_{M-L} is correlated with BPD (r=.239)		

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Table 2.3 *(continued)*

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Søndergaard et al. 2010 *(continued)*	Sample entropy of centre of pressure (COP) displacement (anterior-posterior; medial-lateral) over time	BPD index (6–point scale)	Sample Entropy of $COP_{A\text{-}P}$ is correlated with BPD (r=-0.271) Sample Entropy of $COP_{M\text{-}L}$ is correlated with BPD (r=0.278)	N=9 participants watched a movie whilst sitting on a force platform with no back- or foot support, no armrest and no cushions for 90 mins.	Correlations were found between centre of pressure displacement and discomfort, which indicates when discomfort increases, the sitting movement patterns became larger and more regular.
Gyi and Porter 1999	Average seat ratio (ratio between seat mean and back mean)	Body part discomfort on 7–point scale ranging from very comfortable to very uncomfortable for the right buttock, right thigh and the lower back	The only correlation that was found in Experiment 1 was for female participants in their preferred seat: a negative correlation was reported between mean lower back pressure and lower back discomfort. No correlation coefficients were reported.	Exp. 1: N=14 participants sat on their most preferred and least preferred car seat (out of 7 seats) for a 2.5–hour static drive. Exp. 2: N=12 participants sat on the most overall preferred seat from experiment 1 for a 2.5–hour static drive.	Small number of participants, but representing a wide range of statures.
	Maximum pressure for different areas		Significant correlations were found for the sample of tall males between buttock discomfort and IT area pressure variables (no correlation coefficient reported).		

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Gyi and Porter 1999 *(continued)*	Mean pressure for different areas	Body part discomfort on 7–point scale ranging from very comfortable to very uncomfortable for the right buttock, right thigh and the lower back	No associations reported	Exp. 1: N=14 most and least preferred car seat, 2.5–hour static drive. Exp. 2: N=12 most overall preferred seat from Exp. 1, 2.5–hour static drive.	
	Standard deviation of mean pressure for different areas		No associations reported		
	Pressure area for different areas		No associations reported		
Kyung and Nussbaum 2013	Mean contact area and ratio (local measure relative to sum) for 6 body parts: left/right thigh, left/right buttock, lower/upper back	Overall rating (combination of comfort and discomfort) Whole–body comfort rating Whole–body discomfort rating	Sign. correlations found for lower back (⍰=-.20) with overall rating; for left thigh (⍰=-.23), right thigh (⍰=-.20), right buttock (⍰=.21), and lower back (⍰=-.26-0.3) with whole–body comfort rating; for left buttock (⍰=.17), right buttock (⍰=-.20), and upper back (⍰=-.20) with whole–body discomfort rating	N=22 car drivers; 2 age groups: older (≥60 years, N=11) and younger (20-35 years, N=11); each group had 6 male, 5 female 6 driving sessions: combination of vehicle class (SUV/sedan), driving venue (lab/field), and seat (high/low comfort score)	Significant correlations of weak to moderate effect were found with at least one of the subjective ratings for 22 out of 36 pressure measures (⍰ ranges between -.26 and .31); the highest correlation (⍰=.31) was found between contact pressure at the right buttock and discomfort ratings.
	Mean contact pressure and ratio (local measure relative to sum) for 6 body parts		Sign. correlations found for right thigh (⍰=-.21) with overall rating; for right thigh (⍰=-.23), and upper back (⍰=-.22) with whole–body comfort rating; for left thigh (⍰=.24), right thigh (⍰=.25), left buttock (⍰=.26), right buttock (⍰=.31), and lower back (⍰=.28) with whole–body discomfort rating		

(Table continued on next page)

Table 2.3 *(continued)*

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Kyung and Nussbaum 2013 *(continued)*	Mean peak pressure and ratio (local measure relative to sum) for 6 body parts: left/ right thigh, left/ right buttock, lower/ upper back	Overall rating (combination of comfort and discomfort) Whole–body comfort rating Whole–body discomfort rating	Significant correlations were found for the right thigh (□=-.19-.26), lower back (□=.25)and upper back (□=-.19) with overall rating; for the right thigh (□=-.17-.23), lower back (□=.26)and upper back (□=-.24-.26) with whole–body comfort rating; for the left thigh (□=.24), right thigh (□=-.19), left buttock (□=-.18), lower back (□=.18), and upper back (□=.19) with whole–body discomfort rating	N=22 car drivers; 2 age groups (older and younger) 6 driving sessions: vehicle class x driving venue x seat (2x2x2)	Significant correlations of weak to moderate effect were found with at least one of the subjective ratings for 22 out of 36 pressure measures (□ ranges between -.26 and .31); the highest correlation (□=.31) was found between contact pressure at the right buttock and discomfort ratings.
De Looze et al. 2003	Objective measures of comfort and discomfort, including pressure distribution	Subjective measures of comfort and discomfort		Literature review	Seven studies were found: three of them reported correlations (Yun et al. 1992; Thakurta et al. 1995; Vergara and Page 2000) between pressure variables and comfort or discomfort; two others (Kamijo et al. 1982, Tewari and Prasad 2000) reported associations

ratings (i.e. lower pressure is correlated to higher comfort). Average pressure levels were slightly better correlated with overall comfort ratings than maximum pressure values in the seat cushion or seat back.

Pressure measurements are still often used as indicators of comfort and discomfort. However, the explained variance in comfort and discomfort ratings by pressure is low. This is caused by the many other factors that influence the pressure variables (e.g. anthropometrics and body postures), as well as by the many other factors that influence comfort and discomfort (e.g. posture and movement). Pressure measurements were insufficiently sensitive to indicate differences between seats with different cushions, whereas the subjective comfort ratings were distinctive. This is supported by Porter et al. (2003), who found significant differences between three car seats for mean pressure for only three areas (out of six) and for peak pressure for only one area (out of six).

2.3.4 CONCEPTUAL MODEL

In this section, the conceptual model presented in Section 2.2 is further developed (see Figure 2.2). The variables of the context and seat level are operationalised, based on the findings from the literature. Furthermore, the arrows illustrate the evidence that was found for the relationships between the variables. In this way,

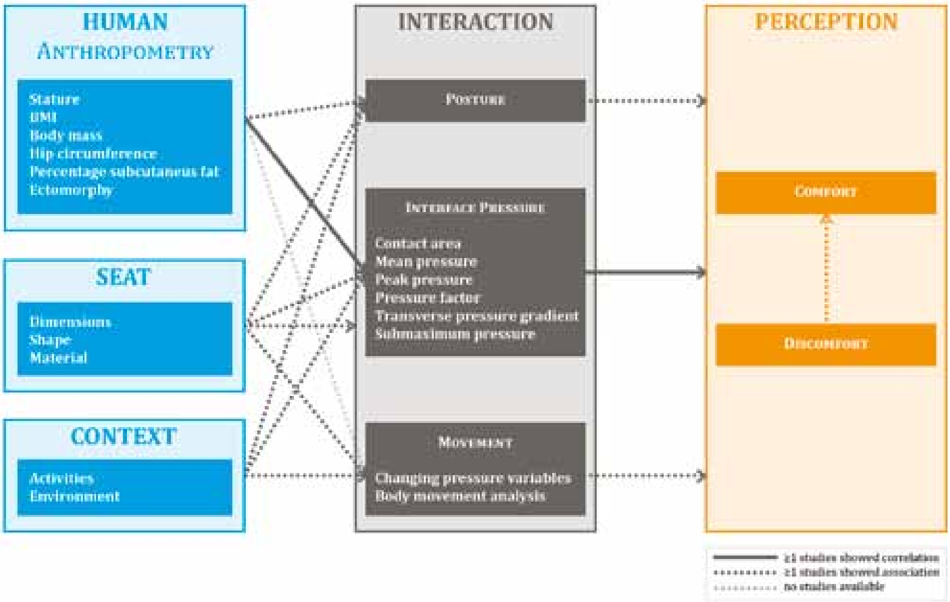

Figure 2.2 Overview of relationships between the variables. Differences in the strength of the evidence are indicated by the different arrow styles.

three levels of evidence were distinguished: statistically determined relationship (dark line), tendency for a relationship without statistical evidence (dotted line) and no studies available (light line).

2.4 DISCUSSION

The aim of this study was to investigate the interaction between human, seat and context variables in order to predict passenger comfort and discomfort, and – if possible – to quantify the relationships between anthropometric variables, activities, postures, movement, interface pressure, and comfort and discomfort. This is important because due to societal developments, such as globalisation and new IT technologies, the variety of people who travel by plane and public transport, as well as the variety of activities they perform, is increasing. Designers need to respond to these developments in their seat design, and airlines and public transport organisations may distinguish themselves from their competitors by providing an optimal environment.

2.4.1 STUDIES FOUND

A large majority of the studies found addressed the comfort and discomfort of car driver's seats and office chairs. The context of use (i.e. the performed activities) and the seat characteristics (adjustability of seat dimensions) for these areas are totally different compared to aircraft seats or seats for public transport. The main difference in both situations is the performed activity. For instance, driving a car imposes a fixed (asymmetric) body posture with hands on the steering wheel and one foot on the accelerator. Body postures in office work are mostly dictated by the adjustment of the chair, desk, screen and keyboard. This does not matter when more fundamental issues are studied (such as the relationship between pressure and comfort and discomfort). However, it was found that body posture affects pressure variables (e.g. Vos et al. 2006; Tessendorf et al. 2009; Moes 2007; Zhiping and Jian 2011; Kyung and Nussbaum 2013), and that activities induce body postures (Ellegast et al. 2012; Kamp et al. 2011; Groenesteijn et al. 2012). Therefore, the studies focusing on car driver's seats should be interpreted with care. It is desirable to have more studies available in the area of passenger seats.

In order to be able to build a predictive model, it is important that the relationships between the variables can be quantified. Therefore, statistical evidence is needed, such as correlation coefficients and effect sizes. However, only a few studies were found in which statistical evidence was found between variables. Furthermore, the different context characteristics (driver's seat, office chair, experimental seat) are hardly representative of passenger seats. It is therefore difficult, if not impossible, to generalise these data for the domain of passenger seats.

2.4.2 RESULTS FOUND

As mentioned before, statistical evidence for many of the relationships in our conceptual model is lacking. Statistical evidence was found only for the correlations between anthropometric variables and pressure variables, and for those between pressure variables and comfort and discomfort. For the correlations between anthropometric variables and pressure variables, the highest correlations were found for contact area and average pressure with BMI, subcutaneous fat, hip width (gender) and somatotype. The study by Moes (2007) is the only study in which the relationship between anthropometric variables and pressure variables was investigated in relation to body posture. For instance, Moes (2007) found that the dependency of the average pressure on a rotation of the pelvis (in the sagittal plane) had a positive correlation with the endomorphic index, and that the dependency of the contact area on a rotation of the pelvis is negatively correlated with the percentage of subcutaneous fat. These findings imply that when looking at the relationship between anthropometric variables and pressure variables, it is necessary to take into account pelvic rotation. This rotation may vary in different body postures from a slumped position to sitting upright. This also means that the correlations regarding this relationship found in the other studies cannot be directly translated into a predictive model without knowledge of the body posture and, more specifically, the pelvic rotation of the participants in these studies.

Although pressure measurements are often used to illustrate the seat quality or to indicate comfort and/or discomfort, no clear scientific evidence for this can be found in the literature. Some studies indicate an association between higher average or peak pressure and greater discomfort, and larger contact areas with less discomfort, but do not present any statistical proof. Others calculate correlation coefficients between average pressure and peak pressure and discomfort. The variation between the reported correlation coefficients is large, even between subjects within one experimental setting, and of course between studies. On the one hand, this can be explained by the differences in measurement methods (e.g. different subjective methods are used for measuring comfort and discomfort) and the way the pressure variables are measured and calculated. On the other hand, variables other than seat design also affect the pressure variables, such as anthropometry and body posture. These variations between studies make it difficult to compare the studies and to conclude whether or not pressure variables are related to comfort and discomfort.

Likewise, if such a correlation indeed exists, what would be the effect on the comfort and discomfort perception of reducing the average pressure by, for example, 1 kPa? Some studies found no differences between pressure variables of different seats or cushion materials, whereas differences in comfort and discomfort perception did occur (Porter et al. 2003). The main issue here is whether pressure measurements are sensitive enough to distinguish between two well-designed passenger seats. Goossens et al. (2005) showed that, around the ischial tuberosity, humans do not notice differences of less than 1.9 kPa. In an extreme situation, pressure variables may only be a suitable measure for objectively indicating differences in comfort and discomfort between seats with very large differences in surface material or shape (i.e. compare a flat, wooden seat pan with a cushioned armchair). This means that in a predictive model, pressure variables (e.g. average pressure, contact area and peak pressure) can only be used to discriminate between extremes (and only in combination with knowledge of the anthropometric data). Therefore, other variables should be incorporated in the model as well, in order to predict passenger comfort and discomfort more precisely.

However, as a seat evaluation method, pressure measurements can still be used since it was also found that a pressure map can be used to predict body posture. By extension, change of body postures (movements) can also be predicted. As the number of changes (caused by fidgeting) is associated with discomfort (Na et al. 2005; Jackson et al. 2009; Le et al. 2014), body pressure measurement changes, as an indicator of fidgeting movements in time, may be a better indicator of discomfort than average pressure, peak pressure or contact area.

Less information was found about anthropometric variables and the effect of body postures on passenger seats. The most detailed information is available on anthropometrics and posture in relation to car driver's seats, and a little information is available on tall and short people on public transport. The context of use and the seat characteristics together with anthropometrics seem to be strongly connected with the adopted posture. Detailed information for public transport on this topic is lacking.

In the present study, the focus was mainly on the physical aspects of the interaction parameters and not on the mental perception of comfort. In future research it is important to address the mental perception as well, as this is an important factor in comfort (Zhang et al. 1996; Ahmadpour et al. 2014).

2.4.3 OTHER VARIABLES THAT AFFECT PASSENGER COMFORT AND DISCOMFORT

The focus of this study was on specific human, seat and context variables, such as anthropometry (human), seat dimensions, shape and material (seat), and activities (context). However, other variables also affect passenger comfort and discomfort. Especially exposure duration (e.g. short-haul or long-haul flight) and personal space (e.g. seat pitch) are important factors in the aviation industry.

Effect of exposure duration on comfort and discomfort

Some studies point out dose–response relationships between duration and comfort and discomfort. Bazley et al. (2012), for instance, found declining physical comfort levels throughout the day in offices. For the driver's seat of a car, Porter et al. (2003) observed an increase in discomfort in the back, buttocks and thighs over time (after a 135–minute drive). Jackson (2009) found that it took about 40 minutes before glider pilots started to make large fidgeting movements to relieve discomfort. Similarly, Sember (1994) concluded that it takes at least 30 minutes for discomfort to become sufficient for a behavioural response to occur. This is supported by Na et al. (2005), who found an increase in whole body part discomfort over time when driving a car for 45 minutes, as well as by Le et al. (2014), who noticed that motion occurred more often as time progressed to alleviate pressure from discomfort. Noro et al. (2005) showed that there is a relationship between discomfort over time in combination with seat pressure dose: the longer the duration, the greater the discomfort. According to Branton and Grayson (1967), the length of time before discomfort occurs can be increased by the design of the seat. Hence, proper seat design may reduce the increase in discomfort over time.

Effects of personal space on comfort and discomfort

Personal space is a broad concept that includes legroom, seat pitch, seat width and cabin environment. These variables affect the perception of comfort and discomfort. For instance, Kremser et al. (2012) found that seat pitch for maximum well-being ranges from 34 to 42 inches (865 to 1065 mm) (corresponding legroom 32 to 40 inches (815 to 1015 mm)), depending on the passenger's anthropometry. After this maximum, the level of subjective well-being decreases. The optimal seat pitch is influenced by the passenger's buttock–knee length, and the sense of subjective well-being is influenced by the passenger's eye height. The 'ease of adopting a comfortable sitting posture' and the 'ease of changing posture', as well as the 'feeling of being restricted', the 'feeling of sitting in front of a wall' and the 'feeling of being lost', were significantly influenced by seat pitch. According to a study by Brauer (2005), the width per seat at seated eye level provided the best correlation with passenger preference for an aeroplane, which indicates that personal space is more important than total space. Row arrangements are important because passengers prefer to be seated next to an empty seat, and the chance of this happening is greater in a 3–3–3 configuration than, for example, in a 2–5–2 configuration. This indicates that a representative environment of an aircraft interior is necessary when testing aircraft seat comfort. This is supported by Ciaccia and Sznelwar (2012), who found that participants used elements from the cabin environment to support their heads and limbs.

2.5 Conclusion

The aim of this review was to study the interaction between human, seat and context variables in order to predict passenger comfort and discomfort. We found that correlations do exist between anthropometric variables and interface pressure variables, and that this relationship is affected by body posture. The correlation between pressure variables and passenger comfort and discomfort has been the subject of many studies, but the results of these studies are not in line with each other, due to large differences in research design. Therefore, the strength of this correlation is not clear. Hence, more research is necessary, especially in the field of passenger comfort and discomfort (as opposed to driver's comfort and discomfort), and more variables have to be taken into account (e.g. personal space and exposure duration) in order to make a better prediction. The results of this review contribute to preparations for building a predictive model of passenger comfort and discomfort, and indicate the knowledge gaps that still need to be filled in order to further develop the predictive model.

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Part I.

CONTEXT

The conceptual model in Chapter 2 presented three levels: Human, Seat, and Context. This first part explores the underlying factors for the Context level, in particular passengers' performed activities. In Chapter 3, the context characteristics that influence comfort and discomfort are described and are illustrated by two case studies. Finally, Chapter 4 describes an observation study on the effects of activities and postures on comfort perception of train passengers.

CHAPTER 3

CONTEXT CHARACTERISTICS THAT INFLUENCE COMFORT AND DISCOMFORT

In this chapter, the context characteristics that influence comfort and discomfort are described (3.1) and are illustrated by two case studies in sections 3.2 and 3.3. The first case study (3.2) describes the influence of performed activities on body postures of passengers in the back seat of a car. The second case study (3.3) describes the influence of activities and duration on discomfort development and comfort of aircraft passengers. Finally, it is concluded in Section 3.4 that the backseat of a car is too restricting to find differences in posture, and that activities can be used to distract aircraft passengers from feeling discomfort. Eating and drinking seem to decrease discomfort, but walking is much more effective.

The case study in Section 3.2 is adapted from the following publication:

Van Veen, S., Vink, P., Hiemstra-van Mastrigt, S., Kamp, I., Franz, M., 2012. Requirements for the back seat of a car for working while travelling. In: *Advances in Social and Organizational Factors, International Conference on Applied Human Factors and Ergonomics*: 6525–6532.

The case study in Section 3.3 has been accepted for publication in Work:

Hiemstra-van Mastrigt, S., Meyenborg, I., Hoogenhout, M., submitted. The influence of activities and duration on discomfort development in time of aircraft passengers. *Work*, Accepted for publication.

3.1 INTRODUCTION ON CONTEXT CHARACTERISTICS

According to De Looze et al. (2003), it is generally agreed that comfort is a reaction to the environment. A product is not comfortable by itself, but how the comfort of a product is experienced depends on the way in which the user interacts with a product (Hekkert and Schifferstein 2011). This interaction between a human and a product always takes place within a specific context. Thus, the comfort experience is influenced by the context in which the human-product interaction takes place (Desmet and Hekkert 2007). This context can vary from physical circumstances, such as lighting conditions or temperature of the room, to a broader cultural and social situation that influences how people experience products (Hekkert and Schifferstein 2011).

In this thesis, the context characteristics that are considered most important for the design of comfortable passengers seats are described. These are the activities that passengers perform and the duration of the journey.

3.1.1 PASSENGERS' ACTIVITIES

Different tasks and activities are associated with different sitting postures. Three studies, in which activities and tasks performed in offices, in semi-public situations and on trains were observed (Ellegast et al. 2012; Kamp et al. 2011; Groenesteijn et al. 2014), clearly illustrate the relationship between activity and posture. Ellegast et al. (2012) show that during telephoning, a large variation in postures is observed, while during computer work, the variation in posture is very limited, although the same furniture was used. Kamp et al. (2011) observed that for train travellers, the posture is significantly more slouched while relaxing than while using a mobile device. For talking, Groenesteijn et al. (2014) observed postures with the head and trunk rotated (turned to the side), which is hardly seen in other activities.

3.1.2 DURATION OF THE JOURNEY

As already discussed in Chapter 2, exposure duration plays a role in the perception of comfort and discomfort. For instance, Bazley et al. (2015) found declining physical comfort levels throughout the day in offices. Other studies report an increase in discomfort over time (Porter et al. 2003; Jackson 2009; Sember 1994; Na et al. 2005; Le et al. 2014), concluding that it takes between 30 and 45 minutes before discomfort occurs. Additionally, there is a relationship between discomfort over time in combination with seat pressure dose: the longer the duration, the greater the discomfort (Noro et al. 2005).

On the other hand, duration also determines which activities passengers are likely to perform. For example, Ettema et al. (2012) found in a survey study that the activities undertaken most frequently during travel are relaxing and entertaining, while less frequent activities are work/study, talking to other passengers and using information and communication technologies (ICT) devices. However, in this study, the majority of trip lengths were shorter than 20 minutes, which could be too short to start up work activities. Lyons et al. (2007) seem to support this, as they suggest there may be 'a possible travel duration threshold below which there is not a suitable amount of time to do other than window gaze/people watch'. On the other hand, a train survey by Gripsrud and Hjorthol (2009) shows that over one third of passengers using their travel time for work, with nearly a quarter of commuters having their travel time paid as work time.

3.1.3 AIM OF THIS CHAPTER

The aim of this chapter is to investigate the influence of the context characteristics, specifically passengers' performed activities and duration of the journey, on body posture and comfort and discomfort perception. Therefore, two case studies will be presented: the first case study investigates the influence of different activities on observed body postures of car passengers, while the second case study investigates the influence of activities and duration on discomfort development and comfort of aircraft passengers.

3.2 CASE STUDY: ACTIVITIES AND OBSERVED POSTURES FOR THE BACK SEAT OF A CAR

3.2.1 BACKGROUND

New ways of work also extends to working while traveling. This knowledge will become of importance for aircraft, train and car interiors as sales figures of tablet pc's are increasing. In 2008, notebook sales were higher than the desktop sales, and tablet sales is also growing rapidly. However, many vehicle interiors are not designed for work.

The opinion of three tablet users in an airplane (see Figure 3.1) on their comfort illustrates this clearly. The tablet user pictured on the right in the back complains about neck discomfort, while watching a video, "*but at least I have my hands free*", he said. The person next to him placed the tablet on the table. After holding it in his hands for 30 minutes, his arms and hands were getting tired. The person on the left side in the picture misses an arm support on the right side as the neighbour is using that armrest and his arm is getting tired after an hour.

The example described above is just anecdotic evidence and not a scientific approach. However, in the literature, indications are found on effects of tablet use on posture. For example, Young et al. (2012) found that head and neck flexion angles during tablet use were greater, in general, than angles previously reported for desktop and notebook computing. However, Albin and McLoone (2014) found that neck flexion decreased significantly as tablet tilt angle increased, but observed no effect for forearm and wrist posture. Similarly, Asundi et al. (2012) found that increasing the tilt angle of laptop computers on inclined wedges decreased neck flexion. A higher display location often leads to reduced neck flexion that approaches more neutral postures, while lower viewpoints often increase the flexed posture which is associated with an increase in neck extensor activity and discomfort (Ariëns 2001; Straker et al. 2008a; 2008b). Hamberg-van Reenen (2008) showed that this neck discomfort increases the chance of getting neck pain by more than two times. A typical difference between working with a desk top and a tablet is that the hands (often the thumbs) are positioned at the location where you have the viewpoint on the tablet, while in the desktop it is possible to type blind and have the keyboard in the position creating optimal hand/arm postures and the screen facilitating optimal neck positions. The laptop is in between as the screen and keyboard are connected, but the position of the keys is not so close to the viewing point.

Figure 3.1 *Three aircraft passengers using a tablet, each in a different way.*

The question is how a vehicle interior, in particular the back seat of a car, could be designed to support working with these small and large electronic devices. However, not much is known yet about the postures of passengers in the rear seat while performing different activities. Kamp (2012) already showed that pictures and observations of passengers in rear seats do not give enough information as the vision is often blocked by glare. Therefore, in this study, we asked passengers to perform different activities in the back seat while the researchers were driving the car.

The research questions are: *What are the differences in posture of passengers reading a book, using a laptop and using a tablet device while sitting in the back seat of a driving car? And what are requirements for the back seat of a car to support these different activities?*

3.2.2 METHOD

3.2.2.1 Participants

Twenty-six people (14 men and 12 women) of different nationalities (European, American and Asian) volunteered to participate in this study. Their average age was 29.4 years (20-67 years), their average weight was 71.2 kg (50-105 kg) and their average stature was 1.76 m (1.63-1.93 m).

3.2.2.2 Measurements and protocol

To observe passengers' body postures and gather information on what passengers prefer in working with a laptop and a notebook, participants were asked to participate in a driving test. A BMW 7-series was used for this study because this is a type of car in which it is feasible that passengers in the back seat would perform work activities, such as reading and working on laptop.

Participants were instructed to perform one of the following tasks: reading a book, working on a laptop or playing a game on a tablet pc. When someone indicated (severe) motion sickness, the task least likely to cause sickness was chosen by the participant. In total nine participants played a game on a tablet pc, nine participants read a book and eight participants worked on a laptop during the ride.

The participants were driven around for approximately 30 minutes by one researcher while being observed by another researcher sitting in the front row. The participants were always sitting in the back seat on the right hand side of the car (diagonally behind the driver). The driving track was the same for all travels and consisted mainly of a highway, as this is probably where these activities are most likely to be performed.

At the end, participants completed a short questionnaire on the suitability of the car interior for performing the task, and received a small compensation.

Body posture observations

During the 30 min drive, several pictures were taken from the front. In Figure 3.2, examples of the observed postures are visualized. These pictures were evaluated using a coding system (see Table 3.1), based on the method described by Branton and Grayson (1967). Three different codes were developed: for overall body posture, arm posture and positioning of the devices.

Figure 3.2 *Examples of postures for the three different tasks, from left to right: working on laptop, reading a book, gaming on tablet*

Body angles (2D)

At the start of the experiment, participants were equipped with stickers positioned on their head (tempor), shoulder (acromion), elbow (lateral epicondylus), wrist (the palpable part of the posterior side of the semilunar bone), hip (greater trochanter), knee (lateral side of the patella), and ankle (lateral malleolus). After the 30 min drive, the car was parked to take a picture from the side, while participants remained in the same posture in which they performed the activity. Next, they were asked to adopt two additional postures for performing the other two activities as well. The body angles were calculated by drawing lines between the stickers on top of the pictures (see Figure 3.3). The body angles for each of the three activities were compared using Friedman's ANOVA with post-hoc Wilcoxon Signed Ranks Test (IBM SPSS Statistics 20). Significance was accepted at $p<0.05$.

Table 3.1 *Coding system for body posture observation*

	Body posture				
	Task	Arms	Upper body	Head	Legs
1	Laptop	Both along body	Upright, in seat	Upright	Straight together
2	Tablet	One arm supported	Leaning (left), in seat	Bent forward	Apart
3	Read	Both supported	Leaning (right), in seat	Bent forward strongly	Other
4			Upright, shoulders forward		

	Arm posture				
	Task	Left arm	Left hand	Right arm	Right hand
1	Laptop	Alongside body	On lap	Alongside body	On lap
2	Tablet	On middle console	Up	On door rest	Up
3	Read		Performing task*		Performing task*
4			On middle console		

** Performing task for laptop: typing; for tablet: touching the screen; for reading: on page.*

	Positioning of device (laptop/tablet/book)			
	Task	Support	Holding with ...	Positioning of paper
0			N/A	N/A
1	Laptop	On both legs	Both hands	On middle console
2	Tablet	On left leg	Left hand	On lap
3	Read	Suported by lap	Right hand	In hand

Questionnaire

The short questionnaire at the end of the drive consisted of three questions: *What activities would you want to perform on the back seat of the car? Did you miss support while performing the task? Did the dynamics of the car influence performing the task?*

3.2.3 Results

Body posture observations

For working with the laptop, only one dominant posture was found. For both other tasks (reading and tablet), two dominant positions have been observed (see Table 3.2). When working with the laptop, participants tend to sit upright in the seat with both legs together, supporting the laptop, and both hands active in typing.

While gaming on the tablet, the head was often bent forward, with one arm always supported. The body was upright or leaning to the left in the seat, and the legs were apart from each other. The tablet was on the lap or on one leg. This supporting leg was always the left leg. Participants were either using one hand to hold the tablet and the other to touch the screen, or the tablet was held in two hands using the thumbs to control the functions. While reading a book, the arms were alongside the body, the trunk upright or leaning to the left and the book was held by two hands or only the right hand. The book was on the lap or only supported by the hand(s) with the legs apart.

Figure 3.3 *Example of body angles observed from the side for reading a book (left) and gaming on tablet (right)*

From Table 3.2, it is clear that working on the laptop is the most restrictive activity compared to reading a book and gaming on tablet. Only one dominant posture was observed for the laptop activity, while for the other two activities, two dominant postures were observed.

Body angles (2D)

As shown in Figure 3.4 and Table 3.3, little variation was observed in mean body angles between the three activities. However, significant differences were found for head angle ($p<0.01$ $\chi^2(2) = 20.72$), the torso angle ($p<0.05$ $\chi^2(2) = 6.67$) and fore arm angle ($p<0.05$ $\chi^2(2) = 7.28$). The angle of the head was significantly more horizontal (more neck flexion) for the gaming on tablet compared to reading a book and working on laptop. For reading a book, the torso was more reclined compared to gaming on tablet. The fore arm angle was significantly larger (more vertical) for reading a book compared to working on laptop and gaming on tablet.

Table 3.2 *Typifying of the observed postures*

	Activity				
Position	Book		Laptop	Tablet	
Legs	Legs apart		Legs together	Legs apart	
Trunk	Leaning to the left	Upright	Upright	Upright	Leaning to the left
Arm	Alongside body		Alongside body	One arm supported	Alongside body
Hands	One on book	Both on book	On keyboard	One hand holding tablet, one controlling	Both thumbs controlling the tablet
Device	On lap	Supported by two hands	On lap	On left leg	On lap
Head	Bent forward		Bent forward	Bent forward	

Table 3.3 *Mean and standard deviation of body angles for each activity (n=25)*

Body angle	Working on laptop	Reading a book	Gaming on tablet
Head (head-shoulder)	50.9 (14.6)	53.0 (10.1)	**44.2** (11.7)
Torso (shoulder-hip)	115.8 (7.7)	**117.1** (8.3)*	115.4 (8.0)
Upper leg (hip-knee)	18.4 (5.0)	19.8 (5.0)	20.1 (4.7)
Lower leg (knee-ankle)	-72.4 (8.4)	-72.7 (7.8)	-73.7 (7.3)
Upper arm (shoulder-elbow)	-67.5 (7.2)	-67.1 (6.0)	-66.9 (7.3)
Fore arm (elbow-wrist)	6.08 (9.5)	**14.6** (15.9)	9.25 (14.2)

Figure 3.4 *Observed body angles observed from the side for three activities; black lines are mean values for each task, grey areas indicate the variation between minimum and maximum angle.*

Questionnaire

More than 80% of participants indicated they would perform this activity on the back seat of a car (see Figure 3.5). The motivation for performing the different tasks differ: working on laptop is performed when work needs to be finished, while reading and using the tablet (or other small electronic devices, such as smartphone) are seen as a way to pass the time. Other activities that were mentioned by participants which they would like to perform on the backseat of a car were: listening to music, looking out the window, relaxing and sleeping, and talking to other passengers.

As can be seen from Figure 3.5 as well, working on the laptop appeared to be more difficult to perform in the back seat of the car than reading a book or gaming on tablet. Participants experienced difficulties caused by the dynamics of the car (87.5%), especially while driving in corners. For working on laptop, this meant the laptop and the paper shifting. Hence, 85.7% of participants also indicated that they missed support for the laptop and space for the paper. For reading a book and gaming on tablet, participants mentioned they missed support for the device (book or tablet), but the lack of support for the arms was only mentioned for the tablet activity.

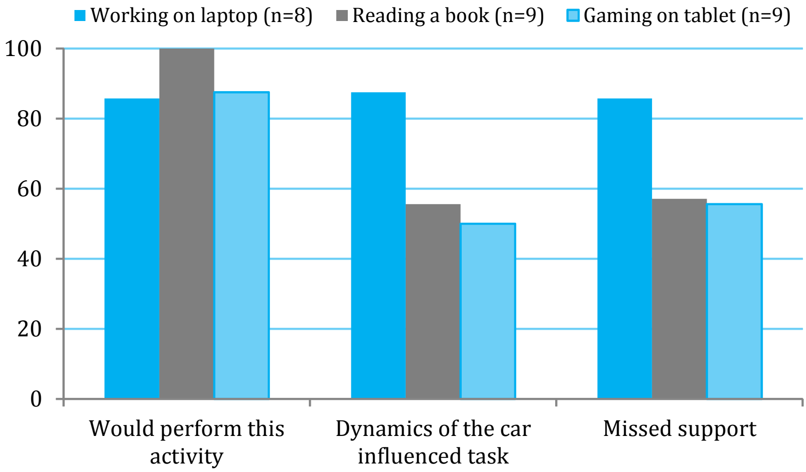

Figure 3.5 *Responses to the questions from the questionnaire (% that answered 'yes')*

Possible design improvements

From the results described above, it can be concluded that passengers in the back seat of a car want to use small and larger electronic devices, such as smartphones, tablets and laptops, but that support is missing in the current car interior. There is a need for a solid laptop support, which prevents shifting but also minimizes vibrations.

An arm rest could support various activities, for example to support typing while working on a laptop, or to hold up the devices (such as tablets) to prevent a flexed neck. Participants in this study also searched for possibilities to turn/lean to one side while seeking support, to enable variation in body posture, but also to have conversations with fellow passengers or to look out the window. Future car seats could offer more flexibility to do this. Finally, there is a need for varying the backrest angle in relation to the intensity level of the activity (low level, relaxed activities vs. high level, intense activities).

3.2.4 DISCUSSION

This study has illustrated how much the body posture of car passengers is restricted by the car interior and the performed activity. Especially working on a laptop seems to restrict variation in body posture. For this task, only one preferred posture was observed. The head was bent forward strongly for working on a laptop and gaming on tablet, indicating that the screens were positioned too low. This amount of neck flexion could result in neck discomfort, and even neck pain.

Different postures of car passengers have not been the topic of many scientific studies. Zhang et al. (2004) used video-observations at highway tollbooths in order to determine postures of front passengers. They distinguished 29 different postures, with one posture (upright sitting, facing forward with feet touching the floor) occurring predominantly (45%), while the other postures occurred in less than 10% of observed situations. More than 80% of observed front passengers (n=1344) adopted an upright sitting posture (combined total of six postures). Similarly, Zenk (2008) found that 90% of front passengers were sitting straight upright when he observed the postures of car drivers and front passengers during 130 travels on the German highway during the summer holiday period.

Thus, compared to Zhang et al. (2004) and Zenk (2008), this study shows similar results. However, compared to other studies on postures and activities, this study shows less diversity in postures. For example, Gold et al. (2012a) found 22 self-selected different postures when using a laptop at home. During train journeys and leisure situations, Kamp et al. (2011) observed at least eight different postures when using small and larger electronic devices. On the other hand, this study confirms some characteristics of using a touchscreen shown by Zhu and Shin (2011), like the fact that the arms demanded support or the neck bent forward. Straker et al. (2008b) emphasize the importance of display height to reduce neck and upper limb muscle activity for different tasks (working on a computer and book use) in a desk setting.

The variation in body angles observed from the side was small, probably caused by the restrictions of seat and seat belt. Furthermore, subjects were not allowed to change the settings of the seat. However, significant differences were found for head angle, torso angle and fore arm angle. These results correspond with the different body postures as observed from the front. It seems that the participants reading a book held the book closer to their eyes, increasing the fore arm angle, while the tablet users lowered their head to bring their eyes closer to the tablet, which was supported in their lap. Gold et al. (2012b) also observed a flexed neck when using a mobile device for 91% of all subjects (n=782). This difference between body postures could be explained by the intensity of the task. On the tablet, participants were playing a simple game, but the book had regular size letters, which could require higher visual demand. Perhaps reading on a tablet or e-reader would result in a similar posture as reading a book. For working on the laptop, however, the hands as well as the eyes are demanding (Lueder 2004), which results in a restricted posture. Consequently, the variation in posture for this activity was lower than for reading a book or gaming on tablet.

The observed body postures in this study do not necessarily reflect the preferred postures for car passengers, because these postures are most likely restricted by the seat and rest of the car interior. For example, a study observing people at home while watching television (Van Rosmalen et al. 2009) showed that people change their body posture often and that the variation of postures is large. In this case, the subjects were not as limited by the seat and space as in a car, indicating that more freedom in varying the body posture is desirable. Groenesteijn et al. (2009) suggest that a wider range of available backrest angle could better adapt to individual preferences in adjustability for the task performed.

3.3 CASE STUDY: THE INFLUENCE OF ACTIVITIES AND DURATION ON DISCOMFORT DEVELOPMENT OF AIRCRAFT PASSENGERS

3.3.1 BACKGROUND

Many people who spend most of their time sitting down have an increased health risk. Hu et al. (2003) state that, for women, each 2 hours increase in sitting time at work per day increases the risk of obesity by 5% and the risk of diabetes type II by 7%. Besides health, there are studies that show that prolonged sitting increases discomfort. According to several studies, discomfort increases when the duration of sitting is longer. For instance, Porter et al. (2003) observed an increase in discomfort in the back, buttocks and thighs over time in a 135–minute drive. Na et al. (2005)

established an increase in whole body discomfort over time when driving a car for 45 minutes, while Le et al. (2014) noticed that motion occurred more often as time progressed to alleviate pressure from discomfort.

Discomfort can be seen as "*an unpleasant state of the human body in reaction to its physical environment*" (Vink and Hallbeck 2012). According to Zhang et al. (1996), comfort and discomfort are two independent factors associated with different underlying factors. Discomfort is associated with feelings of pain, soreness, numbness and stiffness, and is caused by physical constraints in the design. On the other hand, comfort is associated with feelings of relaxation and well-being. Thus, reducing discomfort will not necessarily increase comfort, but in order to accomplish a high level of comfort, the level of discomfort should be low (Helander and Zhang 1997).

Aircraft passengers are subjected to prolonged sitting in a restricted posture; depending on the duration of the flight, this could be up to 15 hours. Although previous studies have investigated the development of discomfort in time, these studies have been performed in work environments (Bazley et al. 2015), for car driver seats (Porter et al. 2003; Na et al. 2005; Le et al. 2014) or for glider pilot seats (Jackson et al. 2009), but not yet for aircraft passenger seats. Furthermore, it is important to take into account the activities that aircraft passengers perform (Vink and Hallbeck 2012), as has been demonstrated for office seats in the studies by Groenesteijn et al. (2012) and Ellegast et al. (2012).

Therefore, the research question for this study was: *What is the effect of duration on discomfort development in time of aircraft passengers? Is this different for different activities?* On the other hand, feeling refreshed is associated with feelings of comfort, which is why a second research question has been formulated: *What is, according to aircraft passengers, the most refreshing activity? Is there a difference for different flight durations?*

3.3.2 METHOD

In an aircraft seat test supporting an airline in selecting new economy seats, there was a possibility to study the effect of activities and duration on the development of discomfort. Participants had to sit in three types of seats in order to evaluate whether there were differences between the seats. The results of this test are proprietary information. However, this experiment provided the possibility to add various activities like eating, sleeping and reading, and participants were able to walk around between seat test sessions.

In a consecutive study, a short survey was posted online, asking respondents after which activity they felt most refreshed.

3.3.2.1 Participants

Eighteen people (8 male, 10 female) volunteered to participate in the aircraft seat test. Their average age was 33 years (18-61 years), average stature 1.72 m (1.57-1.97 m) and average weight 68 kg (52-94). Twelve participants were Dutch, six were international, of which three from Asia. Participants were carefully selected in order to obtain a representative sample of the expected passenger population, in terms of diversity in age, nationality and anthropometry (stature and weight).

Respondents for the online survey were contacted through e-mail and social media (Facebook). In total, 134 respondents accessed the questionnaire; only 114 people completed the questionnaire (54 male; 55 female; 5 unknown). The nationality of respondents was 68.5% German, 17.6% Dutch and 13.9% other (e.g. Austrian, Belgian, Italian, Spanish). Their average age was 30 years (range 16-63 years). Nearly all respondents were economy class passengers (96.5%), and a large majority was travelling for holiday purposes (64.9% vs. 35.1% business).

3.3.2.2 Experimental setting

In the aircraft seat test, three most common economy class seats from leading aircraft seat manufacturers (selected by the airline) were used,. The airline is a flag carrier and the seats are intended for regular economy class on medium to long-haul flights, which is why the seats in the experiment were separated at a pitch of 32" (813 mm). The placing of the seats, in a laboratory environment, was done in two rows of three seats per type of seat, with participants seated in the second row, as illustrated in Figure 3.6. Seats were placed on a 3 degrees inclined floor to simulate the slope of an airplane at cruising altitude. The different seats were visually separated and given code names.

Three groups of three people participated in the aircraft seat test simultaneously. The order in which the seats were presented to the participants was systematically varied. As illustrated in Figure 3.7, each group of three participants received a specific order of seats (six different orders: ABC, BCA, CAB, BAC, CBA, ACB).

3.3.2.3 Measurements

During the aircraft seat test, discomfort was measured using the Local Perceived Discomfort (LPD) method (Van der Grinten and Smitt 1992). A body map consisting of 22 regions was presented to the participants, who were then asked to rate their perceived discomfort in the body regions on an 11–point scale (ranging from 0=no discomfort to 10=extreme discomfort, almost maximum). This was done at the start of the test and then every 15 minutes. During the experiment, participants were not allowed to talk to each other to prevent influencing each other.

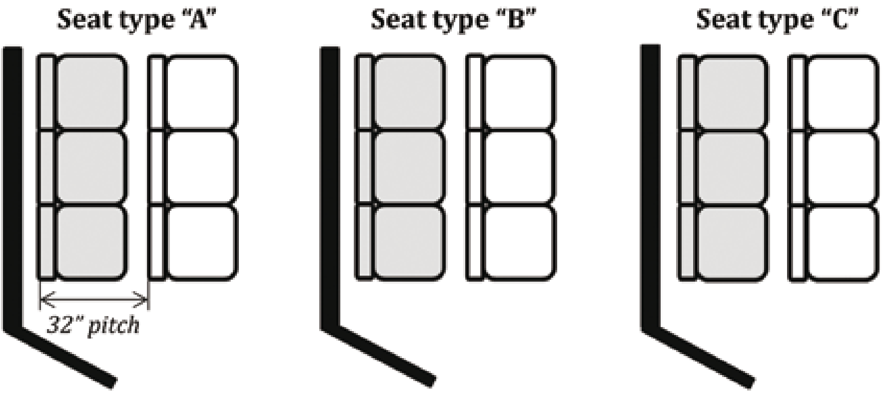

Figure 3.6 *Top view of experimental setting; participants were always seated in the second row.*

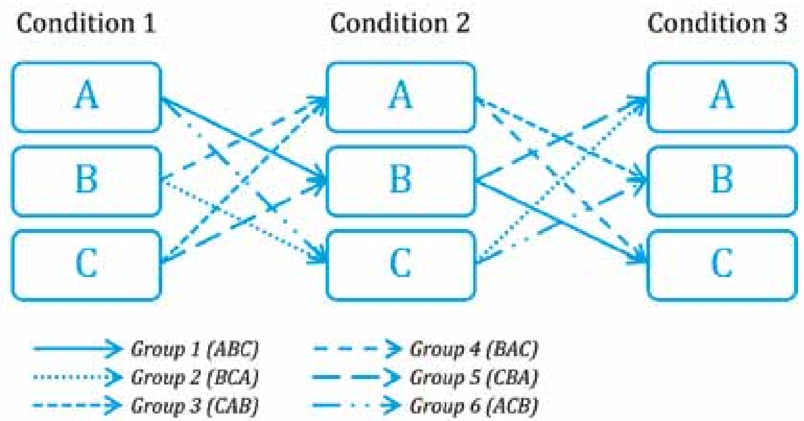

Figure 3.7 *Order of different type of seats for six groups of participants*

The online survey was a small survey aimed to identify the most refreshing activity for an aircraft passenger based on last flight experience. Respondents were asked details about their last flight, such as how long ago this was (last week; last month; last six months; last year; over a year ago), which airline they flew with, the duration of the flight (<2 h; 2-4 h; 4-6 h; >6 h), the class (economy; premium economy; business), and with which purpose (business; holiday). Questions on personal information included gender, nationality, age, standing height and weight.

Respondents were asked when they felt most refreshed during their last flight: after getting food; after watching a movie; after sleeping; after reading; after walking through the plane (e.g. visit bathroom). It was also possible to provide comments on this question.

3.3.2.4 Protocol

Three groups of three people participated in the aircraft seat test simultaneously. Each participant sat for 1.5 hour in each seat (total sitting duration was 4.5 hours). During each condition, four activities were simulated: upright sitting (for 'take-off'), eating and drinking, reading (an inflight magazine), and sleeping or relaxing (reclined). After every 1.5 hour sitting, participants were allowed a 15 min break to walk around, stretch their legs and have a toilet break. After the break, they completed the next condition in a different type of seat. The total experiment duration was approximately 6 hours and took place in one day.

At the start of each condition, the seats were covered by a white sheet, which was taken away just before sitting down. So, the first impression of the seats was based only by physical contact and not by visual appearance, as research has shown that this first view can have an influence on perceived comfort (Bronkhorst et al. 2001).

The survey (on most refreshing activity for aircraft passengers) was available online for one month in April 2013.

3.3.2.5 Data analysis

Local Perceived Discomfort scores were analysed in two ways: the development of discomfort in time and the average increase in discomfort per activity. First, the LPD scores from the participants at t=0 were subtracted from the LPD scores at consecutive times of measurement (t=15, t=30, t=45, t=60, t=75, t=90 min). One LPD score was calculated by summing up the LPD scores from each of the 22 body regions. These corrected and summed LPD scores were compared for each measurement time using Friedman's ANOVA (IBM SPSS Statistics 20). Furthermore, General Linear Model (GLM) repeated measures was used with condition (1, 2, 3) and time of measurement (t=15, t=30, t=45, t=60, t=75, t=90 min) as within subjects factors, and order of the seats as between subjects factor. Significance was accepted at $p<0.05$.

Second, the development of discomfort in time (ΔLPD) was calculated by subtracting each LPD score from the next time of measurement (e.g. T30-T15), thereby obtaining scores for T0-15, T15-30, T30-45, T45-60, T60-75 and T75-90. The duration of activities varied, which is why the increase in discomfort was averaged for a 15 min interval (i.e. activity take-off was done during T0-15, food during T15-30, reading during T30-45 and T45-60, and sleeping during T60-75 and T75-90). This resulted in an average 15 min increase in Local Perceived Discomfort per condition. Additionally, GLM repeated measures was used with condition (1, 2, 3) and activity (take-off, food, reading, sleeping) as within subjects factors, and order of the seats as between subjects factor. Significance was accepted at p<0.05. The activity walking was done between two conditions, and was calculated by subtracting T90 from the T0 from the next condition.

For the results from the survey, a Chi-square Test was used to compare the responses between short, medium and long haul passengers (<2 h, 2-4 h, 4-6 h, >6 h). Significance was accepted at p<0.05.

3.3.3 RESULTS

3.3.3.1 Local Perceived Discomfort

The development of Local Perceived Discomfort in time for each condition is shown in Figure 3.3. The first 15 minutes, participants were sitting upright for ‘take-off’ (T0-15). Food and drinks were served after 15 minutes (T15-30), followed by the activity reading (T30-60). For the last 30 minutes of every condition, participants were sleeping or relaxing (T60-90).

From Figure 3.8 it seems that the development of perceived discomfort is lower in the middle condition (condition 2) compared to the first and last condition. However, only at t=30 min (‘food’ activity), a significant difference (p<0.01, $\chi^2(2)=11.63$) was found between conditions, with the average LPD score for condition 2 being significantly lower than for conditions 1 and 3. A significant effect was found for time (p<0.01, F(2.76)=13.0), but no significant main effect was found for condition, nor were there significant interaction effects between condition, time and order.

Figure 3.9 shows the average 15 min development in local perceived discomfort (*ΔLPD*) for each of the four activities per condition. The activity walking was done between conditions 1 and 2 and conditions 2 and 3 and is shown separately. It seems that during take-off, *ΔLPD* is lower for the second and third condition compared to the previous conditions. Contrarily, for sleeping, *ΔLPD* seems to increase during the successive conditions. During the food activity in condition 2, *ΔLPD* is negative, meaning that the discomfort reduces during these 15 minutes. However, no significant main effects were found for condition or activity, nor were there significant interaction effects between condition, activity and order.

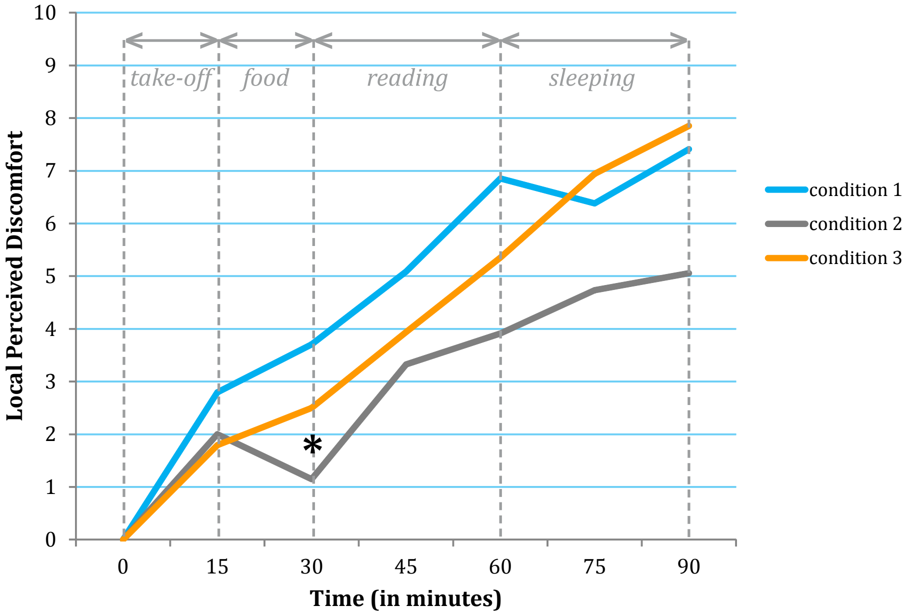

Figure 3.8 *Development of Local Perceived Discomfort in time for each condition (condition 1 is the first condition, condition 3 is the last condition). The asterisk (*) indicates a significant difference (p<0.01) at t = 30 min.*

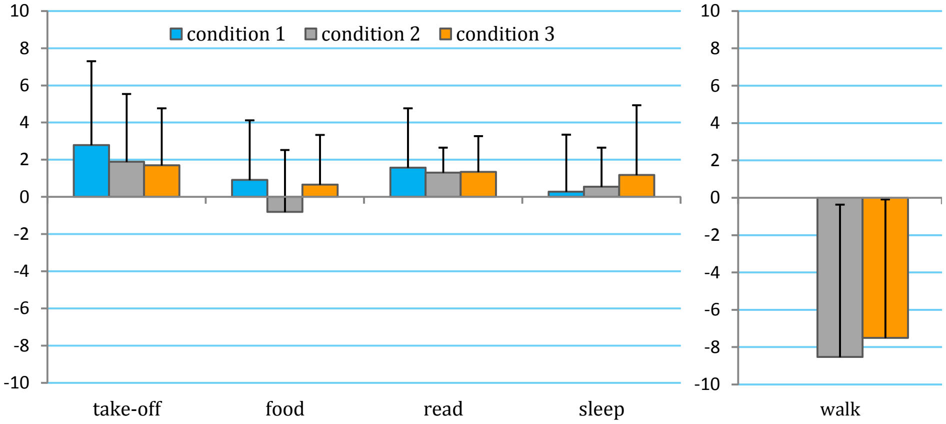

Figure 3.9 *Average 15 min development of discomfort for each activity per condition (left) and between two successive conditions (right). The activity walking was done between conditions 1 and 2 and conditions 2 and 3. Error bars indicate the standard deviation.*

3.3.3.2 Survey results

Overall, respondents from the survey indicated that they felt most refreshed during the flight after food (34.8%), after sleeping (27.0%) and after walking through the plane (25.2%), as shown in Figure 3.10. However, differences exist between passengers from short-haul (<2 hours) and long-haul flights (>6 hours). For short-haul passengers (n=38), most refreshing activities are food and sleeping, whereas for long-haul passengers (n=35), the most refreshing activity is walking through the plane.

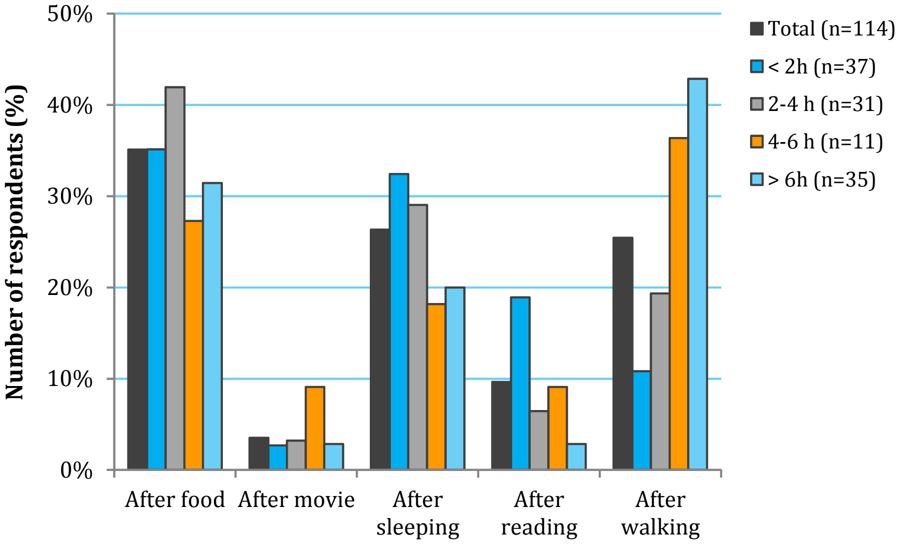

Figure 3.10 *Most refreshing activity according to respondents of the online survey (n=114), for short flights (<2 h), short-medium flights (2-4 h), medium-long flights (4-6 h) and long flights (>6 h).*

No significant effects were found for the duration of the flight. However, the percentage of respondents that felt most refreshed after walking through the plane seems to increase with the duration of the flight; where a little over 10% of short haul passenger (<2 h flight) indicated that they felt most refreshed after walking, this is more than 40% for long haul passengers (>6 h flight).

Four respondents (all with >6 h flights) additionally mentioned that they felt refreshed after getting a warm towel for refreshing the face and the hands.

3.3.4 DISCUSSION

The aircraft seat test has shown that the increase in discomfort is different for different activities. The survey seems to indicate that, depending on the duration of the flight, other activities are contributing to the refreshed feeling of passengers.

According to Helander and Zhang (1997), sitting discomfort is related to more physical aspects, such as uneven pressure, while comfort is related to luxury and refreshment. Short haul passengers (<2 h) indicated they felt most refreshed after food and sleeping, whereas long haul passengers (<6 h) indicated they felt most refreshed after walking through the plane. The results from the airline test also seem to indicate that the increase in discomfort is lower after participants had a 15 min break in which they could walk around the room.

Bazley et al. (2015) studied patterns of discomfort during the workday and throughout the workweek, and found that physical discomfort increased during the workday. During the workweek, discomfort was low at the beginning, increasing towards the middle of the week and decreasing again by the end of the workweek. From the results of the aircraft seat test, it seemed that the development of discomfort was lowest in the middle condition, and higher in the first and last condition. Although this seems the opposite of the findings by Bazley et al. (2015), perhaps the same mechanisms play a role here with regard to expectations and mood: during the first condition, participants do not know what to expect, while during the middle condition, participants are already halfway through the experiment and might get bored during the last condition, increasing their awareness of discomfort.

Since the survey was available online, it was possible for everyone to complete, and the authenticity of respondents could not be controlled. The answers from one respondent were deleted since these were clearly not authentic. Furthermore, respondents were asked to recall their last flight experience, which might be difficult to remember. For the majority of respondents (66%), their last flight was within the past six months. However, for 16% of respondents, their last flight was over a year ago.

That body movement is a key issue in preventing discomfort and providing comfort is in line with Hiemstra-van Mastrigt et al. (2015), who found that passengers who played an active seating game on the back seat of a car felt significantly more refreshed and more fit than when they were performing other activities, such as reading a book, working on a laptop or gaming on a tablet pc. From an airline point of view, passengers crowding in the aisle might not be a desirable prospect, but providing passengers with the possibility to play a game and move around in their seat could perhaps be a possibility to contribute to passengers feeling refreshed during a longer flight. This could be an opportunity for aircraft seat manufacturers. The development of discomfort (LPD) is not compared to a different order of activities. The order of the seats systematically varied for each participant, but the order of the activities was the same because this is the expected order when passengers are on a flight (i.e. first upright sitting for take-off; sleeping only after already sitting for a while). The durations of activities might be rather short for long-haul seats, but observations of train passengers by Groenesteijn et al. (2014) showed that the average duration of the activities reading and staring/sleeping were 28 min and 29 min, respectively. Furthermore, the activities performed in this study were imposed, which could have influenced comfort and discomfort ratings. In a natural setting, passengers might perform different activities besides reading and sleeping, such as using the in-flight entertainment system (IFE), for example to watch a movie, listening to music or talking to other passengers.

A significant difference was found in LPD score after 30 minutes (‘food’ activity) for condition 2 compared to conditions 1 and 3. Also, the *ΔLPD* during the food activity for condition 2 was negative, meaning that discomfort reduced in this time, however, this was not found to be significant. A possible reason for the difference in perceived discomfort during this time of measurement is that participants were offered a hot beverage (coffee/tea) and a biscuit during the first condition (1), and cold soft drinks and a candy bar in the last condition (3), whereas they received a complete hot meal during condition 2.

3.4 CONCLUSIONS ON CONTEXT CHARACTERISTICS

The aim of this chapter was to investigate the influence of the context characteristics, specifically performed activities and duration, on body posture and comfort. Two case studies have been described, one that investigated the influence of activities on posture and comfort in the back seat of a car, and the second that investigated the influence of activities and duration on discomfort and comfort perception of passengers in an aircraft.

Based on the first case study, several recommendations for car interior design supporting desired tasks can be formulated. There is a need for a solid laptop support, which will enable posture variation for the user, prevent shifting and minimizing the difference in vibrations between user and laptop. An arm support is needed for various tasks: for the laptop activity, arm support is needed while typing, whilst for using books, e-readers, tablets and smart phones arm support is needed to operate the devices, and to hold them up in order to prevent a flexed neck. People also looked for possibilities to turn/lean to one side while seeking support, to enable variation in posture, to create more leg room, to have conversations with fellow passengers or to look out the window. Future seat should offer more flexibility to do this. Finally, there is a need for varying the back rest angle in relation to the level of activity (low level, relaxed activities vs. high level, intense activities).

The aircraft seat test, part of the second case study, has shown that the discomfort increases in time, but that activities seem to have an influence on the development of discomfort. During eating and drinking, the increase of discomfort was lower than for other activities, and even decreasing when participants were offered a complete meal (compared to just drinks and a snack). Discomfort decreased significantly, however, after each 15 min break between conditions, in which participants were able to stretch their legs and walk around.

Respondents from the online survey indicated that they felt most refreshed after walking through the plane, especially the passengers from long-haul (>6 hours) flights. Similarly, in a study by Hiemstra-van Mastrigt et al. (2015), it was shown that car passengers felt significantly more fit and more refreshed after playing an active game while sitting on the back seat. It seems that movement is important to feel refreshed.

The results of the second case study therefore offer an interesting suggestion for airlines to distract passengers from feeling discomfort by providing food and drinks, and stimulate walking in the plane. Seat manufacturers, on the other hand, could minimize seat discomfort by stimulating passengers to move in their seat, e.g. by playing a game, to improve comfort by giving a more refreshed feeling.

This chapter has shown that it is important to support different activities, and that activities can also be used to distract passengers from feeling discomfort. Because different activities are associated with different postures, research is needed to investigate the different postures and how these could be supported by the seat.

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CHAPTER 4

ACTIVITIES, POSTURES AND COMFORT PERCEPTION OF TRAIN PASSENGERS

The previous chapter described different context characteristics and showed that the activities that passengers perform can influence their posture, and comfort and discomfort perception. However, for the design of comfortable passenger seats, insight is needed on the type of activities that passengers perform while traveling, in order to define the corresponding body postures, and shape the seat to accommodate these postures to improve the comfort of the seat.

This chapter describes what activities train passengers mainly perform and what corresponding postures occur. Based on observations during actual train rides, four main activities are identified: ‘Reading’, ‘Staring/sleeping’, ‘Talking’ and ‘Working on laptop’. Associated with these four activities, a top eight of different corresponding postures were observed. Results (Section 4.3) showed that body posture varied for each activity, and that comfort scores differed for different combinations of posture and activity. In Section 4.5, it is concluded that to create optimal support for different activities and corresponding postures, a variety of adjustability options is needed.

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4.1 INTRODUCTION

The way we work is changing (Manoochehri and Pinkerton 2003). Nowadays, information technology enables new ways of working. For example, in the USA, the number of teleworkers has grown by 73% between 2005 and 2011, reaching 3.15 million workers in 2011 (Global Workplace Analytics 2012) and indicating that telework is becoming an increasingly common work arrangement. Teleworking or telecommuting means working outside the company office building, which can be done not only at home or at an external location, but also while travelling. In the US, WorldatWork 2010 Telework Trendlines (2011) reported that, of the total of the US labour force, 16% had worked on an airplane, train or underground railway. For both employer and employee, it is efficient that travel time can be used to perform work tasks, and it allows employees to balance their work and private life better (Beauregard and Henry 2009).

Rail travel is a common way to travel to and from work in (sub)urban areas. Unlike driving in cars, trains allow the commuter to work using a palmtop computer, tablet, smartphone or laptop, particularly since some trains now offer Internet access. Ettema et al. (2010) showed that especially train passengers compared with other public transport passengers showed higher levels of engagement in, amongst other activities, working and making mobile phone calls. However, trains are still designed to transport people and not to provide them with a workspace (Vartiainen and Hyrkkänen 2010). Therefore, a potential disadvantage of working while travelling by train is that this mobile workplace may not facilitate an optimal working posture and that it is less comfortable and less productive for the worker compared to the office workplace.

Several studies in different countries on activities performed during train travel were carried out with survey or observations (Lyons et al. 2007; Watts and Urry 2008; Gripsrud and Hjorthol 2009; Thomas 2009; Russell et al. 2011; Ettema et al. 2012). The study of corresponding postures is not involved in these studies.

Although there have been studies regarding postures and activities on the train (Branton and Grayson 1967; Bronkhorst and Krause 2005), the way of working and telecommuting possibilities using technological devices have extremely changed since. Thus, new knowledge on postures and activities is needed to optimise train seats so that the traveller can both optimally work and relax. Kamp et al. (2011) recently published about observations of the activities performed and the associated postures adopted, while in semi-public/leisure situations and during train journeys, as inputs for seat design in cars. Not considered in this study is the duration of the activities, the experienced comfort, the gender, age and morphology of observed subjects. To create a comfort experience, it is important to consider the behaviour, the perception and also the diversity of users.

The aim of this study is to define scientifically based train seat requirements to make design guidelines for comfortable seats for current and future travelling by train. The study, presented here, is the first phase of an extensive study, and the aim is to determine the main activities performed by the passengers, their mainly adopted postures and their comfort experiences in a train seat. After this study two experimental studies will follow with adjustable mock-up seats for further definition of train seat requirements. The objectives of this study were:

1. to define what train's passengers mainly performed activities were in frequency and duration and which corresponding postures were adopted for the main morphology groups and;
2. to evaluate the comfort in relation to the performed activity and the required seat adjustments to provide a comfortable posture, adapted to the activity and corresponding postures.

In this study, this was done by observing the main activities performed by the passengers, observing their mainly adopted postures, and by questioning about their comfort experiences in a train seat.

4.2 METHODS

The activities and postures of the train passengers were observed during actual train rides mainly in France, and also in Belgium, the Netherlands and the UK. The observations were made in four different train types with five different seat types in both first and second classes. A part of the observed travellers (numbers are presented in results) completed a short questionnaire to evaluate the comfort experience in the context of their performed activities and in combination with their seat.

4.2.1 OBSERVATION TYPES

The goal of the observations was (1) to select the most performed activities, (2) to define for these activities the duration and frequency of occurrence and (3) to indicate the corresponding postures. In order to gather these data, two types of observations were performed. First, observations of momentary activities and corresponding postures were performed, in order to define the most performed activities of a large group of passengers (aimed at 500–1000 passengers) with the intention to define the most performed activities. Every passenger was observed only once, in order to get as many different persons' postures and activities.

Second, a smaller population (aimed at 50 passengers) was observed for longer period of time to study durations of performed tasks/activities and variations of activities in one journey. The duration of observation lasted approximately 1–2 h. The passengers' activity and postures were determined at the beginning of the observation, and after that real-time activity changes, posture changes and micro-movements (short movements without an actual posture change) were recorded.

4.2.2 OBSERVATION MEASUREMENT SYSTEM AND CONFIGURATION

Both the momentary and longer observations were performed with handheld personal digital assistants (PDAs) using a fully configured observation protocol. The observers were guided through the observations by this configuration and protocol. Every activity was indicated as a new data row in the database. Observing seat contact of body parts and the postures of body parts allows defining precisely what was the posture adopted by the passenger. The coding technique for postures was based on the coding technique of Branton and Grayson (1967) and is also used by Kamp et al. (2011). Each posture was represented by a set of five figures for seat contact and three for body part postures. The definition of the positions is more extended as the study by Branton and Grayson (1967) in order to obtain more detailed information of the postures, i.e. rotations and bending in different directions of body parts. The following variables were recorded per subject:

- Main characteristics of the ride (four inputs): train, car, class and type of seat.
- Main characteristics observed in a person (five inputs): seat position, seat number, sex, estimated age category (18–60 years or >60 years) and estimated morphology category (according to SNCF's earlier analysis on distinguishing morphology categories as input for seat design: (1) medium male or female, which is approximately within the 25th and 75th percentiles of length and weight; (2) small female, which is below the 25th percentiles of length and weight and (3) tall and large male, which is above 75th percentiles in length and weight. The fourth category 'other' is the exception in the former categories (for example tall in combination with low weight).
- Equipment (one input): book, laptop and position on table, lap or bag.
- Main activities (one input): working on laptop, listening to music, reading from paper, talking, writing, using PDA, making a call, staring or sleeping, eating or drinking and 'other activity'.

- Corresponding seat contact of body parts (five inputs); head contact on back/side/no contact, backrest contact on upper/middle/lower back, seat contact on back/middle/front part, foot contact on footrest/floor/wall/seat, arm contact on armrest/table/no contact (and all possible combinations).
- Corresponding postures of body parts (three inputs); head straight/ forward/ sideward/ asymmetric, trunk straight/ forward/ sideward/ asymmetric/ slumped, legs parallel or not/ crossed/ bended/ stretched (and all possible combinations).

4.2.3 COMFORT QUESTIONNAIRE

A comfort questionnaire was developed to evaluate the passengers' comfort experiences in combination with the tasks performed and in relation to seat design aspects. On a 10-point scale (1 = low, 10 = high), the passengers were asked about:

- their overall comfort experience;
- their seat comfort experience given their performed activity;
- their comfort experience on chair parts such as headrest, backrest and seat pan given their performed task/activity;
- their comfort experience on seating space and for the table.

In addition to the closed questions, passengers were asked to motivate their answers. They were also asked how to improve their comfort experience in interaction with the seat. Also, with graphic representations of seat parts (such as headrest, backrest, seat pan, footrest and tablets) passengers were asked which adjustments (height, length and depth) they preferred to support their activities. The questionnaires were offered in French, English or Dutch according to the language preference of the respondent.

4.2.4 PROTOCOL

The observers began the observation of momentary activities after a two-day training in observing and recording with the PDA. According to a predefined schedule, train rides were made to assess passengers during peak hours and more quiet periods. An observation scheme, of which seats to observe, was made to ensure random selection and to avoid selection due to preference of the observer. When the observers entered the rail car, they began observing passenger by passenger according to the observation scheme. Observations and the registration by PDA were done without notification of the passengers. Other than age (children and adolescents were excluded from observation), there were no specific exclusion criteria for observed passengers.

After the observations of the rail car were finished, the questionnaires were handed out to both observed and unobserved passengers. Questionnaire and PDA data were marked using a code, which typified seat number, time and train type. The observers then moved on to the next car and repeated the procedure.

In the second observation period, the duration observations were made. This protocol was similar to the momentary observations protocol except that the observers followed ongoing activities and postures of 2–3 persons simultaneously. After entering the initial activity and posture, real-time registrations were made of micro-movements, activity changes, posture changes and partial changes in posture during the observation period. The observation was ended when passengers left the train or when it was not possible to observe them anymore for other reasons.

4.2.5 DATA ANALYSIS

4.2.5.1 Momentary observation analysis

The aim was to identify the most common activities, i.e. the activities with the highest percentage of observation. The activities and postures with a low percentage of total observation were excluded from further analysis. Therefore, the following analysis steps were made:

1. removal of incomplete/faulty data files;
2. generation of an overview of frequencies of all activities and frequencies of morphology;
3. selection of the four main activities by identifying the observed activities with the highest frequencies of all observed activities;
4. selection of the main postures corresponding to the four main activities by identification of the highest frequencies of the combination of body part posture and seat part contact codes (head position, backrest contact, back posture and buttock seat contact). These recorded inputs represent the most important body parts and contact areas in relation to seat design. Arm and leg postures were excluded to reduce the possible combinations, as they appear less relevant than other criteria observed;
5. identification of a top eight of postures by selecting the posture-contact codes that cover 60% for each of the four main activities. This arbitrary cut-off was based on majority and data distribution. In order to find out whether the morphology distribution of the sample on which the top eight postures was based represents the observed population, it was compared to the morphology distribution of all observational data.

4.2.5.2 Duration observation analysis

The following analysis steps were made for the duration observation:

1. removal of incomplete/faulty data files;
2. generation of the frequencies of observed changes in activities and the variation in activities per observed subject;
3. determination of the average duration of activities over the subjects.

4.2.5.3 Comfort questionnaire analysis

The comfort scores for the seat, for the seat parts and for the preferred adjustments in seat parts were analysed in combination with the activity that passengers performed. Statistical analysis to compare comfort scores for different activities was done using the non-parametric Kruskal–Wallis test (for not normally distributed data) with a significance level of 0.05. For post hoc comparison, Mann–Whitney U analysis was used.

For each of the top eight postures, the average comfort score for the seat was extracted from the data using the connecting codes for observation and questionnaire per passenger. In this case, the data groups were too small and groups were very unequal in group size to carry out a sound statistical analysis.

The answers of the open questions were categorised and summarised per activity. When a topic was mentioned in more than 10% of the cases it was considered in interpretation.

4.3 RESULTS

4.3.1 OBSERVATIONS

4.3.1.1 Subjects momentary observations

After removal of incomplete/faulty data files, 786 observations were used for further analysis and characterised as:

- 287 females and 499 males;
- 702 persons of 18–60 years and 84 persons of >60 years;
- 293 first- and 494 second-class passengers.

Figure 4.1 shows the observation distribution in morphological groups for the momentary observations. The largest observed group by far is the ‘medium male or female’ category.

4.3.1.2 Activities momentary observations

The distribution of all momentary observed activities is shown in Figure 4.2. The selected top four mainly performed activities were Reading, Staring/sleeping, Talking and Working on laptop. This selection of activities covers 78% of all observed activities.

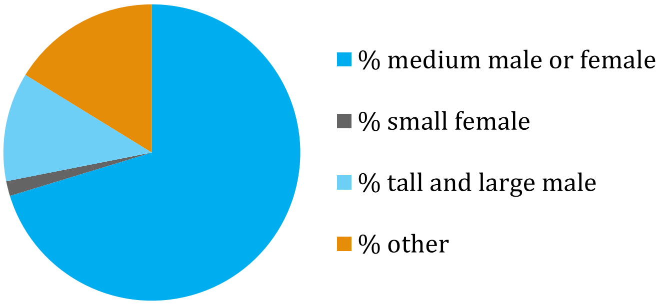

Figure 4.1 *Distribution of estimated morphology categories (in percentages of total) of the observed population (n = 786). Medium male or female is approximately within the 25th percentiles of length and weight; small female is below the 25th percentiles of length and weight and tall and large male is above the 75th percentiles in length and weight. The category 'other' 'represents the exceptions in the former categories (e.g. tall in combination with low weight).*

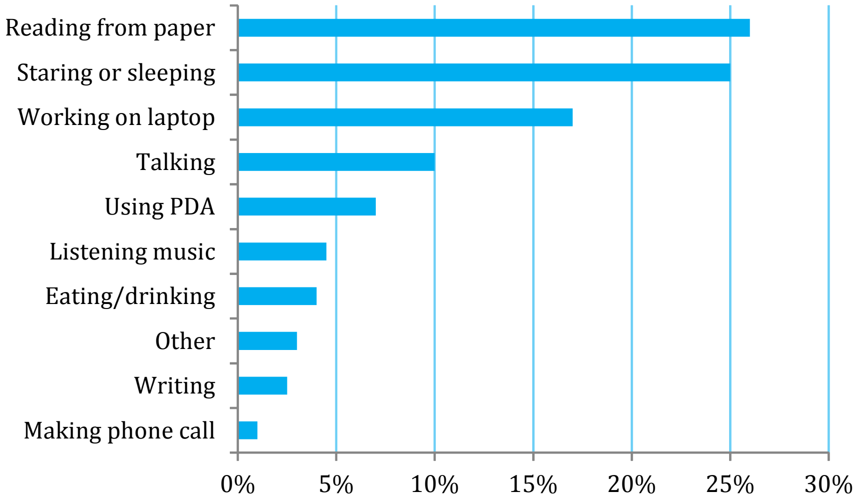

Figure 4.2 *Distribution of activities (in percentages of total) based on frequencies of 786 short observations.*

4.3.1.3 Subjects' duration of observations

Out of 48 subjects' observations, 30 observations contained useful data with observations of at least 10 min, for analysis. The distribution in subject characteristics was as follows:

- 9 females and 21 males;
- 25 persons of 18–60 years and 5 persons of >60 years;
- 21 middle/female, 4 tall large male and 5 others;
- 8 first- and 22 second-class passengers.

4.3.1.4 Duration for main activities

The observation time depended on the passengers' travel time in the seat and varied from 16 min to 2 h and 5 min. The average of 30 observations was 1 h and 11 min. During the observations, passengers changed activities between 2 and 26 times and the number of activities performed varied between 2 and 6. There is much variation between subjects in the number and duration of performed activities.

Figure 4.3 shows the average duration and the standard deviation for the main activities. Working on laptop was observed with the longest average duration of 53 min (range 14 min–1 h 52 min). Staring/sleeping (range 1 min–1 h and 29 min) and Reading (range 1 min–1 h and 8 min) were on average close with 29 and 28 min, respectively. Talking had an average duration of 17 min (range 1 min 36 min). All main activities had large standard deviations in duration showing the large inter-subject variety in observed activity duration.

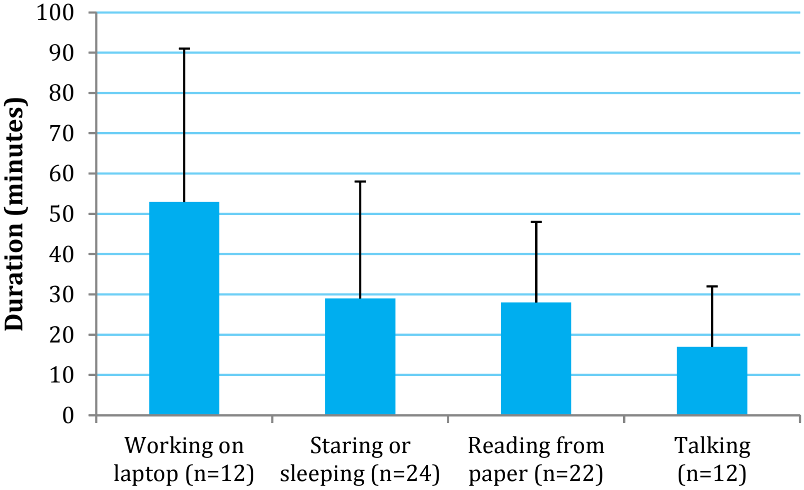

***Figure 4.3** Average duration (min) and standard deviation of four main activities of observed subjects.*

4.3.2 PERCEIVED COMFORT AND PREFERRED ADJUSTABILITY FOR TOP FOUR MAIN ACTIVITIES

4.3.2.1 Subjects comfort questionnaires

Out of the responses of 350 (146 female and 204 male) passengers who completed the questionnaires, 77 subjects were Working on a laptop, 56 subjects were Staring or sleeping, 111 subjects were Reading and 25 subjects were Talking.

4.3.2.2 Comfort scores

The average scores for the seats (as a whole) in relation to the mainly performed activities were not significantly different. In ranking, both Talking and Staring/ sleeping scored highest followed by Reading. Working on laptop scored lowest out of these four activities. Large standard deviations showed for all activities a large variety in perceived comfort in the seats.

For the seat parts, the comfort score for the headrest was significantly higher for Staring/sleeping compared with Reading. The average comfort scores for the headrest were in ranking the lowest compared with the other seat parts. For all seat parts, the large standard deviations showed a large variety in perceived comfort.

4.3.2.3 Preferred adjustability

The percentages of subjects who responded on the question "*To practice activities, which parameters of the < specific seat part > would you like to make adjustable?"* are shown in Table 4.1.

Table 4.1 *Percentage of subjects who prefer adjustability options on seat parts for the four main activities.*

Seat part	Laptop work	Reading	Staring/ sleeping	Talking
Headrest	71%	66%	66%	76%
Seat pan	62%	55%	48%	56%
Backrest	77%	74%	66%	64%
Table	79%	66%	48%	68%

The majority preferred adjustability options for nearly on all activities in combination with seat parts. For the activity Working on laptop, the table has the highest preferred adjustability followed by headrest. For reading, the backrest was the most important chair part to adjust. With Staring/sleeping, both headrest and backrest were most important to adjust. For talking, the headrest had the highest preferred adjustability.

4.3.2.4 Comments on open answer questions

The comments made in open answer part of the questionnaire showed that passengers preferred more legroom independent of the performed task. For Working on the laptop, passengers mainly addressed improvements for the table in format and adjustability. For Reading, the main issues that passengers mentioned to improve comfort were inclination of seat and backrest, and also the headrest adjustability is mentioned a couple of times. Regarding Staring/sleeping, passengers wished improvements in lumbar support and adjustability of the headrest. And for passengers who were Talking, they liked improvements in adjustability of the table and the seat inclination.

4.3.3 CORRESPONDING POSTURES AND PERCEIVED COMFORT

For the main activities Reading, Staring/sleeping, Talking and Working on laptop, the top eight most observed postures are shown in Table 4.2. It was verified that for this selection of eight postures, the morphological group had a distribution similar to the overall observed train passenger population.

Table 4.3 shows the observed posture–activity combinations and the corresponding comfort scores. Different postures were observed per activity and comfort scores varied in relation to the combination of posture and activity. For Reading, the posture with the highest comfort score was the posture with the head upright, the trunk backwards and full seat contact. This posture was also observed as one of the most corresponding postures of the three other main activities, but not with the highest comfort score for these activities. For Staring/sleeping, the posture with the highest comfort score was the posture with the head upright, the trunk upright and full seat contact. This posture was also observed in combination with reading and working on the laptop. Talking was rated highest on activity related comfort with the posture with the head sideward, the trunk backwards and full seat contact. This posture was also related to Staring/sleeping with a lower comfort score. For the activity Working on laptop, the comfort notes showed the least variation. The posture with the head forward, the trunk upright and with full seat contact was with 7.5 just higher than the other three postures. This posture was also one of the most frequently observed postures for reading.

Table 4.2 *Top eight of observed postures; for every posture the body part positions of head, trunk and seat contact are described and illustrated in a schematic representation.*

Number	Body part position	Schematic representation
1	Head upright Trunk backwards Full seat contact	
2	Head upright Trunk upright Full seat contact	
3	Head forward Trunk upright Full seat contact	
4	Head sideward Trunk backwards Full seat contact	
5	Head forward Trunk backwards Full seat contact	
6	Head sideward Trunk upright Full seat contact	
7	Head sideward Trunk slumped Middle and front seat contact	
8	Head sideward Trunk upright, rotated Full seat contact	

Table 4.3 *Main activities, corresponding postures and comfort scores (Question: How do you evaluate your comfort on your seat to practice this activity? Scale from 1 = not comfortable at all to 10 = very comfortable).*

Main activities	Postures and corresponding comfort scores							
Reading	8	7	7		7			
Staring/sleeping	6	8		6.5			6	
Talking	6.5			8		5.5		7
Working on laptop	7	7	7.5		7			
Posture								

4.4. DISCUSSION

The goal of this study was to define the activities that are mainly performed by train passengers and the corresponding postures that are adopted. Based on the momentary observations, four main activities were selected, presenting 78% of all performed activities: Reading, Staring/sleeping, Talking and Working on laptop. Associated with these four activities, the eight different postures that were mostly observed were defined based on the variations in head position, back posture and seat pan contact. The posture with the head upright, the trunk backwards and full seat contact was the observed posture that occurred in all four activities. Working on a laptop was the longest observed activity (average 53 min) and talking had the shortest duration (average 17 min). Comfort scores were not significantly different between activities except for headrest comfort. A significantly higher comfort score was found for the headrest with Staring/sleeping compared with Reading.

Nearly on all activities in combination with seat parts the majority prefers adjustability options to fit the chair to the performed activity. The passengers' comments show that besides improvements of seat parts such as seat and backrest inclination, headrest adjustability, tablet adjustability, improvement of space and mainly leg space are important issues. The top eight corresponding postures combined with comfort scores showed that per activity different postures were observed and the comfort scores varied in relation to the combination of posture and activity.

4.4.1 Activities

The four most observed activities concern both working activities and leisure activities are important to consider for train seat design. Interestingly, a comparable study of momentary observed passengers in German trains by Kamp et al. (2011) resulted in a slightly different main four of activities with talking/discussing, relaxing, reading and sleeping. The study considered only the frequency of the activities and not the duration or the perceived comfort. Kamp et al. (2011) observed as 5th activity 'using smaller and larger electronic devices', which includes PDA's and laptops as well. Ettema et al. (2012) found in a survey study that the activities undertaken most frequently during travel are relaxing (sleeping, resting and gazing outside or at fellow travellers) and entertaining (reading, gaming and listening to music). Less frequent activities are work/study, talking to other passengers and using information and communication technologies (ICTs) (phone calls, email and laptops).

In this study, the majority of trip lengths are shorter than 20 min, which could be too short to start up work activities. This appears partly supported by the study of Lyons et al. (2007) where window-gazing was high on short journeys and the authors suggest there may be 'a possible travel duration threshold below which there is not a suitable amount of time to do other than window gaze/people watch'. In a large British survey, reading for leisure, window gazing/people watching and working/studying were the frequent activities reported by passengers (Watts and Urry 2008). In Norway, Gripsrud and Hjorthol's (2009) train survey found well over a third of passengers using travel time for work, with nearly a quarter of commuters having their travel time paid as work time. In a New Zealand study (Thomas 2009), results showed that about a quarter of passengers had verbal interactions, and a quarter engaged in activities, the most common being reading/writing and listening to music. The reported differences between the main activities in these studies could be related to cultural diversity and habits between countries besides the above-mentioned travel time. There are also differences in scored categories for activities between the studies, which interfere with a detailed comparison of the studies.

4.4.2 Postures

For most observed postures, a full comparison cannot be made to the study of Kamp et al. (2011), as the observation categories and analyses are different. The first two mainly observed postures appear comparable to the postures found in this study though. According to the activity or performed task, passengers adopt different postures. Only one of the eight postures was observed in all four tasks.

This is supported by the study of Ellegast et al. (2012) who concluded that postures and the muscle activities of the erector spinae and trapezius muscles depend more on the tasks performed than on the use of a particular type of (office) chair. Mörl and Bradl (2013) also found a strong relation to lumbar spine posture within each task. Caneiro et al. (2010), demonstrated that the different observed sitting postures can affect the muscle activity. Different sitting postures affect head/neck posture and cervico-thoracic muscle activity. Slumped sitting was associated with increased muscle activity of cervical erector spinae compared with upright sitting with lordosis and stretched or relaxed thorax. Upright sitting showed increased muscle activity of thoracic erector spinae compared with slumped postures. According to the study of O'Sullivan et al. (2012), the use of a novel ergonomic chair facilitates a less flexed lumbar spine posture, while requiring less intense activation of the lower paraspinal muscles during a brief seated typing task. In this study, both upright and slumped sitting were observed. Neck symptoms are associated with forward head postures (Falla et al. 2007; Yip et al. 2008; Young et al. 2012), especially with performing a computer task. To reduce the muscle load and to avoid symptoms, it appears important to optimally support the train passenger in the most occurring postures and activities by the design of the seat.

4.4.3 COMFORT

In comfort scores, there are not many significant differences between activities and seat parts. This might be due to large variability in comfort scores and limited distinction on seat type and morphology group. Remarkable for the presented data is that for Staring/sleeping the highest average comfort note is related to a more upright posture. For staring, it might be useful to have a more upright posture for having a view out of the window, although this is still possible when leaning backwards. For sleeping, it is expected that a more backward leaning posture is preferred to give more support for the relaxation of body parts. The higher comfort score for the headrest with Staring/sleeping compared with Reading can be explained by more necessity of using the headrest for relaxation and the position of the headrest in relation to the Reading activity. The visual demands of the position of the reading material in this activity can play a role in a more forward head position (also stated by Lueder 2004). Without adjustable headrest it is not possible to use the headrest unless having the arms raised to bring the reading material in a higher position.

The slumped posture observed with Staring/sleeping has nearly the lowest comfort rate. This is only indicative as no significant differences were found. This is in line with the study of Vergara and Page (2000), where slumped postures with no lumbar contact report lower comfort level, while postures with back support of the lumbar area contribute to non-appearance of discomfort in the area.

With the combination of posture and activity, the comfort scores varied per activity in relation to the adopted posture. For example, for Reading, the posture with the highest comfort score was the posture with the head upright, the trunk backwards and full seat contact. This posture was also observed as one of the most corresponding postures of the three other main activities, but not with the highest comfort score for these activities. Another example was Talking, which was rated highest with the posture with the head sideward, the trunk backwards and full seat contact. This posture was also related to Staring/sleeping with a lower comfort score. From this, considering both activity and optimal corresponding posture appears important to create a comfort experience.

From the open comments, it is observed that passengers comment more often their negative note than their positive note. In addition, they often add a negative comment in a positive note. The responses to open-ended questions can clearly identify the negative aspects of the seat more than the positives. When they positively assess the seat comfort it is because the seat allows them to practice their activity properly. The ideal seat is an adjustable seat and (leg) space is an important issue. This is reported for airplanes as well (e.g. Vink et al. 2012). Ettema et al. (2012), in a more general sense, illustrated that the relationship between activities during travel and travel satisfaction is not straightforward. Activities during travel may not be undertaken to make the trip more pleasant, but to achieve satisfaction in other life domains at other times.

4.4.4 ADJUSTABILITY

The second main issue of this study was to see which seat adjustments are preferred by passengers to provide a comfortable posture while performing the activity and the various morphologies. The preferred adjustability by the passengers and the given suggestions are also found in other studies. Ziefle (2003) found that, with adjustable seat and backrest, individual work settings yielded a superior performance in a search computer task as compared with the standard. In addition, both performance and comfort improved when participants knew that they had adjusted the workplace. In the study of Groenesteijn et al. (2009), the preference for a more backwards (reclined) backrest in relation to a reading task was found compared with more upright backrest with computer use. This also implies the need of adjustability in relation to different tasks or activities. Lueder (2004) stated that the visual demands of the task and the reach distances can play a role in leaning forward, which assumes the necessity of also an adjustable table to create a better visualisation with (more) optimal posture. Rossi et al. (2012) also found that when using a front-back regulation for the laptop it is possible to stay closer and it provided a better view on the laptop screen. The participants in the study of Shin and Zhu (2011) positioned the touch screen closer and lower with more tilt when using the touch interfaces, in comparison to input devices such as keyboard and mouse, which also shows preferred adjustability of the table. Also, Young et al. (2012) showed the relationship between touchscreen tablet user configurations, which affect head and neck flexion angles. The study of Franz et al. (2012) showed that the majority of participants favoured the headrest with the adjustable neck support.

4.4.5 LIMITATIONS OF THE STUDY

By selecting the four main activities, 22% of the data were not used for further analysis. A second limitation of the study was the selection procedure of postures. The arm and legs postures were excluded. This was done because variability was really small for these variables. The third limitation was that no statistical analyses were performed between observed postures in relation to activities, as the variety in group sizes based on frequencies was too diverse and capriciously divided.

Another limitation is that the activity-specific findings in this study are influenced by the current design of train interiors. New elements to facilitate activity-specific design could be neglected. Other additional forms of research could be helpful this way.

Although this study described the postures and activities that a train interior should facilitate, the findings are useful for global requirements, which need more specification to be translated into design recommendations for train seats.

4.4.6 FUTURE RESEARCH

In future studies, the activity ‘Using PDA’ might be interesting to consider as the usage of this is growing. The goal of this observational study is to give directions for the design of train seats. As several researchers have shown (Corbridge and Griffin 1991; Khan and Sundström 2004; Krishna Kant 2007; Khan and Sundström 2007; Bhiwapurkar et al. 2010), a dynamic situation often influences the chosen activities. Vibrations and unexpected movements of the train have an influence on the comfort experience of passengers and should therefore be studied as well in onward experiments. For the development of comfortable passenger seats that allow mobile working or teleworking, it is important to consider the different activities passengers want to perform, and the difference in morphology between passengers should be addressed in relation to seat characteristics.

4.5 CONCLUSION

This research is the first phase of an extensive study, and the aim here was to determine the main activities performed by the passengers, their main corresponding postures and their comfort experiences in a train seat. Based on the momentary observations, four main activities were selected, presenting 78% of all performed activities: Reading, Staring/sleeping, Talking and Working on laptop. The type of activities performed also appears to be related to the length of the journey and on cultural properties (Ettema et al. 2012; Watts and Urry 2008; Lyons et al. 2007; Gripsrud and Hjorthol 2009). Associated with these four activities, eight different postures were found based on the variations in head position, back posture and seat pan contact. The posture with the head upright, the trunk backwards and full seat contact was the observed posture that occurred in all four activities. For passenger seat design, it is important to optimally support at least this posture with the seat. Second, the seat should support different activities, at least the main four activities mentioned earlier with their corresponding postures. To reduce the muscle load and to avoid symptoms, optimally supporting the train passenger in the most occurring postures and activities by the design of the seat appears important. Working on a laptop is the longest observed activity, but it is also the most constraining activity due to the connectedness with input devices and screen. Therefore, it is really important to create optimal support for postures with this activity to avoid musculoskeletal risks.

The second objective of this study was to evaluate the comfort in relation to the performed activity and to define the required seat adjustments to provide a comfortable posture adapted to the activity and corresponding postures. Comfort scores were not significantly different between activities except for headrest comfort. A higher comfort score was experienced for the headrest with Staring/sleeping compared with Reading. The headrest appears to have a better fit for Staring/sleeping. Nearly on all activities in combination with seat parts the majority of passengers prefer adjustability options to fit the chair to the performed activity. Adjustability options for seat parts can provide different postures, can meet the variety in morphology and can provoke a better task performance when optimally adjusted. The passengers' comments show that besides improvements of seat parts such as seat and backrest inclination, headrest adjustability, tablet adjustability, improvement of space and mainly leg space are important issues. This is also reported in other transportation studies (Vink et al. 2012). The top eight corresponding postures combined with comfort scores showed that per activity different postures were observed and the comfort scores varied in relation to the combination of posture and activity. Again, this supports the conclusion that to create optimal support for different activities and corresponding postures a variety of adjustability options are needed.

The outcomes of this study are used as input for two experimental studies with a mock-up passenger seat for both static and dynamic experiments.

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CONCLUSIONS FROM PART I. CONTEXT

This first part explored the underlying factors for the Context level.

Chapter 3 described the context characteristics, in particular passengers' performed activities, that influence comfort and discomfort. The first case study showed that posture characteristics of passengers in the rear seat of a car are dictated by the seat, and that differences in posture and differences in the amount of variation in postures are seen for different activities. From the second case study, it appeared that performed activities in an aircraft seat influences the development of discomfort in time. Food, in particular a complete meal compared to drinks, seemed to reduce discomfort. Respondents from the online survey indicated that they felt most refreshed after food, after sleeping and after walking through the plane. The importance of walking in the plane to feel refreshed increases with the duration of the flight.

In Chapter 4, four main activities and eight corresponding postures have been defined for train passengers based on an observation study. Comfort scores were not significantly different between activities except for headrest comfort, which was higher for staring/sleeping activities compared to reading activity. Adjustability options for seat parts are preferred by passengers, so the seat can provide different postures, to provide better support for the performed activities and to meet the variety in human characteristics.

The next part will discuss the influence of human characteristics on the perception of comfort and discomfort of passengers.

Part II.

HUMAN

The conceptual model in Chapter 2 presented three levels: Human, Seat, and Context. The previous part explored the Context level; subsequently, this second part explores the underlying factors for the Human level, in particular passengers' anthropometry. In Chapter 5, the human characteristics that influence comfort and discomfort are described and are illustrated by two case studies. Chapter 6 describes an experimental study on the comfort and discomfort perception of a train seat for different activities and postures. It is studied what ideal seat parameters are, and which of these are related to anthropometric dimensions, and which to the activities or postures of passengers.

CHAPTER 5

HUMAN CHARACTERISTICS THAT INFLUENCE COMFORT AND DISCOMFORT

In this chapter, the human characteristics that influence comfort and discomfort are described (5.1) and are illustrated by two case studies in sections 5.2 and 5.3. The first case study (5.2) compares the anthropometric characteristics of passengers with common dimensions for economy class aircraft seats. It shows that aircraft seats exclude 8-21% of passengers based on seated hip width, not due to the width of the seat pan but due to the distance between the armrests. Furthermore, the seat pan height is too high for up to 50% of passengers. The second case study (5.3) describes the correlations between anthropometric measures and body posture measured in an aircraft seat. Finally, it is concluded in section 5.4 that, although the width of the seat pan is wide enough for 95%, 8-21% of the Dutch male and female population aged 20-60 years does not fit between the armrests of the seat, due to their seated hip width. Furthermore, the comfort and discomfort ratings seem to differ for passengers of different stature.

The case study in Section 5.3 is submitted for publication:

Hiemstra-van Mastrigt, S., Brauer, K., Vink, P. (Submitted). Effects of anthropometry and tasks on posture and discomfort in an aircraft seat. *International Journal of Human Factors and Ergonomics*, Submitted.

5.1. INTRODUCTION ON HUMAN CHARACTERISTICS

Human characteristics include a number of characteristics, such as age, nationality, gender and body dimensions. In this thesis, the focus is on anthropometric variables, such as stature and weight. However it is important to keep in mind that anthropometric variables are related to age, nationality and gender, and is also subject to secular trends.

Anthropometry is the scientific study of measurements of the human body. When designing passenger seats, anthropometric data are a valuable source of information to determine seat dimensions, but also to evaluate seats. It is important to note, however, that the average passenger does not exist, and that it is very uncommon for a person to have multiple body dimensions that are average. A tall person in stature might not have the largest measurement for other body dimensions as well. Consequently, there is also no 5th or 95th percentile passenger. The level of correlation between different body dimensions varies;, for example, the correlation coefficient between stature and popliteal height is 0.82 (with 0 = no relationship and 1 = a perfect positive relationship), while the correlation between stature and hip breadth is considerably less with 0.37 (Kroemer 1989).

5.1.1 ANTHROPOMETRIC VARIABILITY

Anthropometric variability is mostly related with ethnicity, gender and age (Jürgens et al. 1990). However, anthropometric characteristics also change over time, but not always at the same rate. Molenbroek (1994), for example, found that stature in the Netherlands increased between 1965 and 1980 more rapidly, but that the growth rate decreased between 1980 and 1992.

Ethnicity

The majority of body dimensions follows a normal distribution. However, the normal curve looks different for different populations. A 95th percentile male from the Netherlands is taller than the 95th percentile males from Japan or North America, as can be seen in Figure 5.1. In fact, the 95th percentile male from Japan corresponds with a 50th percentile male from the Netherlands.

In addition, populations do not only differ in overall body size, but also in ratio (measure of body proportions). For example, Japanese torsos are proportionally longer than their legs, as compared to most other populations (Kennedy 1976), while the Turkish population has relatively small arms compared to Western European populations (Ali and Arslan 2009).

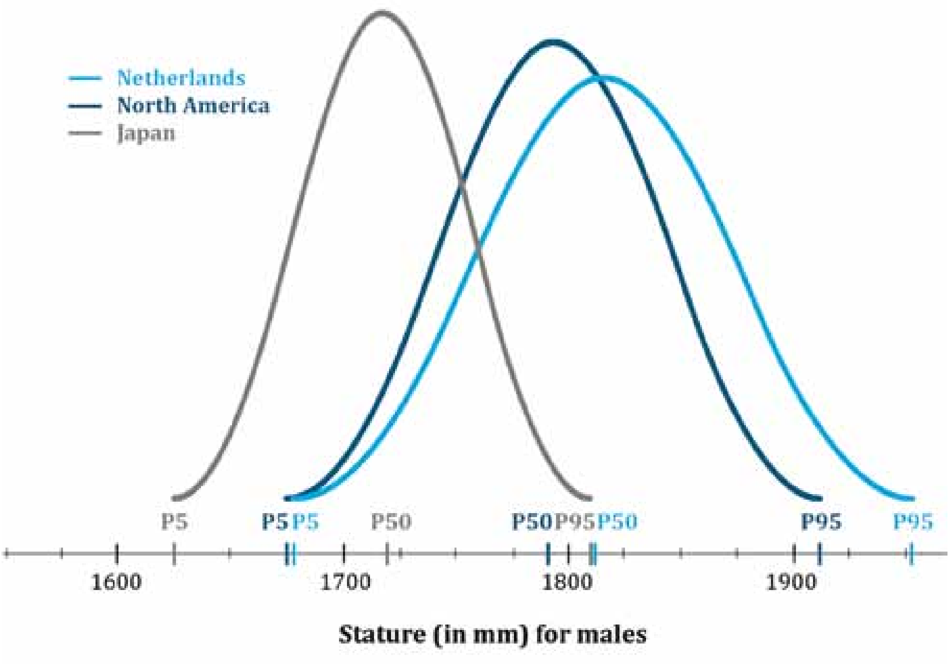

Figure 5.1 *Stature distibution of different male populations: the Netherlands, North America and Japan (dimensions obtained from DINED)*

Age

According to Perissinotto et al. (2002), specific anthropometric reference data are needed for elderly populations, because the anthropometric standards from adult populations may not be appropriate due to changes in body composition that occur during ageing. For example, stature decreases with age, most likely due to shrinkage that occurs in the intervertebral discs of the spine. This starts at around 40 years of age, and is very rapid between age 50 and 60 (Ali and Arslan 2009). Weight, however, increases steadily until the age of 50-55 years, after which it starts to decrease (Ali and Arslan 2009).

Furthermore, the mobility of passengers decreases with age, which is especially relevant for the in- and egress in aircraft seats. For example, a study by Lijmbach et al. (2014) shows that elderly people need more time before sitting down and use more hand and foot movements compared to students.

Ortman et al. (2014) state that the US will experience considerable growth in its older population between 2012 and 2050, where in 2050, the population aged 65 and over will have almost doubled to 83.7 million.

Gender

The average stature of a Dutch male between 20 and 30 years old is 1848 mm, which is 161 mm taller than the average Dutch female (1687 mm). A seat that is designed for the 5th to 95th percentile male would therefore fit 90% of men, but less than 40% of women, since the stature of 5th percentile male, 1716 mm, corresponds with a 66.7th percentile female. Seats should be designed for a population of male and female passengers.

Furthermore, the body proportions differ for males and females. For example, the average hip breadth sitting is approaching the average shoulder breadth (bideltoid) for Dutch females (402 vs. 422 mm), whereas this difference is 82 mm in Dutch males (388 vs. 470 mm).

Secular trends

Changes in life styles, nutrition and ethnic composition of populations lead to changes in the distribution of body dimensions (Pheasant and Haslegrave 2006), which is why regular updating of anthropometric data collections is necessary.

Although the trend of increasing height has been gradually slowing or stopping in many populations (Godina 2008), there is a strong tendency towards increasing weight and obesity in many European countries and the USA (Komlos and Baur 2004). In the last twenty years, the number of people in the USA who are considered “obese” has doubled. Matton et al. (2007) also found an increase in weight, stature and BMI in Flemish adolescents between 1969 and 2005, while physical fitness declined.

For products with a relative short lifetime, this might not be relevant, but for vehicles such as aircrafts and trains, the development time is long, as well as the expected lifetime, and designers have to anticipate on changing body dimensions. For example, the hip width of the P95 Dutch male has increased from 408 mm in 1982 to 440 mm in 2004 (DINED 2004).

5.1.2 ANTHROPOMETRIC DATABASES

Anthropometric databases can be very helpful for designers. However, a disadvantage of a majority of anthropometric databases is that these have been obtained for military populations. This means that the database is often restricted to males of a specific height and age.

DINED is an open dataset, available at www.dined.nl (Figure 5.2). With DINED, it is possible to select different populations, e.g. Dutch children (2-3 years) or North American adults. Populations can also be combined, to create a new group, e.g. combining specific age groups or male/female distribution. Although this will decrease the reliability of the information, this might be a good way to obtain an indication of the characteristics of the passenger population.

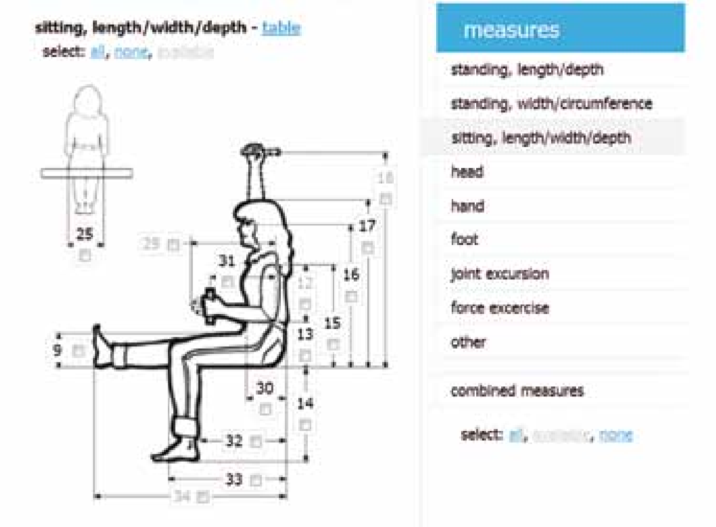

Figure 5.2 *Anthropometric database DINED (screenshot obtained from dined.nl)*

After selecting or combining populations, percentiles can be calculated by entering dimensions (for evaluation), or body measurements can be calculated by entering percentiles (for design). To illustrate this with an example, the P95 seated hip widths can be obtained from the DINED database. P95 means, in this case, that 95% of the males have a smaller hip width. The P95 hip width for males living in the Netherlands is 440 mm (see Table 5.1). So, in the Netherlands, 95%, of the male passengers fit into a seat that has a width of 440 mm (17.3 inch). As can be seen in Table 5.1, the hip width in Japan and North India is smaller, and in those countries, a seat with a width of 348 mm and 330 mm, respectively, would be sufficient for 95% of the male population.

Most adjustability is needed for the body dimensions that have the greatest variation. Dowell et al. (1995) for example, found a large diversity in lumbar heights. Preferably, a lumbar support should therefore be adjustable in height.

Table 5.1 *The P95 hip width for males in different regions of the world (figures obtained from DINED.nl; last accessed February 3, 2015)*

Region	Hip width of 95th percentile males (in mm)
North India	330
Japan	348
Australia	370
Middle East	370
Latin America	388
North America	394
Central Europe	404
The Netherlands	440

5.1.3 AIM OF THIS CHAPTER

A well-designed seat should fit the passenger. Taking into account the anthropometric variability of passengers is one of the ways to provide a better fit. Using information from anthropometric databases is useful for designers. However, passengers usually change their posture during the trip, and passengers of different body sizes might perceive comfort and discomfort differently. Therefore, the aim of this chapter is to investigate the influence of the human characteristics, specifically passengers' anthropometry, on body posture and comfort and discomfort perception. To do that, two case studies will be presented: the first case study compares current seat dimensions to anthropometric measurements, while the second case study investigates the influence of anthropometry on body posture and comfort of aircraft passengers.

5.2 CASE STUDY: ANTHROPOMETRIC CHARACTERISTICS VS. AIRCRAFT SEAT DIMENSIONS

5.2.1 BACKGROUND

In the home environment, Teraoka et al. (2005) found that shorter people had a preference for smaller chairs, and taller people for larger chairs. A wrong seat height can cause uncomfortable pressure on the backs of the thighs (Bush 1969). A too wide seat pan prevents the passenger from using the armrests, while a too deep seat pan prevents the passenger from using the backrest (Occhipinti and Colombini 1985), and restrict blood flow to the legs. Thus, anthropometrics need to be considered when designing a seat.

For example, aircraft manufacturer Boeing has set up spatial comfort guidelines, which are largely used in the airline industry. These Boeing guidelines are based to a large degree on selected data from CEASAR (2000). Various attributes of a seat rated as an A, B, C, or D. The Boeing guidelines are illustrated in Figure 5.3 and Table 5.2 (obtained from Vink and Brauer 2011).

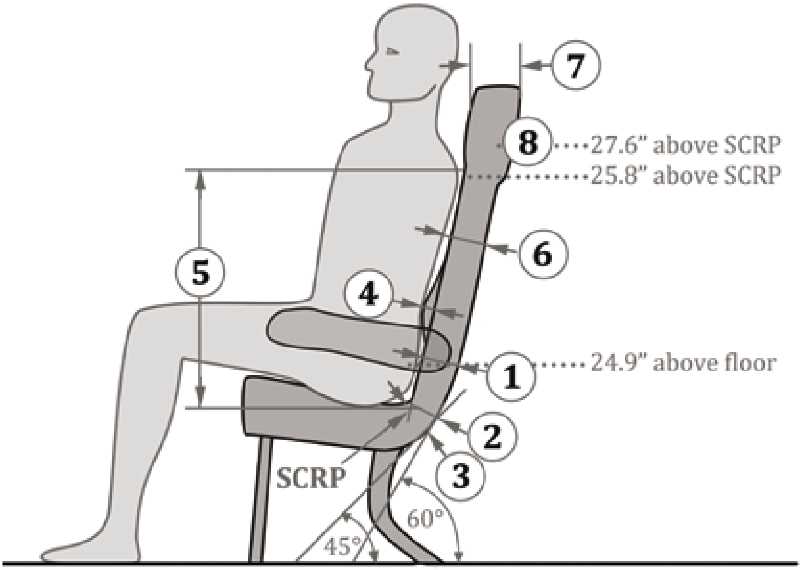

Figure 5.3 *Boeing guidelines for seat comfort (illustration redrawn by author)*

Table 5.2 *The thickness or space (in inches) required to get a comfort grade for a seat according to Boeing guidelines (numbers in left column correspond with Figure 5.3)*

		Comfort grade			
Legroom space		A	B	C	D
1	Thickness at knee height (24.9” above floor)	<1”	1”–2”	2”–3”	>3”
2	60° shin clearance (from SCRP)	<0.8”	0.8”–1.7”	1.7”–2.5”	>2.5”
3	45° shin clearance (from SCRP)	<0.5”	0.5”–1.2”	1.2”–1.9”	>1.9”
Back and shoulder space		A	B	C	D
4	Lumbar depth	<0.5”	0.5”–0.8”	0.8”–1.1”	>1.1”

Table 5.3 *(continued)*

5	Shoulder obstruction height	>25.8”	24.8”–25.8”	23.7”–24.8”	<23.7”
		Comfort grade			
	Working, eating and visual space	**A**	**B**	**C**	**D**
6	Upper back thickness	<1.5”	1.5”–2.5”	2.5”–3.5”	>3.5”
7	Headrest thickness	<1.5”	1.5”–2.8”	2.8”–4”	>4”
8	Space between seat backs (27.6” above SCRP)	>4”	3”–4”	2”–3”	<2”

The aim of this case study is to evaluate how well current aircraft seats fit the passenger. This will be done by comparing the dimensions of three aircraft seats to corresponding anthropometric measurements.

5.2.2 METHOD

For three most common economy class seats from leading aircraft seat manufacturers, the dimensions of the seat have been measured. These dimensions have been compared to a database with anthropometric dimensions (DINED, 2004). The percentage of passengers has been calculated that does not fit or cannot reach the floor. The Dutch population aged 20-60 years has been used for this study because this database has the most complete body dimensions. In Table 5.3, the related anthropometric measurement is shown for each of the seat dimensions.

Table 5.3 *Seat dimensions and related anthropometric measurements*

Seat dimension	Anthropometric measurement
Table-seat pan distance	Thigh clearance
Seat pan width	Seated hip width
Distance between armrests	Seated hip width
Knee space	Buttock-knee depth
Seat pan height	Popliteal height

Table-seat pan distance was measured from the bottom of the table to the top of seat pan cushion. The width of the seat was measured at the seat pan cushion. The distance between the armrests was measured at the top (widest part) of the armrests. The knee space was measured from the backrest to the back of the backrest of the row in front, at 10 mm above the seat pan, and was measured for a straight as well as reclined backrest. Finally, the seat pan height was measured from the top of the seat pan cushion (front) to the floor.

5.2.3 RESULTS

As can be seen in Table 5.4, the percentage of the Dutch population (mixed male and female) aged 20-60 years that does not fit changes per seat and seat dimension. Almost 100% of this population will have enough thigh clearance to fit between the table and the seat pan (note that elbow height is not considered for this dimension). The width of the seat pan is comparable for the three seats, fitting 95% or more of this population. Seat B, which had the widest seat pan, also has the narrowest armrest, limiting the percentage of passengers that does not fit between the armrests to 7.9%. Seats A and B, however, exclude 18.5% and 21.4%, respectively, of passengers that have a seated hip width that is greater than the distance between the arm rests.

Less than 1 percent of this population has a buttock-knee depth exceeding the length between the backrest and the back of the backrest of the row in front. However, the percentage of this population that will not be able to reach the floor due to the seat pan height which is too high ranges from 27.4% (Seat B) to 51.0% (Seat C).

Table 5.4 *Seat dimensions and percentage of the population that does not fit (DINED 2004, age 20-60 years, mixed male and female population).*

Seat dimension	Percentage of population that does not fit		
	Seat A	Seat B	Seat C
Table-seat pan distance	1.2% (183 mm)	<0.01% (209 mm)	0.01% (205 mm)
Seat pan cushion width	0.4% (475 mm)	0.3% (480 mm)	0.5% (473 mm)
Distance between armrests	18.5% (425 mm)	7.9% (440 mm)	21.4% (422 mm)
Knee space (upright-reclined)	<0.05% (750 mm)	<0.2% (730-750 mm)	<1.0% (710-740 mm)
Seat pan height	38.2% (451 mm)	27.4% (439 mm)	51.0% (464 mm)

From this comparison, it appears that the number of passengers that will fit into the seat will probably be highest for Seat B. Furthermore, the armrest needs to be taken into account when designing for the seated hip width. For 27.4-51% of passengers, the seat pan height is too high to reach the floor. On the other hand, lowering the seat pan height might result in problems for the taller passengers, as they would have to increase their upper leg angle, and getting up from the seat might be more difficult. Perhaps this seat height could be a compromise if shorter passengers are able to use a footrest. Also, the use of high heels could increase the popliteal height.

5.2.4 Discussion

Since the 70's (Oborne 1978; Richards and Jacobsen 1977; Vink and Brauer 2011), leg room has been reported as the biggest problem for passengers. However, results from this study show that knee space of these three aircraft seats is sufficient when compared to the buttock-knee depth. This could be due to the used seat pitch (distance between seats) in this study, which was 32", while the pitch in regular economy class can vary between 28" and 34" (SeatGuru.com). For instance, Spirit Airlines in the USA has a pitch of 28" in their A320, while JetBlue in the USA has a pitch of 34" in their A320 (SeatGuru.com). In addition, comparing to anthropometric measures considers a static posture of the passenger, while passengers perform different activities during a flight, thereby changing their posture (e.g. Groenesteijn et al. 2014). The thickness of the backrest is very relevant here; a seat with a thin backrest provides more leg room than a seat at the same pitch with a different thickness of the backrest. In addition, buttock-knee depth is not the only relevant body dimension, but shin clearance determines the freedom of movement.

Another result from this study is that the width of the seat pan is not so much a problem (>95% fits), but the distance between the armrests is. Up to 21.4% of the population in this study (Dutch, 20-60 years, male and female) has a seated hip width which is wider than the distance between the armrests. While the seat pan width is comparable for the three seats, Seat B has a more narrow armrest (40 mm compared to 50/51 mm), allowing more passengers to fit between the armrests. If the armrests are foldable, this might not be a problem during ingress and egress, but it might be uncomfortable for the passengers who put the armrests down while seated. On the other hand, a more narrow armrest can provide less support for the arms, especially if it is shared by two passengers. One solution could be to provide more space under the armrest, i.e. a large surface on top but tapered towards the bottom (see Figure 5.4) to provide more space for the passengers' hips.

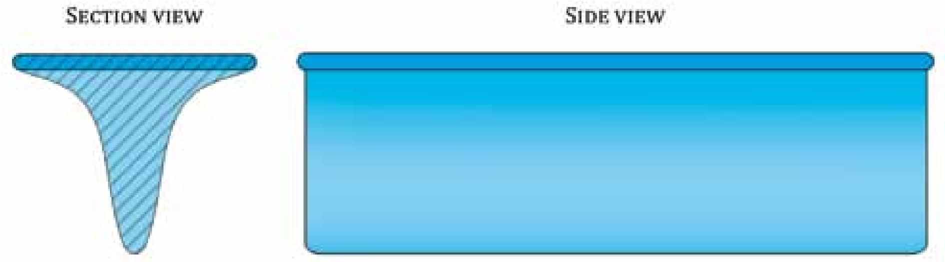

__Figure 5.4__ Section view of a tapered armrest (illustration by author)

5.3. CASE STUDY: EFFECTS OF ANTHROPOMETRY AND TASKS ON POSTURE AND DISCOMFORT IN AN AIRCRAFT SEAT

5.3.1 BACKGROUND

Today, people are constantly on the move, travelling for many reasons, such as business, leisure and family visits. Travelling by plane is growing and opportunistic for airlines. A study of Vink et al. (2011) among 10,032 passengers shows that the interior of airplanes is significantly improved, but especially in the seat there is still much possibility for improvement. Legroom and personal space (space for arms, shoulders and head and stowage close to the passenger) in particular result in lower comfort ratings. According to Brauer (2004), an increase of 1% passenger revenue has an impact on profitability for the airline which is fourteen times greater than 1% reduction in maintenance costs. In order to attract more passengers, data are needed to determine the selection behaviour of passengers, according to Brauer (2004). It appears that passengers first select on point-to-point transport, time and price, then on aspects like marketing (frequent flyer programmes), followed by comfort, past experiences and delays. For short distances the delay aspect is more important as opposed to long distance travel, where the comfort aspect plays a more important role.

Several studies showed that performing different tasks or activities in work environments causes variations in user postures and movements (Babski-Reeves et al. 2005; Dowell et al. 2001; Ellegast et al. 2011; Groenesteijn et al. 2012; Van Dieën et al. 2001). Therefore, it is likely that different activities need different seat characteristics to accommodate the variety in postures and movements. An indication was found that office workers performing a reading task preferred a larger backrest inclination range compared with a VDU task, in an experiment by Groenesteijn et al. (2009) with a focus on activity support of the office chair.

Branton and Grayson (1967) were the first with their observation of train passengers to report that tall persons sat longer than short persons in postures with knees crossed, particularly when slumped. Compared to the tall persons, the short persons sat more with two feet on the floor. In research about home furniture, Teraoka et al. (2005) also found differences between tall and short persons. In comparison with tall persons, short persons had in this case less feet contact with the floor or less contact with the backrest in combination with a slumped posture. Ciaccia and Sznelwar (2012) concluded based on an observational study with only five participants that these participants adopted very similar postures for both reading and resting in order to avoid discomfort, despite having different anthropometric characteristics.

It also appears that users' seat preferences in relation to function type differ in divergent functions (Legg and Mackie 2002). It is assumed that this is related to a different mixture of activities with different relative duration of activities causing different body dynamics during seat use over the day. To build support for this assumption, firstly, more knowledge is needed on posture characteristics in different tasks and their corresponding comfort experience, leading to the research question:

What are the effects of anthropometry on posture in aircraft seats while performing different activities (reading and relaxing), and how does this influence the comfort and discomfort perception of the passenger?

5.3.2 METHOD

5.3.2.1 Research seat

For the research seat, dimensions were chosen to reflect the upcoming generation of aircrafts, such as the Boeing 787 and Airbus 350. Therefore, the angle of the seat pan was set at 7 degrees with respect to the horizontal plane (corresponding with 4 degrees to the inclined floor) and the backrest at 19 degrees with respect to the vertical, corresponding to a typical aircraft seat when partially reclined. A 3 degrees inclined floor was used for the tests to simulate the slope of an airplane at cruising altitude. The dimensions of the 2011 Pinnacle seat from B/E Aerospace were used to determine the dimensions of the wooden frame of the seat in the research set-up. The pitch was set at 30 inch (0.762 m), which is comparable to an average economy class airplane. The depth, width and height of this seat were 480, 450 (between the armrests) and 336 mm, respectively (Figure 5.5, left). A row of aircraft seats was placed in front of the seat to simulate legroom (Figure 5.5, middle). In the seat, on top of the pressure mat, a free-formable mattress was used that could be moulded by the participants so that they were able to find the most comfortable position possible (Figure 5.5, right).

5.3.2.2 Participants

A careful selection of people from Asia, America, Europe and Africa was made and care was taken that participants varied from 5th to 95th percentile (P5-P95) regarding stature and weight, and that enough people older than 40 years were involved. Therefore, we asked students and citizens of Delft to complete a list with their nationality, age and anthropometrics. We selected from this group and searched specifically for additional participants to include for missing representatives.

In total 28 people (13 female, 15 male) were selected to participate in the research. Their average age was 34 (SD=12.9) years in a range between 22 and 65 years old. Concerning nationalities, 6 of the participants were Asian, 3 were African, 17 were European and 2 were South-American. The mean stature of participants was 1.71 (SD=0.11) m with a minimum of 1.51 m and a maximum of 1.93 m. Their mean body mass was 73.7 (SD=19.9) kg with a minimum of 45 kg and a maximum of 116.8 kg.

Figure 5.5 *Research seat, from left to right: dimensions; complete construction with row of seats in front and inclined floor; free-formable mattress*

5.3.2.3 Measurements

5.3.2.3.1. Posture

The position of participants' head, torso, upper leg, lower leg, feet, upper arm and forearm with respect to the horizontal plane were determined. Stickers were positioned on participants' head (tempor), shoulder (acromion), elbow (lateral epicondylus), wrist (the palpable part of the posterior side of the semilunar bone), hip (greater trochanter), knee (lateral side of the patella), ankle (lateral malleolus) and toes (at the end of the fifth phalangus) and lateral pictures were made 2 m sideward from the participant and 0.8 m above the floor. On top of the pictures, lines were drawn between the stickers to estimate the angle between this line and the horizontal line. Mean angles, minima and maxima and standard deviation were calculated per activity.

5.3.2.3.2. Comfort experience

For each posture, participants had to indicate whether they felt comfort or discomfort by marking different areas on a body map with a green (for comfort) and a red pen (for discomfort). If they marked neither green nor red, it meant they noticed neither comfort nor discomfort. Additionally, the participants were asked to indicate the overall comfort experience after every task and to mention the most comfortable and least comfortable posture of the three in the end.

5.3.2.3.3. Anthropometric measurements

Besides stature and body mass (weight), hip breadth was also measured for every participant. Stature was recorded with an anthropometer from the floor to the highest point on the head while standing, having the head in the Frankfurt plane. Body mass (weight) was measured with a scale and hip breadth while seated was measured by putting the anthropometer on the most lateral point on the femur at hip level. Age, nationality and gender were also noted. The shoe height of the participants was measured as well and it was logged if participants were wearing their shoes during the performance of tasks. They were instructed to choose to wear their shoes like they would normally do during a flight.

5.3.2.4 Protocol

Three tasks were defined: reading, watching the in-flight entertainment system (IFE) and sideward sleeping. For each of these tasks, corresponding postures were defined (Figure 5.6). For reading, this was upright sitting and holding a book or magazine. For watching IFE, this was a slouched position, relaxing. For sideward sleeping, this was turned to the right side of the body.

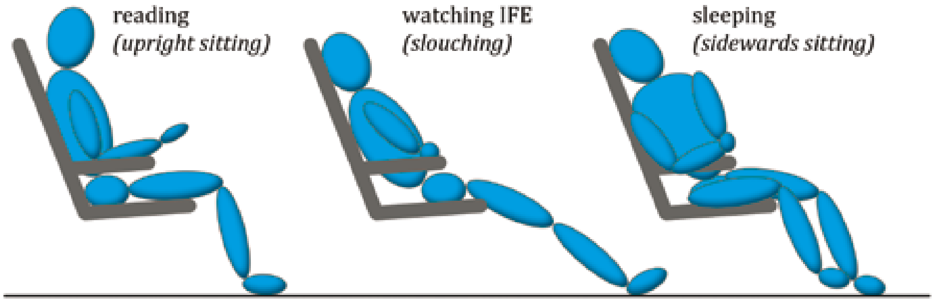

Figure 5.6 *Selected tasks (reading, watching IFE, sideward sleeping) with corresponding postures*

Participants were instructed that they were going to perform three tasks in three different corresponding postures (pictures of the different postures had been shown) in the research seat. Every participant started with the reading activity (upright sitting), followed by watching IFE (slouching) and sideward sleeping. They were asked to take a seat in the research set-up and make themselves as comfortable as possible for the task. If they were, measurements and pictures were taken and they were asked to complete the questionnaire.

5.3.3 RESULTS

5.3.3.1 Posture

The stickers were difficult to observe as parts of the research seat or clothes of the participants interfered with the line of sight. Due to this and the asymmetrical posture of sideward sleeping, it was impossible for the third posture to position the angles in a 2D-plane. Therefore, only postures of reading and watching IFE are shown (Figure 5.7). For the upright sitting condition (reading activity) compared with the slouched sitting condition (watching IFE), the head is more bent forward, the torso is more upright, the upper legs are more horizontal and the lower legs are more vertical.

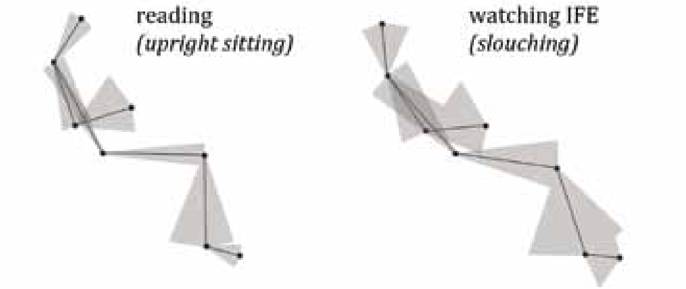

Figure 5.7 *Visual representation of the angles of the body observed for the postures corresponding with the tasks reading and watching IFE. The black lines represent the mean values; the grey areas represent the minimum and maximum observed angles.*

5.3.3.2. Comfort experience

The number of areas that were marked green (comfort) by the participants is lowest in the sideward sleeping position (see also Figure 5.8). Only the right side of the upper and lower back and the right shoulder were marked green by more than 10 participants. Reading and watching IFE had more green scores than the sideward sleeping position, particularly in the upper legs (14 and 13 out of 28, respectively), buttock (11 and 11) and upper (11 and 20) and lower back (10 and 13). The upper back region in the watching IFE position was rated most often green by the participants (20).

Discomfort (marked by a red pen) was rated most in the lower back area (11) while watching IFE (see also Figure 5.9). So, 11 out of 28 rated discomfort in this lower back area while watching, while 13 out of 28 rated comfort (compare with Figure 5.8). Discomfort was rated also in the right buttock by 12 out of 28 participants in the sideward sleeping position. The stature of the participants that rated discomfort in the feet for the reading position was below 1.65 m for all four participants.

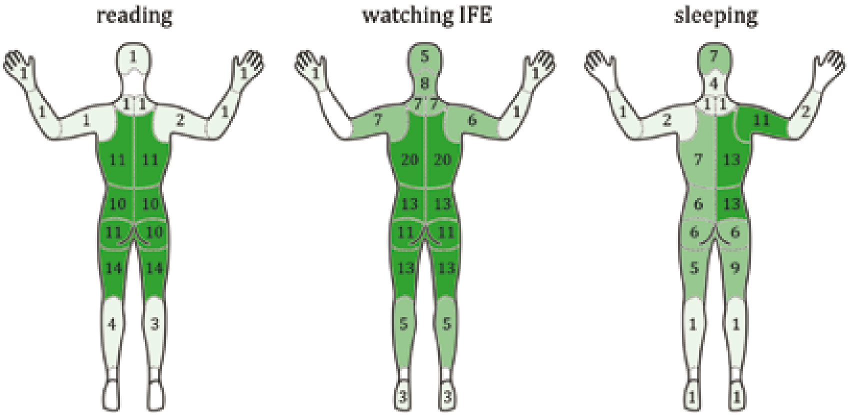

Figure 5.8 *Experienced comfort in the reading, watching IFE and sideward sleeping posture. The total number of participants reporting comfort in that specific body region is shown.*

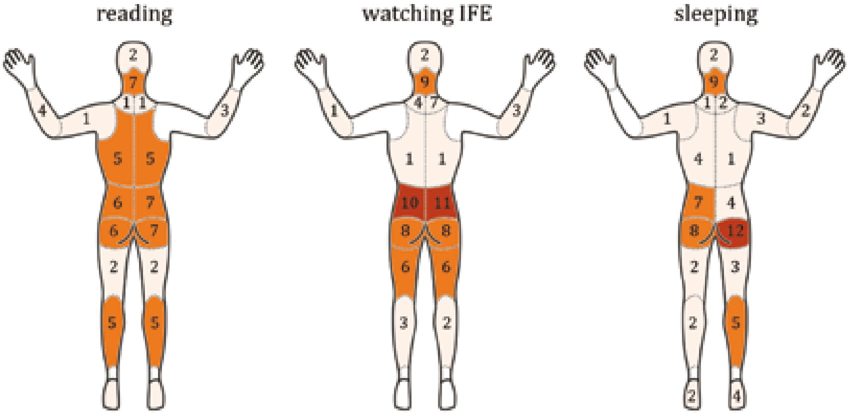

Figure 5.9 *Experienced discomfort in the reading, watching IFE and sideward sleeping posture. The total number of participants reporting discomfort in that specific body region is shown.*

5.3.4 DISCUSSION

This study has shown that the anthropometry of the passenger influences posture and comfort perception in aircraft seats while performing different activities.

Ideally, a seat facilitates these differences in postures in a comfortable way, which is a challenge for seat designers, but is becoming more feasible as new materials are becoming available. The fact that activities do influence the posture has been described before (Groenesteijn et al. 2009). For watching television, it has been shown that a more backward rotated backrest is preferable (Van Rosmalen et al. 2009), and if we follow the vision of Goossens and Snijders (1995) that shear forces should be prevented, a tilted seat with the front of the seat upwards is a consequence of this posture. However, for smaller passengers this introduces another problem that the feet do not reach the floor anymore. This study indicates that there is discomfort for short people who cannot reach the floor. This phenomenon is seen before in a study among tram drivers (Osinga 2003), where height adjustable pedals were needed to create a comfortable tram driving posture for shorter persons.

One of the disadvantages of this study could be that the study is done in a laboratory environment and that participants were instructed on their activity and posture. However, real life observations also show much variation in posture. Van Rosmalen et al. (2009) showed large differences while watching a screen, from an upright to a 30 degrees reclined trunk as well as various asymmetric postures. Kamp et al. (2011) observed a large variety of postures in trains and lounge areas and found also differences in posture between reading and watching. Even within one task, differences in posture are found. Gscheidle and Reed (2004) describe a variation in observed back rest angles between 20 to 40 degrees backwards at one task (office work). Park et al. (2000) describe a variation between 103 and 131 degrees in observed trunk-thigh angle while driving in a car. The observations of Kamp et al. (2011), Gscheidle and Reed (2004) and Park et al. (2000) were done with seats that have a fixed shape and could restrict the freedom of posture choice. In this study, a free formable mattress was used which could be formed by the participants, allowing more freedom in posture. This could be unrealistic as in real life you are also not free to change your posture, but was chosen to make it possible to choose the ideal posture. On the other hand, the average variation in torso angle found in our study for the task reading (13 degrees) and watching (26 degrees) is comparable to the ranges found in the other studies described above. Several studies show the importance of varying your seated posture (e.g. Lueder 2004; Nordin 2004).

Another difference of this study with real life studies is the focus on knee space. Two studies among passengers (Vink et al. 2011; Blok et al. 2007) showed that the main problem is knee space. That is not the outcome of this study, probably because the pitch in this study was 30 inch (762 mm), which is comparable to an average economy class airplane. However, due to the use of the free-formable mattress participants were able to sink deep into the mattress, leaving a very thin (<20 mm) backrest, which is comparable to the more spacious economy class airplanes.

If we compare posture and comfort, it is remarkable that in all positions, participants can be appointed that feel themselves comfortable in this position. Ten participants experienced the reading (upright) position as most comfortable, 12 the watching (slouched) and 6 the sideward sleeping posture. Interesting is that for the watching situation, both many discomfort and comfort experiences are reported among the 28 participants around the lower back area. This is probably due to the fact that some people experience a convenient pressure in the lumbar region that follows their body contour, while others do experience too much or too little pressure. Other studies (De Looze et al. 2003; Zenk et al. 2011) have shown that there is a relationship between pressure distribution and comfort. The comfort in the neck/head region is often mentioned as an area of discomfort in this study; sometimes because of the lack of support, sometimes because the head is pushed forwards. The taller participants needed more head support, while the shorter participants preferred a situation where their head could be positioned more backwards.

ACKNOWLEDGEMENTS

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5.4 CONCLUSION ON HUMAN CHARACTERISTICS

Human dimensions vary for passengers of different ethnicity, gender and age, as well as over time. Anthropometric characteristics are not only important for the seat to fit the passenger, but also influences passengers' body posture as well as their comfort and discomfort.

In the first case study, the dimensions of three aircraft seats were compared to anthropometric measurements obtained from the DINED database. This study has shown that, although the width of the seat pan is wide enough for 95%, 8-21% of the Dutch male and female population aged 20-60 years does not fit between the armrests of the seat, due to their seated hip width. Furthermore, the seat pan height is too high for up to 51% of the population.

The second case study has shown that passengers of different stature obtain different postures, and that their comfort and discomfort ratings differ. For example, taller participants reported more often discomfort in the head and neck region, while shorter participants more often reported discomfort in the feet and lower legs. It can be difficult for shorter passengers to reach the floor with their feet. Wearing high heels or changing posture (e.g. slouched) can sometimes be a solution for them, but the seat should also provide them with a footrest, for example integrated in the frame of the seat in front.

The anthropometric data used in this chapter are one-dimensional and static. New techniques allow designers and researchers to make better use of anthropometric data by including a three dimensional representation of the human body. In many studies, researchers have tried to model the human body (e.g. Grujicic et al. 2009; Siefert et al. 2008; Verver et al. 2004); however, these studies often consider the human body in a static posture. Although human modelling can aid designers to set dimensions, for the evaluation of comfort, real human participants will remain necessary.

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CHAPTER 6

COMFORT OF A TRAIN SEAT FOR DIFFERENT ACTIVITIES AND POSTURES

The previous chapter described different human characteristics and showed how anthropometric characteristics of passengers are related to seat design, and that anthropometry also has an influence on passengers' posture, and in turn, influence their comfort and discomfort perception. However, for the design of comfortable passenger seats, knowledge is needed on which seat parameters exactly are related to anthropometric characteristics – and, thus, need to be adjustable – and for which seat parameters a compromise is possible.

This chapter describes an experimental study on the comfort and discomfort perception of a train seat for different activities and postures. It provides a link between the previous part on Context (activities), and the next part on Seat, for it discusses the implications of activities and anthropometry on seat design, and the effect on comfort and discomfort perception. Based on the results from the observational study on activities and postures of train passengers (Chapter 2), this chapter describes two consecutive experiments. First, an initial comfort experiment, in which 12 combinations of activities and postures were measured for 5 minutes, and second, a long-term comfort experiment, in which four combinations of activities and postures have been measured for 40 minutes.

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NOTE: Some of the dimensions reported in this chapter have to remain confidential until 2016. Therefore, these have been undisclosed in this thesis, but will be part of the future publication.

6.1 INTRODUCTION

6.1.1 BACKGROUND

Today, new technologies allow people to use laptops, tablets and smart phones everywhere. Consequently, the number of activities that people are able to perform when traveling increases. From a study by Groenesteijn et al. (2012), it was concluded that office workers preferred a chair which optimally facilitated the performed activities, such as computer work and telephoning. Similarly, comfort can increase repeat purchase by aircraft passengers, according to Vink et al. (2012). Ideally, vehicle interiors, in particular passenger seats, support these different activities.

Due to the developments in high speed trains, train journeys could be faster compared to short and medium distance flights, in particular for high-speed lines covering distances up to 800 km (European High Speed Rail – An Easy Way to Connect 2009). Only a few studies on passenger comfort are focused on activities and postures during traveling by train. Although train interior comfort has been the subject of a number of scientific studies, most studies on train passenger comfort focus on noise and vibration (e.g. Krishna 2007; Shafiquzzaman Khan and Sundstrum 2007; Nassiri et al. 2011) or climate (e.g. Chen et al. 2012).

Recently, Groenesteijn et al. (2014) and Kamp et al. (2011) studied the activities people perform when travelling by train or semi-public situations, and the postures in which they perform these activities. However, their findings are not sufficiently specific to be translated into design recommendations for train seats. Another study of Bronkhorst and Krause (2005) is more specific, but is restricted to optimising the interior of a specific commuter train seat in the USA. Besides the different geographic area,, the activities of passengers on a commuter train might differ from those on a high speed train due to differences in travel purpose (business or leisure) and duration of the journey. Furthermore, the use of mobile devices has been increasing considerably since the introduction of the notebooks and smartphones (2003), and more recently, tablet pc's (2010), which is changing the activities that passengers will perform during their journey.

Besides performed activities, anthropometric characteristics might influence passengers' posture as well. Already in 1967, Branton and Grayson evaluated train seats and investigated whether people would sit differently due to the variation in seat design. They reported that tall people sat in postures with knees crossed for longer periods than short people, particularly when slumped. For home furniture, Teraoka et al. (2005) also found differences between tall and short people, for example, that short people have less foot contact with the floor compared to tall people. Contrarily, the participants from the study by Ciaccia and Sznelwar (2012) adopted similar postures in an aircraft seat, despite their different anthropometric characteristics.

A systematic approach to design passenger seats for a high-speed train has been described by Jung et al. (1998). The design is based on three different postures (upright, relaxed and extended) and Korean anthropometric data. However, these postures might not be representative anymore, and European passengers differ from Korean passengers in anthropometric characteristics.

Summarizing, previous studies show that passengers prefer different postures when performing different activities, and that this might be influenced by anthropometric characteristics. However, it is not yet studied how these different activities performed in a high speed train can be optimally supported by the seat.

6.1.2 AIM AND STRUCTURE OF THIS STUDY

The aim of this study is to improve train passenger comfort in high speed trains, by setting recommendations for the design of train seats. This will be achieved by defining the most comfortable postures and seat dimensions which fit to the passengers' anthropometry and activities while travelling. This should lead to recommendations which can be used by designers as input for train seat design. It will be investigated which train seat dimensions are influenced by passengers' anthropometry or activity – and should therefore be adjustable – and which seat dimensions can be fixed.

Therefore, the research questions for this study are:

What is the most comfortable body posture for each of the four main observed activities (reading, relaxing, talking, working on laptop) for train passengers?

And, subsequently:

What are the most comfortable train seat dimensions or adjustments for these combinations of activity and posture?

This study consists of three parts, illustrated in Figure 6.1. First, twelve conditions (i.e. twelve combinations of the four most frequent activities with eight basic postures of train passengers) were selected from a study by Groenesteijn et al. (2014). Second, these twelve conditions were tested in the initial comfort experiment (5-6 min each), resulting in one most comfortable posture for each activity together with seat dimensions that were preferred to support this posture. Third, these four conditions (i.e. four combinations of the four most frequent activities with the most comfortable posture) were tested in the consecutive long-term comfort experiments (40 min each). This will lead to recommendations for the design of train seats that accommodates the most comfortable posture for four different activities.

Figure 6.1 *Overview of the three parts of this study; the two blue boxes indicate the two experiments that are described in this paper*

6.2 SELECTION OF ACTIVITIES AND POSTURES FROM OBSERVATION STUDY

In order to select activities and postures for the initial comfort experiment, the results of the study by Groenesteijn et al. (2014) were used. They observed 786 passengers (after removal of incomplete or faulty data files) in high speed trains in Europe. Their observations showed four most performed activities (reading, staring/sleeping, talking and working on laptop; covering 78% of all observed activities) and eight most often seen basic body postures. The basic postures are composed of the position of the head (forward, straight, turned), back (straight, slouched, reclined) and legs (both on the floor, 90 degrees bent). Body posture appeared to depend on the performed activity, resulting in sixteen different combinations of activities and postures (shown in Table 6.1). Twelve combinations of activity and posture with the highest comfort ratings in the observation study by Groenesteijn et al. (2014) were selected as conditions for the initial comfort experiment (see Section 6.3).

6.3 INITIAL COMFORT EXPERIMENT

The goal of the initial comfort experiment was to select the most comfortable posture and the corresponding seat parameters for each activity. The results of this study will be used as input for the long term experiment (see Section 4). Therefore, this first experiment focused on initial comfort evaluation (5-6 min) of the twelve combinations of activities and postures that were selected from the observation study (see Table 6.1).

Table 6.1 *Overview of activities and basic body postures based on the observations of Groenesteijn et al. (2014). Grey areas indicate combinations of activities and basic postures that have been observed; letters A to K indicate the 12 conditions which were used during the initial comfort experiment.*

Activities	**Postures**							
Reading	**A**	**B**	**C**					
Staring/sleeping	**D**	**E**					**F**	
Talking				**G**				**H**
Working on laptop	**I**	**J**	**L**		**K**			
Posture								

6.3.1 METHODS OF INITIAL COMFORT EXPERIMENT

During this experiment, twelve combinations of postures and activities were studied in a laboratory setting. Participants were sitting in a research seat that was adjustable by the researcher (e.g. backrest angle, height of the armrest and depth of the headrest) to support the different postures and to fit the participants' anthropometry and activity.

6.3.1.1 Participants of initial comfort experiment

In designing a train seat, it is important that a representative sample of the passenger population is used. Therefore, participants were carefully selected on the basis of their anthropometric characteristics (e.g. length and weight), but also their age and nationality. In total 24 people volunteered to participate in this study (8 male, 16 female) of different nationalities (European, Asian, South-American). The average age of the participants was 34.8 years (20-65 years), their average standing height was 1.69 m (1.55-1.93 m), their average weight was 72.3 kg (43-118.3 kg) and their average Body Mass Index (BMI) was 24.9 kg/m^2 (16.2-38.2 kg/m^2). Participants were divided into four different morphological groups to investigate the effect of seat parameters within a group. Afterwards, they received a small compensation for participating in the experiment.

6.3.1.2 Experimental setting of initial comfort experiment

A research seat was built that could be adjusted by the researcher. To simulate the activities, the participants were provided with a magazine for the reading conditions and a laptop with a typing task during the working on laptop conditions. The researcher sat next to the participant and started a conversation for the talking activity. For the staring/sleeping activity, participants were asked to relax, because this was more feasible for the short duration (5-6 min).

As illustrated in Figure 6.2, nine seat parameters were adjustable. For every adjustable seat parameter, the participant had to choose between three experimental variations (e.g. 200, 230, 250 mm). The angle of the seat pan was fixed at 6°. The possible adjustments and the fixed dimensions, such as length of the backrest, were determined according to actual, current train seat dimensions.

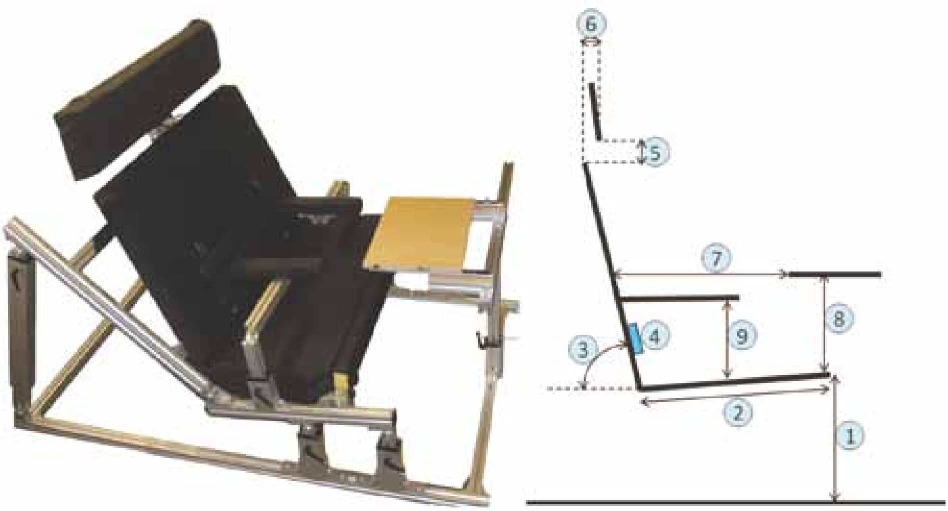


Figure 6.2 *Research seat (left) and adjustable seat parameters (right) used in initial comfort experiment: [1] seat pan height and [2] seat pan length; [3] back rest angle; [4] size, position and thickness of the lumbar support; [5] head rest height and [6] head rest distance; [7] table distance and [8] table height; and [9] height of the arm rest.*

6.3.1.3 Measurements of initial comfort experiment

Overall comfort measurements

The overall comfort was measured on a 10–point scale (ranging from 0=not comfortable at all to 10=extremely comfortable). Furthermore, participants rated the comfort of the separate seat elements (head rest, seat pan, lumbar support) on the same 10–point scale and were asked to write comments on what could be improved on the seat.

Participants' preferred dimensions

Immediately after each condition, the seat dimensions preferred by the participant were noted by the researcher.

Anthropometric measurements

At the end of the experiment, the following anthropometric measurements were gathered: standing height (stature) and body mass (weight). More data were obtained to control for anthropometric variability, but where not analysed.

6.3.1.4 Protocol of initial comfort experiment

All participants were offered all twelve experimental conditions and the order of conditions was systematically varied over the participants. Each condition lasted 5-6 minutes; the total experiment lasted for 2 hours.

The settings for seat pan length, seat pan height and lumbar support were determined at the start of the experiment and had to remain unchanged during the rest of the experiment. Therefore, firstly, participants were asked to sit in the research seat and to adjust the seat pan length and seat pan height to their preference. Then, they were asked if they preferred a lumbar support, and if so, the researcher would offer different heights (3 positions) and thickness (15 mm or 30 mm) for the lumbar support, after which the participant could compose the most comfortable lumbar support.

For the following twelve test conditions, the participants were asked to adopt one of the basic postures while performing one of the activities (e.g. condition "A" was the activity reading in combination with posture 1). Then, they were asked to make a choice for each of the nine adjustable seat parameters (see Figure 2). When the seat was adjusted according to their preference, they were asked to sit in this position and perform the activity for 5-6 minutes. After that, they were asked to rate their overall comfort as well as the comfort for each of the seat elements. This was repeated for all twelve conditions. After completing the last condition, the anthropometric measurements were taken.

The backrest angle is related to posture, and therefore participants were not free to choose each of the three different angles, but sometimes had to choose between two angles, or a specific angle was imposed. For example, condition E is a combination of posture 2, with the trunk upright, and the activity relaxing. Therefore, the choice was limited to backrest angle 1 (106°) or angle 2 (112°).

6.3.1.5 Data analysis

For each of the four activities, the comfort scores of the different body postures were compared using Friedman's ANOVA (IBM SPSS Statistics 20). Significance was accepted at $p<0.05$. Friedman's ANOVA with post-hoc Wilcoxon Signed Ranks Test was used for comparing the comfort scores between activities and postures.

In order to find out whether a relationship exists between anthropometry and preferred seat dimensions, correlations were calculated between preferred seat depth, seat height, lumbar support and stature using Spearman's rho. Significance was accepted at $p<0.05$.

For the other adjustable seat parameters, statistical testing was not possible due to the unequal distribution of participants. Therefore, only descriptive statistics are used to show the preferred dimensions for each activity.

Finally, for the possible improvements, comments from each participant were categorized for each condition and summed and analysed.

6.3.2 Results of initial comfort experiment

6.3.2.1 Overall comfort measurements

The overall comfort scores are shown in Table 6.2. No significant differences were found between the postures for each activity (see Table 6.3). However, a significant difference was found for the average comfort score between activities ($\chi^2(3)=8.724$, $p<0.05$). Pairwise comparisons showed that the average comfort score for the reading activity was significantly higher than the average comfort score for the talking activity ($z=-2.23$, $p<0.05$). No significant difference was found for the average comfort score between the eight body postures.

Table 6.2 *Overall comfort scores (1-10) for different conditions (standard deviation between brackets)*

	Posture								
Activity	1	2	3	4	5	6	7	8	**Avg.**
Reading	7.1 (1.0)	7.0 (1.0)	**7.4** (1.1)						**7.15** (1.02)
Relaxing	6.9 (1.4)	**7.2** (0.8)					6.8 (1.2)		6.93 (1.15)
Talking				6.8 (1.1)				6.5 (0.9)	6.69 (1.01)
Working on laptop	7.1 (1.1)	6.9 (1.1)	7.0 (1.1)		7.2 (0.9)				7.05 (1.06)
Posture									

Table 6.3 *Results of Friedman ANOVA*

Activity	Postures	Chi-Square	df	Sig.
Reading	1, 2, 3	5.429	2	0.066
Relaxing	1, 2, 7	1.162	2	0.559
Talking	4, 8	0.474	1	0.491
Working on laptop	1, 2, 3, 5	0.750	3	0.861

6.3.2.2 Preferred seat pan length, seat pan height and lumbar support

In Table 6.4, the frequencies of the preferred seat parameters are shown. The preference for seat pan length is equally distributed across the three experimental variations (short, medium, long). The lowest seat pan height seems to be too low; the majority of participants prefers the highest adjustment. Two third of participants preferred to use a lumbar support. In the 11 out of 16 cases that a lumbar support was chosen, it was preferred at the middle position (16-20 mm from seat pan cushion), and 14 out of 16 preferred a thickness of 15 mm.

Table 6.4 *Frequency table for seat parameters seat pan height, seat pan length and lumbar support.*

Seat pan length	Position 1 (short)	Position 2 (medium)	Position 3 (long)	Total
Number of participants	8	8	8	24

Seat pan height	Position 1 (low)	Position 2 (middle)	Position 3 (high)	Total
Number of participants	2	7	15	24

Lumbar support	Position 1 (100-160 mm)	Position 2 (160-220 mm)	Position 3 (220-280 mm)	Total (24*3)
- No lumbar support	22	13	21	56
- Thickness 15mm	1	10	3	14
- Thickness 30mm	1	1	0	2

Seat pan length and seat pan height were both highly correlated to stature, as shown in Table 6.5. Additionally, a significant correlation was found between seat pan length and seat pan height, i.e. participants who prefer a large seat pan length are more likely to prefer a large seat pan height. Lumbar support did not show a significant correlation with participants' stature and is therefore not shown in the table.

***Table 6.5** Spearman correlations between stature, preferred seat pan length and preferred seat pan height.*

Spearman's rho	Stature	Preferred seat pan length	Preferred seat pan height
Stature	1	–	–
Preferred seat pan length	**.568****	1	–
Preferred seat pan height	**.552****	**.474***	1

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

6.3.2.3 Preferred backrest angle

The majority of participants preferred a backrest angle of 112° over 126° for reading; a backrest angle of 112° over 106° and 126° for relaxing and a backrest angle of 112° for talking and working on laptop (see Table 6.6).

***Table 6.6** Frequency table for preferred backrest angle. The dash (–) indicates that this angle could not be selected by participants for this condition.*

	Angle 1 (106°)	Angle 2 (112°)	Angle 3 (126°)
Backrest angle reading			
- Posture 1	–	21	3
- Posture 2	24	–	–
- Posture 3	24	–	–
Backrest angle relaxing			
- Posture 1	–	–	24
- Posture 2	3	21	–
- Posture 7	1	13	10
Backrest angle talking			
- Posture 4	–	21	3
- Posture 8	8	16	–
Backrest angle laptop			
- Posture 1	–	24	–
- Posture 2	24	–	–
- Posture 5	–	23	1
- Posture 3	24	–	–

6.3.2.4 Preferred dimensions for armrest, table and headrest

Armrest height

In more than half of the cases (61.6%), participants preferred the lowest armrest (see Table 6.7), while in only 8.8% of cases, the highest armrest was selected. No differences in preference of armrest height between activities were observed, except for the reading activity, where a number of participants preferred a higher armrest height compared to other activities.

Table 6.7 *Frequency table for preferred armrest height. Note that reading and relaxing consisted of 3 conditions (n=72), talking of 2 conditions (n=48), and working on laptop of 4 conditions (n=96)*

Armrest	**Number of cases**	**Armrest height**		
		1 (200 mm)	**2** (230 mm)	**3** (250 mm)
For reading	72	55.6%	29.2%	15.3%
For relaxing	72	63.9%	27.8%	8.3%
For talking	48	62.5%	33.3%	4.2%
For laptop use	96	64.6%	28.1%	7.3%
Total	*288*	*61.6%*	*29.6%*	*8.8%*

Table height and table distance

The table was not used for the activities relaxing and talking. For one of the conditions that included the working on a laptop condition, a laptop cushion was used instead of the table. Therefore, this condition is not included in the analysis of preferred table height and distance. For that condition, however, 54% of participants indicated that they preferred the laptop cushion over a fixed wooden table.

The table was more often used in the conditions for working on a laptop (86.1%) than for reading (37.5%) (see Table 6.8). Participants seem to prefer a higher table for reading compared to working on laptop. In general, table height 1 seems too low. For table distance, distance 3 seems too far away for most participants; however, for the reading activity more participants seem to prefer a table further away compared to working on laptop.

Table 6.8 *Frequency table for preferred table height and table distance. The dash (–) indicates that the table was not used for this activity.*

Table use	Number of cases	Table height 1 (low)	 2 (middle)	 3 (high)
For reading	27	3.7%	59.3%	37.0%
For relaxing	0	–	–	–
For talking	0	–	–	–
For laptop use	62	4.8%	64.5%	30.6%
Total	*89*	*4.3%*	*61.9%*	*33.8%*

Table use	Number of cases	Table distance 1 (close)	 2 (middle)	 3 (far)
For reading	27	37.0%	48.1%	14.8%
For relaxing	0	–	–	–
For talking	0	–	–	–
For laptop use	62	61.3%	37.1%	1.6%
Total	*89*	*49.2%*	*42.6%*	*8.2%*

Headrest height and headrest distance

For two of the conditions (C and K), the use of the headrest was not allowed. For the other conditions, the headrest was used in 60% of all cases. Headrest use was highest in conditions for relaxing (91.7%) and lowest in conditions for working on laptop (37.5%). For talking and reading, participants preferred to use a headrest in about half of the cases (56.3% and 54.2%, respectively). For the activity relaxing, headrest use was 100% in the position with the trunk backwards, and the backrest reclined to angle 3 (126°).

Table 6.9 shows that 80% of participants selected a low headrest height (adjoining the backrest). For laptop use, however, some participants seem to prefer a higher headrest height compared to the other activities. Preferences for the distance of the headrest are more distributed, but in a large majority of cases (65.8%), the middle position was selected. For relaxing, almost a third of the participants prefer a headrest that is more backwards (behind the backrest).

Table 6.9 *Frequency table for preferred headrest height and headrest distance.*

Headrest use	**Number of cases**	**Headrest height** **1** (0 mm)	 **2** (30 mm)	 **3** (80 mm)
For reading	26	88.5%	11.5%	0.0%
For relaxing	66	77.3%	18.2%	4.5%
For talking	27	92.6%	7.4%	0.0%
For laptop use	27	74.1%	18.5%	7.4%
Total	*146*	*83.1%*	*13.9%*	*3.0%*

Table use	**Number of cases**	**Headrest horizontal distance** **1** (100 mm)	 **2** (30 mm)	 **3** (-30 mm)
For reading	26	19.2%	73.1%	7.7%
For relaxing	66	21.2%	53.0%	25.8%
For talking	27	25.9%	70.4%	3.7%
For laptop use	27	25.9%	66.7%	7.4%
Total	*146*	*23.1%*	*65.8%*	*11.1%*

6.3.2.5 Possible improvements (comments made by participants)

In total, 313 comments were made on possible improvements of the seat (see Table 6.10). In general, most of the comments concerned the backrest and the headrest (25.2% and 24.9%, respectively), followed by the armrest (17.3%). Posture (12.1%), seat pan (7.3%) and table (5.1%). Two participants mentioned that they would like to have a footrest. Posture was most often commented on during the talking condition, especially in condition H where the participants had to sit with their trunk turned to the side. Other comments on posture were, for example, "*I want to sit with my legs crossed to rest the book on my lap*".

Comments on the seat pan were made on the angle, length and height of the seat pan. The seat pan was most often commented on during the reading and relaxing conditions. For the relaxing condition, for example, participants mentioned that the angle of the seat pan should be increased when reclining the backrest.

The backrest was the same in all conditions, only the angle varied. Backrest was most often commented on during the talking and the relaxing conditions. Most of the comments on the backrest were about the angle and shape of the backrest. The lack of curvature of the backrest was often mentioned, as well as a lack of support, especially in the lower back. Although the lumbar support was adjustable by the participants at the start of the experiment, almost 10% of comments were specifically on the lumbar support.

Table 6.10 *Number of comments on possible improvements on elements of the seat.*

Possible improvements	Number / percentage
Number of comments	*313*
Number of conditions	12
Backrest	25,2%
Headrest	24,9%
Armrest	17,3%
Posture	12,1%
Seat pan	7,3%
Other/don't know	5,8%
Table	5,1%
Footrest	2,2%

The number of comments on the armrest was the same for all conditions. In general, participants wanted to have the armrests closer together, especially in the laptop conditions. Furthermore, participants wanted to have support for their hands or for the book to support the reading activity. During the relaxing conditions, participants commented that they would like to rest their whole arm on the armrest, and that it should therefore be longer and wider.

The table was not used in the conditions with the activities relaxing and talking, so comments were limited to reading and working on laptop conditions. Besides the height and distance of the table (which were adjustable), comments included the angle of the table. For example, when reading, participants would like to lay down their book or magazine on a tilted surface.

Besides the angle and position of the headrest, participants most often commented on the lack of neck support of the headrest. Several participants suggested the use of a U-shaped cushion, or a headrest with side support (especially for the talking and relaxing conditions). The headrest should be more in front of the backrest for the reading and working on laptop conditions.

6.3.3 DISCUSSION OF INITIAL COMFORT EXPERIMENT

This initial comfort experiment has shown that for a specific activity in combination with different postures, passengers' preference for seat adjustments may differ. The differences in comfort scores between postures for each activity were not significant. Probably, this is due to the short duration (5-6 min) of the experiment. Therefore, a longer exposure is chosen for the second experiment (40 min).

A significant difference was found for the average comfort score between activities, with a higher average comfort score for the reading activity compared to the talking activity. However, the postures in which these activities have been performed are different, so the difference might be caused by the posture. No significant differences were found between the average comfort scores for the different postures, but the postures from the talking conditions could not be compared to other activities.

Seat pan length and seat pan height are correlated with stature, and people who prefer a large seat pan length are more likely to prefer a higher seat pan height. This is in line with Teraoka et al. (2005), who compared different sizes of home furniture and found that short people preferred a small chair, whereas tall people preferred a large chair.

Two third of the participants in this study preferred a lumbar support, almost all of which preferred a thickness of 15 mm over 30 mm. Likewise, Carcone and Keir (2007) state that a lumbar support should not exceed 30 mm thickness. The mean lumbar depth (at its maximum curvature) measured by Dowell (1995) was 24.9 mm (female) and 22.1 mm (male), indicating that women are more lordotic than men, but also that mean lumbar depth is less than 30 mm. Lumbar support was not found to be correlated to stature, but seems to be depending on activity and posture. In a study measuring the anthropometry of South-Africans, Korte (2013) found a large variation in shape of lumbar spine while seated, but suggests that the middle of lumbar support should be 192 mm above the seat pan on average. This is considerably lower than the average lumbar height according to Dowell (1995), who measured 773 seated persons (U.S. population) in a 90 degree upright posture and reported a mean lumbar height (at the deepest part of the lumbar curve) of 248 mm for females and 253 mm for males. The range that was offered in this study was 100 to 280 mm, and, in line with Korte (2013), a large majority of participants preferred the middle position from 160 to 220 mm, which has the middle at 190 mm.

Remarkably, the participants in this study preferred an upright posture with a backrest angle of 112°, for the activity relaxing, as opposed to a more reclined posture, with a backrest angle of 126°. Several participants mentioned to feel that they were "*sliding forward*" in the seat. Possibly shear forces play a role here (Goossens and

Snijders 1995), and the angle of the seat pan should be change together with the backrest. A backrest angle of 112° is most preferred for the activity working on laptop, although participants indicated the backrest could be more inclined. This is comparable to Groenesteijn et al. (2009), who suggest that a backrest angle of 105° is ideal for VDU work, while for reading, a more reclined backrest (120°) is preferred.

The use of the table is dependent on the performed activity, e.g. for relaxing no table is used, but for the activity reading, table use is preferred by 37.5% of participants. Interestingly, the preferred height of the table also seems to depend on the performed activity: for the activity reading, a higher table is preferred compared to the activity working on a laptop. Possibly, this is due to a different angle of the object that requires eye focus, leading to a different neck flexion (Lueder 2004). Besides the different posture, perhaps the thickness and position of the keyboard plays a role here.

Although the initial comfort experiment appeared to be a good method to select conditions for the long term comfort experiment, participants commented on the amount of repetition with twelve conditions. Some of the participants said they "*got bored*", which implies there could be an order effect. However, due to the systematic variation of conditions over participants, the order effect will probably not have a large influence on the obtained results.

6.3.4 CONCLUSIONS OF INITIAL COMFORT EXPERIMENT

Although no significant differences in comfort scores were found between postures for each activity during the initial comfort experiment, the conditions (i.e. combination of activity and posture) for the long-term comfort experiment were selected on the basis of the highest comfort score for each activity (see Table 6.2). The highest comfort score for the reading activity is seen in combination with posture 3. For the relaxing activity, the combination with posture 2 had the highest comfort score. For the talking activity, this was posture 4, whereas for working on laptop, posture 5 had the highest comfort score. These are the combinations that have been selected for the long-term comfort experiment (Section 6.4).

In addition, modifications were made to the research seat for the long-term comfort experiment on the basis of the results from the initial comfort experiment. To prevent participants from sliding forward in the seat, the seat pan should recline together with the backrest (i.e. fix the angle between seat pan and backrest). Therefore, the seat pan angle will be fixed at 18° for the backrest angle of 124°, and fixed at 6° for the backrest angle of 112°. A lumbar support with a thickness of 15 mm and rounded edges will be constructed for the long-term experiment. Other modifications, such as the width of the research seat, the design of the headrest and adjustment possibilities are described in more detail in section 6.4.1.2 (Experimental setting).

6.4 LONG-TERM COMFORT EXPERIMENT

This consecutive experiment focused on long-term comfort evaluation (40 min) of the four most comfortable postures per activity, which resulted from the initial comfort experiment. The aim of the long-term comfort experiment is to identify the optimum seat dimensions for each activity.

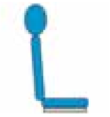
6.4.1 METHODS OF LONG-TERM COMFORT EXPERIMENT

For each activity, one most comfortable posture has been selected from the initial comfort experiment, resulting in four conditions (see Table 6.11). For the reading activity, participants were allowed to bring a magazine, book or other paper document. During the relaxing activity, participants were allowed to listen to music (small earphones only). For the talking activity, people participated in an online language course (e.g. Dutch to French or English to Dutch), in order to simulate visual eye-contact, listening and talking. Participants were allowed to bring their own laptop (no tablet pc), as long as they used it for a keyboard activity, such as writing an e-mail or a report.

6.4.1.1 Participants of long-term comfort experiment

For the long-term experiment, participants were carefully selected based on their stature, weight, age and nationality. They were evenly distributed over four morphological groups. In total 24 participants (11 male, 13 female) of different nationalities (European and Asian) volunteered to participate in the long-term experiment. People that participated in the initial comfort experiment were excluded. The average age of participants was 26.3 years (15-50 years), their average standing height was 1.75 m (1.56-1.96 m), their average weight was 70.3 kg (49.1-94.9 kg) and their average Body Mass Index (BMI) was 22.9 kg/m^2 (16.6-33.8 kg/m^2). After the experiment, which lasted for 4 hours, participants received a small compensation.

***Table 6.11** Four conditions (activities with corresponding body postures) of the long-term comfort experiment, with fixed and adjustable seat dimensions of the research seat.*

Condition (activity)	Body posture		Fixed seat dimensions	Seat adjustment options
For each condition			*Seat pan height* *Armrest height*	*Seat pan length* *Lumbar support* *Headrest height*
Reading	Head forward Trunk upright Full seat contact		Headrest type	Table height Table distance
Relaxing	Head upright Trunk upright Full seat contact		Headrest type No table	Backrest angle
Talking	Head sideward Trunk backwards Full seat contact		Headrest type No table	Headrest distance Headrest type *(flat or with side support)*
Working on laptop	Head forward Trunk backwards Full seat contact		Table height	Table distance

6.4.1.2 Experimental setting of long-term comfort experiment

Fixed parameters of the research seat for the long-term experiment (see Figure 6.3) were: armrest height (210 mm), seat pan height (confidential) and headrest height (0 mm, thus adjoining the backrest). The height of the lumbar support was fixed at 160 mm, but participants were free to use it or not. For seat pan length, three experimental variations were available (short, medium, long) at the start of each condition. Headrest distance and table distance were continuously adjustable in a fixed range between 9 and 98 mm (headrest) and 300 and 400 mm (table). The height of the table was fixed for the working on laptop condition, but for the reading condition, two variations were available (low and high). Two variations of the backrest angle (112° or 124°) were available for the relaxing condition. Here, if the backrest was reclined to 124°, the seat pan angle was changed accordingly (from 6° to 18°), so the angle between seat pan and backrest would remain 106°. For the talking condition, participants could choose between two types of headrest: flat or with side supports.

Figure 6.3 *Adjustable research seat for the long-term experiment*

6.4.1.3 Measurements of long-term comfort experiment

Comfort and local perceived discomfort

Comfort was measured by a questionnaire after every condition where participants were asked to indicate their comfort on a 10−point scale (ranging from 1 = not comfortable at all to 10 = extremely comfortable).

Discomfort was measured using the Local Perceived Discomfort (LPD) method (Grinten and Smitt 1992). This method uses a body map consisting of 22 regions. In this experiment, the left and right buttock were added as 23d and 24th region. The LPD method was introduced to the participants before the start of the experiment. The participants were asked to rate their discomfort in the different body regions on an 11−point scale (ranging from *0 = no discomfort* to *10 = extreme discomfort, almost maximum*) at the start of the experiment (t = 0) and then every ten minutes (t = 10, t = 20, t = 30, t = 40).

Preferred seat pan length

In the long-term experiment, the seat pan height was fixed, but participants were allowed to choose between three different seat pan lengths (short, medium, long) per activity.

Backrest angle and lumbar support

The backrest angle was fixed for the conditions reading, working on laptop and talking. For the relaxing condition, participants could choose between 112° and 124°. Due to this unbalanced design, only descriptive statistics are used. The use of lumbar support is expressed as a percentage of participants.

Preferences for table and headrest

The table was used in two conditions: reading and working on laptop. Participants were free to choose between two different heights (low and high) for the reading activity, but for the working on laptop condition the table height was fixed (low). Due to this unbalanced design, only descriptive statistics are used.

Anthropometric measurements

At the end of the experiment, the following anthropometric measurements were gathered: standing height (stature) and body mass (weight). More anthropometric measurements were taken to control the anthropometric variability, but were not analysed.

Evaluation of seat elements and possible improvements

At the end of each condition, participants were asked to rate the different seat elements (*How do you evaluate this seat element to practice this activity?*) on a 10–point scale (from 1 = inappropriate to 10 = very suitable). Furthermore, they were asked for each activity what they would like to improve on the seat.

6.4.1.4 Procedure of long-term comfort experiment

Participants were asked to sit in the research seat and to adopt one of the basic postures while performing one of the activities. Before every condition, participants had to make a choice for each of the adjustable seat parameters. The basic postures were a combination of the position of the head (forward, straight, turned), back (straight, slouched, reclined) and legs (both on the floor, 90 degrees bent). After that, the local perceived discomfort (LPD) at t=0 was rated. Then, the participants started with the activity. After 10, 20, 30, 40 minutes, they rated LPD again. After 40 minutes, they completed the comfort questionnaire. Furthermore, they rated the comfort of the seat elements and mentioned possible improvements on the seat. Participants were offered all four experimental conditions and the order of conditions was systematically varied. After completing the final condition, the anthropometric measures were taken.

6.4.1.5 Data analysis

The comfort ratings for each of the four conditions were compared using Friedman's ANOVA with post-hoc Wilcoxon Signed Ranks Test (IBM SPSS Statistics 20). Significance was accepted at $p<0.05$.

Discomfort ratings for left and right were averaged due to expected symmetry of posture, resulting in 12 body regions. First, discomfort ratings were adjusted by subtracting the perceived discomfort rating before the start of the condition ($t = 0$) from the perceived discomfort rating at $t = 10$, $t = 20$, $t = 30$, and $t = 40$. Local perceived discomfort outcomes *LPDavg* and *LPDmax* were calculated by taking the average of body regions with discomfort >0 (*LPDavg*) and the highest rating from one of the body regions (*LPDmax*). Then, General Linear Model (GLM) repeated measures were used with condition (reading, relaxing, laptop, talking) and measure ($t = 10$, $t = 20$, $t = 30$, $t = 40$) as within subjects factors. Pairwise comparisons were used with Bonferroni adjustment. Significance was accepted at $p<0.05$. Furthermore, in order to compare the LPD ratings at the end of the condition (at $t =40$) per body region, GLM repeated measures were used with condition (reading, relaxing, laptop, talking) and the 12 body regions as within subjects factors.

Correlations between preferred seat pan length and stature were calculated using Spearman's rho. Then, stature has been recoded into short (less than 25th percentile, <1.635 m), medium (between 25th and 75th percentile, 1.635−1.765 m), and tall (more than 75th percentile, >1.765 m). Dimensions are obtained from the DINED international database, France, mixed (male and female) population (DINED 2004). Chi-square statistic (IBM SPSS Statistics 20) was calculated for preferred seat pan length and stature category. Significance was accepted at $p<0.05$.

The ratings for the evaluation of the different seat elements (backrest, seat pan, armrest, table, headrest) were compared using Chi-square statistic (significance level at $p<0.05$). Finally, for the possible improvements, comments from each participant were categorized for each condition and summed and analysed.

6.4.2 Results of long-term experiment

6.4.2.1 Comfort and discomfort

The overall comfort rating after 40 minutes was 6.6 on average for all conditions. A significant difference was found between the four conditions ($\chi^2(3) = 8.73$, $p<0.05$). Pairwise comparisons showed that the comfort rating for relaxing (average 7.2) was significantly higher than the comfort rating for talking (average 6.0) ($p<0.01$).

For the Local Perceived Discomfort (LPD) scores, results are shown in Figure 6.4. A significant difference between conditions was found for *LPDavg* ($F(3) = 2.98$, $p<0.05$). Pairwise comparisons showed that the average discomfort rating for relaxing was significantly lower than the average discomfort rating for reading ($p<0.05$). No significant differences were found for *LPDmax* between conditions.

For both *LPDavg* and *LPDmax*, a significant effect was found for measure (p<0.01), meaning that discomfort increased in time for all conditions. Furthermore, there was no significant interaction effect between condition and measure; thus, the increase of discomfort in time was not significantly different between conditions.

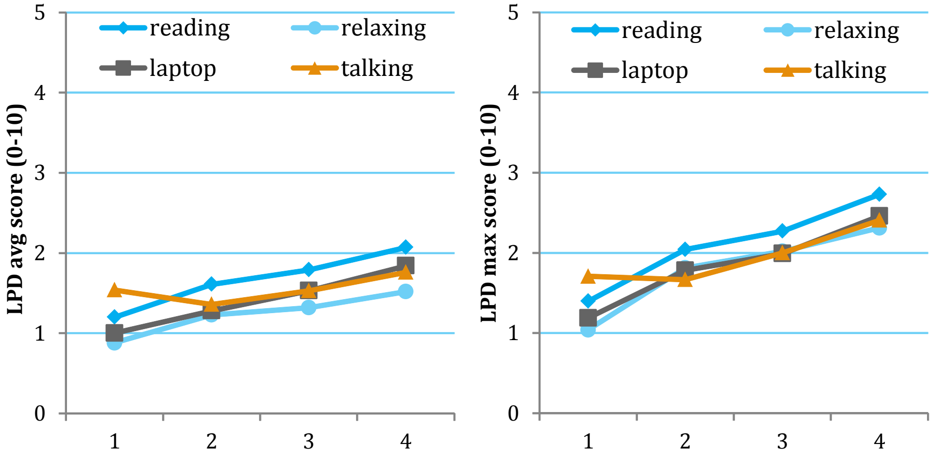


Figure 6.4 *Average local perceived discomfort ratings (*LPDavg*, left) and highest local perceived discomfort ratings (*LPDmax*, right) at measurements 1 (t=10), 2 (t=20), 3 (t=30) and 4 (t=40).*

For the local perceived discomfort rating per body region after 40 minutes, no significant effects of condition were found. The highest discomfort was reported in the neck and the shoulder region (see Figure 6.5). Discomfort ratings for the neck and the shoulder regions were significantly higher than the head, lower legs, ankles/feet, lower arms and wrists/hands regions. The shoulder region also obtained a significantly higher discomfort rating than the upper arms region.

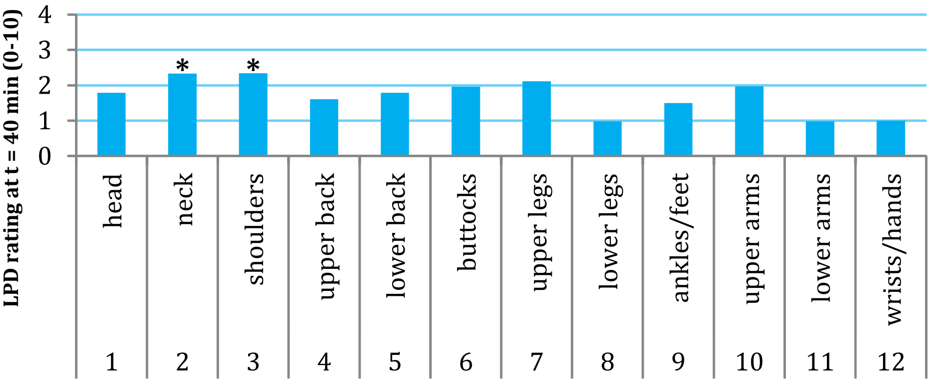


Figure 6.5 *Average perceived discomfort ratings of twelve different body regions after 40 minutes, averaged over the four conditions. The asterisk (*) indicates a significant difference (p<0.05).*

6.4.2.2 Preferred seat pan length

For seat pan length, no significant differences were found between activities. However, seat pan length was highly correlated to stature (Spearman's $\rho = .742$, $p<0.01$). In Table 6.12, the preferred seat pan length for reading is displayed for participants with short, medium and tall stature. Participants with a tall stature were more likely to select a large seat pan length than participants with a short stature ($\chi^2(4) = 12.5$, $p<0.05$). The large seat pan (470 mm) was preferred by 58.3% of participants, perhaps because relatively more participants (50%) had a tall stature.

***Table 6.12** Frequency table for preferred seat pan length for participants with short, medium and tall stature.*

Participants' stature	**N**	**Preferred seat pan length for reading**		
		Short	Medium	Large
Short (<1.635 m)	7	42.9%	42.9%	14.3%
Medium (1.635–1.765 m)	5	20.0%	40.0%	40.0%
Tall (>1.765 m)	12	0%	8.3%	91.7%
Total	*24*	*16.7%*	*25.0%*	*58.3%*

6.4.2.3 Backrest angle and lumbar support

The backrest angle was fixed for the conditions reading, working on laptop and talking. For the relaxing condition, participants could choose between 112° (n=9) and 124° (n=15); see Table 6.13.

***Table 6.13** Preference for backrest angle and use of lumbar support for each condition.*

Condition	**Number of participants**	**Backrest angle**	**Use of lumbar support**	
Reading	24	104°	95.8%	
Relaxing	9	112°	66.7%	70.8%
	15	124°	73.3%	
Working on laptop	24	112°	87.5%	
Talking	24	112°	91.7%	

On average, 86.5% of participants preferred to use a lumbar support. Lumbar support use was highest for the conditions reading (95.8%) and talking (91.7%), but lowest for relaxing (70.8%). For relaxing, participants could choose between a backrest angle of 112° or 124°. Use of the lumbar support was somewhat higher for the backrest angle of 124°. For the backrest angle of 112°, the use of lumbar support was lower for relaxing than for the other two activities with the same backrest angle (working on laptop and talking).

6.4.2.4 Preferences for table and headrest

Table height and table distance

For reading, the majority of subjects (66.7%) preferred the higher table. The table distance was continuously adjustable in a range (confidential). The full range was used by participants, and was similar for the reading and working on laptop conditions. On average, shorter participants (<1.635 m) preferred a table distance closer to the backrest than taller participants (>1.765 m).

Headrest distance

For the headrest, participants could choose whether or not to use it for the laptop and talking conditions. For the working on laptop condition, 33% of participants wanted to use the headrest in the working on laptop condition, compared to 46% for the talking condition. Headrest use was highest in the relaxing condition with 88% of participants. For the talking condition, participants could also choose between a headrest with side support (flaps) and a flat headrest. If used, they preferred the flat headrest for this activity (88.9%).

The headrest was not used in the reading condition. The average headrest distance for the other three conditions was 52.3 mm; for relaxing and working on laptop the average headrest distance was larger (55.1 and 55.5 mm, respectively) than for talking (44.6 mm). However, the variation in distance was very large for all conditions: the horizontal distance ranged between 9 and 98 mm, as shown in Table 6.14.

Table 6.14 *Preference for horizontal headrest distance; average and maximum selected values (lowest and highest).*

Condition	**Preferred headrest distance**		
	Average (SD)	Lowest value	Highest value
Reading	–	–	–
Relaxing	55.1 (20.6)	10.0	90.0
Working on laptop	55.5 (34.2)	10.0	98.0
Talking	44.6 (25.5)	9.0	75.0
Total	*52.3 (24.8)*	*9.0*	*98.0*

6.4.2.5 Evaluation of seat elements and possible improvements

The average rating on the question "*How do you evaluate this seat element to practice this activity*" was 6.7 for all seat elements. No significant differences were found in the comfort rating per seat element between conditions. A significant difference was found between the average evaluation ratings for the different seat elements ($\chi^2(4) = 12.404$; $p<0.05$), with the average evaluation rating for the headrest being significantly lower compared to the average evaluation ratings for the backrest, seat pan, armrest and table (see Figure 6.6).

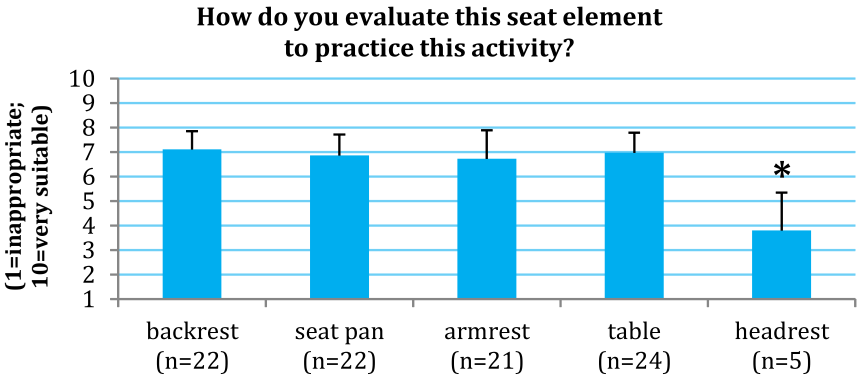


Figure 6.6 *Average evaluation ratings of different seat elements on how suitable it is to practice this activity. Only the participants who gave a rating for the seat element for each activity are included in the average. The asterisk * indicates a significant difference (p<0.05).*

Backrest and lumbar support

The average comfort score of the backrest was highest for the relaxing condition, especially with a backrest angle of 124° (see Table 6.15).

Table 6.15 *Preference for backrest angle and average evaluation of the backrest on a 10-point scale (with 1=not comfortable at all and 10=very comfortable).*

Condition	Number of participants	Backrest angle	Average evaluation of the backrest (1-10)	
Reading	24	104°	7.0	
Relaxing	9	112°	6.7	7.3
	15	124°	7.8	
Working on laptop	24	112°	7.0	
Talking	24	112°	7.2	

For the working on laptop condition, 25% of participants would like to have the back more inclined (straight up), into a more active position. Curvature of the backrest is most often mentioned as possible improvement of the backrest.

Armrest, table and headrest

The armrest was fixed at a height of 210 mm, following the results obtained from the initial comfort experiment. In total, 21 comments were made that the armrest was too low, opposed to 3 comments that the armrest was too high. Other comments were that the armrests should be longer so that the full lower arm can rest upon the armrest (in the relaxing condition) and that the armrests should be closer together, especially in the laptop condition. For the working on laptop condition, participants indicated that they want support of the elbow while typing. A possible improvement that has been mentioned several times is to rotate the armrest around the vertical axis (like seen in office chairs).

It was suggested by the participants to have the angle of the table parallel with the angle of the armrests. It is expected to be more comfortable if the elbows are supported by the armrest while the hands and wrists are supported on the table.

The ratings of evaluation of the headrest to support the activities were very low, below 4.5 for both the headrest with flaps and for the flat headrest. Almost no comments were made on headrest height; participants would like to have the headrest more forward (7%) and made from a softer material (7%). For working on laptop, the head is bent forward and therefore, the headrest cannot be used. In general, participants indicated they need a support for their neck.

6.4.3 DISCUSSION OF LONG-TERM EXPERIMENT

The duration of this experiment was 40 minutes, which is considered long-term as it is longer than 30 minutes, whereas train journeys can easily take more than 2 hours. However, Groenesteijn et al. (2014) showed that working on laptop was the activity that was performed the longest, with an average of 53 minutes. On the other hand, talking had the shortest duration (average 17 min) (Groenesteijn et al. 2014). Therefore, it is probable that passengers will adopt a different posture or perform a different activity after 30-50 minutes of travel, and the duration in this experiment was representative for this specific combination of posture and activity.

Considering the overall comfort and discomfort ratings, the relaxing condition was significantly more comfortable than the talking condition, and discomfort ratings were significantly lower for the relaxing condition compared to the reading condition. From this, it seems that the least comfortable condition is not necessarily the condition with the most discomfort. This is in line with Zhang et al. (1996), who stated that comfort and discomfort during sitting are two independent factors associated with different underlying factors. It is generally agreed that comfort is affected by physical, physiological and psychological factors (De Looze et al. 2003). Perhaps the activity (e.g. reading a nice book) can distract someone from feeling discomfort, but also from feeling comfortable.

The highest discomfort was rated in the neck and shoulder region. After 40 minutes, the average LPD score was 2 or higher, which, according to Hamberg-van Reenen et al. (2008), is a predictor of future musculoskeletal pain. This underlines the importance of the headrest. In this experiment, ratings for the evaluation of the headrest were very low (<4). Neck support is, just like in the initial comfort experiment, often mentioned by participants as a possible improvement of the headrest. Similarly, the questionnaire results from the study by Groenesteijn et al. (2014) showed that the average comfort score for the headrest was lower than for the other seat parts. The comfort score for the headrest was significantly higher for the staring/sleeping activity compared to reading (Groenesteijn et al. 2014).

Seat pan length was significantly correlated to participants' stature. Similar results were obtained by Jonsson et al. (2008), who reported a high correlation between driver stature and lateral adjustment of the car seat. Therefore, an adjustable seat pan length is recommended.

Concerning the armrest, the fixed height of 210 mm was too low for a large majority of participants. A recommendation is to make the height and angle of the armrest equal to the height and angle of the table. It seems that the low table height was sufficient for the laptop condition, while for the reading activity the majority of participants preferred the higher table height. Table distance seems to be related to stature and performed activity and should be adjustable, at least within the investigated range.

Lumbar support is preferred for all activities, but least for relaxing. The use of the lumbar support was somewhat higher for the backrest angle of 124° compared to 112°. Relaxed sitting flattens (flexes) the lumbar spine (Lueder 2004), which can explain why less participants preferred a lumbar support for relaxing. Andersson et al. (1979) found only a minor effect of the backrest inclination on the lumbar lordosis. Lumbar lordosis decreases when sitting down from a standing position due to rotation of the pelvis. When reclining, the lumbar curve is reinstated due to the increased angle between the torso and the legs (Lueder 2004). However, in this study, the angle between back rest and seat pan was fixed, so the pelvic angle would have remained the same, but while reclining, the weight of the torso also shifts back against the backrest (Lueder 2004). The recommendation is to use a lumbar support in all conditions, but to adapt this the support when the backrest is moved backwards. More research could be done regarding the ideal depth (and height) of a lumbar support in combination with different backrest angles and different activities. The ideal curvature of the backrest has been the subject of further studies by SNCF, but results have not been published yet.

According to Andersson et al. (1974), the ideal backrest angle, i.e. with lowest lumbar disc pressure and myoelectric back muscle activity during sitting, is 120°. However, a visual demand, such as looking at a screen of laptop, leads to forward bending of the neck, thereby contributing to forward bending of the thoracic and lumbar spine (Lueder 2004). Harrison et al. (2000) showed that a reclined posture with a visual demanding task, such as driving, increases neck flexion. They state that the ideal back rest angle of 120° degrees is therefore not suited for car drivers, since the neck flexion would be 30° degrees. Instead, Harrison et al. (2000) propose a back rest angle of 100° to reduce the neck flexion to 10° degrees. This could probably explain why participants in this long-term comfort experiment preferred a more upright posture for the working on laptop activity, since they had to look down at the screen of the laptop, and the neck flexion caused by the 112° backrest angle perhaps resulted in discomfort in the neck.

This long-term experiment has resulted in one most comfortable posture per activity, with corresponding optimal seat parameters. An ideal train seat would be adjustable and support these four different activities. This would allow passengers to change their posture, which is an effective way to maintain a seated posture for extended durations (Lueder 2004). However, adding adjustability also means adding complexity and weight to the seat, which might not be preferable. An alternative solution could be to provide different types of seats, so passengers can select the seat that is best fitted to their desired activity.

6.5 GENERAL DISCUSSION

The research questions for this study were: *What is the most comfortable body posture for each of the four main observed activities (reading, relaxing, talking, working on laptop) for train passengers?* And, subsequently: *What are the most comfortable train seat dimensions or adjustments for these combinations of activity and posture?*

In a previous observation study by Groenesteijn et al. (2014), a top four activities and top 8 body postures had been defined. In this study, first, twelve combinations of activities and corresponding body postures have been selected from Groenesteijn et al. (2014) and evaluated in the initial comfort experiment (5-6 min). Second, the most comfortable posture has been selected for each activity and has been evaluated in the long-term comfort experiment (40 min). The results from the initial comfort experiment have also been used to make adjustments to the research seat for the long-term comfort experiment.

In the initial comfort experiment, participants preferred a more upright posture for the relaxing activity (112° over 124°). Probably this was caused by shear forces (Goossens and Snijders 1995), which is why in the long-term comfort experiment, the seat pan angle was changed accordingly to prevent sliding out of the seat. In the long-term comfort experiment, participants indeed preferred the 124° backrest angle (with 18° seat pan angle) over the 112° angle for the relaxing activity. The recommendation is therefore to tilt the seat pan angle together with the backrest angle. The seat pan height is an important issue, since the front of the seat pan will be higher if the seat pan angle increases, restricting blood flow in the upper legs, unless the pivot point is at the front of the seat pan. During the long-term experiment, this was compensated for, so the seat pan height remained the same, but for seat designers this is an attention point.

In general, the comfort ratings are rather low. Preferably, this should be 7 or higher, but only the relaxing condition in the long-term comfort experiment obtained a comfort rating above 7, despite the fact that seat parameters were optimally adjusted for the performed activity. Compared to the initial comfort experiment, the comfort was rated higher in the long-term comfort experiment. The comments from participants showed that there are still improvements possible, such as the back rest curvature (which has been the subject of further studies by SNCF), or softness and shape for the seat pan. This could have influenced the comfort rating. Furthermore, the appearance of the experimental seat, which is a basic prototype, could have influenced the comfort. The talking activity was perceived as least comfortable in both of the studies, similar to the findings from the observation study by Groenesteijn et al. (2014).

This has been a very extensive study, which provides insight into the complex relationship between seat design and activities. Most of the results are only indicative since no significant differences were found. Future research should focus to improve only one seat aspect at a time, and better control the experimental variation.

Results show that especially the head and neck area could be improved by a different headrest design. Van Veen et al. (2014) showed that discomfort in the neck could be reduced by providing special armrests that support the use of handheld devices. This increases the screen height, thereby reducing neck flexion.

Lumbar support was not correlated with stature in the initial comfort experiment, therefore it was assumed that the preference for lumbar support might be correlated to activity. This was confirmed in the long-term comfort experiment, where a difference was found for use of lumbar support between activities. The use of lumbar support was lowest in the relaxing condition, probably due to a flexed lumbar spine (Lueder 2004). It is possible that the use of lumbar support also has a relationship with the backrest angle. Although Andersson et al. (1979) found only a minor effect of the backrest inclination on the lumbar lordosis, in this study, use of the lumbar support was highest in a more upright posture (112°). The recommendation is to use a lumbar support in all conditions, but to adapt this support when the backrest is moved backwards.

The research seat used in this study did not completely replicate that of a train interior. For example, no other passengers were present, there was no glare from the window and no lateral movements and vibrations. There was no seat in front, that could have obstructed the use of, for instance, the laptop. In addition, on the train, the table might be fixed and might obstruct activities in which the table is not used. In addition, the average table distance found in this study (confidential)might lead to problems with in-/egress (getting in and out of the seat). Abdominal depth is a relevant issue here as well. Therefore, the table should be foldable as well as adjustable.

The postures in these experiments were imposed. The resulting preferences for seat parameters are therefore preferences for imposed postures and activities. If participants would be completely free to choose posture and seat adjustments, different results may have been obtained, but then, results could not have been compared between and within subjects. For example, according to Groenesteijn et al. (2012), the backrest angle for reading should be 120°, whereas in this experiment, participants preferred a backrest angle of 104°. Groenesteijn (2015) suggests this backrest angle for reading in an office environment, whereas in a study on train passengers by Groenesteijn et al. (2014), an upright posture for reading was observed.

Due to the unbalanced design (especially in the initial comfort experiment), it was not possible to perform statistical analysis for all parameters. Also, groups will become too small for statistical analysis if divided into e.g. backrest preference, armrest preference. Much more participants are needed in that case. Therefore, most of the results are only indicative; however, these do provide much insight and as such, are a basis for further research.

The results of this research have shown the optimal seat dimensions for four different activities (reading, relaxing, working on laptop, talking). The challenge is now to design one seat that supports these activities by offering all of these adjustments. The perceived comfort and discomfort of this seat should be measured in an experiment with a duration that is representative for the activity. Preferably, also the effects of a moving train should be investigated, which has been done in a subsequent study by SNCF (results not published yet). Furthermore, the design of the headrest could be improved to provide support for the head and neck region.

6.6 CONCLUSION

In this study, seat pan length is correlated to stature; tall people prefer a larger seat pan length than short people. For reading, a higher table height is preferred compared to working on laptop. In addition, some participants recommended that the table height should be the same height and angle as the armrest, and that for relaxing, the armrest should be longer to support the full lower arm. If the backrest angle is reclined, the seat pan angle should change accordingly to avoid shear forces and to improve comfort. A lumbar support is preferred, but the thickness of the lumbar support should not exceed 15-30 mm and should change according to the backrest angle. From this study, it seems that for the adjustability of the headrest, the horizontal distance is more important than the height (vertical distance). The headrest should be redesigned to support variation in anthropometry and activities, and provide more neck support. Finally, performed activities seem to influence the perception of comfort and discomfort.

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CONCLUSIONS FROM PART II. HUMAN

This second part explored the underlying factors from the Human level, in particular for passengers' anthropometry.

In Chapter 5, the human characteristics that influence comfort and discomfort were described and illustrated by two case studies. The first case study showed that current aircraft seats exclude 8-21% of the Dutch population based on seated hip width. The width between the armrests is the problem here, not the width of the seat pan. Additionally, for up to 51%, the seat pan height is too high. The second case study discussed the differences between tall and short passengers in body posture and perceived comfort and discomfort, while performing different activities.

Chapter 6 described an experimental study on the comfort and discomfort perception of a train seat for different activities and postures. The main conclusions from this study were that seat pan length is correlated to stature: tall people prefer a larger seat pan length than short people. Participants preferred different seat parameters for different activities. Furthermore, the performed activities seem to influence the perception of comfort and discomfort. If the backrest angle is reclined, the seat pan angle should change accordingly to avoid shear forces and to improve comfort. A lumbar support is preferred, but should also adjust according to the backrest angle and performed activity.

The next part will investigate the influence of seat characteristics on comfort and discomfort perception, in relation to the context and human characteristics.

Part III.

SEAT

The conceptual model in Chapter 2 presented three levels: Human, Seat, and Context. The previous two parts explored the Context and Human level, respectively. This third part explores the underlying factors for the Seat level and consists of three chapters. In Chapter 7, the seat characteristics that influence comfort and discomfort are described and are illustrated by two case studies. Chapter 8 describes an evaluation study on the effects of active seating on the comfort perception of car passengers. Finally, Chapter 9 describes an experimental study on the effects of different seat cushion materials on the comfort perception of train passengers.

CHAPTER 7

SEAT CHARACTERISTICS THAT INFLUENCE COMFORT AND DISCOMFORT

In this chapter, the seat characteristics that influence comfort and discomfort are described (7.1) and are illustrated by two case studies in sections 7.2 and 7.3. The first case study (7.2) describes how the design of innovative armrests can support the use of handheld devices in the back seat of a car. The second case study (7.3) shows how an ideal seat contour for aircraft seats can be designed using 3D scanning techniques. Finally, it is concluded in Section 7.4 that it is possible to improve comfort of passengers by seat design features and using new technologies.

Section 7.2 has been adapted from the following publication:

Van Veen, S.A.T., Hiemstra-van Mastrigt, S., Kamp, I., Vink, P., 2014. Improving car passengers' comfort and experience by supporting the use of handheld devices. *Work* 49(2014): 215–223.

7.1 Introduction on seat characteristics

As discussed in Chapter 2, various seat characteristics can affect body posture and movement whilst sitting. The angles of the backrest and the seat pan are most apparently determining the overall body posture, such as the trunk–upper leg angle, but other seat characteristics might have a more subtle effect.

7.1.1 Shape of the seat

The effect of seat shape on body posture was studied by Noro et al. (2012). In their study on surgical seats, they found that the seat shape following the contour of the buttock and providing sacral support led to more pelvic tilt compared to a seat without sacral support.

Different shapes of cushions lead to different pressure distributions (Chen et al. 2007). Noro et al. (2012) found a larger contact area and lower average pressure for a prototype of surgical seat that followed the buttock–sacral contour of the human body compared to a conventional surgical seat. Kamp (2012) studied three different seat contours and found that hard seats with rather high side supports are evaluated as sporty, whereas softer seats were more often rated as luxurious. Cultural differences might play a role here, since a study by Vercaygne (2008) showed that German drivers, compared to drivers from other countries, more often prefer wings.

7.1.2 Material of the seat

Not much studies investigated the effect of cushion material on comfort and discomfort of passenger seats. Wang et al. (2014) compared three cushions with different hardness (hard, medium, soft), and found that when peak pressure reduces, the tolerance sitting time increases. Other scientific studies that compare material properties of cushions evaluate for instance damping characteristics (Mehta and Tewari 2010) or thermophysiological properties (Bartels 2003), but not the users' perceived seat comfort.

7.1.3 Seat dimensions

Park et al. (2013) observed that the sitting strategy adopted for lower-body was influenced by car driver's seat height (determined by occupant package layout). The posture with knees bent predominantly occurred in the SUV condition, but hardly occurred in the coupe condition, whereas the posture with the knee extended hardly occurred in the SUV condition, but did appear in the coupe and sedan conditions.

Kyung and Nussbaum (2008) found significant effects of different seats on pressure variables, such as average pressure on buttock and thigh, peak pressure on buttock and thigh, and contact area on buttock and thigh. This may be due to the different dimensions of the tested seats, but may also be caused by different shapes and cushion materials. According to Reed et al. (2000), cushion length is an important determinant of thigh support. A cushion that is too long can put pressure on the posterior portion of the occupant's legs near the knee. Pressure in this area will lead to local discomfort and restrict blood flow to the legs. This is supported by Mergl (2006), who defined the ideal pressure distribution for car driver's seats. He showed that comfort is rated high when there is an ideal pressure distribution under the legs and buttocks. Additionally, Hostens et al. (2001) found that a smaller backrest inclination angle leads to higher sub-maximum pressures on the seat pan and smaller sub-maximum pressures on the backrest. However, Park et al. (2013) did not find significant effects of car driver's seat height (determined by occupant package layout) on pressure distribution of lower-body parts (i.e. buttock and thighs).

7.1.4 AIM OF THIS CHAPTER

The aim of this chapter is to investigate the influence of seat characteristics that influence comfort and discomfort. Therefore, two case studies will be presented: the first case study describes how the design of innovative armrests can support the use of handheld devices in the back seat of a car, while the second case study shows how an ideal seat contour for aircraft seats can be designed using 3D scanning techniques.

7.2 CASE STUDY: ARMRESTS TO SUPPORT HANDHELD DEVICE USE IN THE BACK SEAT OF A CAR

7.2.1 BACKGROUND

Current car seat development has been primarily focusing on drivers instead of car passengers and as a result, their postures and activities are not optimally facilitated (Kamp 2012a). However, a competitive advantage can be achieved if a car manufacturer also considers car passengers' needs and desires.

Possible passenger activities found are reading, using mobile devices, relaxing, sleeping, using the entertainment system and having conversations (Kamp et al. 2011). People could also deal efficiently with travel time by using it for work. A previous study (Van Veen 2012) has shown that people state that they would also use travel time to finish work. Kamp et al. (2011) observed passenger activities during train journeys and report working/using larger electronic devices as one of the eight most observed activities.

Personal computing will become even more mobile in the years to come, influencing the way people work and subsequently their posture, as the field of mobile devices is developing fast (Albin et al. 2011). Use of mobile devices (the product group of laptops, PDAs, smart phones, e-readers and tablet-PCs) is increasing, as illustrated by sales figures. In 2008, for the first time, desktop computer sales dropped in 2008 in favour of laptops. Then – a month after the introduction of the Apple iPad was announced – laptop sales slowed down in February 2010. It is expected that the growth of the tablet-PC's market share will continue in the coming years.

However, working with mobile devices affects posture and might lead to discomfort and pain. For example, Young et al. (2012) showed that using a tablet resulted in more neck flexion than for desktop computing. The neck flexion was far from neutral, which might result in discomfort. Although this research was conducted in a living room-setting, it pin-points the general problem related to the use of handheld devices. Other studies show that working with touch screen devices results in more muscle activity in the neck and shoulders (Shin and Zhu 2011), caused by lifting the arm in higher positions. In the study of Gold et al. (2011), a bent neck for the use of mobile devices was also observed and it was concluded that the posture of the wrists in this activity also creates a risk for musculoskeletal disorders in wrists, arms and hands.

When using a tablet PC in a car, people reported that they were missing support for this activity (Chapter 3). During this study, it was observed that people search for support (for instance on the middle console). However, the support of the middle console is insufficient.

Figure 7.1 *Design of the innovative armrests to support mobile device use (design and illustration by Sigrid van Veen)*

Therefore, a concept seat is designed with innovative armrests, that can provide the desired arm support and decreases neck flexion by enabling a higher position of the handheld device (see Figure 7.1). The armrests were developed using anthropometric data and a 3D human model aimed at creating a more comfortable body posture. The design was evaluated in a user research using a mock-up of the armrests. The goal of the research was to evaluate the effect of the armrests on neck flexion, perceived comfort and discomfort, and user experience. The research questions are:

1. *What is the effect of armrests on posture, i.e. is neck flexion decreased by use of the armrests compared to without armrests?*
2. *Is perceived discomfort of the seat positively influenced by the armrests?*

7.2.2 METHOD

7.2.2.1 Participants and seat design

Ten people (6 male, 4 female), aged 18–67 years (average=36.8, sd=18.1), volunteered to participate in the mock-up test. Their standing height ranged from 1.57 to 1.90 m (average=1.74, sd=0.10). The mock-up model of the seat with armrests is shown in Figure 7.2. The seat pan angle (10°) and backrest angle (120°) are adapted from Harrison (2000) since these have been specifically developed for car passengers. The dimensions and angles of the armrests were estimated based on anthropometric data from DINED database (Molenbroek 2004).

The height of the armrests was adjustable over the angle of the backrest in five steps of 50 mm using slots, with the highest position at 650 mm above the seat pan. This point is located under the user's armpit. The length of the upper arm support was 360 mm. The support for the fore arms angled inwards (24°). The width of the armrests was 90 mm, in order to create enough support for the handheld device.

***Figure 7.2** Pictures of the mock-up model of the seat (left) and dimensions (mm) of the model with armrests positioned in the second slot from above (right).*

7.2.2.2 Protocol

The participants were asked to perform three tasks on a tablet (Yarvik TAB 420, 10 inch) for six minutes: typing, playing a game and reading. It was estimated that this would be long enough to find differences and evaluate if the concept is promising to pursue. The different tasks were chosen to be able to determine potential difficulties the participants could have with the different types of interaction. The participants were asked to perform the tasks in two positions: without armrests (position 0) and with armrests (in the same chair) on a height determined by the researcher approaching the ideal position as designed (position 1). Finally, the participants were asked to choose their own preferred height for the armrests. The order in which the conditions were presented to the participants was varied, i.e. five participants first performed the tasks without armrests and five participants started with armrests.

For each position, the experiment started with the participant performing the three tasks, during which the neck flexion was recorded for each task. After each task, the participant completed the comfort/discomfort questions (as described in Section 7.2.2.4).

7.2.2.3 Neck flexion

Markers were placed on the C7 and tragus according to Young et al. (2012), in order to evaluate the neck flexion with and without the armrests. Neck flexion was determined by taking pictures during each task in order to record the body angles while seated.

7.2.2.4 Perceived comfort and discomfort

After using the tablet for 6 minutes, the participants were asked to rate their comfort and discomfort on a body map in order to determine where they perceived comfort and where they perceived discomfort. With a red pen, they had to indicate body parts that suffered inconvenience and/or required comfort improvement and rate them on an 11-point scale with 0 = no discomfort and 10 = extreme discomfort (Van der Grinten and Smitt 1992). Next, using a green pen, they were asked to determine the body parts where they experienced comfort and rate these on a 10-point scale with 1 = no comfort at all, 10 = extreme comfort.

7.2.2.5 Data analysis

A paired samples t-test ($p < 0.05$ analyzed with SPSS 19.0) was conducted to compare the neck flexion for using the tablet without armrests (position 0) and while being supported by armrests (position 1).

The discomfort data were evaluated to determine if there is a significant difference (t-test for paired samples, $p < 0.05$) in comfort and/or discomfort overall and for several particular body areas between the two positions. For the overall comfort and discomfort evaluation of the total body, the scores of all participants are added up for each of the 22 body areas. These data are compared statistically between position 0 and position 1 using a Wilcoxon Signed Ranks test. The comfort and discomfort scores are also statistically compared (Wilcoxon Signed Ranks test, $p < 0.05$) for the three most important body areas for this design: the neck region, the arms and the hands.

7.2.3 RESULTS

7.2.3.1 Neck flexion

A significant difference was found in the scores in neck flexion angle between both positions for all tasks ($p < 0.01$). The recorded neck flexion is significantly less with armrests compared to using a tablet without armrests for all tasks. In Table 7.1, the minimum, maximum and average neck flexion for tablet usage with and without armrests is shown.

Table 7.1 *Minimum, maximum and average neck flexion angles for both positions*

Neck flexion angle	Position 0 (without armrests)	Position 1 (with armrests)
Minimum observed value	36°	29°
Maximum observed value	68°	58°
Average value	*52.2°*	*41.2°*

7.2.3.2 Perceived comfort and discomfort

For the configuration without armrests, discomfort in the neck region is highest. Discomfort (extremely little to very little discomfort on the Borg-scale) in the arms and hands is reportedly caused by holding the device, tilting the screen and/or holding it up. Comfort in the back and (dis-)comfort in the legs is reported to be due to the seat angles. Using the armrests also results in reported comfort in the upper back. Discomfort (extremely little discomfort) in the arms is found. Discomfort in the hands is caused by difficulties in holding and/or tilting the device, especially when typing. Discomfort in the neck is reported by two participants: one mentions that multifocal glasses cause the participant to bend the head backwards, and the other mentions overstretching due to being shorter.

Overall discomfort compared between position 0 and 1

Discomfort decreases for 15 body parts, increases for one body part and there is no change for 6 body parts. Comfort decreases for none of the body parts, increases for 17 body parts and 5 body parts experience no change in comfort. A Wilcoxon Signed Ranks Test shows that the armrests elicit a significant change in overall discomfort for using a tablet device while seated (Z=−3.467, P=0.001). Furthermore, there is a significant difference in comfort between position 0 and 1 (Z=− 3.624, P=0.000). Therefore, it can be concluded that overall comfort is increased while overall discomfort is decreased when using the designed armrests for operating a tablet device while seated.

Neck, arms and hands discomfort compared between position 0 and 1

Figure 7.3 shows the sum of discomfort and comfort of the selected body areas (neck, arms and hands), mediated over the number of participants for both positions. It suggests that discomfort decreases for the neck, and the arms and that comfort increases for all three body areas.

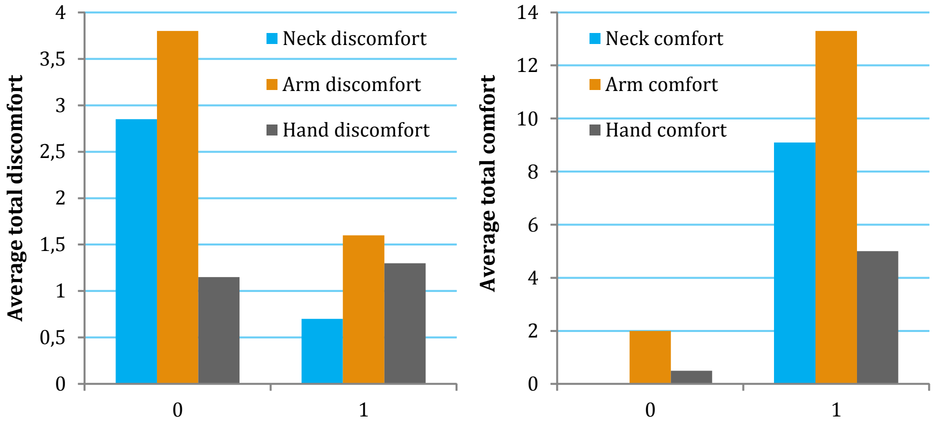


Figure 7.3 *Average of the total discomfort (left) and comfort (right) per body area at position 0 (no armrest) and position 1 (with armrest).*

The results of the Wilcoxon Signed Ranks test, conducted to compare the sum of both comfort and discomfort per body area for using the tablet without armrests (position 0) and while being supported by armrests (position 1), show that for the neck region, a significant difference is found between both positions for comfort (Z=−2.023, P=0.043) and discomfort (Z=−2.550, P=0.011). There is no significant difference for comfort (Z=−1.612, P=0.107) and discomfort (Z=−1.156, P=0.248) of the arms. Also for the hands, no significant difference was found for comfort (Z=−1.461, P=0.144) and discomfort (Z=−0.368, P=0.713). Thus, the results suggest that for neck region, comfort increases significantly when the car passenger is supported with the armrests when using a tablet. However, this is not the case for the two other body areas (arms and hands). Discomfort decreases significantly for the neck region when using armrests, but not for the arms and hands.

7.2.4 DISCUSSION

7.2.4.1 Neck flexion

The use of armrests indeed decreased the neck flexion significantly. Several studies have been conducted in order to determine neutral angles for neck flexion: for an erect posture, Raine and Twomey (1997) found an angle of 41.1 degrees and Johnson (1998) found 40.6 degrees. Ankrum and Nemeth (2000) found that 43.7 degrees was perceived as most comfortable. The average neck flexion for tablet usage while supported by the armrests is 41.2 degrees, which corresponds with the neutral angle for neck flexion found in the literature. This indicates that the armrests contribute to a better posture of head and neck.

7.2.4.2 Perceived comfort and discomfort

The discomfort in the neck region in the condition without armrests is probably caused by bending the neck to look at the display. This could also be the reason for discomfort in the upper back and shoulders according to the participants. For the configuration with armrests, comfort is reported for the neck region, probably due to the upright posture. Participants like the high position and relaxed posture (angles) of the arms, resulting in comfort scores for the upper and fore arm. The support of hand and wrist is also valued positively as the comfort scores in the hand show.

It is remarkable how often discomfort is reported in the neck without armrests within this short amount of time and how comfort reports increase for the neck, back and arms when using the armrests. Participants affirm this result when asked about their overall comfort experience when using the tablet with armrests, stating it was "*relaxed*", "*created a good body posture*", "*pleasant, also without using the tablet*", "*very attractive*" and "*comfortable*".

7.2.4.3 Recommendations

This study has shown that the effects of the armrests were already noticeable when using them for a short amount of time. However, further research is necessary to determine the effects of the armrests on experienced comfort and discomfort over a longer period (for instance 30 to 60 minutes). Further research is also needed to determine comfort and usability when using the armrests in a moving vehicle. Performing activities in a dynamic situation differs from doing these activities in a static situation. Several studies have shown the influence of dynamics on the executed activities (e.g. Bhiwapurkar et al. 2010; Corbridge and Griffin 1991). Therefore, it is also important that further research is conducted to evaluate the armrests in a dynamic situation, i.e. a driving car. The designed armrests could also influence the car passenger's perception of safety and space when in a car. Hence, this should be evaluated. In such a research, comfort improvements of the armrests could be compared to using the middle console or door for support.

It could be also of interest to learn the effects of such armrests on comfort when using other types of handheld devices, such as e-readers. This research suggests the importance of combining subjective comfort data like comfort scores on a body map with interviews, in order to be able evaluate the results, as also suggested in other studies (Vink et al. 2012). This does not only give insight in the motivations of the comfort data, but also enables the researcher to put them into perspective. In this case, there are no significant comfort improvements for the arms found but participants state that they appreciate them: they prefer working on a tablet supported by the armrests and think that they enable a good and natural posture.

The research also results in three design recommendations. The first is a change in dimensions, to avoid overstretching when shorter participants use the armrests. However, the design should still enable one armrest shape to be sufficient for a large range of the population. The second recommendation is the need for an additional feature, that enables users to rest the weight of the device on the armrests while still holding it, i.e. preventing the device from sliding down the armrest. Finally, cushioning of the armrests should be added to prevent discomfort in the elbows.

7.3 CASE STUDY: DEVELOPING AN IDEAL AIRCRAFT SEAT CONTOUR USING 3D SCANNING TECHNIQUES

7.3.1 BACKGROUND

High fuel prices demand for lighter vehicles to reduce energy consumption. Another reason to develop vehicles with less and lighter materials might be to achieve a more environmental image and meet the sustainability regulations. Seats contribute to the weight of airplanes, cars, buses and trains, and therefore, lighter materials or new light weight designs are preferred for passenger seats as well (Vink et al 2012).

One of the challenges for aircraft seats is to reduce weight without compromising on comfort, or perhaps even increase comfort. One option to create a light weight seat is to make a seat contoured shell of composite which follows the human body closely, thereby reducing the need for thick foam. For example, for the Vision EfficientDynamics concept car (the predecessor of the current i8 model), BMW has realized a weight reduction of more than 50% by using thin profile seats, with increased legroom for rear passengers (see Figure 7.4).

Figure 7.4 *BMW Vision EfficientDynamics concept car (left) and interior with thin profile front seats (right) © BMW AG*

The development of this prototype thin profile seat, shaped by a human body contour, is described by Franz et al. (2011). Their prototype seat consists of a hard shell with inflatable cushions to fill the gaps between the tallest and shortest persons. However, the contour for this seat has been developed based on the driving posture for a car, which will be different than the sitting posture of, for example, an aircraft passenger. Furthermore, the inflatable cushions that are used in the car might not be suited for use in aircraft due to changes in air pressure.

Instead of inflatable cushions, a spacer fabric could be used to compensate the differences between passengers with smallest and largest body dimensions. For example, AMES DISTO® Spacer Fabrics (Ames Europe) is a warp knitted 3D textile that is available in thicknesses between 7 and 55 mm (see Figure 7.4). With this material, zoned constructions are possible, which means that different parts of the seat can have different thicknesses and different compression values. For a new aircraft seat, this provides a design opportunity to produce the outer contour of the seat (based on the tallest passengers) from carbon fibre or another composite material, while the inner contour (based on the shortest passengers) could be filled by spacer fabric.

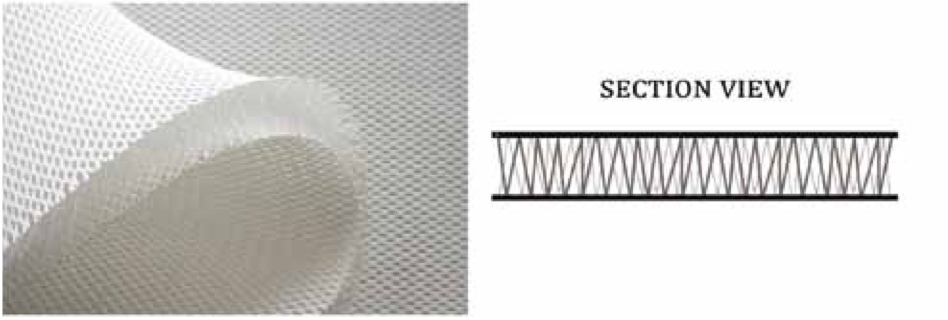


Figure 7.5 *Example of spacer fabric material, with a front face and a rear face connected to each other by an intermediate layer (illustration by author)*

7.3.2 METHOD

In order to answer these research questions, 3D scanning will be used to collect a number of human body contours, and several different methods will be applied in order to find the method with the smallest differences between the outer and inner seat contour. This process is illustrated in Figure 7.6.

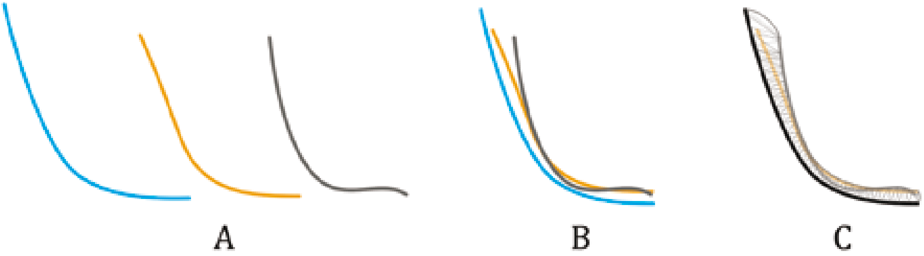


Figure 7.6 *Section view of individual human body contours (A), integration of body contours into largest and smallest compiled contours (B), and translation into outer and inner seat contour (C)*

7.3.2.1 Participants

In order to ensure that the variation in body dimensions was as large as possible, participants were selected based on their declared body stature, weight, and body proportions (e.g. ‘hourglass’, ‘rectangular’, ‘spoon’ or ‘inverted triangle’ figure). This allowed the researchers to include 5th percentile (P5) until 95th percentile (P95), for example small and light females as well as tall and heavy males, but also participants with more ‘extreme’ body dimensions, such as small hips or broad shoulders. Sixteen participants (8 male, 8 female; 11 Dutch, 5 other) were selected and volunteered to participate in this study.

Table 7.2 shows the anthropometric measurements obtained from the anthropometric database DINED (Dutch adults, 20-60 years, mixed male and female) compared to the anthropometric measurements of the participants. The goal was to represent the P5 as well as the P95 values for each anthropometric measurement.

***Table 7.2** Anthropometric measurements obtained from DINED (P5, P50, P95) compared to participants smallest (MIN), average (AVG) and tallest (MAX) measurements.*

Anthropometric measurement	P5	MIN	P50	AVG	P95	MAX	*unit*
Stature	1.57	1.55	1.74	1.72	1.92	1.91	*m*
Weight	52	52	75	73	98	114	*kg*
Buttock-popliteal depth	457	438	505	506	553	542	*mm*
Sitting height	827	788	911	884	995	969	*mm*
Shoulder height sitting	532	498	598	583	664	651	*mm*
Buttock-knee length	568	531	627	609	686	661	*mm*
Popliteal height sitting	397	411	463	459	529	546	*mm*
Elbow height sitting	203	185	252	221	301	253	*mm*
Abdominal depth sitting	193	182	270	233	347	374	*mm*
Breadth over the shoulders (bideltoid)	389	360	445	439	501	545	*mm*
Hip breadth sitting	351	322	399	370	447	450	*mm*
Breadth over the elbows	402	334	478	443	554	562	*mm*

7.3.2.2 Experimental setting

Free formable mattress

A vacuum mattress (VTI-Futur, 2000 x 800 x 150 mm) was used to capture the participants' body contours. The filling of this mattress consists of small polystyrene balls, which can form close to the human body, like a bean bag. When air is sucked out, the shape fixates and remains visible in the mattress, also after the person leaves the seat.

Basic wooden frame

A basic wooden frame was built to support the vacuum mattress (Figure 7.7). The research seat was placed on a 3 degrees inclined floor to simulate the slope of an airplane at cruising altitude. The angle of the seat pan was set at 4° with respect to the inclined floor (corresponding with 7° to horizontal plane), and the angle between the backrest and the seat pan was set at 108°.

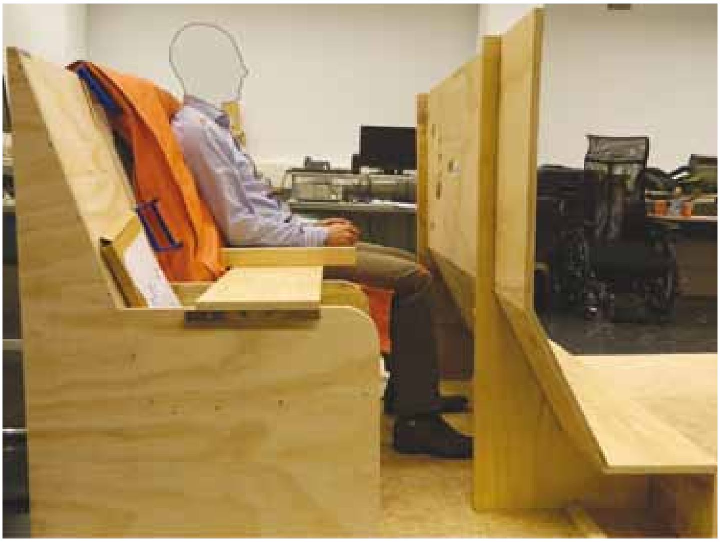


Figure 7.7 *Experimental seat: basic wooden frame with vacuum mattress (orange) and seat row in front to simulate restricted legroom*

7.3.2.3 Measurements

3D scanning

Instead of scanning the human body, the imprint of the human body in the mattress was scanned. A handheld 3D scanner (Artec Eva) was used to scan the body imprints and saved to a 3D surface (see Figure 7.8).

Figure 7.8 *Body imprint in the mattress (left) and scanned 3D surface (right)*

Anthropometric measurements

The following anthropometric measurements were taken: Stature, Weight, Buttock-popliteal depth, Sitting height, Shoulder height sitting, Buttock-knee length, Popliteal height sitting, Elbow height sitting, Abdominal depth sitting, Breadth over the shoulders (bideltoid), Hip breadth sitting, Breadth over the elbows.

7.3.2.4 Protocol

One person at a time participated in the experiment. Participants were asked to sit on top of the vacuum mattress and to adopt a comfortable, upright posture. The researcher assisted them to shape the vacuum mattress around their body and to smooth out creases as much as possible. Once the participant was sitting comfortably, the mattress was drawn vacuum so their body contour would remain visible in the mattress. Then, the a 3D scan was made of each imprint of the body contour. Afterwards, anthropometric measurements were taken and participants received a small compensation. This process was repeated for each of the participants.

7.3.2.5 Data analysis

Pre-processing steps

First, the axes of all scans have been placed equal to each other. Then, the height of the scans was adjusted using orientation landmarks from the scans (i.e. the front of the armrest).

Data processing

Four different methods were used for superimposing the contour scans. The first two methods (A and B) use the lumbar area (A) and the lumbar area and ischial tuberosities (B) to superimpose the scans. The next two methods use least squares, in which the scans are fitted so as to minimize the sum of the squares of the differences between the scans. Method C only allows translation of the scans in the YZ-plane, whereas method D also allows rotation of the scans in the YZ-plane.

Post-processing steps

The result from the best fitting method will be combined into two surfaces: one inside contour (smallest) and one outside contour (largest). The surface between the legs was flattened and the overall surface was smoothed (manually) as well. As a final step, the surface was symmetrized by averaging the values for left and right.

7.3.3 RESULTS

Four participants (2 male, 2 female; out of sixteen) did not contribute to the overall scan and were therefore excluded from further analysis. Table 7.3 shows the contours of the remaining twelve participants for the four different methods, in which each line represents the body contour of one participant (vertical cut through the seat).

The best result (i.e. the smallest difference between the inside and outside contour) is obtained using method D, using least squares translation and rotation in YZ-plane. For the backrest, the largest difference between the inside and outside contour is smaller than 55 mm. For the seat pan, the difference becomes larger towards the front of the seat pan and is larger than 55 mm, but not exceeding 100 mm.

The contours as organized in method D are used to translate into an outer and inner contour. As mentioned before, it would be possible to produce the outer contour out of a composite material such as carbon fibre, and the difference between the outer and inner contour can be ‘filled’ by the seat foam (spacer fabric) to provide support for small passengers. The result is shown in Figure 7.9.

These combined outer and inner contours also lead to an ideal outer and inner curvature of the backrest (Y-slice) and ideal outer and inner curvature of the seat pan (Z-slice), as shown in Figures 7.10, 7.11 and 7.12. From these figures it can be seen that the average variation for the backrest is smaller than 55 mm. For the seat pan, the difference between the inside and outside contour is less than 55 mm in the middle, but increasing towards the side; however, nowhere exceeding 100 mm.

Table 7.3 *Results of contour alignment using four different methods*

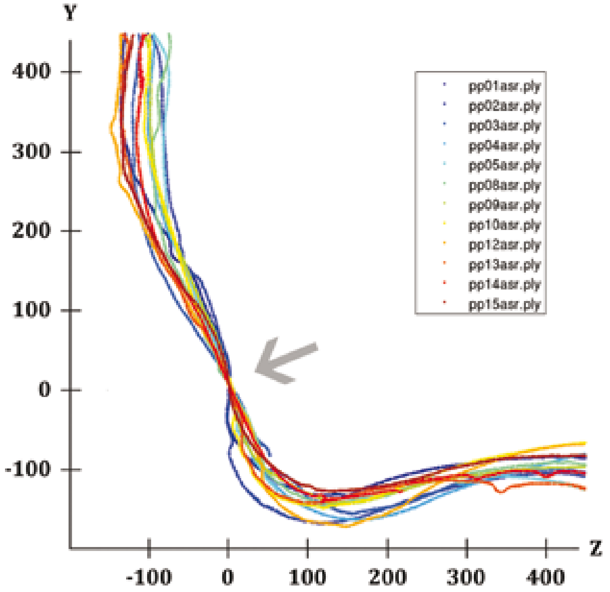
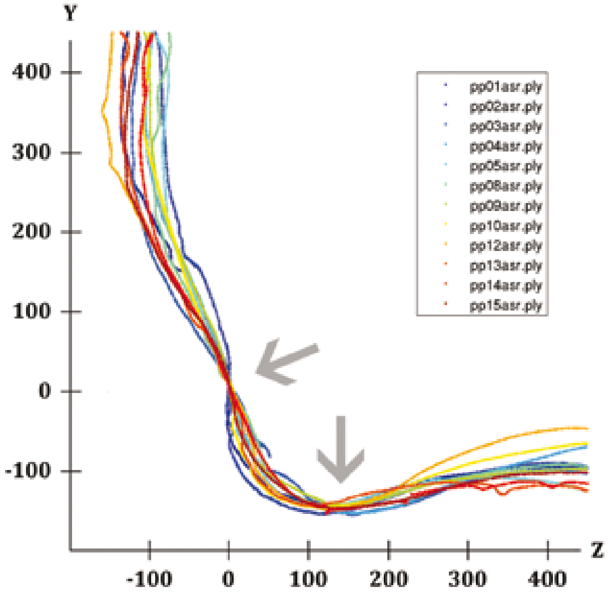
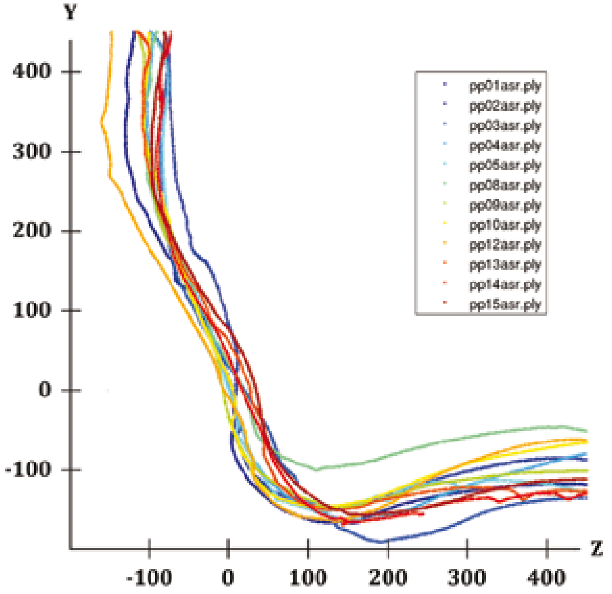
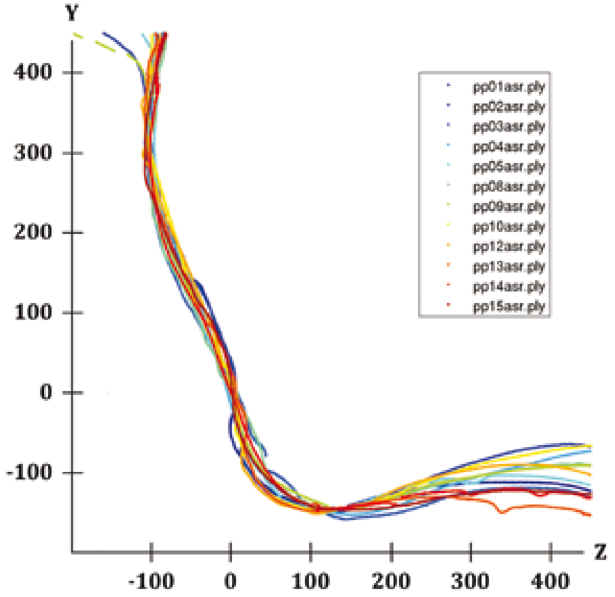
Method	Contour alignment	Result
A	On lumbar area	
B	On lumbar area and ischial tuberosity	

Table 7.3 (continued)

Method	Contour alignment	Result
C	Using least squares translation in YZ-plane	
D	Using least squares translation and rotation in YZ-plane	

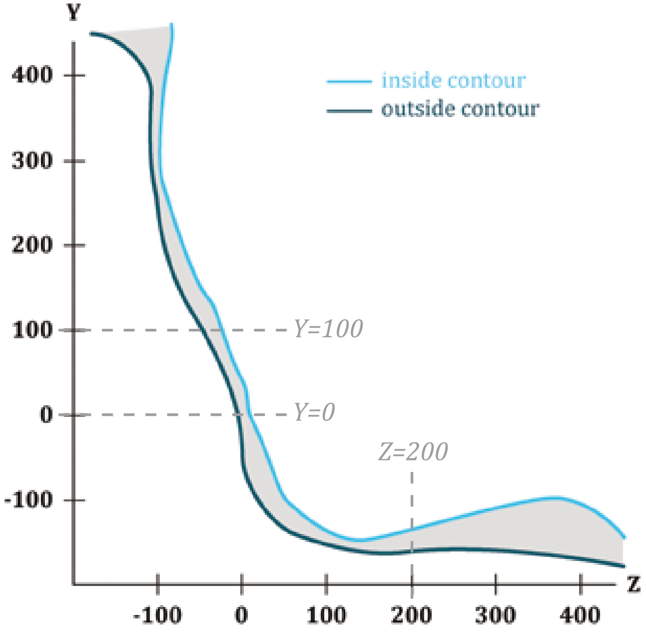


Figure 7.9 *Combined contour: dark blue line is the outside (largest) surface, and light blue line is the inside (smallest) surface*

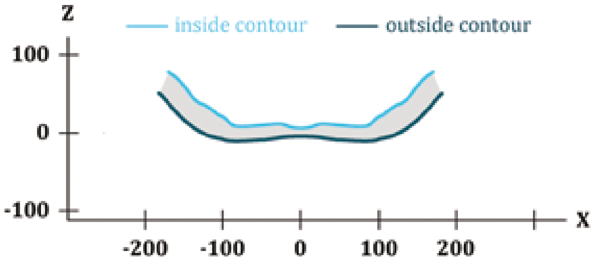


Figure 7.10 *Curvature of the backrest surface (horizontal cut through the backrest at Y=0)*

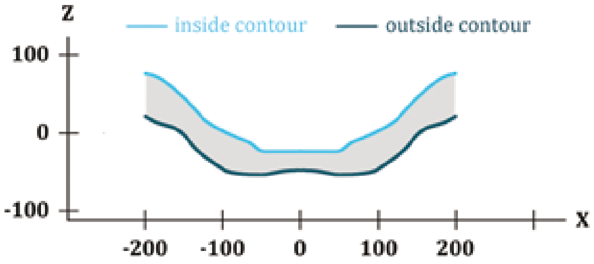


Figure 7.11 *Curvature of the backrest surface (horizontal cut through the backrest at Y=100)*

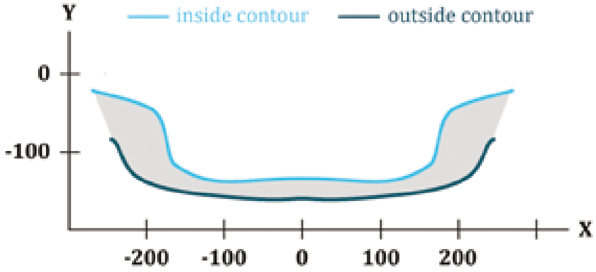


Figure 7.12 *Curvature of the seat pan surface (vertical cut through seat pan at Z=200)*

7.3.4 DISCUSSION

This study has shown that it is possible to design a lightweight aircraft seat using 3D scanning to determine the ideal seat contour following the human body. Instead of scanning the participants, the imprint left by the participants in the seat was scanned. The differences between the outer and inner contours was, at some points, larger than 55 mm, but nowhere did it exceed 100 mm. This means that one layer of spacer fabric will not be sufficient to compensate for the difference between passengers with smallest and largest body dimensions. However, adding another layer of spacer fabric at specific locations (e.g. at the front of the seat pan) might be enough to overcome this difference.

Sixteen participants were carefully selected to represent a large anthropometric range, covering from 5th percentile to 95th percentile. Overall, a good distribution of anthropometric measurements and approximation to P50 average was obtained. The smallest anthropometric measurements from participants were smaller than P5, except for the popliteal height sitting. Not all measurements were equal or larger than P95, e.g. sitting height and buttock-knee length. However, because a Dutch database was used (DINED 2004), the participants used in this study are more representative for an international P5-P95 range, because the Dutch are one of the tallest populations. The careful pre-selection of participants proved to be a good method to limit the number of scans needed to develop an ideal contour. During the processing of the scans, it appeared that four participants did not contribute to the end-result, i.e. their body dimensions were too close to P50. Therefore, only participants with extreme body dimensions should be used to develop a seat contour, however, evaluation of the seat should be done with a wide variation of passengers, including 'average' body dimensions.

This study only describes a method to design an aircraft seat based on human body contour. The effect on comfort perception, however, has not been studied. Franz et al. (2011) found that their prototype car driver seat with inflatable cushions was comparable to a current conventional BMW seat, and according to their participants, especially the lumbar/lower back region was better supported by the prototype seat. However, this comparison was made only for short term and with the same participants that contributed to the contour of the prototype seat. In a different study, Kamp (2012b) compared the same prototype seat based on human body contour to two different seats: one from a luxurious car and one from a sports car. Like Franz et al., she did not find a significant difference on comfortable feeling between the three seats, but also in this study by Kamp, participants sat in each seat for only several minutes. Long-term comfort evaluation of a human body contoured seat compared to a current seat is therefore necessary.

Fitting the contour scans from the participants into one combined contour has been done only in a 2D-view (the YZ-plane), in the middle of the seat (at X=0). A better 3D fit might be obtained using more cross sections.

The smallest differences between the outside and inside contour were found using the least squares method allowing translation and rotation in the YZ-plane. However, rotating the body contour scans indicates that passengers have to sit with a different body angle, e.g. more upright, which might not feel comfortable anymore. A tall person might have sat with his upper legs upwards due to his popliteal height, and a posture with his upper legs horizontal might not be feasible. Furthermore, which method is the best also depends on the type of material used.

There is a discrepancy between the smallest contour and the lowest seat height, i.e. taller persons are often heavier and can compress the seat cushion to better fit their body. However, this means that smaller persons using the inside contour sit in a higher position, whereas they would like to have a lower seat pan height. This difference is caused by the difference in lower leg length, and might be compensated by using a footrest. However, this will add weight to the seat. Perhaps a footrest could be integrated in the frame of the seat.

Finally, the contour scans were made for only one posture, upright sitting. During a flight, however, passengers will perform different activities and this will lead to a variation in posture (Groenesteijn 2014). This will increase the variation in body contours as well. It will be interesting to see how these different postures influence the combined seat contour.

7.4 CONCLUSION ON SEAT CHARACTERISTICS

The study on the effects of the designed armrests when using a handheld device (7.2) shows positive effects on the posture of the neck. The neck flexion was found to be significantly less when operating the tablet device with the developed armrests compared to the configuration without armrests. Thus, the body posture is partly improved. Furthermore, the average neck flexion corresponds with the neutral values found in literature and this is an objective indication that discomfort in the neck region could be prevented for operating a tablet-device with the use of these armrests. This could also be true for using other handheld devices such as e-readers, books, smart phones using armrests.

Both the comfort and discomfort ratings on the body map and the responses of the interview show that the support of the armrests while using a tablet improves the user's comfort. The overall comfort significantly increases, while the overall discomfort significantly decreases when using the armrests compared to not being supported by any armrests. Furthermore, the subjects prefer the configuration with armrests and evaluate the resulting body posture as relaxed and natural.

When looking at the neck region, specifically, comfort is also significantly increased while discomfort is significantly decreased as a result of the improved body posture. Discomfort is not significantly decreased for the arms and hands. This is due to hard materials and problems with holding the device, especially when typing. Design improvements should be able to solve these problems.

Section 7.3 showed that it is possible to develop a seat contour based on twelve participants, if carefully selected based on body dimensions. The differences between the outer and inner contours was, at some points, larger than 55 mm, but nowhere did it exceed 100 mm. This provides opportunities for seat manufacturers to provide a better fit to the human body, while at the same time reducing weight by application of new materials. Further research is needed to build prototype seats and to evaluate the comfort and discomfort and possible improvements on the contour shape.

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CHAPTER 8

ACTIVE SEATING TO IMPROVE CAR PASSENGERS' COMFORT

The previous chapter described different seat characteristics and showed that seat design can influence passengers' comfort and discomfort perception. The majority of studies investigate the effects of seat design on interface pressure. However, from the model presented in Chapter 2, it was shown that two other interaction variables play a role in the perception of comfort and discomfort, namely posture and movement. Movement is not only an indicator of discomfort, but can also be used to reduce discomfort. This chapter evaluates an active seating system developed for the back seat of a car.

The study described in this chapter evaluated three different aspects of active seating compared to other tasks (reading, working on laptop, and gaming on tablet). In Section 8.2, the three different methods are explained: a 30-min driving test in which discomfort and comfort perception were measured; heart rate measurements; and electromyography (EMG) measurements. The results in Section 8.3 show that discomfort was very low for all activities and participants felt significantly more challenged, more fit and more refreshed during active seating. Second, heart rate measurements indicated a light intensity, but nevertheless non-sedentary, activity. Third, the average and variability in activity of six postural muscles showed a higher muscle activity and higher muscle variability for active seating compared to other activities. Section 8.4 discusses the used methods and the drawbacks of this study. In Ssection 8.5, it is concluded that active seating might stimulate movements, thereby increasing comfort and well-being of passengers.

This chapter has been published as:

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8.1 INTRODUCTION

In the last decades, the amount of work-related physical activity has decreased considerably in the working population due to economic and industrial innovations, such as the introduction of computers and increased automation. As a result, physical inactivity of workers in many occupations is becoming an increasing problem (Straker and Mathiassen 2009). This so-called sedentary work is associated with several significant health risks, such as musculoskeletal disorders due to prolonged static muscle exertions (Sjøgaard and Jensen 2006), and an increased risk of chronic diseases including coronary disorders and type II diabetes due to whole body physical inactivity (USDHHS 2008). Furthermore, there is increasing evidence that sedentary behaviour is an independent factor in the development of the metabolic syndrome: a combination of high blood pressure, diabetes, increased levels of cholesterol and obesity (Ekblom-Bak et al. 2010).

Moderate-intensity physical activity, which requires a moderate amount of effort and noticeably accelerates the heart rate (WHO 2012), has been shown to have a positive effect on health disorders like cardiovascular diseases, type II diabetes, colon cancer, depression and anxiety, and on health determinants like body fat, blood pressure, cholesterol levels and bone mineral density (Pollock et al. 1998). Increasing the amount of physical activity during leisure time therefore seems crucial in improving the health of sedentary workers (Holtermann et al. 2012). Several studies (e.g. Siegel et al. 2009; Grieser 2010; Miyachi et al. 2010) have shown that an activity level of 3e6 Metabolic Equivalents (METs) is possible to achieve with activity-promoting video games such as Wii Fit from Nintendo. In order to reduce sedentary behaviour, stimulating people to move by means of a game seems a promising concept. On a local level, temporal changes in activity have also shown to have positive effects on fatigue development and discomfort. More temporal variability in the electromyography (EMG) amplitude of back muscles (Van Dieën et al. 2009) and more spatio-temporal variability of the EMG amplitude within the trapezius muscle (Farina et al. 2008) have been shown to be associated with slower development of electromyographic manifestations of fatigue.

In the office environment, several studies have investigated the effects of dynamic workstations. Straker et al. (2009), for example, studied the effects of walking and cycling computer workstations on keyboard and mouse performance, while John et al. (2009) and Funk et al. (2012) studied the effects of a treadmill workstation on health and performance. However, besides work performance, these studies mostly focused on medical implications such as reducing obesity and preventing disorders on long term, while the effects on short term comfort and well-being were not studied.

Because sedentary behaviour does not only occur at home or at the office, but also during the daily commute, car manufacturer BMW AG has developed a new concept, the active seating system. This active seating system consists of sensors in the back rest of the back seat of the car that can capture movements of the upper body and makes it possible for the passenger to control a game with his or her physical movements (Kamp 2012). The goal of the active seating system is to promote a more active experience, to reduce the amount of static muscle activity and to increase the global level of activity, in order to increase perceived comfort and well-being of car passengers. However, due to the novelty of this system, effects of such a system are unknown, neither its acceptance.

Therefore, the objective of this study is twofold: *Is there a difference in perceived discomfort, perceived comfort and activity levels of active seating compared to normal seating on the back seat of a car when performing different activities?* Furthermore, we investigated: *How is the active seating concept perceived by its users?*

8.2 METHODS

The study consisted of three experiments. The main study is the driving test (8.2.3), in which the comfort and discomfort levels and the user-acceptance were evaluated. Due to disturbances of the signals by the engine of the car and the active seating equipment, global levels of physical activity expressed by heart rate (8.2.4) and local levels of muscle activity (8.2.5) were obtained from two separate stationary experiments.

8.2.1 RESEARCH CAR

A BMW 7-series with the active seating system installed in the back seat was used for the experiments (Fig. 8.1). The active seating system was an extension of the light-weight massage system currently installed in BMW cars (Franz et al. 2011) and consisted of two pressure sensors that were able to capture pressure changes exerted by the passenger. These sensors were located approximately at the lower point of the scapula, one on the left and one on the right side of the back rest. By pressing their upper body into the left or right side of the back rest, and thereby activating one or both of the back rest sensors, participants were able to control a video game. This video game was presented to the participant on a tablet pc (iPad; Apple) which was mounted on the headrest of the front seat. For this study, BMW developed a game in which a ball needed to be balanced in the middle of the screen (Figure 8.1). The pressure sensors in the back rest captured the movements of the participant which resulted in the ball either moving to the left or to the right of the screen. The game automatically proceeded to the next level when participants balanced the ball in the middle for a certain amount of time, indicated by the squares at the top of the screen which were coloured blue as long as the ball was balanced in the middle of the screen.

Figure 8.1 *The back seat of the BMW 7-series research car (left) and a screenshot of the game (right).*

8.2.2 TASKS WHILE SITTING ON THE BACK SEAT

Three different tasks were selected to perform while sitting on the back seat: reading, working on a laptop (typing), and gaming on a tablet. This selection was based on previous observations of Kamp et al. (2011) and Groenesteijn et al. (2012). Although they observed train passengers, it might be translated to car passengers, as they often are passive travellers as well. Also, a further growth of tasks using small or larger electronic devices is anticipated, the BMW7-series is a business car, and these three tasks are often performed for a longer time (Groenesteijn et al. 2012). For the driving test and the EMG measurements, all participants performed the test with active seating as well as with one of these three tasks.

8.2.3. DRIVING TEST

8.2.3.1. Participants

Twenty-six healthy participants (14 male, 12 female; mean age 29.4 (SD = 14.5) years; mean weight 71.2 (SD = 13.4) kg; mean height 1.76 (SD = 0.1) m) volunteered to participate in the study. Participants were a mix between students and middle-class working population and had different ethnicities (European, American and Asian). Participants gave their written informed consent prior to the start of the study.

8.2.3.2. PROCEDURE

All participants were measured in two conditions: the active seating condition and a reference task condition. For the task condition, participants were randomly divided into one of three groups: reading a book (n=9), working on a laptop (n=8) and gaming on a tablet pc (n=9). In both situations, the same questionnaire was completed and the duration of each condition was 30 min. The active seating game was played for five minutes and alternated with five minutes rest. The other task (reading, working or gaming) was done constantly and only interrupted by completing a short questionnaire.

Two participants were invited at the same time and received an introduction on the study. When sitting in the car, the active seating game was calibrated for the participant in the left rear seat. Calibration was needed to adjust for the different body weights of the participants. A short explanation was given to inform participants where and how they should press into the seat in order to control the game. The participant in the right rear seat was instructed to do one of the following tasks: reading a book, working on a laptop, or playing a game (Angry Birds; Rovio Mobile Ltd.) on a tablet pc (GalaxyTab; Samsung). During the test, one researcher drove the car and another researcher sat in the front row observing the participants and giving them instructions.

After the instructions, the two participants in the rear seats were driven around for 30 min. After these 30 min, the participants changed seats and the research was repeated for the other condition (active seating or selected task). A trip duration of 30 min was chosen, because this is similar to the average length of a one-way commuter trip in the Netherlands (Nielander et al. 2012). The driving track was the same for all participants and consisted mainly of highway as this is probably the circumstance where the active seating system will be used. Traffic was not controlled for, but was similar for all conditions, since the timing of the experiments was outside rush hours.

8.2.3.3. Measurements and analysis

Three aspects were measured during the driving test: perceived discomfort, perceived comfort and acceptability.

Perceived discomfort

Discomfort was measured using the local perceived discomfort (LPD) method (Van der Grinten and Smitt 1992). A body map consisting of 22 regions was presented to the participant. The participants were asked to rate perceived discomfort in the body regions on a 10-point scale (ranging from 0 = no discomfort to 10 = extreme discomfort, almost maximum) at the start of the driving test ($t = 0$), after 10 min ($t = 10$), after 20 min ($t = 20$), and after 30 min ($t = 30$). The LPD method was introduced to the participants before the start of the driving test. Local perceived discomfort outcomes were calculated by taking the sum (*LPDsum*) and maximum (*LPDmax*) scores of the 22 body regions. A multilevel model analysis was used with active seating as a reference condition. Repeated measures were indicated by measurements 1 to 4, corresponding with time intervals $t = 0$, $t = 10$, $t = 20$, and $t = 30$ (Twisk 2003). The data were centred to distinguish main effects from interaction effects (Aiken and West 1991). To model the correlation between conditions and measurements within subjects, a diagonal matrix was specified. Significance was accepted at $p < 0.05$.

Perceived comfort

To evaluate the participants' comfort perception and first impression of the system, a short questionnaire was used. Participants were asked to rate their comfort on a 10-point scale (ranging from 1 = not comfortable at all to 10 = extremely comfortable). They were also asked about their feelings while performing the activity: *I feel challenged, I feel irritated, I feel entertained*, and their feelings after performing the activity: *I feel fit, I feel relaxed, I feel tired, I feel refreshed*. These items were rated on a 5-point scale (ranging from 1 = not at all to 5 = extremely) and were adopted from the Chair Evaluation Checklist (Helander and Zhang 1997). The single rating scales were analysed using a paired-samples t-test ($p < 0.05$), comparing the active seating condition to the other tasks.

Acceptability

Additional questions on acceptability of the active seating system were: *Do you think this is a fun way to stimulate movement; Would you use this system if it was installed in the back seat of your car (and why or why not); Where and when do you think this feature is appropriate (and why) (e.g. on the highway, in the city, on your way to work, etc.); Did the car dynamics (driving) have an influence on performing the activity; Do you think these movements are suitable in a car (and why)?* The rating scales were analysed, comparing the active seating condition to the other tasks.

8.2.4. HEART RATE MEASUREMENTS

8.2.4.1. Participants

Six healthy participants (one male, five females) with a mean age of 31.7 (SD = 8.5) years volunteered to participate in the heart rate measurements. Participants gave their written informed consent prior to the start of the study. The participants of the heart rate study did not participate in the driving test.

8.2.4.2. Procedure

This study was performed in a laboratory setting. A short introduction was given and participants were asked to wear a chest strap with electrodes and a wireless transmitter (Wear Link + Bluetooth Heart rate belt LS-14; Polar). The transmitter was connected to a smartphone with a software application installed (Endomondo Sports Tracker) to read the heart rate values in beats per minute (bpm). For the resting heart rate, the lowest heart rate was taken that was measured while the subject was sitting still in the back seat of the car for three minutes. The active seating system was then calibrated and the subject was asked to play the active seating game for three minutes, during which the heart rate was measured.

8.2.4.3. Measurements and analysis of heart rate

The lowest heart rate measured while sitting in the back seat of the car was taken as the resting heart rate. The maximum heart rate (MHR) was estimated by means of age using the formula:

$MHR = 208 - 0.7 * age$ (Tanaka et al. 2001).

The heart rate reserve (HRR) was calculated by subtracting the resting heart rate from the predicted maximum heart rate. The average heart rate during the last minute of active seating was taken as the average heart rate for the active seating task. The heart rate during active seating was expressed as a percentage of the estimated maximum heart rate ($\%MHR$) and as a percentage of the heart rate reserve ($\%HRR$). The average heart rate index (HR_{index}) was calculated by dividing the average heart rate during active seating ($HR_{absolute}$) by the average resting heart rate (HR_{rest}). The HR_{index} was used to estimate the number of MET levels by applying the formula:

$METs = 6 * HR_{index} - 5$ as suggested by Wicks et al. (2011).

The resting heart rate and the heart rate during active seating were compared with a paired-samples t-test ($p < 0.05$).

8.2.5. EMG MEASUREMENTS

8.2.5.1. Participants

To get an indication of the muscle activity during active seating compared to other activities, four students (three males, one female) volunteered to participate in the electromyography study. Their average age was 20.3 (SD = 0.5) years. Their average weight was 73.6 (SD=4.2) kg and their average height 1.84 (SD=0.13) m. Participants gave their written informed consent prior to the start of the study. The participants of the EMG measurements did not participate in the driving test, nor did they participate in the heart rate measurements.

8.2.5.2. Procedure

Muscle activity of upper leg (m. rectus femoris), abdominal (m. obliquus externus abdominis), lower back (m. erector spinae at L2 level), upper back (m. erector spinae at T10 level), shoulder (m. trapezius pars transversa) and neck (m. trapezius pars descendens) muscles (see Figure 8.2) was measured by a porti 16/ASD system (TMS, Enschede, The Netherlands). Bipolar Ag/AgCl (Medicotest, Ambu A/S, Baltorpbakken 13, DK-2750 Ballerup) surface electrodes were positioned according to Hermens et al. (2000), using an interelectrode distance of 20 mm. A reference electrode was placed on the C7 spinous process. Before the electrodes were applied, the skin was shaved, scrubbed and cleaned with alcohol. EMG signals were band-pass filtered (10e400 Hz) and continuously sampled at a sampling rate of 2000 samples per second. Skin impedance was not measured, but the raw EMG signal was visually inspected to check its quality.

All participants tested the active seating system by playing one game before the EMG electrodes were placed to make them familiar with the movements and goal of the game. After the EMG electrodes were placed, participants were asked to sit in the right rear seat of the test car and to perform the four different tasks for approximately three minutes. All participants had to do all the tasks, and the muscle activity of active seating was compared with the other activities (within-subjects design). During every task, the EMG signal was recorded twice for 10 s. The first recording was done when the participant started the task and the second approximately 10 s after the first measurement.

8.2.5.3. Data processing and analysis of EMG signals

For each 10 s recording, the mean EMG amplitude was determined for all muscles by averaging the band pass filtered (10e400 Hz) and rectified signal, obtained by taking the absolute value of each sample (ARV). EMG variability was calculated for all muscles and expressed in terms of the median absolute deviation (MAD), as described by Shevlyakov and Vilchevski (2002). As indicated by its name, this estimator is the median of the absolute differences between individual sample values and their common median. This estimator of variability is more robust to outliers than the standard deviation or the coefficient of variation (Chau et al. 2005). The average amplitude as well as the EMG variability was averaged for both 10 s recordings.

First, in order to determine if there is an overall effect, both parameters were examined using a one-way ANOVA for repeated measures with condition (active seating, reading, working on a laptop and gaming on a tablet) as independent variable ($p < 0.05$). Degrees of freedom were adjusted using Greenhouse-Geisser's epsilon to compensate for the effects of possible violations of the sphericity assumption. Subsequently, simple planned contrasts were used to investigate differences between active seating on the one hand and reading, tablet use, and laptop use on the other hand.

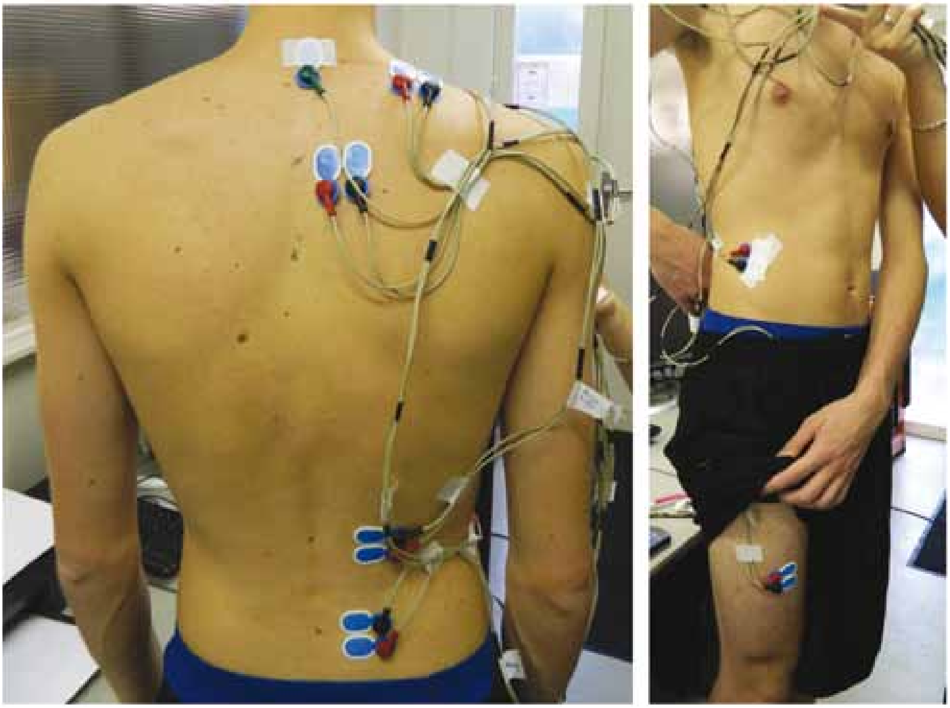

Figure 8.2 *Electrode location setup for the neck, shoulder, upper back and lower back muscles (left) and for the abdominal and upper leg muscles (right).*

8.3 RESULTS

8.3.1. DRIVING TEST

During the driving test, local perceived discomfort was very low for both conditions. Participants felt significantly more challenged, more fit and more refreshed during and after active seating. The majority of participants would use this system if installed in the back seat of their car. Detailed results are described below.

8.3.1.1. Local perceived discomfort

The local perceived discomfort ratings were generally very low. After 30 min, the highest maximum discomfort rating of body parts was less than 2 (little discomfort) (Figure 8.3). Results of the multilevel analysis are shown in Table 8.1. A significant increase of *LPDsum* ($t = 5.9$; $p < 0.01$) and *LPDmax* ($t = 4.7$; $p < 0.01$) across measurement was found for both the active seating condition and the other conditions (tablet, book, laptop). For *LPDsum*, the tablet and book conditions were significantly different from the active seating condition ($p < 0.05$), where tablet condition had lowest discomfort. For *LPDmax*, the laptop condition was significantly different from the active seating condition ($p < 0.01$). No significant interaction effects were found between condition and measurement. Thus, the increase of discomfort across time was not significantly different for active seating compared to the other tasks.

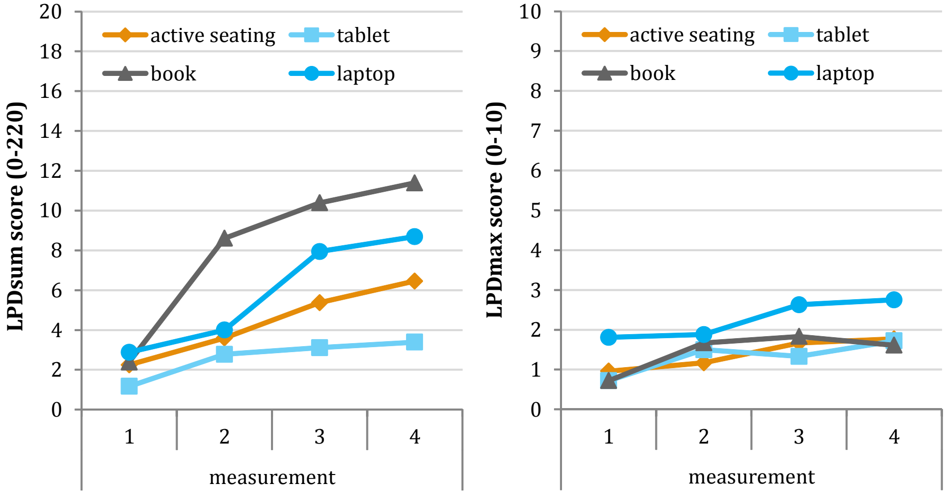

Figure 8.3 *Perceived discomfort ratings LPD sum (left) and LPD max (right) at measurements 1 (t = 0), 2 (t = 10), 3 (t = 20) and 4 (t = 30).*

Table 8.1 *Estimates of mixed model with fixed effects for the LPD sum and maximum LPD scores. Significant results are marked bold (p < 0.05).*

	LPD sum			**LPD max**		
	df	*t*	*p*	df	*t*	*p*
Intercept *(active seating condition)*	73.3	-0.25	0.81	95.8	2.8	**0.01**
Tablet condition	75.2	-2.9	**0.01**	49.0	-0.37	0.72
Book condition	25.5	2.0	**0.05**	35.0	-0.03	0.97
Laptop condition	51.0	1.6	0.12	39.6	4.0	**0.00**
Measurement	83.9	5.9	**0.00**	124.7	4.7	**0.00**
Tablet condition * Measurement	72.4	-1.2	0.25	36.8	0.16	0.88
Book condition * Measurement	28.9	1.7	0.09	34.6	0.49	0.63
Laptop condition * Measurement	34.7	0.95	0.35	32.2	0.50	0.62

8.3.1.2. Perceived comfort

For active seating, participants scored significantly higher on the items *I feel challenged*, *I feel fit*, and *I feel refreshed* than for the other tasks combined, as shown in Figure 8.4.

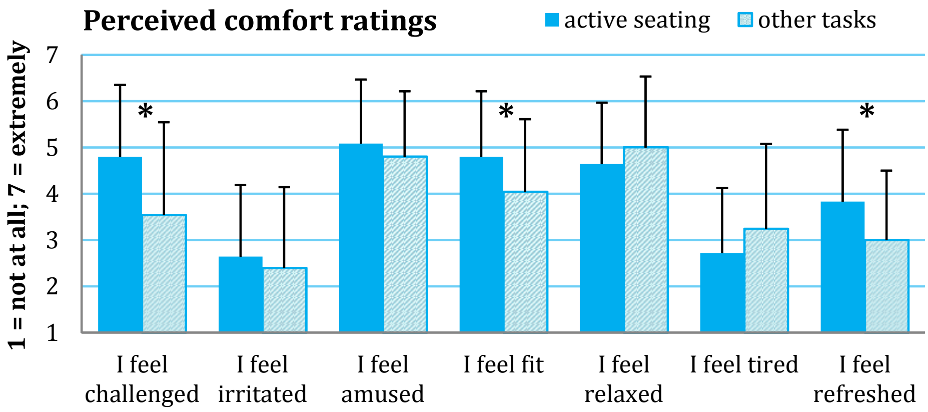

Figure 8.4 *Mean values of items expressing perceived comfort during and after the performed activity. The active seating showed a significantly higher rating compared to the other tasks, indicated by the asterisk * (p < 0.05). Error bars show the standard deviation between participants.*

8.3.1.3. Acceptability

The responses to the questions regarding acceptability of the active seating system are shown in Figure 8.5. The majority of participants thought the active seating system is a fun way to stimulate movement (79%), that they would use this system if installed in the back seat of their car (77%), and that these body movements are suitable for use in a car (85%). The car dynamics (driving) had an influence on performing the activity (84%) and was experienced mostly when cornering, in which case the amount of force needed to control the game is different (higher or lower depending on whether it is a left or a right turn). A large majority (81%) thinks the active seating system is mostly suitable for use on the highway (longer journeys). Nine out of 26 participants had additional remarks, six of which mentioned that the game could be more challenging. The following suggestions were given to improve the system: add a competition element to the game (e.g., with the passenger next to you or with other car passengers), add more sensors (e.g., not only pressure sensors but also sound sensors), offer more levels, and create more engaging games. Additionally, three participants mentioned that the system responded a bit slow.

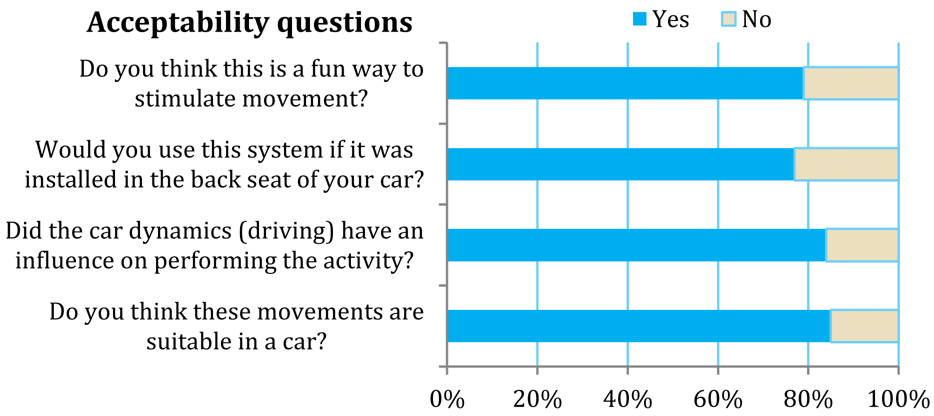

Figure 8.5 *Overview of responses to the acceptability items.*

8.3.2 HEART RATE MEASUREMENTS

The heart rate during active seating (87.0 bpm) was significantly higher compared to the resting heart rate (71.8 bpm) ($p < 0.01$). Results are shown in Table 8.2. The average heart rate during active seating expressed as the percentage of the estimated maximum heart rate was 46.8% (SD = 5.9). The average heart rate during active seating expressed as the percentage of the heart rate reserve was 13.4% (SD = 3.8). The average MET levels during active seating was found to be 2.3 (0.4) METs.

Table 8.2 *Results of the heart rate measurements.*

Value	Explanation	Average (SD)
Age	Age (in years)	31.7 (7.8)
HR_{rest}	Resting heart rate (in bpm)	71.8 (9.0)
$HR_{absolute}$	Heart rate during active seating (in bpm)	87.0 (10.9)
HR_{index}	Heart rate index ($HR_{index} = HR_{absolute} / HR_{rest}$)	1.2 (0.1)
MHR	Maximum Heart Rate, calculated by age (in bpm) ($MHR = 208 - 0.7*age$)	185.8 (5.4)
%MHR	Heart rate during active seating as percentage of maximum heart rate	46.8 (5.9)
HRR	Heart Rate Reserve (in bpm)	114 (11.0)
%HRR	Heart rate during active seating as percentage of heart rate reserve	13.4 (3.8)
METs	Metabolic equivalent ($METs = 6*HR_{index} - 5$)	2.3 (0.4)

8.3.3 EMG MEASUREMENTS

The average EMG amplitude was significantly higher for 4 out of 6 muscles during the active seating condition compared to reading, laptop use and tablet use as shown in Figure 8.6 and Table 8.3. In Figure 8.7, the average variability in muscle activity of all participants is shown. Again, EMG variability was significantly larger for the m. obliquus externus abdomini, m. erector spinae at T10 level, m. rectus femoris, and m. trapezius pars transversa, as shown in Table 8.3.

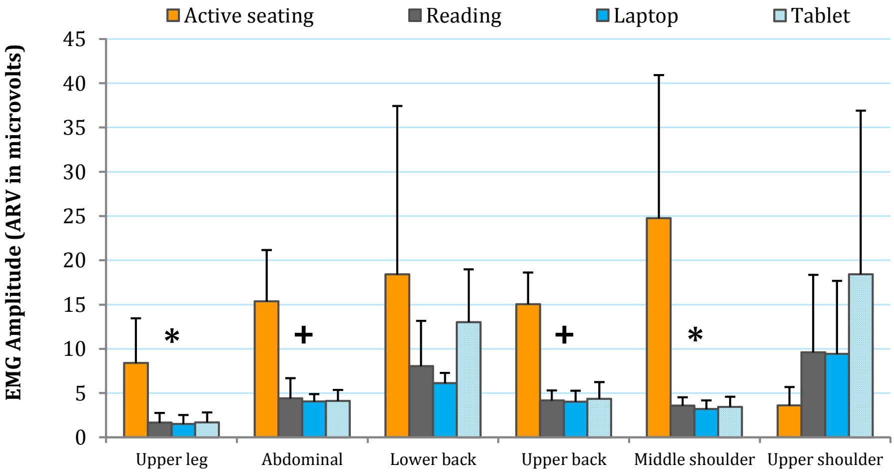

Figure 8.6 *The mean amplitude of the muscle activity expressed as the average rectified value (ARV) for all muscles averaged over all participants. The active seating showed a significantly higher average EMG amplitude compared to the other tasks as indicated by the* ***+*** *($p < 0.05$) and the * ($p < 0.1$). Error bars show the standard deviation between participants.*

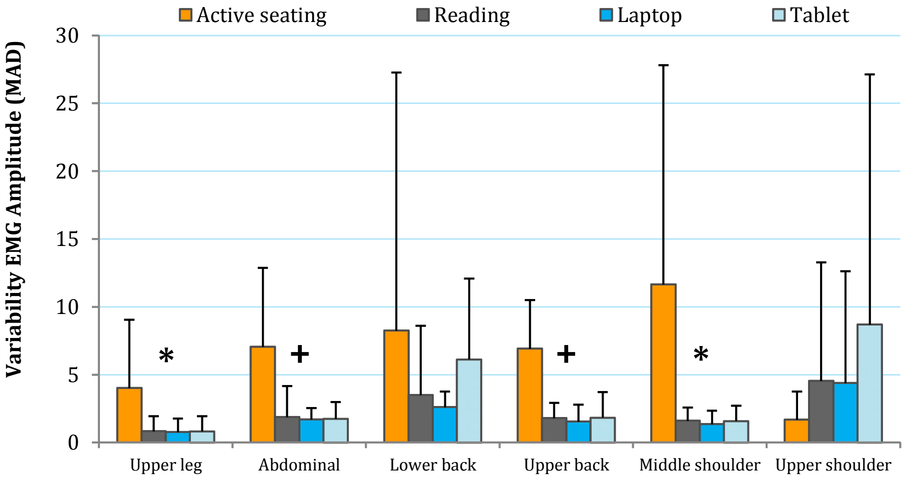

Figure 8.7 *The EMG variability in muscle activity expressed as the median absolute deviation (MAD) averaged over all participants. The active seating showed a significant higher EMG variability compared to the other tasks as indicated by the* ***+*** *($p < 0.05$) and the * ($p < 0.1$). Error bars show the standard deviation between participants.*

Table 8.3 *ANOVA and planned contrasts for the average EMG amplitude and variability in EMG activity. Significant results are marked bold ($p < 0.05$) or italic ($p < 0.10$).*

	Average EMG amplitude			**EMG variability**		
	df	F	*p*	df	F	*p*
Upper leg	1	5.98	*0.092*	1	5.58	*0.099*
AS vs. Read	1	5.93	*0.093*	1	5.54	*0.100*
AS vs. Laptop	1	6.16	*0.089*	1	5.57	*0.099*
AS vs. Tablet	1	5.86	*0.094*	1	5.65	*0.098*
Abdominal	1	20.26	**0.016**	1	24.68	**0.010**
AS vs. Read	1	25.42	**0.015**	1	32.92	**0.011**
AS vs. Laptop	1	19.02	**0.022**	1	23.59	**0.017**
AS vs. Tablet	1	21.19	**0.019**	1	25.86	**0.015**
Lower back	1	1.62	0.290	1	1.75	0.273
Upper back	1	71.33	**0.003**	1	44.4	**0.006**
AS vs. Read	1	61.89	**0.004**	1	42.05	**0.007**
AS vs. Laptop	1	74.51	**0.003**	1	41.47	**0.008**
AS vs. Tablet	1	101.7	**0.002**	1	61.08	**0.004**
Middle shoulder	1	6.77	*0.080*	1	6.69	*0.081*
AS vs. Read	1	6.54	*0.083*	1	6.38	*0.086*
AS vs. Laptop	1	6.59	*0.083*	1	6.54	*0.083*
AS vs. Tablet	1	7.31	*0.074*	1	7.35	*0.073*
Upper shoulder	2	1.63	0.282	2	1.62	0.284

8.4 DISCUSSION

The aim of this study was to evaluate three different aspects of the active seating system. Perceived discomfort and perceived comfort were measured in a 30-minute driving test, whereas heart rate and muscle activity were measured in two other stationary experiments.

Local Perceived Discomfort ratings were very low for both active seating and other tasks (reading, tablet, laptop), indicating that the seats are of such quality that no discomfort occurs within the 30 min of the driving test. A significant increase of total perceived discomfort (LPD sum) and maximum perceived discomfort (LPD max) across measurement was found for all conditions. No significant interaction effects were found between condition and measurement. On the other hand, participants did feel significantly more challenged, more fit and more refreshed while or after using the active seating system according to the comfort perception questionnaire. In line with Zhang et al. (1996), who showed that discomfort is related to physical aspects like pain and stiffness, and that comfort is associated with feelings of relaxation and wellbeing, it could be concluded that the active system has a positive effect on short term comfort and well-being.

While playing the active seating game, the average %MHR was about 47%. According to Garber et al. (2011), an activity with a heart rate below 57% MHR is classified as very light intensity. The average %HRR during active seating was approximately 13%. It is assumed that physical activity has to be at least moderate intensity, meaning 40%HRR or higher, in order to prevent heart and coronary diseases and type II diabetes (Garber et al. 2011). With the current activity levels, active seating does not qualify for this. The average MET level during active seating was estimated at 2.3 METs. This is comparable to very slow walking (<2 mph) or light cleaning (dusting, straightening up) according to the Ainsworth Compendium of Activities (Ainsworth et al. 2000). For an activity to be classified as non-sedentary, it should be >1.5 METs (Sedentary Behaviour Research Network, 2012). With 2.3 METs, active seating would qualify for this. However, the relationship between METs and heart rate becomes increasingly inaccurate at low levels (near resting/ sedentary), so the estimation of 2.3 METs could be under or overestimated (Wicks et al. 2011), which is why we should be cautious in drawing conclusions from this. In addition, the formula used to calculate MET levels has not yet been validated for the prediction errors of individuals.

Although the EMG study was a pilot study with a minimal number of participants, significant differences were found for most of the muscles included. The average EMG levels showed a significantly larger involvement of postural muscles in the abdominal region and upper back. Furthermore, the upper leg muscles showed a trend towards more muscle activity during active seating. Although we can only speculate, dynamic stimulation during active seating might reduce oedema in the lower extremities (Van Deursen et al. 2000a) and relief spinal distress due to spinal length increase (Van Deursen et al. 2000b). Furthermore, research has shown that interruptions of sedentary behaviour are only effective in preventing diabetes type II if the postural muscles are active (Hamilton et al. 2008) to absorb glucose and fats from the blood, which was the case in the current study.

The EMG variability was significantly larger for active seating compared to the other tasks. A study by Van Dieën et al. (2009) showed that more variability in the EMG amplitude of the back extensor muscles resulted in less fatigue development, consistent with an earlier finding that participants with a better ability to alternate activity between parts of the lumbar extensor muscles had a better endurance in isometric back extension (Van Dieën et al. 1993). Temporal interventions like periodic increases in activity might stimulate motor unit substitution within muscles (Westad et al. 2003) or shifts in activity to other muscle parts (e.g. Falla and Farina 2007) or muscles with similar biomechanical functions (e.g. Palmerud et al. 1998), thereby counteracting fatigue effects and discomfort. The EMG results indicate that active seating might result in these positive effects. The driving test results only partially confirmed this. Local perceived discomfort was not affected by active seating, whereas the perceived comfort showed significantly higher ratings for active seating.

In conclusion, active seating can be considered a low-intensity physical activity similar to very slow walking. Although active seating might not qualify as a moderate intensity activity that has a positive effect on general health, there is emerging evidence that increasing the amount of low-intensity physical activity can have similar health benefits (Levine et al. 2005; Hamilton et al. 2008). Active seating can interrupt static sitting and reduce sedentary behaviour, indicating a positive effect on comfort and well-being. Participants felt significantly more fit and more refreshed, which is supported by the EMG measurements that showed a significantly larger involvement of postural muscles in the abdominal region and upper back. Increasing the intensity level of active seating might be possible by, for instance, equipping the system with more sensors in different places and designing different games.

One of the drawbacks of this study is that the experiment was split into three tasks. Ideally, one would measure perceived discomfort and comfort at the same time while measuring heart rate and EMG. However, this was not possible due to disturbances of the signals while driving. The EMG signals were influenced by the engine of the car, so EMG measurements could only be performed while stationary, whereas the infrared signal from the heart rate seemed to be disturbed by the active seating system itself. The heart rate measuring system eventually used in this study was a Bluetooth system, which did not have this problem. For the heart rate measurements, it appeared during the driving test that other equipment was necessary, which is why the heart rate had to be measured in another separate study.

Furthermore, the heart rate and EMG could have been measured for a longer time and with more participants. However, although the heart rate and EMG measurements were performed with a minimal number of participants, results do show significant differences.

The sales market of BMW is worldwide, hence, cars are sold from Europe to the US to Asia. Therefore, it is difficult to describe a "typical" BMW driver in terms of age and anthropometry. It is even more difficult to describe a typical passenger in the back seat of a BMW. This is also why we tried to include these different ethnicities in this study, as well as different ages and body sizes. Several students participated in this study and for most of them it was probably the first time in a BMW 7-series. This could have influenced their opinion on the active seating system. However, the EMG and heart rate results are less subject to bias, since these are physiological responses.

8.5 Conclusion

The active seating system is a promising concept to stimulate passengers to move. The system also offers opportunities for other transportation vehicles, such as aircrafts or trains, to increase the comfort level of their passengers. Especially on long flights or train journeys it can be difficult for passengers to stay fit. This study showed that already after 30 min alternating static sitting with active seating, participants felt significantly more fit and more refreshed. Although 30 min might be relatively short, Sember (1994) concluded that it takes 30 min for discomfort to become sufficient for a behavioural response to occur. More research could be done to see if this effect holds for longer durations as well and what the minimum duration and frequency of playing should be to find sustainable positive effects on comfort and well-being.

Another possible application of the active seating system could be the office workplace. Several studies have been investigating the effects of dynamic workstations (John et al. 2009; Straker et al. 2009; Funk et al. 2012) on health and performance, but these workstations often consist of fitness-like equipment such as a treadmill. Integrating pressure sensors in the back rest of an office seat might be less obtrusive, and the gaming element might help motivate office workers to alternate their office tasks with a more active task.

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CHAPTER 9

EFFECT OF DIFFERENT CUSHION MATERIALS ON PERCEIVED COMFORT OF A TRAIN SEAT

Chapter 7 described different seat characteristics and showed that seat design can influence passengers' comfort and discomfort perception. One of the seat elements is the cushion, more specifically, the characteristics of the seat cushion. Due to the frequent use of passenger seats in public transport, the quality of the seat cushions reduces in time. However, little is known about the effects of deterioration on passenger comfort. This chapter describes an experiment in which the comfort and discomfort is compared of four different train seat cushions (two different materials, one new and one mechanically deteriorated from both).

The study described in this chapter investigated the effects of materials and aging of train seat cushions on comfort and discomfort perception of passengers. The experimental setting is explained in Section 9.2. The results described in Section 9.3 show that participants in this study seem to prefer softer cushions. In Section 9.5, it is concluded that softness of material should be varied in different areas of the seat pan to provide comfort in the buttock area and to reduce discomfort in the lower back area.

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9.1 INTRODUCTION

Comfort can contribute to a pleasurable product experience and is thought to play an important role in product-buying decisions. Therefore, much attention is given to comfort in vehicles, like cars (e.g., Franz 2010; Kamp 2012), where the buyer is often the user. A positive product experience can increase usage or induce a repeat purchase. This is also relevant for providers of public transport, such as trains, because providing comfort can attract more passengers (Vink and Brauer 2011).

However, establishing the ideal comfortable seat for public transport is complex. Reducing the level of discomfort does not necessarily lead to more comfort, as Zhang et al. (1996) showed that for seating, discomfort and comfort are two separate entities with different underlying factors. For comfort, factors such as softness, temperature and humidity play a role (Helander and Zhang 1997), whereas discomfort is influenced by factors such as pain, stiffness, and numbness. Next to seat properties, the interaction between the seat and the passenger is also influenced by usage and personal characteristics (Vink and Hallbeck 2012). This means that for investigating comfort and discomfort (and applying this knowledge to seat design), it is necessary to study the interaction between the passenger (and his activities) with the seat (and its characteristics), in the specific context in which the passenger uses the seat.

In this way, it is clear that studies that describe the development of a seat-buttock model to investigate seat comfort (Mohanty and Mahapatra 2014; Grujicic et al. 2009; Siefert et al. 2008; Verver et al. 2004), using comfort-quantifying parameters, such as maximum pressure level, to determine the comfort level, are lacking the comfort and discomfort perception of people. Likewise, studies that compare material properties of cushions evaluate for instance damping characteristics (Mehta and Tewari 2010) or thermophysiological properties (Bartels 2003), but not the users' perceived seat comfort.

Bronkhorst and Krause (2005) found significant effects on comfort perception after comparing a benchmark seat to a new design of a train seat. Modifications of this seat included the lumbar support, backrest angle and the headrest. Another important seat property that affects comfort is softness of the material. Zenk et al. (2012) found that cushion softness determines the pressure distribution, and that the ideal pressure distribution of a car driver's seat differs for various regions of the body. However, the activities and corresponding postures performed in a train seat are different from those in a car drivers' seat, and the interior around the seat is different as well in a train compared to a car. Hence, the ideal pressure distribution for train seats as well as the ideal softness is unknown.

Furthermore, due to prolonged use of the cushions for years, material properties such as softness, elasticity, and cushion shape will change over time. This might affect passenger comfort as well, especially in public transport vehicles with a high occupancy rate, such as trains. In addition, it may depend on the type of material in what way and to which extent the material properties change, and how these changes affect the perception of comfort. However, the effect of different types of material and the material property change in time on comfort and discomfort perception is unknown.

Therefore, the aim of this study is to evaluate whether the comfort and discomfort perception of passengers is influenced by the material properties of the cushion and by changing properties due to aging of the seat cushion. Polyurethane foam (PU) is the traditional type of foam used in many train seats at the moment. This will be compared to a relatively new material, Silicone, which is claimed to be more resilient to mechanical fatigue. The question is, if the passengers' comfort perception is different between cushions of these two materials, and whether this comfort perception is different for new and deteriorated cushions. Thus, this leads to the following research questions:

1. *Is there a difference in passengers' comfort and discomfort perception between polyurethane foam and silicone seat pan cushions?*
2. *Is there a difference in passengers' comfort and discomfort perception between new and deteriorated seat pan cushions?*
3. *Is the difference in passengers' comfort and discomfort perception between new and deteriorated seat pan cushions different for polyurethane foam and silicone?*

9.2 METHODS

9.2.1 EXPERIMENTAL SET-UP

9.2.1.1 Cushion materials

In this study, two types of material and two types of age are compared. Therefore, four commercially available seat pan cushions were used: a new polyurethane (PU) cushion, a deteriorated PU cushion, a new silicone cushion, and a deteriorated silicone cushion. The difference between the new and deteriorated cushions is a 10 year wear that has been simulated via jounce and squirm equipment (100.000 cycles). Table 9.1 lists the material properties of the new and deteriorated cushions (hardness testing in accordance to ISO 2439). The cushions were double blind tested and therefore referred to as cushions A, B, C, D during the experiment to avoid bias from the participants and from the researcher.

Table 9.1 *Cushion material properties*

Material	Initial hardness	Hardness after simulated wear	Stiff loss (%)
Polyurethane	345 N	160 N	54%
Silicone	438 N	376 N	14%

9.2.1.2 Train seat

A research set-up of a train seat was built for this test. The wooden frames ensured that the cushions of the seat pan could easily and quickly be replaced. The cushions of the backrest were fixed on the frame and remained the same in all conditions. The seats were covered by a black fabric because the original upholstery of the deteriorated cushions showed signs of wear and tear. The dimensioning of the seats is shown in Figure 9.1. The seats were placed facing each other, but were separated by a wall in such a way that the participants would not be able to see each other (see Figure 9.1), to prevent them from influencing each other.

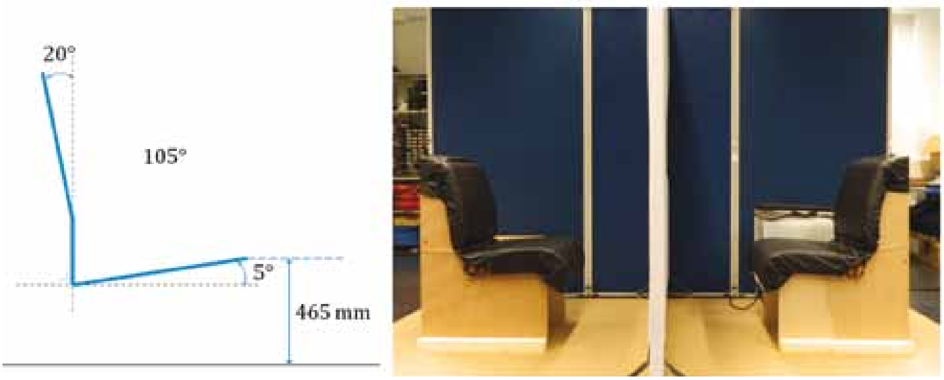

Figure 9.1 *Dimensions (left) and photograph of the experimental set-up of the two train seats facing each other with a separation wall in between them.*

9.2.1.3 Tasks

The way the seat is used is determined by the activities of the passenger. Branton and Grayson (1967), Bronkhorst and Krause (2005), Kamp et al. (2011), and Groenesteijn et al. (2014) observed train passengers while travelling. Frequently seen activities performed by passengers in trains are reading, relaxing/sleeping, using handheld electronic devices, talking and watching.

9.2.2 PARTICIPANTS

Differences in anthropometrics and gender have to be taken into account as well, because these also influence comfort (Branton and Grayson 1967; Kolich 2003). Therefore, care was taken to include participants of different anthropometrics and gender, which makes it easier to generalize results to train passengers.

In the main study on perceived comfort and discomfort, 24 people (11 male, 13 female) of different nationalities (18 European, 1 South-American, 5 Asian) participated. Their average age was 33.3 years (sd 16.3; range 18-65), their average weight was 66.9 kg (sd 12.8; range 41-111) and their average standing height was 1.71 m (sd 0.07; range 1.60-1.86). They received compensation for participating in this study.

9.2.3 MEASUREMENTS

9.2.3.1 Local Perceived Discomfort

Discomfort was measured using the Local Perceived Discomfort method (Van der Grinten and Smitt 1992), which uses a body map with 20 body regions. In this study, two body regions were added to separate the regions for the buttocks and upper legs. The intensity of perceived discomfort per region was rated on a scale from 0 to 10 (0 meaning no discomfort at all to 10 meaning extreme discomfort). Discomfort was rated four times for each cushion. In this way, the change of discomfort in time could be calculated.

9.2.3.2 Adapted Chair Evaluation Checklist

Comfort and discomfort of each cushion were measured using an adapted version of the Chair Evaluation Checklist by Helander and Zhang (1997). The discomfort descriptors that were selected are: *I feel stiff; I feel uneven pressure; I feel tired; Part(s) of my body feel numb; I feel uncomfortable*. The comfort descriptors that were selected are: *I feel relaxed; I feel refreshed; The chair feels soft; I feel fit; I feel comfortable*. Furthermore, three items were added: *Practicing this activity, the seat pan feels comfortable; Practicing this activity, the backrest feels comfortable; I am well supported by the seat to practice this activity*. All items were rated on a 7-point Likert scale.

9.2.4 PROTOCOL

Two participants were invited at the same time and received an introduction on the study. In order to prevent bias, they were not informed that the aim of the study was to test the effects of different cushion materials. Instead, they were told by the researcher that the study was about the difference in comfort between the two tasks (reading and working on a laptop). After signing the informed consent, one of the participants was asked to perform a reading task, the other participant was asked to perform a typing task on a laptop.

After that, the participants were asked to sit down and find a comfortable, freely chosen posture in which they thought they would be able to perform the allocated task for 30 minutes. A screen capture was made of this posture. In this way, the researcher was able to check whether the participants remained in the same posture during the experiment. Then the participant filled out the LPD for the first time.

After these preparations, the subjects started with either the typing task or the reading task. After 10, 20 and 30 minutes the LPD was rated by the participants, while they remain in the same posture. After 30 minutes, the participants were asked to finish the LPD and the adapted chair evaluation checklist. Then a five minutes break started. The participants left the room and walked up and down the corridor, and up and down the stairs to reduce discomfort due to prolonged sitting in the same posture. Furthermore, they were able to have a toilet break. During this break, the researcher changed the cushions without the participants noticing. After the break, the next condition started. This procedure was repeated for the four cushions. The order in which the cushions were tested, was systematically varied among the participants to avoid order effects. The total sitting duration was 120 minutes.

When participants completed the questionnaires after the fourth and last cushion, they were informed about the real purpose of the study and asked if they noticed any changes in the seat during the experiment. Finally, general information, such as age and nationality, were noted and anthropometric data, such as weight and stature, were measured.

9.2.5 DATA ANALYSIS

9.2.5.1 Local Perceived Discomfort

Two types of local perceived discomfort scores (maximum and sum) for three body regions were taken by combining the scores of the involved body parts. The three selected body regions are the back (consisting of lower back left and right, upper back left and right), buttock (buttocks and both upper legs), and the neck (left and right). This resulted in six variables: maximum discomfort (*LPDmax*) of the back, buttock and neck, and the sum of discomfort (*LPDsum*) of the back, the buttocks and the neck. Each LPD score was calculated for three time intervals by subtracting the initial LPD score from the LPD score after 10, 20 and 30 minutes of sitting.

9.2.5.2 Adapted Chair Evaluation Checklist

For the adapted Chair Evaluation Checklist, two scores were calculated: the comfort score (adding the ratings of all comfort descriptors) and the discomfort score (adding the ratings of all discomfort descriptors). Furthermore, these comfort and discomfort descriptors and the three added questions were analysed separately as well.

9.2.5.4 Statistics

General Linear Models (GLM) for repeated measures (IBM SPSS Statistics 20) was used with task as between subject factor and material (PU, Silicone) and age (new, deteriorated) as within subject factors. For the LPD scores, time interval (10 min, 20 min, 30 min) was considered as another within subject factor.

9.3 RESULTS

9.3.1 COMFORT AND DISCOMFORT PERCEPTION

None of the participants noticed that anything changed in the seat during the experiment. Each of them was very surprised to hear the actual purpose of the study.

9.3.1.1 Local Perceived Discomfort

Results of the Local Perceived Discomfort sum scores (*LPDsum*) and maximum (*LPDmax*) are shown in Table 9.2. A significant increase of *LPDsum* and *LPDmax* in time was found for all cushions and all body parts. A significant difference was found for material. The *LPDmax* in the back was significantly higher for PU than for Silicone. This affected the *LPDmax* of the total body in the same way.

For the total body, no interaction was found for material*age. This means that the change in local perceived discomfort – due to changes in the cushions by the ageing process – was the same for both materials. A significant interaction of material*time was found for *LPDsum* and *LPDmax* for the buttock (Figure 9.2). This implies that the increase in time of discomfort of the buttock differs between both materials. After 20 minutes, both *LPDmax* and *LPDsum* for the buttock increase more for the Silicone cushions compared to the PU cushions.

Table 9.2 *Results of the Local Perceived Discomfort sum (LPDsum) and maximum (LPDmax).*

LPDsum	Time	Material	Age	Material* age	Material* time	Age* time	Material* age* time
Neck	F=9.2212 (p.002)	ns	ns	ns	ns	ns	ns
Back	F=16.578 (p.000)	ns	ns	ns	ns	ns	ns
Buttock	F=14.436 (p.000)	ns	ns	ns	F=4.482 (p=.022)	ns	ns
Body	F=23.439 (p.000)	ns	ns	ns	ns	ns	ns

LPDmax	Time	Material	Age	Material* age	Material* time	Age* time	Material* age* time
Neck	F=6.750 (p.007)	ns	ns	ns	ns	ns	ns
Back	F=15.957 (p.000)	F=8.058 (p.010)	ns	ns	ns	F=5.605 (p.009)	ns
Buttock	F=13.135 (p.000)	ns	ns	ns	F=3.557 (p.054)	ns	ns
Body	F=23.152 (p.000)	F=7.604 (p.011)	ns	ns	ns	ns	ns

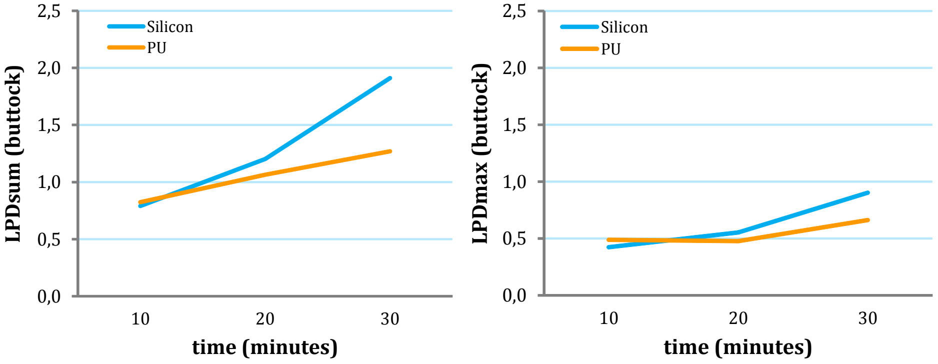

Figure 9.2 *Interaction effect of material*time for the LPDmax and LPDsum of the buttock*

No effects were found for the age of the cushion, for any of the discomfort variables, which means that no differences in local perceived discomfort exist between the new and deteriorated cushions. However, an interaction effect of *LPDmax* of the back was found for age*time (Figure 9.3).

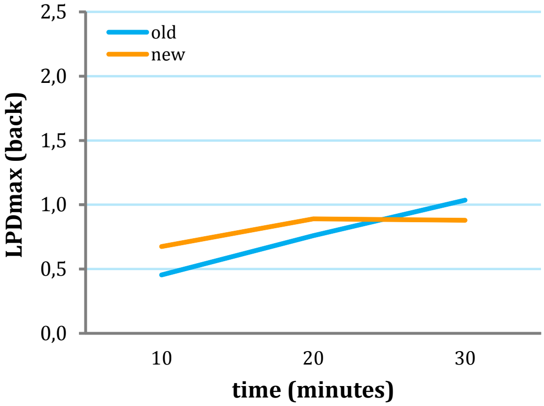

Figure 9.3 *Interaction effect of time*age for the LPDmax of the back*

During the first 20 minutes, for both the new and deteriorated cushions, the *LPDmax* of the back increases. After 20 minutes, the *LPDmax* of the back still increases for the deteriorated cushions, whilst the *LPDmax* of the back of the new cushions remains constant (for the average of PU and silicone).

9.3.1.2 Adapted Chair Evaluation Checklist

The comfort score and the discomfort score (consisting of the comfort and discomfort descriptors, respectively) were calculated for all cushions. No significant differences were found for material (PU, Silicone) and age (new, deteriorated), nor significant interactions for material and age.

Furthermore, the single rating scales were analysed. A significant difference was found for "*I feel uncomfortable*" for age of the cushion (F=5.243, p=.032). The new cushions were rated as more uncomfortable than the deteriorated cushions for both materials.

Finally, the way in which the seat provided support and whether the seat pan and the backrest felt comfortable were questioned. A significant difference was found for "*I feel well supported to perform this activity*" for material (F=7.092, p=0.014). The participants found that the PU cushion provided a better support than the Silicone cushion. Furthermore, a significant difference for material (F=5.159, p=.033) was found for "*The backrest feels comfortable*". The same Silicone backrest felt more comfortable when sitting on a PU cushion compared to a Silicone cushion. For "*The seat pan feels comfortable*", significant differences were found for material (F= 9.064, p=.006) and a tendency was seen for age (F=4.109, p=.055). The PU cushion was rated as more comfortable than the Silicone cushion and the deteriorated cushions tend to be more comfortable than the new cushions.

9.4 Discussion

This study has shown that there are differences in passengers' comfort and discomfort perception for train seat cushions of two different materials (polyurethane foam and Silicone), and for cushions of different age (new and deteriorated). No interaction effects have been found between material and age, i.e. the change in comfort and discomfort perception for new and deteriorated cushions was not affected by the type of material.

The initial material properties of the polyurethane (PU) and Silicone cushions differed: even after 100.000 cycles of simulated wear, the hardness of Silicone was higher than the initial hardness of the PU cushion. Therefore, the participants experienced the differences between the materials of the cushions mainly by the hardness of the material, with PU being softer than Silicone, and with deteriorated cushions being softer than new cushions.

Regarding the first research question, *Is there a difference in passengers' comfort and discomfort perception between PU foam and silicone cushions*, this study has shown that discomfort ratings for the buttocks region were lower for PU cushions, which were softer than the Silicone cushions. For the back region, however, the discomfort ratings were significantly lower for the Silicone cushions. Furthermore, the participants found that the PU cushion provided a better support than the Silicone cushion, and the comfort of the seat pan with PU cushion was rated higher than the Silicone cushion. Furthermore, the comfort ratings for the backrest were higher when sitting on a PU cushion compared to a Silicone cushion.

In a study on car seats, Ebe and Griffin (2001) found that comfort ratings were lower for foam samples with greater stiffness compared to samples with less stiffness. Although they did not find a linear relationship between hardness and comfort, participants reported to feel uncomfortable if the hardness of the foam was too large. This is in line with Franz et al. (2012), who found for a headrest that the hardness should be between an upper and lower boundary to be experienced as comfortable.

In this study, while the back rest cushion remained the same in all conditions, a difference in discomfort ratings has been found between different cushion materials, which is apparently caused by the change in material of the seat pan cushion. According to Mergl (2006), a deviation from the ideal pressure distribution of the seat pan has an influence on the perceived discomfort in the lower back. This could be caused by tension in muscles, for example in the m. illiopsoas that connects the thigh bone (femur) with the lumbar spine (Mergl, 2006). Another possible explanation for the higher discomfort ratings in the back is, that when the material of the seat pan is harder, the motility of people increases, which could reduce discomfort in the back. For example, in a study by Van Dieën et al. (2001) on the effects of dynamic sitting, it was found that more movement lengthened the spine more than sitting in static postures.

Furthermore, there seems to be a difference between the subjective evaluation of the comfort of the backrest and the local perceived discomfort in the back. Both are significantly different between the materials: the comfort of the backrest is rated higher when sitting on a PU cushion compared to a Silicone cushion, whilst the discomfort in the back is higher for PU as well. This reaffirms the statement of Helander and Zhang (1997) that comfort and discomfort are not two extremities on the same scale, but need to be measured on separate scales. Probably, in the evaluation of seating comfort, other factors play a role than the absence of physical discomfort only (Helander and Zhang 1997).

Perhaps it could be explained by the hardness of the cushions as well. For the softer PU cushion, the same mass is distributed over a larger surface, leading to lower average pressure. Wang et al. (2014) found similar results when comparing three cushions with different hardness (hard, medium, soft). The softer the cushion, the lower the scores for maximum and average pressure and the larger the contact area. In addition, they found a negative relationship between peak pressure and tolerance sitting time, i.e. when peak pressure reduces, the tolerance sitting time increases.

Regarding the second research question, *Is there a difference in passengers' comfort and discomfort perception between new and deteriorated cushions*, this study has shown that participants preferred deteriorated cushions, indicating a preference for softer materials for the buttock region. These results correspond with the findings regarding the first research question on the difference between materials.

Regarding the third and last research question, *Is the difference in passengers' comfort and discomfort perception between new and deteriorated cushions different for polyurethane foam and silicone cushions*, no statistically significant results were found; i.e. the difference between new and deteriorated cushions was not significantly different for polyurethane and silicone.

The duration of sitting in this experiment was 30 min per cushion. This is rather short, as Zenk (2008) found a difference in comfort after 2.5 hour driving in a car seat between a self-adjusted seat and a seat adjusted according to the ideal pressure distribution. However, for all four cushions in this study, an increase in discomfort in time was found for all body regions, and the significant interaction of discomfort with time shows that the duration of the experiment was long enough to find results in discomfort.

The cushions used in this study were rather hard. Ebe and Griffin (2001), for example, used 5 foam samples for car seats varying in softness between 120 and 285 N. Only the hardness of the deteriorated PU cushion (160 N) lies within this region. This means that the initial hardness of the cushions was too high, which can explain why subjects preferred the softer, deteriorated cushions. In this case, the PU cushions were softer than the Silicone cushions, and due to loss of stiffness, the deteriorated cushions were softer than new cushions. Probably, no interaction of material*age could be found on comfort and discomfort perception, as the differences in hardness due to deterioration were relatively small compared to the large difference in initial hardness between the materials. It is advised in future research to pay attention to having more comparable initial material properties, as well as carefully choosing the hardness based on previous research and not only commercially available cushions or materials.

Furthermore, it is recommended to study cushions with a pressure distribution that approaches the ideal pressure distribution as described by Mergl (2006). However, it should be studied whether these values are also applicable to train passenger seats as the study of Mergl (2006) was performed on car driver seats. Not only the dimensions of car seats differ from train seats, also the posture of the passengers is different.

Another drawback of this study could be the shape of the cushions, which were not ideal to study comfort, especially the pressure in the front of the seat could have been too high. Care should be taken that the shape of the seat does not cause participants any discomfort when studying the effect of materials. Kamp

(2012) showed that the shape of a car seat influences the comfort experience of the occupant. However, this does not affect the outcomes of the research questions in this study, as the shape was the same for all cushions, although slight differences exist due to the process of deterioration.

Unfortunately, due to the double-blind set-up of the study on comfort and discomfort perception, it was not possible to perform the pressure measurements during the main study. For example, this would require additional calibration and thereby participants could have noticed that the cushions had changed during the experiment. Additionally, a pressure mat could influence the comfort perception.

However, due to the double blind set-up of the study, the researcher did not know which cushion was new or deteriorated, or PU or Silicone, but they were referred to as A, B, C, D. The great advantage of this was that participants in this study were not aware of the different cushions and therefore, were able to rate their sitting comfort and discomfort without being biased. None of the participants had noticed that the researcher changed the cushions during the breaks.

9.5 Conclusion

Usually, when seat cushion deterioration is concerned, the effects on comfort are not considered. However, this study has shown that it is relevant to know the stiff loss for different materials, because hardness influences the comfort and discomfort perception of the seat. This is not only relevant information for seat manufacturers, but also for buyers. When making a purchase decision, the hardness of the seat at that time is used, however, years of usage reduces the hardness of the seat. Therefore, the comfort life span of the seat should be considered, i.e. depending on the type of material, choose a hardness that will be perceived as comfortable for the longest duration.

The participants in this study seemed to prefer softer cushions. However, softer cushions led to higher discomfort ratings in the back. A recommendation for seat design is therefore to vary the softness of material in different areas of the seat pan, i.e. harder under the ischial tuberosity (comparable to deteriorated Silicone), and more soft for the rest of the cushion (front and middle of upper legs). This is in line with Mergl (2006), who found that an ideal pressure distribution of the seat pan can avoid discomfort in the back, and with Chen et al. (2007), who stated that pressure should be highest underneath the ischial tuberosity and more faded towards thighs and sides. Further research is needed to test this hypothesis and to determine the ideal softness for each area. Another possibility to improve seating comfort is to increase the seat pan angle and recline the backrest (Groenesteijn et al. 2009; Van Rosmalen et al. 2009).

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Conclusions from Part III. SEAT

In this third part, the underlying factors for the Seat level have been explored. It has become clear that changes in seat characteristics have a significant influence on comfort and discomfort. In Chapter 7, the seat characteristics that influence comfort and discomfort were described and illustrated by two case studies. The first case study showed that the use of specially designed armrests resulted in a significantly more neutral position for the neck when using a handheld device. In line with these findings, discomfort decreased significantly and comfort increased, especially for the neck region. The second example showed how a seat contour could be designed using 3D scanning techniques, creating opportunities for a better fit to the human body as well as more lightweight seats. Chapter 8 showed that active seating (i.e. playing a game controlled by sensors in the backrest) can improve the comfort perception of car passengers. Finally, the experimental study described in Chapter 9 showed that the material of the seat pan cushion influences comfort, and that the cushion material characteristics change over time. Participants of this study preferred more soft, deteriorated cushions for a train seat, and it is advised to choose the hardness while taking into account the lifespan of the cushion.

LANDING

CHAPTER 10

RECOMMENDATIONS FOR PASSENGER SEAT DESIGN AND RESEARCH

The model presented in Chapter 2 shows that underlying factors at Context, Human, and Seat level determine posture, interface pressure and movement, and that these interaction variables determine the level of comfort and discomfort that is perceived by passengers. In the consecutive three parts, Context, Human, and Seat, the relevance of these underlying factors is demonstrated with case studies and experimental studies. In this chapter, this knowledge is translated into recommendations for designers and researchers in the field of comfortable passenger seats.

This chapter summarizes the previous chapters, translating it into a useful flowchart which can be applied for the design of passenger seats. In Section 10.1, this flowchart is presented, which is composed of nine steps, categorized into the three levels Context (determine), Human (define), and Seat (design). Section 10.2 describes additional aspects which can be relevant for the design of passenger seats, such as the deterioration of the materials that might affect comfort and discomfort.

10.1 FLOWCHART FOR THE DESIGN PROCESS OF PASSENGER SEATS

It is the characteristics of the seat in combination with the user (human) and context that determine passengers' posture and movement and as a result, determine the perception of comfort and discomfort. Therefore, when designing a seat, the first advice is to start by determining the area of use, the duration of the journey, and the activities the seat should facilitate, instead of with designing the seat. On the basis of these context characteristics, the corresponding characteristics at human level can be defined: body dimensions (based on target group characteristics), body movement (variation of posture) and body support. This leads to a specification of the starting points for seat design: seat dimensions, seat adjustability (features) and seat elements. A flowchart that illustrates this proposed design process is presented in Figure 10.1. The successive steps are described in the following subsections (10.1.1–10.1.9).

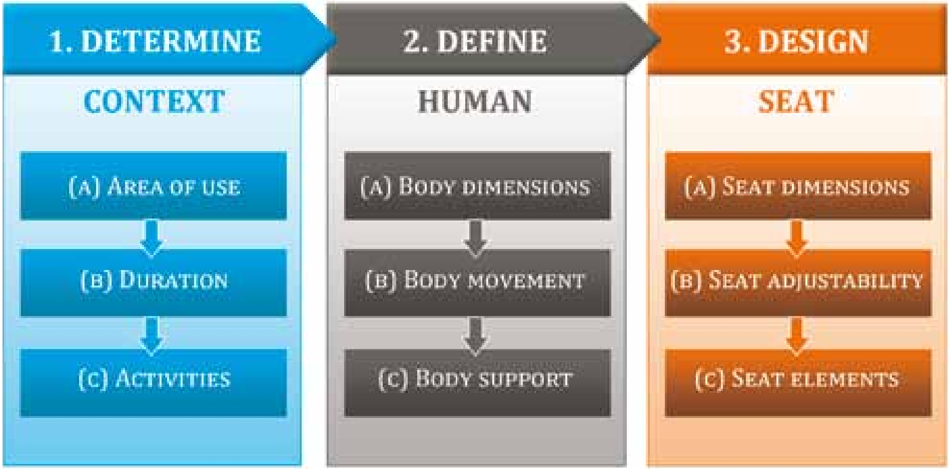

Figure 10.1 *Flowchart for the proposed design process of passenger seats*

10.1.1 DETERMINE AREA OF USE (STEP 1A)

The first step is to determine where the vehicle will be operated in order to determine the target group. For example, a high speed train will probably be traveling in more different countries and regions than a commuter train, which is often limited to one city or region. For cars, market launch might be limited to a number of countries, while for aircrafts, the airline (e.g. country of origin and type of airline) is often a determining factor for the type of passenger. The selected target group is an important aspect, because passengers differ in nationality, gender and age, and therefore also in cultural and anthropometric characteristics. A passenger seat should, for instance, be comfortable for small Asian females as well as for tall Dutch males.

Furthermore, on a commuter train, it is expected that passengers consist mostly of students and working population, so aged between 20 and 65 years old (Bronkhorst and Krause 2005). Besides anthropometric characteristics, the activities passengers perform also seem to be influenced by age, as a study by McMullin et al. (2014) showed that, when asked about their inflight activities, older passengers responded that reading and resting were the most common activities, while playing videogames and using internet were least common (McMullin et al. 2014).

In determining the target group, it is important to note that aircrafts that are designed now will be in service from 2030 to 2060. Demographics will have changed by then, for example, a larger percentage of passengers will consist of elderly people, possibly with reduced mobility, and an increased number of passengers will have obesity. Therefore, the product life span needs to be considered, and possible changes in demographics anticipated for.

The result of this first step is a description of the characteristics of the anticipated target group, which will serve as input for the next steps.

10.1.2 DETERMINE DURATION OF THE JOURNEY (STEP 1B)

For the passenger, the duration of the journey can be anywhere from 5 minutes to 24 hours. On a commuter train, however, trips will likely to be shorter than on a high speed train. Similarly, a compact two-door car is more likely to drive short trips through the city than a large limousine designed for long journeys.

The duration of their journey determines which activities the passenger is likely to perform. For example, on a 2-hour flight, a passenger will probably not sleep, but might open up his laptop to get some work done, whereas on a flight of 6 hours or longer, most passengers will try to sleep. The observations of train passengers (described in Chapter 4), for example, have shown that working on a laptop was the activity with the longest average observed duration (53 min), whereas talking had an average duration of 17 min. The online survey from Chapter 3 showed that walking is increasingly important to feel refreshed when the duration increases.

10.1.3 DETERMINE ACTIVITIES (STEP 1C)

The target group (result of Step 1a) and duration of the journey (Step 1b) provide input for the expected activities. The observations of train passengers (described in

Chapter 4), for example, have shown that passengers perform a number of different activities and change activities. Activities that passengers perform have an influence on their comfort and discomfort perception. For example, the results from the case study in Chapter 3 showed that participants felt less discomfort when they were eating and drinking, and in Chapter 6, the least comfortable experimental condition was not the experimental condition with the highest discomfort.

On the other hand, activities can also be used to reduce discomfort and increase comfort. For example, by stimulating movement in order to feel more fit and refreshed during prolonged sitting (Chapter 8), but also to distract the passenger from feeling discomfort. Research findings by Lewis (2015) suggest that virtual environments can distract people from sources of discomfort which are commonly experienced in air travel, thereby positively influencing passenger's experiences.

10.1.4 DEFINE BODY DIMENSIONS (STEP 2A)

Using the characteristics of the target group following from Step 1a, a prediction can be made on the body dimensions using an anthropometric database. For example, the website DINED (www.dined.nl) contains data on human body sizes for different regions in the world. The characteristics of the anticipated users are important in order to select the proper database (e.g. Dutch adults), or the proper population from the database (e.g. age 20-60 years). It is also possible to compose a specific population according to the characteristics of the anticipated target group.

A more detailed explanation and a case study on how seat dimensions of three current aircraft seats correspond with these anthropometric dimensions is described in Chapter 5.

10.1.5 DEFINE BODY MOVEMENT (STEP 2B)

Body movement is not only important to reduce discomfort and improve comfort. Results from Chapter 3 showed that discomfort reduces after participants were allowed to have a break after 1.5 hours of uninterrupted sitting, and respondents from the online survey said they felt most refreshed after walking through the plane, especially long haul passengers. Walking during flights can also help prevent travel-related thrombosis (Brenner 2009) and leg exercise promotes blood flow, making flying healthier (Hitos et al. 2007).

However, in a restricted space, such as in a car or on an aircraft, it is not always possible to stand up from the seat. In this case, movement in the seat can be stimulated. For example, the active seating system evaluated in Chapter 8 showed that car passengers felt significantly more fit and more refreshed after playing the game compared to when reading a book, working on a laptop or gaming on a tablet. Electromyography showed that besides the upper body, also muscles in the lower leg were active. This helps to prevent negative effects of prolonged sitting.

10.1.6 DEFINE BODY SUPPORT (STEP 2C)

Different activities demand support of different body parts. The results from the train seat experiment (Chapter 6) showed for example that for working on laptop, the armrests together with the table should support the lower arms and wrists, or support the arms while using handheld devices. The table for working on laptop should be closer and lower than the table for reading. Table 10.1 shows an overview of different activities and the desired support from different seat elements, on the basis of the results from the experiments described in this thesis.

Table 10.1 *Overview of desired body support by seat elements for different activities*

Activity	Backrest	Seat pan	Armrest	Table	Headrest
Relaxing / Sleeping	*Fully reclined*	*Upwards to prevent sliding*	*Long to support full arm*	*Not used*	*Side support, neck support*
Reading	*Upright*	-	*Support elbows*	*50% prefers table; high and further, tilted surface*	-
Talking	*Upright*	-	-	*Not used*	-
Working on laptop	*Upright*	-	*Support lower arms and wrists, parallel with table*	*Closer to the body and lower*	-
Smartphone / handheld device	-	-	*High to support hands and reduce neck flexion*	-	-
Watching IFE	*Reclined*	*Upwards to prevent sliding*	-	-	-

There is not always a direct relationship between support of body parts and reduction of discomfort in the same body parts, which is demonstrated for example in Chapter 7. Here, the use of armrests to support handheld devices significantly reduced discomfort in the neck area. Similarly, in Chapter 9, the pressure distribution of the seat pan influenced the perception of discomfort in the lower back. In Chapter 6, participants preferred a more upright posture for working on a laptop, probably in order to decrease neck flexion caused by looking down at the screen.

Furthermore, the use of technologies is also developing in time. New technologies such as Google Glass and smartwatches (illustrated in Figure 10.2) allow passengers to perform new activities and adopt different postures. The type of body support for these activities might be different, as passengers will adopt new body postures using these new devices. This could be translated into new seat elements.

Figure 10.2 *Google Glass functionality (top © Google) and SONY smartwatch (below © SONY)*

10.1.7 DESIGN SEAT DIMENSIONS (STEP 3A)

After determining the context of use and defining the corresponding human characteristics, the next step is to translate the obtained body dimensions from Step 2a into seat dimensions; for example, to use the dimensions of the popliteal height to determine the optimal seat pan height (adjustment range). An overview of body dimensions and corresponding seat dimensions is shown in Table 10.2.

Table 10.2 *Overview of body dimensions and corresponding seat dimensions*

	Body dimension		Seat dimension
1A.	Popliteal height	1B.	Seat pan height with pressed cushion
2A.	Buttock-popliteal depth	2B.	Seat pan length
3A.	Buttock-knee length	3B.	Pitch minus the backrest depth
4A.	Elbow height	4B.	Armrest height
5A.	Hip breadth	5B.	Seat width (distance between armrests)
6A.	Shoulder height sitting	6B.	Lowest part of the headrest position
7A.	Abdominal depth	7B.	Distance between front of table to backrest
8A.	Breadth over the shoulders (bideltoid)	8B.	Backrest width
9A.	Thigh clearance	9B.	Distance between bottom of the table and top of seat pan cushion

Depending on the amount of adjustability that is possible, it will be difficult to select dimensions that will include the entire population. However, it is possible to make a careful and educated selection. As illustrated in Figure 10.4, an increase of 10 mm from 420 to 430 mm will include an additional 11% of passengers, but an increase of 10 mm from 470 to 480 mm will include only an additional 0.4% of passengers[1]. Careful selection of these dimensions will result in an optimum trade-off between including people and an efficient use of space.

10.1.8 DESIGN SEAT ADJUSTABILITY (STEP 3B)

The determined duration of the journey (Step 1b) and performed activities (Step 1c) will help to anticipate passengers' postures and changes in posture. The possibility to vary in posture is influenced by the seat and the environment (i.e. the freedom of movement inside the vehicle). This variation in posture determines the necessary adjustability of the seat. More dynamic sitting and more variation in posture reduces discomfort (Lueder 2004).

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[1] *These percentages are an indication, based on anthropometric dimensions from DINED database (DINED 2004) for a population aged 20-60 years and assuming a 50/50 distribution of male/female passengers.*

On the other hand, the anthropometric characteristics of the anticipated target population obtained from Step 2a will show the variability of body dimensions. Most adjustability is needed for the body dimensions that have the greatest variation. Dowell et al. (1995) for example, found a large diversity in lumbar heights. Preferably, a lumbar support should therefore be adjustable in height.

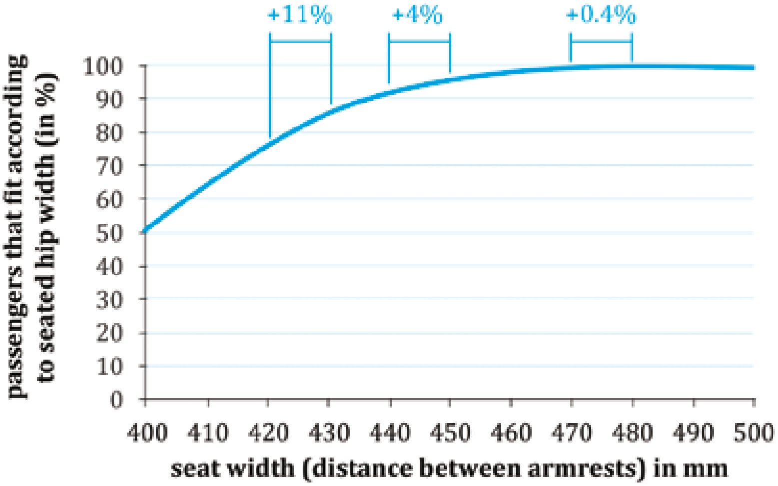

Figure 10.3 *Seat width (distance between armrests), versus percentage of passengers that fit according to seated hip width (DINED 2004, 20-60 years, male and female)*

10.1.9 DESIGN SEAT ELEMENTS (STEP 3C)

Knowing which activities passengers are likely to perform (Step 1c) based on the target group (Step 1a) and the duration of the journey (Step 1b), and corresponding body postures (Step 2b and 2c), the different seat elements can be designed. For different activities, different body support is desired, corresponding with different seat parameters.

Results from Chapter 6 have demonstrated that the preferences of passengers for dimensions and adjustments of a train seat are dependent on the activity they perform and the adopted posture. For example, the use of lumbar support was preferred by almost all passengers (95.8%) for reading, but only 70.8% (on average) preferred a lumbar support for relaxing. Probably, the backrest angle (in relation to body posture) is the reason for this.

Specific design features could be considered to support specific activities, such as the high armrests described in Chapter 7 to support the use of handheld devices. However, these features or seat elements should not interfere with other tasks. A solution could be that passengers can move these elements to adjust to their specific needs, or remove (e.g. by sliding) altogether.

10.2 DESIGNING THE PASSENGER SEAT

Following the flowchart as illustrated in Figure 10.1, the result is a list of requirements for the seat dimensions, seat adjustability (features) and seat elements, targeted at the determined area of use, duration of the journey and expected activities.

10.2.1 DIFFERENT BOUNDARY CONDITIONS

On the basis of these seat dimensions, seat elements and seat adjustability, the requirements for the seat are determined and the seat can be designed. Aspects that have to be designed in this phase are, for example, material and shape. But other aspects such as aesthetics, weight, cost price, and maintenance, also play a role in the design process, as well as crashworthiness, and fire resistance.

The design flowchart is similar for different passenger seats, such as trains, cars and aircrafts. However, the boundary conditions for each of these vehicles is different, which will lead to differences during this phase of the design process. For example, for a car interior, a low roofline is important, reducing the space for the passenger and resulting in a lower seat position, but for an aircraft, the pitch (distance between seats) is important, limiting the knee space and creating a more upright posture. Furthermore, in a car seat, often many adjustability options are available, while on an aircraft, in economy seats, the backrest recline is often the only adjustment. Theoretically, aircraft seats require more adjustability options since the diversity of passengers and activities is very large, but the weight limitations and safety requirements are also very strict.

In conclusion, the flowchart from Figure 10.1 is intended to support designers in determining requirements for the seats from the perspective of passengers. Assuming similar areas of use, duration and activities, these will be the same for different types of vehicles, but the boundary conditions will create differences in the end results.

10.2.2 DESIGN (AND RESEARCH) FOR APPROPRIATE ‘COMFORT LIFESPAN’

The experimental study described in Chapter 9 showed that the seat pan foam influences comfort and the foam characteristics change over time. Participants preferred more soft, deteriorated cushions for a train seat and it is advised to choose the hardness taking into account the life span of the cushion.

The lifespan of the seat does not always match the lifespan of comfortable use. As shown in Chapter 9, the hardness of the cushions reduces in time, influencing the comfort experience of passengers. The amount of stiff loss is depending on the type of material used and should be taken into account, for example, by selecting an initial hardness dependent on material properties. For instance, for PU cushions, cushions should be designed with a higher initial hardness because the hardness will reduce during the first year of use. Silicone cushions, however, are less subject to stiff loss (Chapter 9).

The intensity of use also plays a role in the deterioration of the cushion. The occupant density is much higher in an aircraft or train seat compared to a car seat. Additionally, the car is typically owned by one family for the first years.

10.3 CONCLUSION

The design flowchart described in this chapter is mainly based on results from experiments described in this thesis. It can be used in combination with other design methods (e.g. Van Boeijen et al. 2013). The result is a list of requirements for the seat from a passengers' perspective. Other design aspects, such as technical requirements and aesthetics, were not considered in this thesis, but need to be considered as well.

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Chapter 11

General discussion and conclusion

11.1 INTRODUCTION

This thesis has presented a new conceptual model and design guide on how to design comfortable passenger seats. The model is based on three levels: context, human and seat characteristics, as comfort exists only in the interaction between a human and a product within a certain context (Vink and Hallbeck 2012; De Looze et al. 2003). This means that the characteristics of the potential user population (human), the activities they perform (context) and the physical context in which they are seated should be taken into account when designing a seat.

This model has also served as a structure for a series of experiments in which new relationships between the elements were discovered. The results of these experiments on train seats, aircraft seats and car seats have been used as input for the construction of a flowchart to support designers and researchers involved in the development of comfortable passenger seats.

In this chapter, the findings from the previous chapters will be discussed on the three elements Context, Seat and Human, but first, considerations on the new conceptual model consisting of these three elements will be described.

11.2 DISCUSSION OF MAIN CONCLUSIONS

11.2.1 A NEW CONCEPTUAL MODEL FOR PASSENGER SEAT (DIS)COMFORT

The model of De Looze et al. (2003) provides insight into the underlying factors of sitting comfort and discomfort at the human, seat and context level. This thesis has expanded the model of De Looze et al. into a new conceptual model that is further detailed for seat designers and aims to contribute to the understanding of how designers can apply these factors to design more comfortable passenger seats. Using this new conceptual model (Figure 11.1), the relationships between human, seat and context factors have been investigated, based on results from literature (Chapter 2) as well as experiments on train seats (Chapters 4, 6, 9), aircraft seats (Chapters 3, 5, 7) and car seats and (Chapters 3, 7, 8).

The majority of the studies found in the literature review described in Chapter 2 focused on car driver's seats and office chairs. The results of these studies cannot be directly applied to passenger seats, because the context of use (i.e. the performed activities) and the seat characteristics (e.g. adjustability of seat dimensions) of these seats are different compared to aircraft seats or seats for public transport.

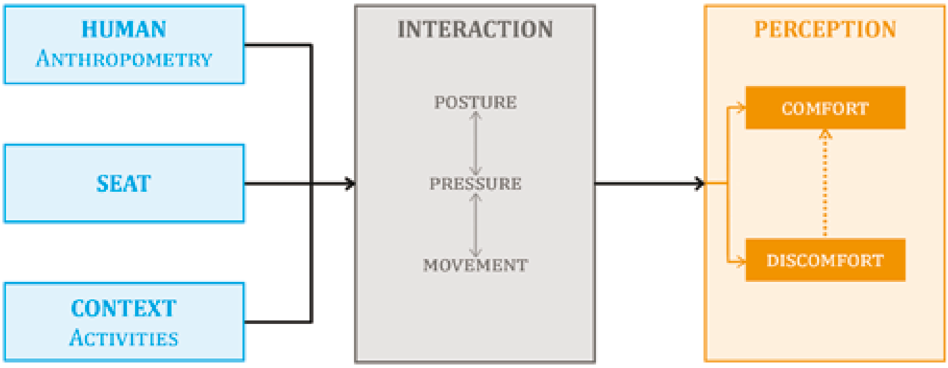

Figure 11.1 *New conceptual model for passenger seat comfort and discomfort*

According to the *passenger seat comfort and discomfort model* illustrated in Figure 11.1, there is no direct relationship between human, seat and context characteristics, and comfort and discomfort perception, but this relationship is mediated by the interaction variables posture, pressure and movement. This is similar to Moes' model of discomfort perception (Moes 2005), who stated that the interaction between a person and a seat results in internal body effects, such as tissue deformation or the compression of nerves and blood vessels. These effects can be perceived by the person and interpreted, for instance as pain, which can lead to feelings of discomfort. Vink and Hallbeck (2012) modified this model, including musculoskeletal complaints that can result from discomfort. They also added expectations and distinguished comfort (C) and discomfort (D) and a neutral feeling (N) as output. A neutral feeling can be interpreted as no perception of comfort together with discomfort level that is so low that the person is not aware of the discomfort. Naddeo et al. (2014) further extended the model of Vink and Hallbeck to incorporate the working environment and evaluation instruments (Figure 11.4).

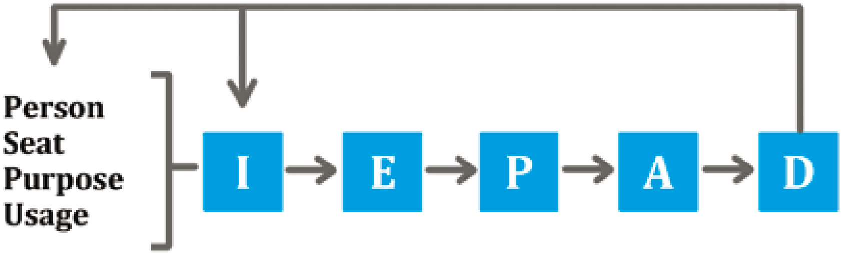

Figure 11.2 *Model of discomfort perception by Moes (2005)*

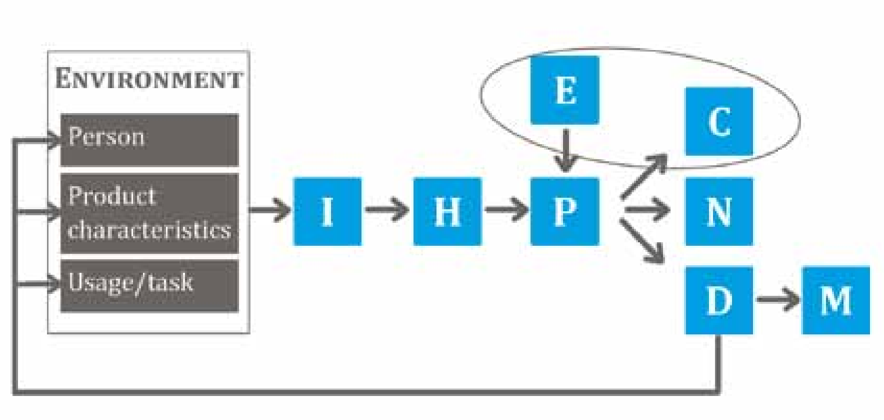

__Figure 11.3__ Model of comfort and discomfort perception by Vink and Hallbeck (2012)

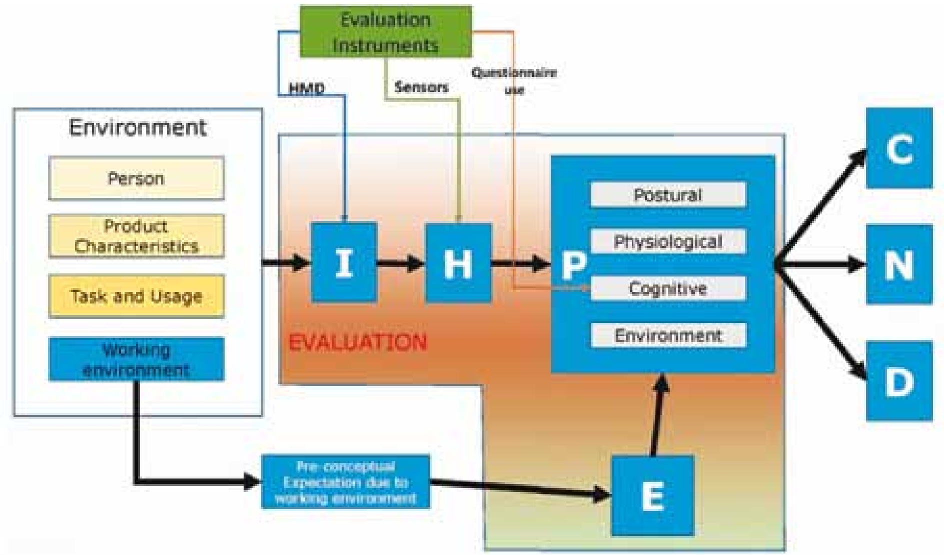

__Figure 11.4__ Model of comfort perception by Naddeo et al. (2014)

This diversity of comfort models also indicates that it is a very complex process. Although most researchers agree that comfort is subjective, that it is affected by various factors and that it is a reaction to the environment (De Looze et al. 2003), the concept of comfort and discomfort remains controversial. The model proposed in this thesis gives designers more practical recommendations. For seat designers, it is interesting to know how seat characteristics affect this interaction and thus, how they can design for comfort.

The resulting flowchart from Chapter 10 is almost exclusively based on experiment results from this thesis. For a wider applicability, it could be supplemented with experiences from other designers and researchers. Preferably, the proposed flowchart is applied to an actual design process of a passenger seat, in order to validate the method. Furthermore, the connection with other, existing design methods could be explored (e.g. Van Boeijen et al. 2013).

11.2.2 THE INFLUENCE OF ACTIVITIES ON PASSENGER COMFORT AND DISCOMFORT (CONTEXT)

In the first part of this thesis, the underlying factors for the context level have been explored, in particular passengers' performed activities and duration of the journey.

The results of this part have shown that train passengers perform various activities, and that they adopt different corresponding postures (Chapter 4). However, in the car, most of the posture is dictated by the seat, as shown in the case study on working in the back seat of a car (Chapter 3). Compared to other studies on postures and activities, this case study showed less diversity in postures. For example, Groenesteijn et al. (2010) demonstrated that different office tasks, such as error correcting, telephoning and file sorting, had an effect on posture and movements of body parts, as well as chair part positions such as backrest inclination and seat pan angle.

On the other hand, activities can also distract passengers from feeling discomfort. Richards et al. (1978) also found that "*a passenger may be so immersed in an activity that they do not attend to their discomfort*". This can also provide opportunities for providers of transport. For example, research results from Lewis (2015) suggest that virtual environments can distract people from sources of discomfort which are commonly experienced in air travel, thereby positively influencing passenger's experiences. In Chapter 3, participants also indicated less discomfort when they were eating and drinking. A complete meal seemed to have a greater effect than only drinks and a snack.

From the case study described in Chapter 3, it appeared that performed activities influence the development of discomfort in time. Discomfort reduced after each new activity, especially after the 15 minute break in which participants were able to walk around after 1.5 hours of sitting in an aircraft seat. Results from the aircraft interior survey (Chapter 3) also indicated that passengers felt more refreshed after walking in the plane, especially during long haul flights. This is in line with the results of Chapter 8, where car passengers felt significantly more fit and more refreshed after playing a game on the back seat which required movement of the upper body and muscle activity in various parts of the body, like trunk and legs.

Physical inactivity is associated with cardiovascular disorders, type II diabetes, depression, obesity and some types of cancer. Long periods of uninterrupted sitting is one of the risk factors. Hu et al. (2003) estimated that each 2 hours sitting time increases the risk of obesity by 5% and the risk of diabetes by 7% in female workers. Variation in posture, but more importantly, movement, should be stimulated, especially for journeys longer than 2 hours.

Summarizing, it has become clear from this part that activities influence passengers' posture and thus, their comfort and discomfort. Activities can also distract passengers from feeling (dis)comfort, which is an opportunity for airlines and seat designers. Discomfort during prolonged sitting can be reduced by regularly changing posture and walking.

11.2.3 THE INFLUENCE OF ANTHROPOMETRY ON PASSENGER COMFORT AND DISCOMFORT (HUMAN)

In the second part of this thesis, the underlying factors at the human level have been explored, in particular passengers' anthropometry. The results of this part have confirmed the direct relationship between seat dimensions and anthropometric characteristics by comparing the dimensions of economy class aircraft seats to anthropometric measurements from a database, which proves the value of defining the anthropometrics of the target population in designing a passenger seat. From this study, it was seen that current economy class aircraft seats exclude up to 21% of passengers due to the distance between armrests which is too narrow for passengers' hip width. The problem with armrests is described in other studies as well. For example, in a study on office chairs (Groenesteijn et al. 2015), the armrests appear to be too wide, meaning that office workers with a small breadth over the elbows could not use the armrests. Perhaps a sliding or foldable armrests could offer a solution.

The correlations between preferred seat dimensions and anthropometric characteristics are described in Chapter 6. Ideal seat parameters are dependent on passengers' anthropometry and their performed activities. For instance, seat pan length was correlated to stature. Teraoka et al. (2005) also found that taller people had a preference for larger chairs, whereas shorter people preferred smaller chairs.

Furthermore, differences were found in the perception of comfort and discomfort between tall and short people (Chapter 5). Tall people more often experienced discomfort in the neck, whereas short people more often experienced discomfort in the feet. This is related to dimensions of the seat, e.g. the headrest can be too low for tall people or the seat pan height too high for short people, but it is also related to the posture: in the slouched posture, shorter people were able to reach the floor with their feet, thereby reducing the discomfort.

11.2.4 THE INFLUENCE OF SEAT DESIGN ON PASSENGER COMFORT AND DISCOMFORT (SEAT)

In the third part of this thesis, the underlying factors for the seat level have been studied. The results of this part have made it clear that changes in seat characteristics can influence comfort significantly.

Results from Chapter 6 indicated that if the backrest angle is reclined, the seat pan angle should change accordingly to avoid shear forces and to improve comfort, in line with (Goossens and Snijders 1995). A lumbar support is preferred, but should be adjustable to accommodate different activities and corresponding postures.

In a study by Hedge et al. (2011), indications were found that the design of the seat in combination with the task has a large effect on the number of complaints from office workers. The presence of correct armrests significantly reduced shoulder complaints. Furthermore, a moving backrest was found to be better compared to a fixed backrest.

The first case study from Chapter 7 showed that the use of specially designed armrests resulted in a significant more neutral position for the neck when using a handheld device. In line with these findings, discomfort decreased significantly, especially for the neck region. The second case study showed how a seat contour could be designed using 3D scanning techniques creating opportunities for a better fit and light weight seats.

From this chapter it has become clear that there are possibilities to improve passenger comfort and discomfort by changing the design of the seat, especially by providing correct body support.

11.3 REFLECTION ON FOCUS AND METHODOLOGY

This thesis consisted of three parts, Context, Human and Seat. However, in reality, this separation is not so strict, as the aspects at these different levels are interacting with each other and overlap.

11.3.1 FOCUS ON PASSENGER SEATS

The focus of this thesis has been on passenger seats; the environment has only been partly considered in the experiments. In Chapters 4 (train), 3 and 8 (car), the experiments took place in a laboratory setting. This environment can have a large impact on the overall comfort experience. In a naturalistic setting, the physical environment can restrict posture (Chapter 3), but it can also be used for body support (Ciaccia and Sznelwar 2012). Ahmadpour et al. (2014) distinguished eight themes for aircraft cabin comfort, of which the seat was one of the most important factors in the perception of comfort. Other physical environment factors, such as temperature, humidity, light, also influence the perception of comfort or discomfort, but sometimes humans are not aware of these influences. Mellert et al. (2008), for example, found a significant increase of awareness of symptoms like swollen feet and muscle pain in the neck with increasing noise level for flight attendants and pilots.

Interestingly, McMullin (2013) found that passenger satisfaction of seat comfort in a Boeing 737 was 78% higher for the new Sky Interior compared to a standard interior. Similar results were seen for cabin cleanliness (+44%), the air quality (+41%) and the temperature during the flight (+40%). Apparently, the Sky Interior created a positive 'halo'–effect on the unchanged cabin features (McMullin 2013).

Figure 11.5 *Boeing 737 standard interior (left) and Sky Interior (right)*
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11.3.2 Focus on physical comfort and discomfort

The focus in this thesis has been on physical comfort and discomfort. However, sitting comfort is also influenced by passenger's expectations and emotions (De Looze et al. 2003; Vink and Hallbeck 2012; Ahmadpour 2014). For example, Vink and Brauer (2011) found no significant differences between comfort ratings of business class seats and economy class seats. Selling the same seats at a different price might also change passenger's expectations and result in different comfort ratings (Fazlollahtabar 2010).

The well-being of passengers before the flight is significantly correlated to their well-being during the flight (Konieczny 2001). Similarly, Ahmadpour (2014) found that the first impressions of the aircraft cabin influence the passenger's overall comfort level and emotions. For the Boeing 787 interior, designers tried to create emotional separation from the travel experience that occur before boarding by welcoming passengers onboard by the vaulted ceiling entryway (Brauer 2005).

Figure 11.6 *Boeing 787 vaulted ceiling entryway © BOEING PHOTO*

Besides the pre-flight experience, the end of the experience can also influence the memory of passenger's comfort experience. According to Ahmadpour (2014), "the retrospective evaluation of comfort is a valid representative of the actual comfort experience during the flight". Konieczny (2001) also found that the well-being of passengers after the flight was highly correlated to their well-being during the flight.

However, differences exist between the actual experience and the memory of the experience. In an experiment by Kahneman et al. (1993), subjects were exposed to two unpleasant experiences in which they were asked to put their hands in icecold water. In the short trial, the water was at 14°C for 60 seconds; the longer trial was similar, but added another 30 seconds in which the water temperature was gradually raised to 15°C. Subjects evaluated the longer trial as less painful overall, less cold, and easier to cope with, and nearly 70% of subjects preferred to repeat the 90-second trial. In line with Kahneman (1993), remembered overall happiness seems to be better predicted by end happiness than by peak or all time low happiness, according to Kemp et al. (2008), who analysed perceived happiness experienced on vacation. Longer holidays did not receive higher overall ratings than did shorter ones (Kemp et al. 2008), which confirms the statement of Kahneman et al. (1993) that duration plays a small role in retrospective evaluations of average experiences, and that the end of an experience influences the memory of the total experience.

So for vehicle designers and airlines, it is not enough to offer a comfortable seat, but they have to offer a pleasant experience before, in the beginning and after the journey as well. Researchers should also be aware of this phenomenon, since the conditions before testing also influence the evaluation. Van Veen et al. (submitted), for instance, discovered that the softness of a seat was evaluated significantly higher by participants after sitting on a hard wooden stool, compared to after sitting on a soft comfortable chair. This also provides opportunities for airports and other waiting rooms.

11.3.3 Reflection on measurements

According to De Looze (2003), pressure measurements seem to be the best objective indicator for discomfort. The correlation between pressure variables and passenger comfort and discomfort has been the subject of many studies, but the results of these studies are sometimes conflicting with each other, also due to large differences in research design (Chapter 2). Therefore, the strength of this correlation is not clear and more research is necessary, especially for passenger seats, since most of the research in this field has been performed on car driver's seats. In addition, more variables have to be taken into account (e.g. personal space and exposure duration) in order to make a better prediction of comfort and discomfort. This, however, has not been the topic of the current thesis. Instead, experiments have been performed to be able to understand the other relationships better, such as between activities, posture and movement.

One of the methods often used for measuring discomfort is the Local Perceived Discomfort method (Van der Grinten and Smitt 1992). The original LPD method is based on the occurrence of muscle discomfort to evaluate workplaces and could be improved to apply in seating comfort research. Currently, the buttocks and upper leg are regarded as one body area, while Mergl (2005) distinguishes at least three different areas (front, middle, and back of the upper leg). Perhaps another scale should be used as well, depending on the duration of the experiment, e.g. yes/no with a red or green pen for initial discomfort and comfort, as done in Chapter 5. The wide variety of comfort and discomfort measurements makes it difficult to compare research results. Pearson (2009) also concludes from her literature review that "further work on development and validation of comfort assessment tools is needed". Some researchers prefer one scale ranging from very discomfortable to very comfortable (e.g. Ahmadpour 2014), while others use separate scales (e.g. Kyung and Nussbaum 2008). In this thesis, comfort and discomfort are considered as separate entities, which is supported by the results.

The number of participants used in the experiments in this thesis is limited, ranging from four (EMG measurements) to 28. Although in most cases, this was enough to find statistically significant results for the research questions of the experiment, the amount of data is not enough to perform, for example, a regression analysis. From Chapter 2 it was concluded that although previous studies have found correlations, hardly any effect sizes are reported. If attempts are made in the future to build a predictive model for passenger comfort and discomfort, the number of participants needs to be considerably higher due to the complex interaction between different parameters. However, as a basis for design, the number of participants used in these experiments is sufficient.

11.3.4 FOCUS ON CARS, TRAINS AND AIRCRAFTS

The focus of this thesis has been on passenger seats, and therefore experiments have been carried out concerning train seats, aircraft seats and car seats. The experiments have been set up in close collaboration with companies, such as railway companies, seat manufacturers and suppliers. This is a very strong point, since the results can immediately be applied in practice. By some, it is also believed that knowledge is generated in the act of designing itself (Stappers 2007): research through design. However, it also provided some limitations regarding the topics of research.

In the experiments in this thesis concerning aircraft, only economy class seats were studied (Chapters 3, 5, 7). This is the most challenging seat due to the restricted, confined space and intensive use. For business class seats, designers have more freedom in providing, for example, adjustability options and weight limitations are less strict. Contrarily, the active seating experiment (Chapter 8) was performed in a luxurious car (BMW 7 Series), but this can be explained by the fact that this a car in which passengers are driven around by a chauffeur. For the train seat observations (Chapter 4), both first and second class passengers were observed, and the results from the experiments (Chapter 6) are applicable to both first and second class seats as well. Because the results give support for the relations in the new conceptual model, instead of for the design of one ideal passenger seat, this is less of a problem.

Furthermore, the results from the experiments have not been validated for other types of transport, such as buses or underground railways. However, the increasing use of handheld devices is a general trend, and providing support (such as the armrests from the case study in Chapter 7) can be an opportunity for all passenger seats. The activities and corresponding postures defined in Chapter 4 for train passengers might not be feasible for the economy class of an aircraft, or the backseat of a car, due to restrictions in space caused by the environment. On the other hand, other activities and postures might occur, such as using the in-flight entertainment system in an aircraft. Other results from this thesis, such as the observation on the age and deterioration of the seat cushion (Chapter 9), inducing movement (Chapter 8) and distracting passengers from feeling discomfort (Chapter 3), are also relevant for all types of seats.

11.3.5 FOCUS ON HEALTHY, ADULT PEOPLE

The people who have participated in the experiments described in this thesis were, in general, healthy and in a limited range of age. Therefore, a generalization of the results, such as the application to children or the elderly, will need additional measurements.

With increasing age, the group of persons with reduced mobility (PRMs) will become larger. This special target group demands attention, as they face difficulties during travel (McMullin et al. 2014), for example during in/egress (Lijmbach et al. 2014). This was, however, not the focus of this thesis.

11.4 RECOMMENDATIONS FOR FUTURE RESEARCH

11.4.1 CHANGING DEMOGRAPHICS AND CHANGING TECHNOLOGIES

In the coming years, a higher percentage of elderly people is expected, as well as more obesity. These changing demographics lead to new requirements for the design of passenger seats.

Even more new activities and postures are possible with increasing use of new technologies such as smartwatches and Google glasses. Virtual reality techniques can also be applied to increase comfort of passengers (e.g. VR hyperspace).

The design process presented in Chapter 10 should enable designers to design for these new contexts as well, but this needs to be evaluated in future research and design projects.

11.4.2 SEAT CONTOUR BASED ON 3D SCANNING TECHNIQUES

In Chapter 7, a method was described to develop an ideal seat contour for aircraft seats using 3D scanning techniques. This allows a much more accurate measurement of anthropometry and therefore seems very promising. In addition, customization of the seat could be a possibility as well. Research is needed on the ideal method how the resulting seat contour should be translated in a seat design. Furthermore, the effects on comfort need to be investigated. For example, Franz et al. (2011) did this for car seats and found that comfort was comparable to an existing seat.

11.4.3 PREDICTIVE MODEL FOR PASSENGER SEAT COMFORT

The aim of the literature review in Chapter 2 was to investigate whether passenger comfort and discomfort perception could be predicted by characteristics at context, human and seat level. A new conceptual model has been introduced, but in order to be able to build a predictive model, it is important that the relationships between the variables can be quantified. Therefore, statistical evidence is needed, such as correlation coefficients and effect sizes. However, only a few studies were found in which statistical evidence was found between variables. Furthermore, the different context characteristics (driver's seat, office chair, experimental seat) are hardly representative of passenger seats. Therefore, more research is needed to obtain correlations between the different variables. The predictive model can be an aid during the design process, taking into account the context, activities and target group. However, it remains important to test with real human participants as well, because comfort is still a subjective phenomenon.

11.5 RELEVANCE FOR INDUSTRY

This thesis provides knowledge to designers, researchers and purchasers of passenger seats. Designing a comfortable passenger seat is a very complex process, and these results might support designers. Considerations for designers are previously described in Chapter 10, where a flowchart is proposed starting with determining context factors and defining human characteristics before designing the seat. Considerations for research and development (11.5.1) and for purchase of passenger seats (11.5.2) are described below.

11.5.1 CONSIDERATIONS FOR RESEARCH AND DEVELOPMENT

Research on seats can be classified into three main categories: aimed at improving the comfort of seats, aimed at advising purchasers on which seat to buy, and fundamental research, aimed at investigating, for instance, the correlation between pressure and comfort. The first two types of research are more related to designers and purchasers, respectively. For the latter, more fundamental, type of research, the following recommendations have resulted from this thesis.

First, the postures obtained by the participant have a large influence on the obtained results. For example, when measuring pressure distribution, this is strongly dependent on the performed task and the corresponding sitting position (e.g. Bendix et al. 1985; Bishu et al. 1991; Drury and Coury 1982).

Second, the activities performed by the participant have an influence on their comfort and discomfort perception. Unwanted effects during research can occur depending on the activities that participants perform during breaks, for instance when measuring long term comfort. Additionally, activities can distract participants from feeling discomfort.

Furthermore, perceived discomfort increases in time, and the more comfortable the seat, the longer it takes before discomfort occurs. It is important that the duration of the test is representative of the duration of the journey, i.e. for seats of a local train, 30 min might be enough, while for seats of long haul aircraft, 6 hours is more appropriate.

The second case study from Chapter 7 has shown that it is possible to conduct an experiment with a limited number of participants, as long as they are carefully selected. In this case, participants were included if they had one or more ‘extreme’ body dimensions, such as broad shoulders or short lower legs. Of course, larger numbers of participants will still be needed to perform a sound statistical analysis.

In the evaluation of the comfort of the seat, it is important to consider the whole body. For example, the active seating system that induced movements of the upper body described in Chapter 8, also led to increased muscle activity of the upper leg. Furthermore, the use of innovative armrests to support the design of handheld devices (Chapter 7) led to a decrease in discomfort and increase in comfort in the neck region, whereas in Chapter 9, the discomfort in the lower back region was different for different seat pan cushions. According to Mergl (2005), a deviation from the ideal pressure distribution in the seat pan can lead to back complaints.

Finally, a consideration should be which age of the seat should be used in evaluating comfort. An aircraft seat is in use for 16 hours a day or more. Seats on trains and other types of public transport have high occupancy rates as well. A car seat is used for 2 hours a day, but has different owners in its lifetime. As shown in Chapter 8, the hardness of the cushions reduces in time, influencing the comfort experience of passengers. Hence, in order to evaluate showroom cushions, new cushions should be used, but in order to evaluate the actual lifetime comfort, a representative deterioration should be applied to the cushions, to simulate the state in which they will be in use the longest.

11.5.2 Considerations for purchase of passenger seats

When the decision is made to purchase new seats, whether for refurbishment or a completely new fleet, often the buying decision is based only on a first impression of the seat and reports of the supplier. In the airline industry, there are even examples of companies where the purchaser is the only one to evaluate a seat (for 5 minutes). However, the initial comfort is not a good prediction of the long-term comfort, or even the short-term comfort. Therefore, this section will describe three recommendations for purchasers.

First, it is important to have a basic knowledge of ergonomics. For example, Mueller and Hassenzahl (2010) compared the subjective evaluation of two chairs, one inferior and one superior, and found that under guided exploration, perceived sitting comfort corresponded with ergonomic chair layout, i.e. the superior chair was perceived more favourably that the inferior chair. However, the inferior chair was preferred by participants who did not receive any guidance. Even simple instructions may sensitize people to consider ergonomics when acquiring products (Mueller and Hassenzahl 2010).

Second, the evaluation of the seat should be done by comfort testing, with a duration representative for the use of the seats, preferably with real passengers that represent the target group well and simulate the activities for the expected duration of the use. Only then, the seat can be evaluated for the different activities passengers perform during their journey, and the different postures they obtain. For long haul seats for example, sleeping is a very important activity for passengers, and providing a comfortable sleeping position can be a competitive advantage because passengers arrive more fit at their destination.

Third, the expected lifetime of the seat is important to consider. As shown in Chapter 8, the hardness of the cushions changes over time. In our study, the seats became softer, influencing the comfort experience of passengers, but this depends on the type of material used. The amount of stiff loss is depending on the type of material used and should be taken into account. For example, the hardness of the cushion could be increased upon purchase, to reach optimum hardness after one year in service and remain comfortable for the next five years, instead of being optimal upon purchase and become uncomfortable after the first year.

In conclusion, purchasers should have basic knowledge on the ergonomics of seats, to prevent them from buying a seat based on first sight and initial comfort, whereas passengers use the seats for more than 4 hours.

11.5.3 POSSIBLE APPLICATION IN OTHER AREAS

The main conclusions from this thesis are not only relevant for passenger seats, but could also be applied to seats in semi-public spaces, such as airport lounges or other waiting rooms, and office seats as well. For example, Groenesteijn (2005) performed research on seat design in the context of knowledge work and found that an office chair should facilitate the variety of tasks that a knowledge worker performs. This is similar to the results obtained from the train seat (Chapters 4 and 6).

The deterioration of the seat cushions is also relevant for other seats; especially in command and control rooms, where the seats are often occupied for 24 hours per day, seats have a high occupancy rate.

11.6 CONCLUDING STATEMENTS

This thesis has presented content for relationships in a new conceptual model on how to design comfortable passenger seats. The model consists of three input elements: Context, Human and Seat. The context influences the design of the seat, for instance different activities ask for different backrest angles and table heights. The human also influences the design of the seat; e.g. a seat for a specific target population needs to take into account the different body dimenions. Together, the context, human and seat characteristics determine the posture, pressure and movement of passengers, thereby influencing their perception of comfort and discomfort.

The results from this thesis can be used by designers and researchers to anticipate on changing demographics of the passenger population, changing technologies, and changing activities that passengers perform, thereby contributing to a more pleasant traveling experience and the well-being of passengers.

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DEBOARDING

SUMMARY

COMFORTABLE PASSENGER SEATS: RECOMMENDATIONS FOR DESIGN AND RESEARCH

The aim of this thesis was to provide new knowledge on how to design comfortable passenger seats and to provide recommendations for design and research. Not only the numbers of passenger transport are increasing, the (cultural) diversity of passengers is increasing as well. Furthermore, a revolution in ICT devices, applications and networks also introduces a larger variation in activities that passengers are able to perform while traveling. Although the first studies on passenger seat comfort appeared already 40 years ago, the activities and context have changed since then. Therefore, more knowledge is needed on the influence of passengers' body sizes, the activities they perform, and the properties of the seat, on the comfort and discomfort perception of passengers.

First, a literature review has been conducted on the current state of knowledge (**Chapter 2**). The result is a new conceptual model that illustrates the relationships between activities (context level), anthropometric variables (human level), and seat characteristics (seat level) on the one hand, and passenger comfort and discomfort on the other hand. These relationships are influenced by the interaction variables, body posture, pressure and movement. In the following chapters of this thesis, experiments have been performed on aircraft seats, train seats and car seats, in order to provide a better and more practical foundation for these relationships.

The first part, **CONTEXT**, studies the influence of context characteristics on comfort and discomfort perception, and consists of two chapters. In **Chapter 3**, two case studies illustrate the influence of activities and duration. The first case study investigated the possibilities for working in the backseat of a car. It appeared that the variation in body posture was restricted by the car interior, and that passengers missed support for their arms or their devices (laptop, book or tablet). The second case study showed that, during an experiment with three aircraft seats, discomfort reduced after participants were able to stand up from their seats after 1.5 hour sitting. Respondents from an online survey, especially passengers from long-haul (>6 hours) flights, indicated that they felt most refreshed after walking through the plane. In **Chapter 4**, four main activities and eight corresponding postures have been defined for train passengers based on an observation study. Comfort scores were not significantly different between activities, except for headrest comfort, which was higher for staring/sleeping activities compared to a reading activity. Nearly for all activities, the majority of passengers preferred adjustability options to fit the seat to the performed activity.

The second part, **HUMAN**, studies the influence of human characteristics on comfort and discomfort perception, and consists of two chapters. In **Chapter 5**, two case studies illustrate the influence of anthropometric characteristics. The first case study compares the body measurements of passengers with dimensions for three economy class aircraft seats, and shows that 8-21% of passengers do not fit based on seated hip width. This is not due to the width of the seat, but to the distance between the armrests. The second case study shows differences in comfort and discomfort ratings between short and tall passengers. **Chapter 6** described an experimental study on the comfort and discomfort perception of a train seat for different activities and postures. Ideal seat parameters for different combinations of activities and body postures (obtained from Chapter 2) are explored in a series of two experiments (initial and long-term comfort). Preferred seat pan length was found to be correlated to stature, but several other seat adjustments were found to be related to the performed activity, such as the table (lower and closer to the body for working on a laptop compared to reading) and the lumbar support (less pronounced for relaxing compared to other activities). Another outcome of this study is that the headrest could be redesigned to support variation in body posture and provide more neck support, thereby increasing passenger comfort. Furthermore, this study has shown that performed activities seem to influence the perception of discomfort.

The third part, **SEAT**, studies the influence of seat characteristics on comfort and discomfort perception, and consists of three chapters. In **Chapter 7**, two case studies illustrate the influence of seat characteristics. The first case study described how the design of innovative armrests can support the use of handheld devices in the back seat of a car. Using the armrests, neck flexion significantly decreased, thereby reducing discomfort in the neck. The second case study demonstrated how an ideal seat contour for aircraft seats can be designed using 3D scanning techniques. This can be an opportunity for a better fit to the human body and a more lightweight seat. **Chapter 8** showed that active seating (i.e. playing a game controlled by sensors in the backrest which respond to body movements) can improve the comfort perception of car passengers, as participants in this felt significantly more fit and more refreshed after playing the game compared to other activities (reading a book, working on a laptop, gaming on a tablet). Additionally, a higher muscle activity was measured during active seating; not only for the upper body, but also for the legs. Active seating can therefore be considered as a possibility to stimulate body movements in the seat. The results from **Chapter 9** demonstrated that the comfort of the seat is influenced by the age of the cushions. Deterioration is not an aspect which is currently taken into account when considering comfort, however, due to the frequent use of passenger seats in public transport, the quality of the seat cushions reduces in time. Participants in this study preferred more soft, deteriorated cushions for a train seat, and it is advised to select the initial hardness taking into account the lifespan of the cushion.

Finally, in **Chapter 10**, the results of the previously described experiments are translated into recommendations for designers and researchers in the field of comfortable passenger seats. It presents a flowchart which can be applied for the design of passenger seats. The flowchart is composed of nine successive steps, categorized into the three levels Context, Human, and Seat. It is advised to start by determining the area of use, the duration of the journey, and the activities the seat should facilitate. On the basis of these context characteristics, the corresponding characteristics at human level can be defined: body dimensions, body movement and body support. This leads to a specification of the starting points for seat design: seat dimensions, seat adjustability and seat elements.

In the final chapter, **Chapter 11**, the findings from the previous chapters are discussed. The concept of comfort and discomfort remains controversial, but the model proposed in this thesis tries to give seat designers more practical recommendations on designing for comfort. The flowchart presented in Chapter 10 is almost exclusively based on experiment results from this thesis and should be validated. Chapter 11 also contains a reflection on the focus of this thesis: physical comfort and discomfort of passengers seats as perceived by healthy, adult people on trains, cars and aircrafts. Recommendations for future research include a predictive model, which can support seat designers during the design process, and takes into account the context, activities and target group. Finally, the relevance for industry is illustrated by considerations for research and development, as well as considerations for the purchase of passenger seats.

The results from this thesis can be used by designers and researchers to anticipate on changing demographics of the passenger population, changing technologies, and changing activities that passengers perform, thereby contributing to a more pleasant traveling experience and the well-being of passengers.

SAMENVATTING

COMFORTABELE PASSAGIERSSTOELEN: AANBEVELINGEN VOOR ONTWERP & ONDERZOEK

Het doel van dit proefschrift was om nieuwe kennis te verwerven over het ontwerpen van comfortabele passagiersstoelen en aanbevelingen te geven voor ontwerp en onderzoek in dit veld. Niet alleen het aantal passagiers neemt toe, maar ook de (culturele) diversiteit van passagiers. Daarnaast is er een groter wordende variatie in activiteiten die passagiers onderweg kunnen uitvoeren, dankzij een revolutie in ICT-apparaten en netwerken. Hoewel de eerste studies naar het comfort van passagiersstoelen al 40 jaar geleden verschenen, zijn de activiteiten en context dus erg veranderd in de tussentijd. Vandaar dat er meer kennis nodig is over de invloed van de lichaamsmaten van passagiers, de activiteiten die zij onderweg uitvoeren en de eigenschappen van de stoel, op comfort en discomfort beleving van passagiers.

Daartoe is eerst een literatuuronderzoek uitgevoerd om de huidige stand der kennis in beeld te brengen (**Hoofdstuk 2**). Het resultaat daarvan is een nieuw conceptueel model dat de relaties beschrijft tussen de activiteiten (context niveau), antropometrische variabelen (mens niveau) en stoeleigenschappen (stoel niveau) aan de ene kant, en de beleving van comfort en discomfort aan de andere kant. Deze relaties worden beïnvloed door de zogenaamde interactie-variabelen lichaamshouding, drukverdeling en beweging. In de volgende hoofdstukken van dit proefschrift zijn experimenten uitgevoerd met vliegtuigstoelen, treinstoelen en autostoelen, om zo een betere en meer praktische onderbouwing voor deze relaties te verkrijgen.

In het eerste deel, **CONTEXT**, bestaande uit twee hoofdstukken, wordt ingegaan op de invloed van eigenschappen van de context op comfort en discomfort beleving. In **Hoofdstuk 3** wordt de invloed van activiteiten en duur van de reis toegelicht aan de hand van twee casussen. De eerste casus onderzocht de mogelijkheden om te werken op de achterbank van een auto. Hieruit bleek dat de variatie in lichaamshouding wordt beperkt door het auto interieur, en dat passagiers ondersteuning mistten voor hun armen of apparaten (laptop, boek of tablet). Tijdens een onderzoek met drie vliegtuigstoelen, beschreven in de tweede casus, bleek dat discomfort afnam nadat proefpersonen na 1.5 uur zitten een kwartier pauze hadden en rond konden lopen. Respondenten van een online uitgevoerde enquête, met name passagiers van een lange vlucht (>6 uur), gaven aan dat zij zich het meest verfrist voelden na lopen door het vliegtuig. In **Hoofdstuk 4** worden, gebaseerd op een observatie studie, vier meest voorkomende activiteiten en acht bijbehorende lichaamshoudingen gedefinieerd voor treinpassagiers. Comfort scores waren niet significant verschillend tussen de activiteiten, behalve voor de hoofdsteun. Het comfort van de hoofdsteun was namelijk hoger voor de activiteit slapen dan voor de activiteit lezen. De meerderheid van de passagiers gaf de voorkeur aan verstelmogelijkheden, om de stoel zo te kunnen instellen dat deze optimaal de uit te voeren activiteit ondersteunt.

In het tweede deel, **MENS**, bestaande uit twee hoofdstukken, wordt ingegaan op de invloed van eigenschappen van de mens op comfort en discomfort beleving. In **Hoofdstuk 5** wordt de invloed van antropometrische eigenschappen toegelicht aan de hand van twee casussen. De eerste casus vergelijkt de lichaamsafmetingen van passagiers met de afmetingen voor drie verschillende vliegtuigstoelen bedoeld voor economy class. Hieruit blijkt dat 8-21% van de passagiers niet past vanwege de heupbreedte zittend. Dit wordt niet veroorzaakt door de breedte van de stoel, maar door de afstand tussen de armsteunen. De tweede casus laat zien dat er verschillen zijn in comfort en discomfort beoordelingen van korte en lange passagiers. **Hoofdstuk 6** beschrijft een studie waarin het comfort en discomfort van een treinstoel is geëvalueerd voor verschillende activiteiten en lichaamshoudingen. Het doel van deze studie was om de ideale instellingen van de stoel te bepalen voor verschillende combinaties van activiteit en houding (verkregen uit Hoofdstuk 2). De voorkeur voor de lengte van de zitting van de stoel bleek gecorreleerd te zijn aan lichaamslengte, maar andere stoel instellingen bleken juist gerelateerd te zijn aan de uitgevoerde activiteit. Zo wilden de meerderheid van participanten de tafel lager en dichterbij het lichaam voor het werken op de laptop vergeleken met het lezen van een boek, en de lendensteun platter voor relaxen vergeleken met andere activiteiten. Een andere uitkomst van deze studie is dat de hoofdsteun opnieuw ontworpen zou kunnen worden, om meer variatie in lichaamshouding te ondersteunen en meer ondersteuning te bieden aan de nek, waardoor het passagierscomfort zal toenemen. Tevens heeft deze studie laten zien dat de uitgevoerde activiteiten de beleving van discomfort kunnen beïnvloeden.

In het derde deel, **STOEL**, bestaande uit drie hoofdstukken, wordt ingegaan op de invloed van eigenschappen van de stoel op comfort en discomfort beleving. In **Hoofdstuk 7** wordt de invloed van stoel eigenschappen toegelicht aan de hand van twee casussen. De eerste casus beschrijft hoe het ontwerp van innovatieve armsteunen het gebruik van handheld apparaten, zoals smartphones en tablets, kan ondersteunen op de achterbank van een auto. Als passagiers gebruikmaken van de armsteunen, zorgt dit ervoor dat de buiging van de nek significant afneemt, waardoor passagiers minder discomfort ervaren in de nek. De tweede casus demonstreert hoe een ideale stoelcontour voor vliegtuigstoelen kan worden ontworpen door gebruik te maken van technieken voor 3D scannen. Dit kan een mogelijkheid zijn voor een stoel die beter aansluit op het menselijk lichaam, en tegelijkertijd meer lichtgewicht is. **Hoofdstuk 8** laat zien dat het comfort van autopassagiers kan worden verhoogd door het gebruik van 'active seating', dat wil zeggen, het bedienen van een spel door middel van sensoren in de rugleuning die reageren op lichaamsbewegingen. Proefpersonen uit deze studie voelden zich significant fitter en meer verfrist na het spelen van een 'active seating' spel vergeleken met andere activiteiten, zoals het lezen van een boek, werken op de laptop of een spel spelen op de tablet. Bovendien bleek dat de spieractiviteit voor active seating hoger was; niet alleen voor het bovenlichaam (waar het spel mee werd bediend), maar ook voor de benen. Active seating wordt daarom beschouwd als een goede mogelijkheid om lichaamsbeweging in de stoel te stimuleren. De resultaten van **Hoofdstuk 9** hebben laten zien dat het comfort van de stoel mede wordt bepaald door de leeftijd van de kussen. Bij het beoordelen van comfort wordt vaak geen rekening gehouden met veroudering, maar zeker bij passagiersstoelen van openbaar vervoer, die veelvuldig worden gebruikt, neemt de kwaliteit van de stoelkussens af in de tijd. Proefpersonen in deze studie gaven de voorkeur aan zachtere, verouderde kussens voor een treinstoel, en het wordt aanbevolen om een initiële hardheid te kiezen op basis van de levensduur en verouderingseigenschappen van het kussen.

Tenslotte zijn de resultaten uit de hiervoor beschreven experimenten vertaald in aanbevelingen voor ontwerpers en onderzoekers van comfortabele passagiersstoelen. In **Hoofdstuk 10** wordt een flowchart gepresenteerd die kan worden toegepast voor het ontwerpen van passagiersstoelen. De flowchart bestaat uit negen opeenvolgende stappen, onderverdeeld in de drie niveaus Context, Mens en Stoel. Het wordt aanbevolen om te beginnen met het bepalen van het toepassingsgebied, de duur van de reis, en de activiteiten die de stoel zou moeten ondersteunen. Op basis van deze context eigenschappen kunnen de bijbehorende eigenschappen op mens niveau worden gedefinieerd: lichaamsafmetingen, beweging van het lichaam en ondersteuning van het lichaam. Dit leidt tot een specificatie van de uitgangspunten voor het stoelontwerp: afmetingen van de stoel, verstelbaarheid van de stoel en stoelelementen.

In het laatste hoofdstuk, **Hoofdstuk 11**, worden de bevindingen uit de voorgaande hoofdstukken bediscussieerd. Het concept van de beleving van comfort en discomfort blijft controversieel, maar het in dit proefschrift voorgestelde model probeert stoelontwerpers meer praktische aanbevelingen te geven over hoe te ontwerpen voor comfort. De flowchart, zoals gepresenteerd in Hoofdstuk 10, is bijna volledig gebaseerd op resultaten uit dit proefschrift en zou gevalideerd moeten worden. Hoofdstuk 11 bevat ook een reflectie op de focus van dit proefschrift:

fysiek comfort en discomfort van passagiersstoelen zoals ervaren door gezonde, volwassen mensen in treinen, auto's en vliegtuigen. Aanbevelingen voor toekomstig onderzoek bestaan onder andere uit het bouwen van een voorspellend model, dat stoelontwerpers kan ondersteunen tijdens het ontwerpproces, en rekening houdt met de context, activiteiten en doelgroep. Tot slot worden er aanbevelingen gedaan voor onderzoek & ontwikkeling, alsmede aandachtspunten voor het inkopen van passagiersstoelen.

De resultaten van dit proefschrift kunnen worden gebruikt door ontwerpers en onderzoekers om te anticiperen op demografische veranderingen van de passagiers, nieuwe technologieën, en veranderingen in activiteiten die passagiers uitvoeren, en draagt daarmee bij aan een aangenamere reiservaring en welbevinden van passagiers.

About the author

Suzanne Hiemstra-van Mastrigt was born on December 20, 1984 in Rotterdam, the Netherlands. In 2002, she finished secondary school (GSG Helinium, Hellevoetsluis) and subsequently started studying Industrial Design Engineering at Delft University of Technology. After obtaining her Bachelor's degree, she continued with the Masters programme Integrated Product Design. In 2008, she graduated *cum laude* with a specialization in Automotive Design. The topic of her graduation project was the design of a future interior for street sweepers, which she conducted for RAVO bv (Alkmaar, the Netherlands).

After graduating, she started working at vhp human performance (The Hague) as a junior consultant command and control rooms and interface design. She has been working at TNO (the Netherlands Organisation for Applied Scientific Research) since 2010, where she studied the effect of working environments on health and productivity.

At the same time, from 2011 to 2015, she has performed her PhD research project at Delft University of Technology, faculty of Industrial Design Engineering, on the topic of comfortable passenger seats. In these four years, she has worked together with seat manufacturers, car manufacturers, railways, airlines and material suppliers, to conduct experiments.

Starting July 2015, she will become a post-doctoral researcher at the faculty of Industrial Design Engineering (TU Delft), within the European H2020 project PASSME (Personalised Airport Systems for Seamless Mobility and Experience). The goal of this project is to reduce travel time at the airport and enhance passenger experience by developing innovative designs for future airports and aircrafts.

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List of Publications

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End.

We’re a thousand miles from comfort, we have traveled land and sea
But as long as you are with me, there’s no place I’d rather be

This thesis provides new knowledge on how to design comfortable passenger seats and provides recommendations for design and research.

Although the first studies on passenger seat comfort appeared already 40 years ago, the activities and context have changed since then. In this thesis, relationships have been mapped out between activities (context level), anthropometric variables (human level), and seat characteristics (seat level) on the one hand, and comfort and discomfort perception of passengers on the other hand. Results obtained from experiments, performed on aircraft seats, train seats and car seats, provide a better and more practical foundation for these relationships.