Seat design in the context of knowledge work

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Chapter 1

Introduction

1.1 General introduction

How are you seated? Assumed that you sit while reading this thesis, think of how you are seated. Where are you sitting? What kind of seat are you using? Which parts of the seat are you actually using? How is your body posture? Do you move frequently or are you mainly sitting still? Does the seat provide you comfortable support or do you perceive discomfort in some areas? Are you slipping off the seat or are you steady? Does the seat fit with your body dimensions? Is the seat adjustable? Is there a risk, concerning the fact you will sit for a while during this task, on neck/shoulder/back pain? Does the seat support your current task 'reading from paper or screen' in such a way that your task performance is optimal? All these questions about user-seat interactions, with the task performed, and in a given environment; that is where this thesis is about. The final goal of this research project is to create input for functional seat design to optimally support knowledge workers in their common work tasks.

This chapter introduces the research performed for this PhD thesis. The background will be described by several paragraphs that contain societal trends, historical facts of seating and current seat designs. After that, the scientific background of knowledge work and seating studies are summarized to further define optimal seating support. A vision on optimal seating support is created, which is presented in a separate paragraph hereafter. From this the research challenge and the research question are formulated. The last paragraphs present the PhD objective and the outline of the thesis.

1.2 Societal trends

During the last decades there is an increase in office work, or in a broader sense, knowledge work, which is not necessarily performed in the office. Over 230 million knowledge workers, 9% of our global workforce, are counted worldwide in 2012 (Manyika et al., 2013). This has resulted from the societal trend that the service sector is catching up with the industrial sector as the leading sector of the economy (Soubbotina, 2004). Most high-income countries today are post industrializing and becoming less reliant on industry. In the European Union almost 70% of employed persons work in the service sector (Eurostat, 2012). This has consequences for how people work: in the service sector more work is done seated, and predominantly performed in offices.

Moreover, the information society keeps on growing. Over 250 million people came online over the last year, and almost 40 per cent of the world's population is using the Internet by the end of 2013 (International Telecommunication Union, 2013). People are connected through all kinds of (mobile) computer devices. Information and communication technologies have a powerful effect on the transformation of labor markets and of the work process (Castells, 2011). As businesses increase their dependence on information technology, the number of fields in which knowledge workers operate has expanded as well. Knowledge workers are workers whose main capital is knowledge. Typical examples may include software engineers, doctors, architects, engineers, scientists, public accountants, lawyers, and teachers, because they "think for a living" (Davenport, 2005). Knowledge workers spend 38% of their time searching for information. They are also often displaced from their bosses, working in various departments and time zones or from remote sites such as home offices and airport lounges (Mcdermott, 2005). These, also called, New Ways of Working with new tasks and new environments are no longer bounded to traditional offices and traditional 'nine to five' workdays (Blok et al., 2011). What all these workers have in common is that, despite where or when they work, they are performing their work mainly seated for many hours and often by use of (mobile) computers or other mobile devices. Therefore, it is important to have acuity for the functional design of seating to support the growing number of users and their new ways of working.

1.3 Some history facts of seating

Over the millennia, seated tasks have ranged from crafting a sculpture for a pharaoh's afterlife to working at a computer. Around 3000 years ago Egyptian furniture makers designed rectilinear chairs to facilitate upright postures, for nobility, consistent with sociocultural status and religious beliefs (Pynt and Higgs, 2010). In the 5th century BC the Greeks designed a more curvilinear backrest chair that encouraged relaxed and slouched posture reflecting the ancient Greeks' sociocultural and medical opinions. Many decades later, in Western society during the 16th and 17th century AD, diversity in chair design appeared due to, amongst others, the Industrial revolution and Chinese influences. Chairs were particularly designed for a purpose, such as a reading chair. In the Victorian age the design of chairs was not very comfortable or ergonomic, as the Victorians believed that hardship strengthened character (Pynt and Higgs, 2010).

Considering the long history of seating it is only since four decades that the ergonomic study of work and office seats has been of special focus. Chairs designed for office work were developed around the mid-19th century as more workers spent their shifts sitting at a desk, leading to the adoption of several features not found on other chairs (Olivares, 2011). The office chair was strategically designed to increase the productivity of clerical employees by making it possible for them to remain sitting at their desks for long periods of time. One of the earliest known innovators to have created the modern office chair was naturalist Charles Darwin, who put wheels on the chair in his study so he could get to his specimens more quickly (Katz, 2009)

1.4 Current chair design for knowledge work

For the design of knowledge work chairs, the societal trends create new challenges on how to support -current and upcoming- activities and work locations in such a way that functionality and comfort for the user is maintained and optimized. An Internet search for innovative and future chair design for office work shows, besides an immense variation of design features in office chairs as seen in nowadays work places, also most striking and divergent concepts of chair designs. On the one hand there are chair design concepts that completely cover for a complete computer workstation like The Emperor 1510 of MWE labs for example (see figure 1a). This chair is completely cushioned and seems to support the user on all body parts to enable computer work with different input devices and multiple screens. On the other hand there are chairs with more minimalistic design like, for example, the LimbIC developed at the American university MIT (see figure 1b). This chair consists of a special dynamic seat that focuses on movements of the body and claims to 'help with posture as well as relaxation'. Another example of striking design is the concept of the Twist chair (see figure 1c) that can support the trunk and head on the chest side for desk and computer work with a more saddle shaped seat. These chair examples are, compared to each other, extremely different in design, but they have in common their (cl)aim to support the user in the most optimal way, without physical inconvenience and for good work performance.

Figure 1a *The Emperor designed by MWE labs*
The home office's manufacturer MWE Lab, based in Canada, describes it as the "ultimate computer workstation" and says "clients have included Microsoft programmers and the US Marine Corps. The adjustable aluminum frame houses an Italian leather chair which allows you to swivel or work while lying on your back, meaning the days of suffering lower back pain from hours sitting hunched over your desk my soon be over."
(Dailymail, 2013)

Figure 1b *The LimbIC designed by MIT*
The design, developed at top American university MIT, focuses "on movements of the body and helps with posture as well as relaxation. And the user is supposed to feel a sense of weightlessness - which can have a positive affect on performance, creativity and also mood. About 60% of their clientele are office workers"
(Dailymail, 2012)

Figure 1c *The concept of the Twist designed by Miray Oktem*

The designer says "While we are studying intensively, we rarely use the backrest of the chair. We mostly lean on the table with our arms and elbows. The twist chair supports the body where the traditional task chairs do not to offer a new way of sitting. The twist chair supports the body in upper chest and the forehead where the shape of the human body does not alter from people to people. The seat extends towards the support to create a saddle like shape that transforms into a seat while sitting in a lower angle."
(ID magazine, 2012)

1.5 Defining optimal seat support

As the former various designs (cl)aim optimal support for performance the question arises "what is optimal seat support that facilitates a good work performance?" To gather scientific background to answer the question, relevant studies about knowledge work and seating are summarized in the next paragraphs. In this context five topics are distinguished: risks for work related disorders, variation in postures and movements, variation in body dimensions, biomechanical aspects and comfort and usability.

1.5.1 Risk of work related disorders

With performing knowledge work there are several risks to appoint. Increased sitting duration is associated with increased lower back discomfort (De Looze et al., 2003). And, in the long run, local perceived discomfort could also result in musculoskeletal disorders (Hamberg et al., 2008). Many studies have discussed general associations between seated work and musculoskeletal disorders (Aarås et al., 2000; Carter and Banister, 1994; Diebschlag and Heidinger, 1990; Hales and Bernard, 1996, Todd et al., 2007). With the increase in working hours spent in seated postures on office chairs, the percentage of musculoskeletal disorders appears to be rising (Ariëns et al., 2000; Carter and

Banister, 1994; Kilbom, 1987; Rohlmann et al., 2002; Waersted and Westgaard, 1996). Lis et al. (2007) states, based on a review of epidemiological studies, that prolonged sitting is not a risk factor by itself, but sitting in a restricted posture is a risk factor for back complaints. Also, an elevated prevalence of neck and shoulder complaints is observed among office employees working in seated postures (Buckle and Devereux, 2002; Mani and Gerr, 2000), with intensive computer users particularly affected (Tittiranonda et al., 1999; Buckle and Devereux, 2002; Gerr et al., 2004). Higher amplitudes of muscle activity, less varied muscle activity and fewer periods of no muscle activity have been suggested to be important biomechanical risk factors (Veiersted et al., 1990; Nordander et al., 2000) as well as increased duration of use of input devices (Ijmker et al, 2007) and awkward postures (Choobineh et al., 2012). As De Looze et al. (2003) and Vink (2005) earlier stated, the design and sitting comfort aspects of office chairs have therefore become an important issue in the prevention of musculoskeletal disorders at office workplaces. From these numerous studies we learn that for optimal chair support one important aspect is to minimize risks of musculoskeletal disorders by sufficient support of the human body.

1.5.2 Variation in postures and movements

There are indications that the performing of different office work tasks causes variations in user postures and movements (Adams et al., 1986; Babski-Reeves et al., 2005; Commissaris and Reijneveld, 2005; Dowell et al., 2001; Ellegast et al., 2007; Van Dieën et al., 2001). Besides variations caused by the tasks also large inter-individual variation was reported in postures and movement behavior (Commissaris and Reijneveld, 2005). So, the variations of postures and movement across tasks and individuals are other elements to take into account when thinking of optimal support for functionality and performance. This is confirmed from the subjective perspective of chair use. There are studies that show that comfort perception of product or workstation lay out is influenced by the performed tasks. Vink & De Looze (2008) conclude in their article that the different described cases showed that it was important to do the measurements on the tasks (or activities) in which the comfort plays a role.

1.5.3 Variation in body dimensions

Then there is inter-individual variation from the diversity in human body's dimensions. In research about home furniture, Teraoka et al. (2004) 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. Recently, Le et al. (2014) found clear relations between body length and discomfort ratings in vehicle seats. Anthropometrics is also the basis for ergonomic guidelines, like for example the European EN 1335 (EN-1335-1, 2000) for determination of dimensions of office chairs. In the selection of a chair, anthropometrics of the user should be taken into consideration for an optimal match between user and chair.

1.5.4 Biomechanical aspects

Biomechanical studies show information on pressure and shear forces while seated. Thakurta et al, (1995) and Ebe and Griffin (2001) found seat pressure linearly related to seat comfort. This is highly influenced by the design of the seat (Vos et al., 2006). And hardness of the seat seemed most evident (Ebe and Griffin, 2001). Park et al., 2012 reported that backpressure was also correlated to subjective evaluation. Zenk et al., (2012) describe an ideal pressure distribution for a car seat pan, where different seat contact parts of the body have different optimal pressure tolerances. Geffen et al, (2008) reported a combination of independent pelvis rotation and seat inclination is effective to regulate the both the net buttock shear force and the sacral interface pressure. In the study of Goossens and Snijders, (1995) a biomechanical model was developed for the combination of seat and backrest inclination to reduce shear forces on the seat in passive seating. Both with respect to the aspect of pressure sores and of comfort, the inclination of backrest and seat are, amongst other factors, important design criteria. In the study of Goossens and Snijders (1995) was reported that when little shear is accepted, a fixed inclination between seat and backrest can be chosen between 90° and 95°. To enhance optimal design a balanced pressure distribution and reduced shear forces are imported elements.

1.5.5 Comfort and usability

Besides the former merely objective elements of chair design, optimal support has also a subjective side like the perception of comfort. Comfort exists in the interaction between a human with a product within a context (Vink and

Hallbeck, 2012; De Looze et al., 2003). In the past, Helander and Zhang studied underlying factors of comfort and discomfort in sitting. They concluded that comfort and discomfort are separate entities with different underlying factors. They also presented a model in which they showed that low comfort ratings could be accompanied by either high or low discomfort ratings. However, when either discomfort or comfort ratings are high, the other entity will be low (Helander and Zhang, 1997). De Looze et al. (2003) extended this model by illustrating the human-seat-context interaction. These models contribute to the understanding of the difficulties of discomfort and comfort perception and the underlying factors of seat characteristics and human characteristics. That there is a task related component is comfort was mentioned earlier to from the study of Vink & De Looze (2008) that shows that comfort perception of product or workstation lay out is influenced by the performed tasks. Besides comfort, usability of the chair in the human-seat-context interaction should also be taken care off. Particularly, studies on adjustability showed that the usability of chairs is an issue, as Singh and Wadhwa (2006) reported that chairs with adjustable seat height were adjusted by only half of the users. Also, Vink et al. (2007) report that 24-61 % of the users never adjusts the chair for reasons like unawareness, complexity of the control system and expected or perceived effects.

1.6 Vision on optimal seat support

Careful attention to the physical layout of chairs is a way to reduce seated and work related risks, and to maintain or improve sustainable work performance of the users. Based on the former paragraphs, the vision on optimal support at this point is to enable variety in sitting positions and sitting dynamics ànd to provide stable support to the body parts where required. The design should be tuned with both user and tasks. Long-term static muscle load should be avoided by stable support of feet, legs, buttocks, back and arms and eventually head to relax muscles. To prevent muscular skeletal strain extreme joint positions should be avoided and natural postures should be enhanced. The body should also be prevented from sliding off and large shear forces. The inclination of backrest and seat are, amongst other factors, important design criteria. Also a balanced pressure distribution should be provided with attention for regional pressures differences and avoidance of high-pressure peaks. Discomfort should be minimalized as a very distracting factor. At least a neutral (unaware) but preferably a positive comfort experience is wanted. And the design should cover for a broad range of diversity of people's anthropometrics by proper dimensioning of the static design parts and adjustability ranges. Last but not least, the usability of the seat design, specifically the adjustability, should be created for a broad range of users and preferably with minimal instructions.

1.7 The challenge for optimal design

Chair users' varying work tasks, body dimensions, postures, habits, and their personal comfort preferences make it difficult to prescribe an optimal design. It is necessary to move beyond the biomechanics of sitting, and consider the nature of work behaviour and to place sitting into context. A citation of Dainoff et al. (2007) report, "A chair is not an isolated object, but needs to be considered as an integrated component in a complex work environment". This statement evokes the need to study not just the chair by itself, but in the context of its use. And, in addition to this statement, also 'in the context of it users'. Over the past few decades, relevant research, standards and guidelines have focused primarily on desktop work, and to a lesser extent, on mobile work devices. Also, the focus was on working in a standard office environment. The nowadays performed work tasks and more diverse work environments play an important role in how the chair is used, but there is lack of knowledge on the most common work tasks, and on the effects of varying environments, and the consequences of these for optimal design.

1.7.1 Defining tasks, movement behavior and comfort

To improve the match between the characteristics of the task and features of the chair we need to define tasks, movement behavior and comfort perception. Chair requirements in the context of task and environment should be based on theory, user experiences and physical parameters. In the past, only a few studies have been performed where task type was distinguished and physical parameters were specified. According to the study of Luttmann et al. (2003), muscular activity and fatigue differ per task during sitting. Across a variety of office tasks, levels of muscle activation appear to vary a lot. For example paper work causes high muscle activity in the shoulder region and mouse work causes high muscle activation in the lower arm. Others showed that spending more time in telephoning leads to an increase of extreme spine postures in the office (Benninghoven et al., 2005). It also appears that users' chair preferences in relation to function type differ in divergent functions (Legg et al., 2002). We assume that this is related to a different mixture of tasks, with different relative duration of tasks causing different body dynamics during office chair use over the day. To build support for our assumption, we want to know more about postures, movements and comfort perception of chairs and chair parts when different tasks are performed. And how these variables are associated with possible WRMSD risks, comfort and performance. With this, knowledge task-specific chair requirements should be defined, based on user-task-chair interactions to evoke minimal WRMSD risk, optimal performance and good comfort perception.

The research question for this thesis is:

Do current chair designs optimally support common tasks of office workers in office, mobile and home environment and what are implications for future chair design?

1.8 PhD objective

The objective of this PhD research is to answer the above research question. Underlying is the aim of gaining more knowledge on postural behavior and (dis)comfort in current chairs in diverse environments in relation to actual office work and activities. This thesis aims to provide insight in optimal functional seating support for a growing population of office workers with a diversity of tasks. The goal is to create general design input for functional work chair design to optimally support office workers, with minimal work related risks, minimal discomfort and maximum comfort as the base for an optimal task performance. The requirements can supplement the current ergonomic guidelines for office work chairs, and can be an aid for the design of chairs for current and future tasks in offices, public transport and home settings. There is focussed on the essentials of optimal seating support in biomechanical and functional way.

1.9 Outline of this thesis

Chapter 2 focusses on design differences of controls to adjust the office chair, and on design variations of the seat and backrest. This was evaluated in the context of computer work tasks and non-computer work tasks. Chapter 3 is about the actual use in a naturalistic office environment of office chair adjustment options by different user groups, namely flexible workspace workers and owned workspace workers. Also, design differences in controls and the effects of an ergonomic instruction on comfort and adjustment quality are evaluated. In chapter 4, the effects on posture, muscle activity and dynamic behavior are studied with a variety of preset office work tasks in a laboratory setting. In chapter 5, this is continued in a field setting where office tasks are observed and categorized. Besides the posture, dynamics and muscle activity, also comfort perception was evaluated in relation to the task duration. From the office environment, we switch to a mobile (working) environment in chapter 6 to research what activities train passengers perform during actual train rides. In relation to these activities the postures and comfort perception were determined. Chapter 7 is focused on one task and how to design the chair optimally for this specific task. Watching television or a screen as futuristic work lay out without manual input devices, is evaluated with both quantitative and qualitative measures in different stages of the design process. In Chapter 8, the epilogue, the findings of this thesis are discussed and the final conclusions are drawn. Also, the implications for practice and the recommendations for future research directions are given.

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Chapter 2

Effects of differences in office chair controls, seat and backrest angle design in relation to tasks

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Abstract

In this study the influence of chair characteristics on comfort, discomfort, adjustment time and seat interface pressure is investigated during VDU and non-VDU tasks: The two investigated office chairs, both designed according to European and Dutch standards are different regarding: 1) seat cushioning and shape, 2) backrest angle and 3) controls. Thirty subjects in total, both male and female, participated in two experiments: twenty in the first and ten in the second.

Significant differences are found for ease of adjustment and adjustment time of controls, independent of the tasks. Related to tasks, a significant difference was found for the backrest range of motion. For non-VDU tasks a larger range of backrest motion was preferred by 70% of the subjects. The chair design differences were most clear for comfort and adjustment time of controls, followed by comfort of backrest angle. No differences are found between seat pan comfort and discomfort, first impressions and peak interface pressure.

Keywords: Office chair; (Dis)comfort; Pressure distribution; Tasks; VDU

2.1 Introduction

Among European manufacturers it is more or less a basic condition in office chair design to apply standard criteria as formulated in the European EN-1335 and the Dutch NPR-1813 standards. These are ergonomic criteria based on anthropometrics and safety standards prescribing for example chair dimensions and ranges of adjustability. The idea behind these criteria is to provide optimal physical support for a range of end-users. The assumption could be made that the application of these ergonomic criteria in seat design automatically leads to comfortable chairs for end-users.

The focus on anthropometry is an important basis to avoid discomfort. Tereoka's study in Vink (2005) affirms this by showing that taller users rated larger sized seats more comfortable and shorter users rated smaller seats as more comfortable. However, to provide comfortable chairs more information is needed. As concluded by Helander and Zhang (1997) and Zhang et al. (1996), sitting discomfort and comfort are based on different factors. Feelings of discomfort are based on associations of pain, tiredness, soreness and numbness where, on the other hand, comfort is associated with feelings of relaxation and well-being. When discomfort factors are present, comfort factors become secondary in the comfort/discomfort perception (Helander and Zhang, 1997). Thus, comfort goes beyond physical aspects. For instance, De Rosario et al. (2006) found that lumbar support height according to the standards was not the height deemed as most comfortable by subjects. They also found that giving end-users the possibility of choosing the ideal lumbar support height, after testing different heights, resulted in positions other than the recommended standards, based solely on physical dimensions.

Apart from perception aspects, task aspects could also play a role in comfort and discomfort. These comfort task aspects are not often mentioned in current office chair design. In brochures and websites distinctions are often made between workstation (Visual Display Unit (VDU)) chairs, meeting/visitor chairs and reception chairs. More attention for task-specific characteristics in design seems useful, particularly for workstation chair. The statement of Dainoff et al. (2007) “a chair is not an isolated object, but needs to be considered as an integrated component in a complex work environment”, is supported by Commissaris and Reijneveld (2005) who found that data entry workers made many more arms and trunk movements in comparison to CAD/CAM workers, while they often have the same chair. Ellegast et al. (2007) recorded more trunk dynamics with sorting files in comparison to intensive mouse use, which could have its consequences for chair requirements. Earlier Adams et al. (1986) described a significant influence of the task on the sitting posture in VDU work and Van Dieën et al. (2001) reported pronounced effects of the task on the investigated indicators of trunk load in office chairs. Similar conclusions were reported by Babski-Reeves et al. (2005) about task demands playing an important role in the loads placed on the body and posture fixity, but also on the level of discomfort experienced. Legg et al. (2002) found that the office chair preferences were different for researchers in comparison to telesales and clerical workers due to differences in movement during their work. In summary, different types of office work tasks influence body dynamics, posture, trunk load, discomfort, and user preference, indicating that task characteristics should influence the chair design requirements.

One way to check whether end-users notice comfort differences in chairs is to vary the chair characteristics and tasks. In a project with an office chair manufacturer, we used two chairs that differ only slightly. This was an opportunity to find out if these small design differences were noticed and whether one seat is better for specific tasks. The chairs were different regarding: 1) seat cushioning and shape, 2) backrest angle and 3) usability of controls.

Cushioning and seat shape could be important for discomfort and comfort in tasks of long duration. Cushioning and seat design affect the pressure distribution at the seat-to-user interface and Ebe and Griffin (2001) found 'ischial' pressure linearly related to seat comfort. When users experience discomfort of the seat at a certain level they start to make macro-movements to reduce the discomfort (Fujimaki and Noro, 2005). To our knowledge, no task-specific design demands for cushioning and seat design can be found in the literature, but we assume that especially for tasks where end-users sit for a long time the seat cushioning is important, perhaps because it induces more frequent "re-sitting" or because it's more comfortable in the long run.

With respect to the backrest angle, Adams (2006) states that the chair should support the back in such a way that back muscles can relax and the spinal loading is minimized. This specifically happens with a backrest inclined backwards. Vergara and Page (2002) found that postural changes of the back are a good indicator for discomfort, and that mobility and backrest use can reduce discomfort and pain. In an earlier study Vergara and Page (2000) found that the lumbar support of the backrest might reduce discomfort. In addition, different types of backrest used, varying with respect to the level of contact of the back to the backrest, are related to different comfort levels in reading and writing tasks. Therefore, backrest contact is important. However, with different tasks the users employ different postures, but in general a variable backrest inclination seems to keep better contact between the users' back and the backrest. Thus, depending on the required postural stability offered by the backrest, both fixed backrest and dynamic backrest use should be supported.

The third aspect in this study is the use of controls to adjust the chair according to body dimensions and task requirements. Chair adjustability is required to give users the possibility to change their postures during the working day (Fujimaki and Noro, 2005, Kroemer et al., 1994 and Vink, 2005). However, many office workers do not adjust their chair to the optimal position (Grandjean et al., 1983, Ong et al., 1988 and Verbeek, 1991). A study among 100 office workers showed that 63% of the end-users never adjust their office chair (Vink et al., 2007). Little is known about the underlying reasons why users do or do not adjust the chair. Are users unaware of the adjustability of the chair, are the controls uncomfortable or unclear or do they not relate their discomfort to a misadjusted chair?

Therefore, a study was performed to determine whether end-users notice small differences between office chairs and to find out whether these differences are task related. Based on the gaps in the literature, the research questions of this paper are:

1. What are the differences in first impression, comfort and discomfort between two office chairs varying only slightly in seat cushioning, backrest angle and control usability?
2. How are the differences in design aspects evaluated and which chair is preferred?
3. Do the differences in cushioning and seat design lead to different pressure distribution profiles?
4. Are any differences found task related?

2.2 Methods

2.2.1 General design

Two office chairs, different with respect to seat cushioning, backrest angle and design of controls, were evaluated by thirty subjects. None of subjects was familiar with the chairs. The subjects were involved either in a short or in a longer-term evaluation experiment. In both experiments, subjective measurements were performed; in the short-term evaluation some objective measures were collected as well, i.e. interface pressure distribution and required time utilized for chair adjustment.

2.2.2 Materials

The chairs that were evaluated were the traditional Ahrend-230 (chair A) and the same chair redesigned on the basis of end user feedback (chair B). In the experiments the brand label was covered. Both chairs meet the European CEN-1335 and the Dutch NPR-1813 standards and both are equipped with a dynamic synchro-mechanism, meaning that both the backrest and the seat are moveable in a fixed ratio. The differences between the chairs are described below. Further, the chairs were exactly similar in colour, type of fabric, armrests, casters etcetera.

2.2.2.1 Controls for adjustment

To increase the ease and speed of adjustment, the control to adjust the armrest height was moved from the inside of the armrest (in chair A) to a location at the outside of the armrest (in chair B) (Fig. 1). With the original design the control has to be pushed with the thumb, which causes an unfavourable posture with ulnar wrist deviation, extreme pronation of the forearm and endorotation of the upper arm. In addition users had difficulties finding the location of the button. It was hypothesized that a new position of control would be easier to locate and increases the adjustment speed, and that it would be more comfortable to operate the control (buttons) due to a more neutral arm, wrist and hand position.

Figure 1 *The armrest height control at the outside of the armrest (chair B). The inset shows the control at the inside of the armrest (chair A).*

The design of the control to set the chair in its dynamic mode was brought more in line with the end user intuition. In the chair B an upward and downward lever position puts the chair in its dynamic and static mode, respectively. In chair A, the same (pulling) movement of the lever puts the chair in its static and in its dynamic mode.

The backrest counter pressure control to adjust for the weight of the user, has been re-positioned from 'the under- and backside of the seat' (in A) to 'the right side of the chair seat' (in B) (Fig. 2). In chair B the user can remain seated while adjusting the backrest pressure. The control itself was changed form a round control to be turned (in A) into a lever to pump the backrest pressure to the aimed level (in B).

Figure 2 *The backrest counter pressure control (chair B). The inset shows the control on the side of the back, under the chair seat (chair A).*

2.2.2.2 Cushioning

As end-users frequently experienced hard parts when sitting on chair A (bottoming effect), the cushioning was thickened by 1 cm in height and made of more dense foam. In addition, the seat pan was given a slightly basin-shaped curvature in chair B. The hypothesis was that these changes avoid bottoming and improves seat comfort.

2.2.2.3 Backrest inclination

The maximum backward inclination of the backrest was enlarged by 11° from 113° to 124°(included angle between seat pan and backrest). It was hypothesized that the possibility to put the chair in a more backward position would be more supportive during tasks like telephone calls, in meetings or when reading print or books.

2.2.3 Experiment I: short term evaluation

2.2.3.1 Subjects

Twenty healthy office workers, 10 males and 10 females, participated in this study. Table 1 shows the demographics of the sample. All 20 had received at least once an ergonomic instruction about workstation adjustment in the past.

Table 1 *Demographics of the samples; experiments I (10 males, 10 females) and II (4 males, 6 females).*

	Range		**Mean**		**SD**	
	Exp. I	**Exp. II**	**Exp. I**	**Exp. II**	**Exp. I**	**Exp. II**
Age (years)	25–60	20–25	43	22	10.8	1.5
Stature (cm)	159–199	168–190	177	177	11.4	0.1
Weight (kg)	60–100	56–83	75	69	11.3	8.5

2.2.3.2 Protocol

Each subject was informed about the study and gave a written informed consent. Subsequently, the first chair was presented to the subject. The subject was allowed to examine the chair closely, to walk around it and to touch the surface. Then, the subject was asked to answer questions related to his/her impression at first sight. The chair was then adjusted by the test leader into default positions of the seat, armrests, and backrest (lowest position armrest, seat, backrest, maximum upright, minimum seat depth). From the default positions, the subject adjusted the chair in a fixed order to his/her personal location and each subject was encouraged to get comfortable in the chair. The order of adjustments was

1. Seat height adjustment.
2. Seat depth adjustment.
3. Armrest height adjustment.
4. Backrest height adjustment.
5. Switch from static into dynamic seating.
6. Backrest weight resistance.

For each of these six adjustments, the subjects were informed which control to use and where the control was located, but they had to find out by themselves how to make the adjustment. The time required to make adjustments 3, 5 and 6 were determined using a stopwatch. After re-setting the chair into the default positions, the subjects were asked to repeat the adjustments and the required times were determined again. Then the subjects were asked to rate the ease of the adjustments.

Next, the subject adjusted the chair again, and the table and computer devices, now to prescribed ergonomic guidelines[1]. With the chair in its static mode, the subjects then performed a standard task comprising reading from the screen, typing a short text and a search on the Internet for 5 min. After 5 min, the subjects answered some questions. The subjects were also asked to rate the backrest of the chair after a short use in the most far backward position while imagining reading, having a meeting or performing a calling task (no actual task was performed).

Then the second chair was presented and the protocol was repeated (in systematically varied order 10 subjects started with chair A and the other ten with chair B).

After the testing was completed on the second chair, the subjects were asked to make comparisons between chairs A and B.

Finally, the static pressure distribution measure of the seat, with the backrest in the upright position, was taken of every subject on both chairs. The subjects were instructed to sit still and upright while maintaining contact with the backrest and without using the armrest (hands on their lap).

2.2.3.3 Measurement

Questionnaires were used to determine the subjective experiences of the chairs. At a six-point scale we asked the subjects to

- Rate first sight impression: 6 questions about external design (very ugly–very beautiful) and comfort expectancy (very bad–very good).
- Rate ease of adjustment: 3 questions about the specific levers/knobs/buttons, which differed between chairs (very bad–very good).
- Rate experience after 5 min use: 8 questions about comfort aspects of seat, backrest and total chair comfort (very bad–very good).
- Compare chair B to chair A: 4 questions about comfort aspects of seat backrest and total chair comfort (much worse–much better) and an interview question about what motivated their score.

[1] *Seat height:* feet flat on the floor and a knee angle of ±90° and the feeling of equal support of upper legs. *Seat depth:* as deep to leave the space of the subjects' fist between the front side of the seat and the subjects lower leg. *Backrest height + lumbar support:* comfortable height of the backrest with the lumbar support's most prominent part approximately just above pelvis height. *Arm support:* arms supported with upper arms in an approximately vertical position and with relaxed shoulders. The elbow is of ±100° flexed in relation to the upper arm. *Seat angle:* comfortable support (no feeling of slipping). *Backrest angle:* comfortably in a fairly upright position for a computer task. *Weight adjustment:* comfortable support for relaxed leaning against the backrest. *Table height:* just above upper legs inline/just below armrest height. *Key board:* as close to table edge within reach with supported arms at armrests. *Mouse:* right or left of keyboard or central between keyboard and table edge. *Screen distance:* as far as comfortable for reading/ watching, approximately between 60 and 80 cm. *Screen height:* as high/low as comfortable, top of screen approximately at eye level.

The time required to adjust the chair from its static into its dynamic mode and to adjust the armrests and the backrest weight resistance was determined by use of a stopwatch. Static contact pressure was recorded using the Novel Pliance-x system (Novel Gmbh, Munich, Germany) with 256 sensors. The data were recorded using the Pliance software. Contact pressure between chair seat and buttock was measured with a sample frequency of 10 Hz during 10 s.

2.2.3.4 Data analysis

The distribution of the subjects' scores on the questionnaire was calculated for each item. Peak pressure values of the sensors during the static measurements were extracted from the Novel software. The distribution pattern over the sensors was qualitatively evaluated by observation of graphic reproductions of the distribution over the 256 sensors.

2.2.3.5 Statistics

A Wilcoxon signed ranked test was performed to compare the questionnaire scores between chairs. A paired T-test was performed to compare the adjustment time and to compare the peak pressures of both chairs. The significance was determined at a 0.05 level.

2.2.4 Experiment II: 3 h sitting

2.2.4.1 Subjects

Ten healthy students of the Faculty of Human Movement Sciences (4 males, 6 females) participated in this study. Table 1 shows the demographics of the sample. The subjects were, based to their course of study, aware of ergonomic principles of chair adjustment.

2.2.4.2 Materials

The same chair types were used as described in experiment I, with the exception of the armrests on chair B. Those were not available at the time of the experiment and chair B was equipped with the same armrests as chair A.

2.2.4.3 Tasks

Two types of office tasks, categorized as non-VDU tasks (like reading hardcopy/books or calling) and VDU tasks with use of input devices (like writing and editing with office software) were performed in order to test two chair options: maximum inclination + dynamic backrest and upright + fixed backrest. The non-VDU tasks were performed to test the maximum inclination + dynamic backrest. The subjects were asked to lean backwards against the backrest. The VDU tasks were performed to test the chair with the backrest in a more upright and fixed position for trunk stabilization to support a more "active" way of working with computer and input devices. Both tasks were performed for 1.5 h.

2.2.4.4 Protocol

The subjects participated in two morning sessions where in every session one chair was evaluated. In the first session, the subjects were informed about the study and gave a written informed consent. Subsequently, the first chair was presented to the subject. Half of the subjects were presented chair A first and the other half were presented chair B first, randomly. The order was reversed for each subject on the second trial day. The subjects got an explanation about the adjustments on the chair and the use of controls. Then the subject adjusted the chair, the table and computer devices to prescribed ergonomic guidelines. The backrest was adjusted according to the type of tasks (VDU or non-VDU). The subjects rated the ease of adjustment. Then, the subjects performed the assigned task and were asked to remain seated. After 1.5 h they were asked to fill out the questionnaire about chair comfort/discomfort and about the task/backrest position. A 15 min break was allowed before the second task. The backrest was again adjusted in accordance with the second type of tasks and the subjects performed the second task. After 1.5 h they were asked to fill in the questionnaire about chair comfort/discomfort and about the task/backrest position. On the second morning the protocol was repeated. At the end of the second morning, they were asked to make a direct comparison between the chairs by a questionnaire.

2.2.4.5 Measurements

Questionnaires were used to determine the difference in experience between chairs. Using a six-point scale, we asked the subjects to

- Rate ease of chair adjustment: 3 questions about the specific levers/knobs/buttons, which differ for the chairs (very bad–very good).
- Rate the Local Perceived Discomfort (LPD) method (Van der Grinten and Smitt, 1992). This method consisted of a map with 12 body regions. Feelings of pain, numbness and pressure, tiredness underlie discomfort. A ten point-Borg scale (Borg, 1990) was used to assess discomfort (ranging from 0 = no discomfort,… to 10 = extreme discomfort, almost maximum) per region.

- Rate experience after the first and the second task: 15 questions about comfort aspects of seat, backrest and total chair comfort (very bad–very good).
- Compare chair B to chair A: 7 questions about comfort aspects of seat backrest and total chair comfort (much worse–much better, final choice and why).

2.2.4.6 Statistics

A Wilcoxon signed ranked test was performed to compare the questionnaire scores of both chairs. The significance was determined using a 0.05 level.

2.3 Results

2.3.1 Results experiment I

2.3.1.1 First impression

At first sight, ten subjects preferred chair A and the other ten preferred chair B. Moreover, no significant differences in the ratings of the chairs were found for first impression. Both chairs were rated rather positive. Chair A was rated 'slightly beautiful' by seven subjects and 'beautiful' by ten subjects. Chair B was rated 'slightly beautiful' by eight subjects and 'beautiful' by also eight subjects. With respect to comfort expectancy for chairs A and B, nineteen subjects score 'slightly good' (7 subjects for A and 6 for B) to 'good' (12 subjects for A and 13 for B).

2.3.1.2 Ease of adjustment

A significantly better rating ($p < 0.01$) of chair B in comparison to chair A was found for the ease of adjusting the static–dynamic mode and the backrest weight resistance. No significant difference was found between the chairs with regard to the adjustment of the armrest height.

Fig. 3 shows the actual time required to make the adjustments. Significantly less time was required to adjust the armrest height and to switch from the static into the dynamic mode in chair B compared to chair A in both the first (respectively, 11 s, $p < 0.01$ and 44 s, $p < 0.01$) and the second trials (respectively, 3 s, $p < 0.05$ and 9 s, $p < 0.01$). No significant difference between chairs was found for the time duration to adjust the backrest weight resistance. Visual examination of the chair and workstation by the researchers revealed that there was sufficient range in adjustability to accommodate the anthropometric variety in the subjects.

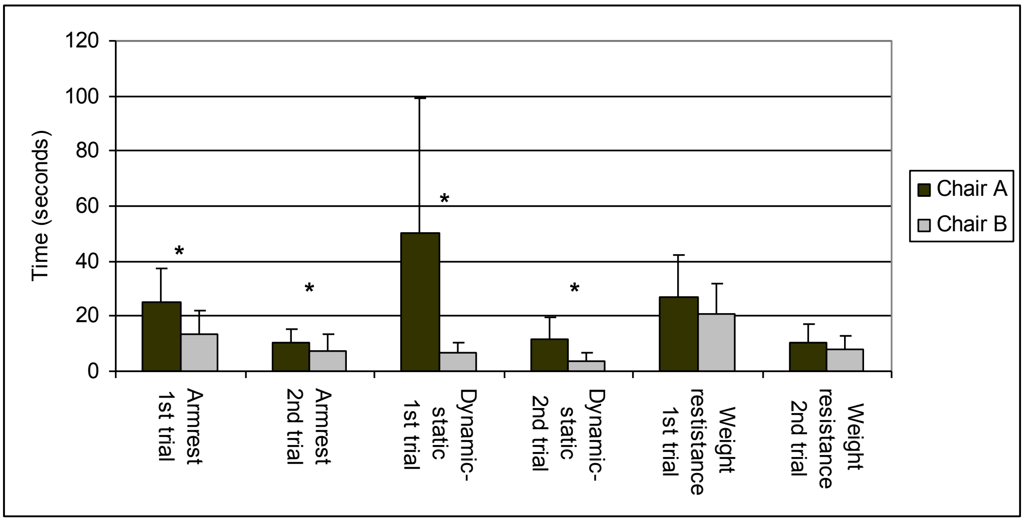

Figure 3 *Mean and standard deviation of adjustment duration time (seconds) of two trials to adjust armrest height, to adjust the chair from its static into its dynamic mode, and to adjust the backrest weight resistance. (* means significant difference between chairs A and B.)*

2.3.1.3 Experience after short seating

After the 5 min computer task, no significant differences between chairs A and B were found for seat comfort, experienced seat hardness and experienced seat support. Both the seats of chairs A and B were rated as 'good' on average. After the short duration sitting with a maximally inclined backrest, no significant differences were found for backrest comfort and uniform support of the backrest. Both the backrests of chairs A and B were on average rated as 'slightly good' to 'good'. Eight subjects rated the maximum inclined backrest of chair A as a pleasant/nice position compared to ten subjects for chair B. Ten subjects rated the maximum inclined backrest of chair A as a workable position compared to nine subjects with regard to chair B. Although the ratings for total comfort seem to show better comfort scores for chair B, no significant differences were found.

2.3.1.4 Direct comparison

With respect to the ease of adjustment, chair B was rated 'slightly better' to 'much better' in comparison with chair A by seventeen out of the twenty subjects. However, with respect to comfort only six subjects rated chair B 'slightly better' to 'much better' for seat comfort and eight subjects rated chair B as 'slightly worse'. For backrest comfort, eight subjects rated chair B 'slightly better' in comparison to two subjects who rated this 'slightly worse' to 'much worse'. With respect to total comfort chair B is rated 'slightly better' to 'much better' by twelve subjects in comparison to six subjects who rated chair B 'slightly worse'. In the case of fourteen subjects, their most decisive reason for preferring chair B was the ease of adjustment and in case of the other six subjects the most decisive reason they preferred chair A had to do with seat comfort.

2.3.1.5 Contact pressure

No significant differences were found in peak pressure between the chairs. Averaged across subjects (n = 20), the peak pressure of chair A was 1.2 N/cm^2 (SD 0.6) and chair B was 1.3 N/cm^2 (SD 0.5). Fig. 4 and Fig. 5 show typical samples (one subject) for chair A and chair B of the distribution pattern. For both chairs the highest pressure values are seen in the buttock area around the bony parts (ischial tuberosity) of the pelvis. The lowest pressure values are seen in the distal upper leg area. This appears to be a normal pressure distribution pattern for office chairs. However there is a difference observed from the pressure distributions; chair B shows a very low pressure in the front part of the seat (black and dark areas) which means that there is hardly/no contact with the upper legs at the front side of the seat. This means that there is hardly any leg support in this area.

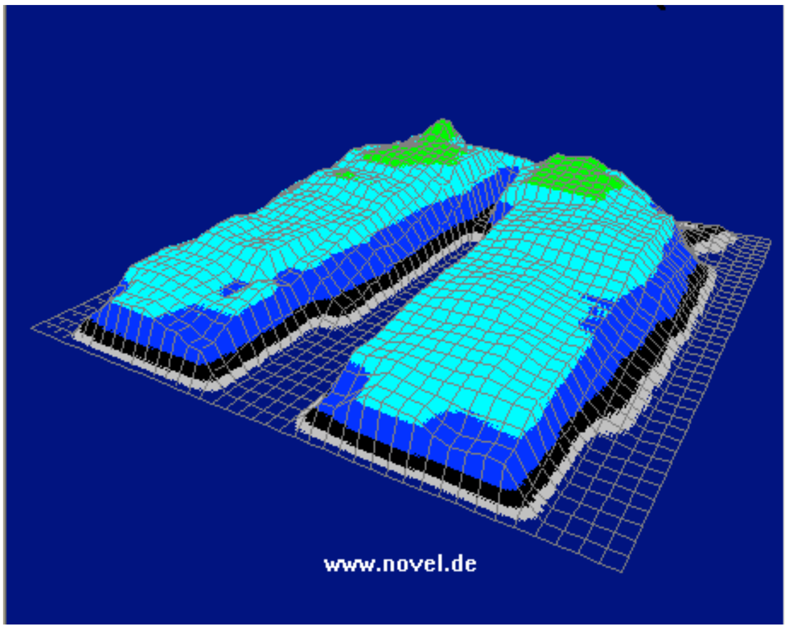

Figure 4 *Typical example of pressure distribution in chair A.*

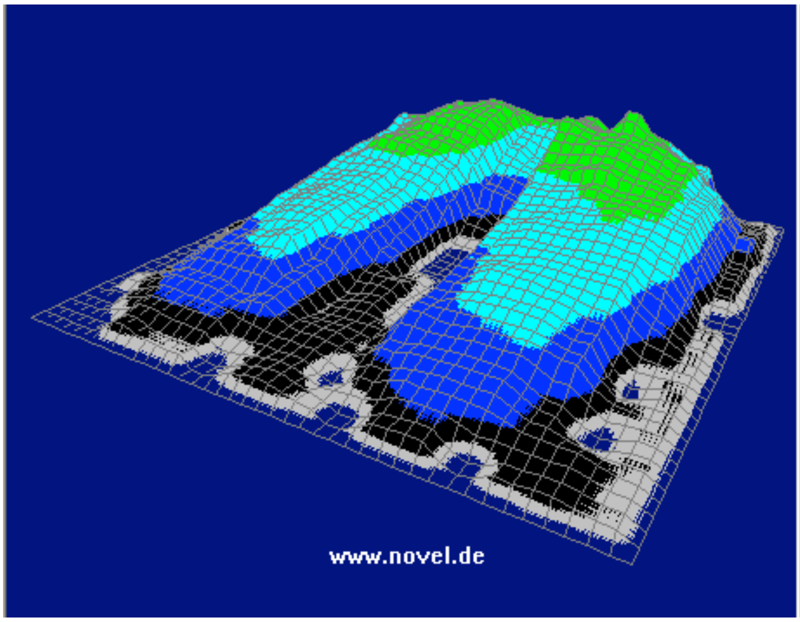

Figure 5 *Typical example of pressure distribution in chair B.*

2.3.2 Results experiment II

2.3.2.1 Ease of adjustment

Fig. 6 and Fig. 7 show the ratings for ease of adjusting the chair from its static into its dynamic mode and to adjust the backrest weight resistance.

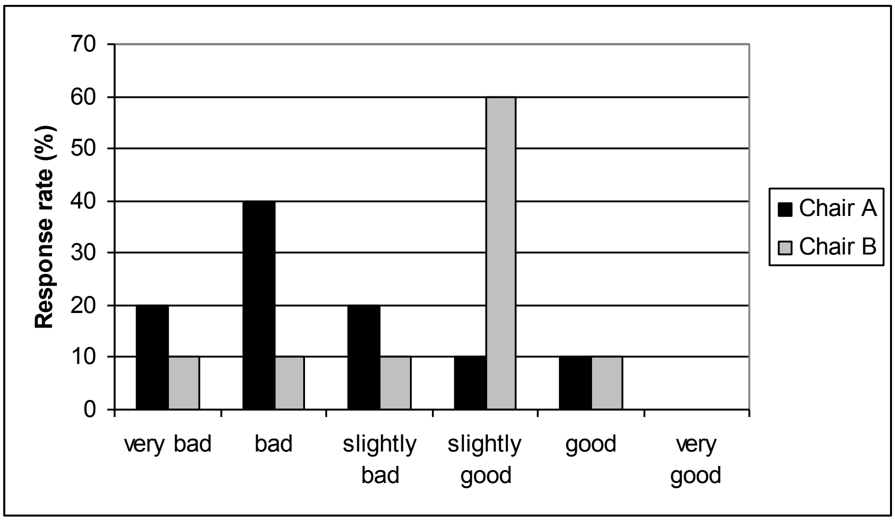

Figure 6 *Scores ratings for ease of adjustment of the chair, from its static into its dynamic mode.*

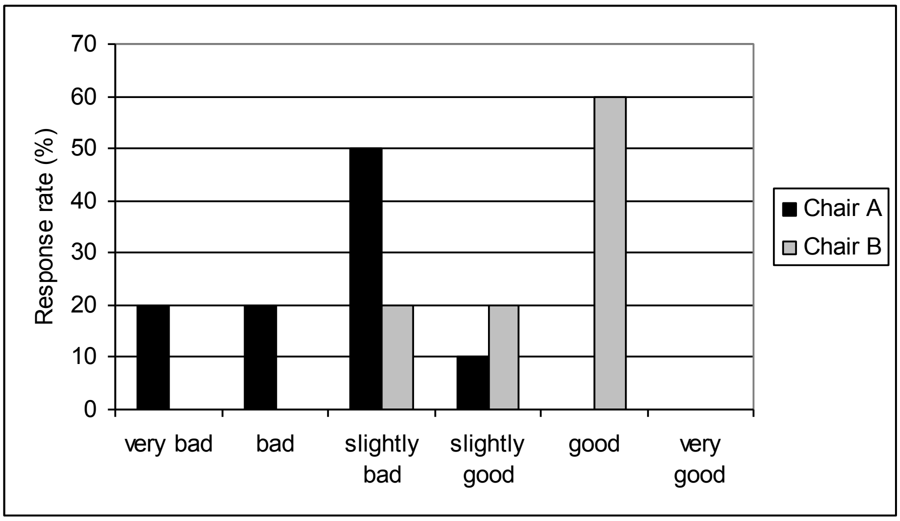

Figure 7 *Ratings for ease of adjustment of the backrest weight resistance.*

A significantly better rating ($p < 0.01$) of chair B in comparison to chair A was found for ease of adjustment to adjust the chair from its static into its dynamic mode and to adjust the backrest weight resistance. This is in line with the results of experiment I.

2.3.2.2 Experience after 1.5 h non-VDU tasks

After 1.5 h, performing reading and/or calling tasks, with the backrest in maximum inclination, no significant differences were found in the experience of backrest comfort or uniformity of the support of the backrest. The task related default was the dynamic mechanism, but for two subjects (one male, one female) a dynamic mode was immediately too uncomfortable, as it felt too unstable and the subjects weren't able to relax. Because this would strongly influence their further judgment of all chair aspects, they were allowed to fix the chair in the most backward position. The mean scores of both the backrests of chairs A and B were 'good'. No significant difference was found for the rating of the experience of the backrest inclination. There seems a minor, but not significant, preference for the backrest inclination of chair B as seven out of ten subjects score 'slightly good' to 'very good' in comparison to chair A where five subjects score 'slightly good' to 'good' against five subjects that score 'very bad' to 'bad'. Chair B scores significantly higher ($p < 0.05$) when the question is whether the 'amount of backrest angle adjustability needs to be improved'. This is shown in Fig. 8. Six subjects would like the amount of backrest angle adjustability of chair A to be increased. In contrast nine subjects rate the amount of backrest angle adjustability of chair B not needing to be improved. Nine subjects preferred dynamic movement when the backrest was tilted backwards.

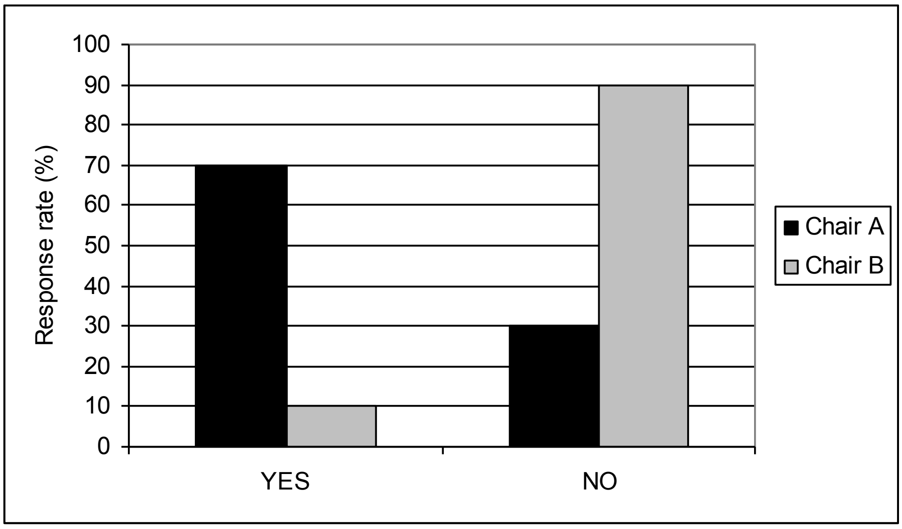

Figure 8 *Scores whether the amount of adjustability in backrest inclination of chairs A and B 'need improvement'.*

No significant differences between the chairs were found for comfort, hardness, equal support or temperature of the seat. The mean scores of both the seats of chairs A and B were 'good' for these four items. Nine subjects answered 'no' to the question whether the 'seat shape should be improved' for both chairs. One single remark was made about a "hard part in the centre of the seat" of chair A and one single remark was made about "improvement of the seat shape" of chair B to have a better "fit to the buttock". For total comfort there was no statistically significant difference between the chairs.

2.3.2.3 Experience after 1.5 h VDU tasks

After 1.5 h of VDU tasks, no significant differences were found for seat comfort, seat hardness, seat temperature or equal support of the seat. The mean scores of both the seats of chairs A and B were rated as 'good'. Although some subjects made remarks about an uncomfortable "slipping off" sensation in chair B. For the question whether the 'seats shape should be improved' eight subjects answered 'no' for chair B and ten subjects answered 'no' for chair A. For the question whether the seat feels 'sweaty', all ten subjects answered 'no' for both chairs. For total comfort there was no significant difference between the chairs.

2.3.2.4 Locally Perceived Discomfort (LPD)

After 1.5 h and in total 3 h seating with hardly any change in position, there was no significant difference in LPD found between the chairs. LPD maximum scores remained low (between 1: very little discomfort and 2: a little discomfort on a 10-point scale).

2.3.2.5 Direct comparison of the chairs

In direct comparison with respect to the ease of adjustment, chair B was rated 'slightly better' to 'much better' in comparison with chair A by nine out of ten subjects. However, only one subject rated chair B 'slightly better' for seat comfort and eight subjects rated the seat comfort of chair B 'comparable' to chair A. For backrest comfort, seven subjects rated chair B 'slightly better' to 'much better' in contrast to three subjects who rated this 'slightly worse' to 'much worse'. With respect to total comfort chair B is rated 'slightly better' to 'much better' by seven subjects in contrast with three subjects who rated chair B 'slightly worse'. The final comfort scores show very similar results compared to experiment I. The most decisive reason stated to prefer chair B was related to the ease of adjustment and backrest comfort. The most decisive reason behind chair A preference was related to seat comfort.

2.4 Discussion

Two chairs, both fulfilling general ergonomic guidelines, different only with respect to seat cushioning, backrest angle and controls, were evaluated before sitting (first impression), after short use (5–10 min), and after longer use (3 h). No differences regarding the first impression prior to sitting were found between the chairs. Higher ratings for 'controls comfort' were given for two of the controls of chair B. During a short trial, shorter adjustment times were measured for armrest adjustment and dynamic mode adjustment. After prolonged sitting 'seat comfort' is valued as 'good' and 'seat discomfort', even after two times of 1.5 h, is low and does not distinguish between the chairs. Peak pressure data are in line with these results, as there is no difference between the chairs and the values are low. The pressure distribution pattern is slightly different between the chairs. 'Backrest comfort' and 'backrest discomfort' are respectively 'good' and low and do not distinguish between the chairs. However, when the question is specified whether or not the backrest angle 'should be improved', a clear significant difference is found in that the original chair should be improved and the redesigned should not. Dynamic use with an inclined backrest is preferred for non-VDU work. In the final score, 70% of the subjects preferred chair B, mentioning the ease of adjustment of controls as the most decisive design aspect. The remaining 30% prefer chair A with the seat, as most decisive design aspect.

Based on the significant difference in 'backrest should be improved' of chair A as compared to chair B, it would be expected that chair B has a comfortable backrest. It is possible that the 6-point comfort measurement scale used is not sensitive enough to detect the value differences when the chairs are evaluated segmental on the same day or at different days. Nevertheless, when a direct comparison was made most users value the chair aspects differently.

Although the comfort of the backrest counter pressure control differed there was no significant difference in adjustment time between the chairs. According to the researchers, this is related to the inexperience of the subjects in adjusting the backrest counter pressure control (in contrast to the other two evaluated types of control). Therefore, they didn't have a reference to which pressure was comfortable for them. When asked to adjust the chair twice in the experiment, they were still working out what their personal preference was and this was included in the adjustment time. This effect could be decreased by using the control more often. This result is interesting, as there is no reason why people are less or inexperienced in using this control. The opinion of the authors is that as it is one of the many functionalities (complexity) of the chair and only used when using the dynamic mode, the majority of users do not get acquainted with this functionality very well. But when using this functionality, particularly for a longer duration of time, it contributes to the comfort experience of users. An automatically adjusting backrest counter pressure, as some manufacturers provide, could create a solution to the complexity issue.

As in this study, design aspects are not noticed only looking at the chair, but after using it a while, it is important to give end-users the opportunity to test the chair for a period of time. De Looze et al., 2003a and De Looze et al., 2003b described this phenomenon for office seats, stating that short term comfort is not always the same as long term comfort. Also, in other products like hand tools (Kuijt-Evers et al., 2007) and train seats (Bronkhorst and Krause, 2005) this phenomenon has been described. Ideally, a product should look comfortable at first sight, be comfortable during short use and remain comfortable after long term use (Vink, 2005).

As pressure distribution appears to be the objective measure with the clearest association with the subjective ratings (De Looze et al., 2003a and De Looze et al., 2003b) contact pressure was recorded in this study. The pressure measurements show no clear chair difference in this study and are in alignment with the experienced comfort results. No difference in peak pressure was found and the values are low according to the numbers of Diebschlag and Hörmann (1987). The authors indicate desired pressure distributions of 1–3 N/cm^2 directly beneath the tuberosities and 0.8–1.5 N/cm^2 in the area around the tuberosities and 0.2–0.8 N/cm^2 in other areas. These levels were not reached in our experiment. However, the distribution pattern shows a slight difference between the chairs with very low pressure values (and therefore hardly any support) at the distal part of the upper legs in the redesigned chair. The slight basin shape of the redesigned seat could be the cause of this. Mergl (2006) describes an ideal pressure distribution for car seats where 49–65% of the load is in the buttock area, 10–28% in the mid thigh area and 6% in the distal part of the upper leg. The current study values of the redesigned chair are below this level in the distal part of the upper leg. Some end-users mention this lack of support specifically in their selection reason by mentioning "a slipping off sense" or "seat should be improved". Goonetilleke and Rao (1999) state in this context that "the ideal pressure profile generally comes from a combination of distribution and concentration". The pressure should be divided along the surface and needs a certain intensity to be supportive as a seat. For 30% of the subjects the seat design is decisive not to prefer the redesigned chair. With a basin shape or "sculpting" surface of the seat it is also more difficult to create a good fit between the diversity of anthropometric dimensions of an end user group and the seat shape. A seat without this shape has automatically more uniformity to fit broader diversity in body dimensions. But when the fit between curvature and body dimensions is good, it can provide more comfort by enlarging the contact area and therefore dividing the pressure more. This effect is also influenced by characteristics of the foam, for instance the density. In this study, we didn't perform specific research on the anthropometric fit, in terms of body dimensions, but only by pressure distribution patterns. For the design of an optimal curvature, a specific anthropometric analysis with the intended user group is recommended.

How is the outcome in appreciation for the specific design aspects related to tasks? The result that the backrest inclination range of chair B needs no improvement was found after the 1.5 h non-VDU tasks. Harrison et al. (2000) describe that for reducing the EMG of the back a backrest angle of 120° is best, 110 and 130° result in more back muscle activity. Harrison et al. also mention that if you have to look in front of you on the road the 120° backrest leads to a neck flexion of 30°, which is far from comfortable. Therefore, for driving a 105° backrest is preferred according to Harrison et al. (2000). For VDU work, a similar reasoning could be held and for reading a 120° backrest should be more comfortable, as the book could be positioned in such a way that a comfortable neck flexion is possible. This could explain our finding that chair B suits this specific type of tasks or at least the wider range in included backrest angle gives greater accommodation for individual preferences in adjustability for the task. For ease of adjustment and adjustment time no specific indications were found for specific tasks, but this wasn't included in our research design. It could be that for flex work or work with shared desks where more employees use the same chair, this ease of adjustability is more important. The assumption is made that the easier the adjustment and the faster the adjustment, the more likely and more frequently people will adjust their chair in relation to task, but this is still a hypothesis as this was not investigated during this study. To answer this question a field research is needed.

The tasks employed in this study represent a part of the deskwork that is being performed in offices but not all. The classification in non-VDU and VDU tasks was determined in this study to contrast between the experimental work postures, but in office work there are more tasks with their variety of postures. This is a limitation of this study. The papers of Dowell et al. (2001) and Graf et al. (1995) show that different types of office jobs have different tasks and therefore different behaviour in (amongst other facilities) chair use. It would provide more specific information to test the chair in other tasks and with more adjustments.

In the introduction section it was stated that ergonomic design criteria do not completely cover comfort. This is partially supported by the findings of this study. Chairs A and B are both designed to Dutch and European ergonomic guidelines. They do not differ in discomfort and discomfort is low. The difference is made by design aspects, which are not elaborated in the ergonomic guidelines. This is similar to studies of Kolich (2003) and De Rosario et al. (2006) in which other specific design aspects of chairs were noticed by end-users that were not part of the guidelines.

The two major points found in this study, ease of adjustment and backrest angle, are design aspects in office chairs that are noticed by end-users and therefore important. Knowing that most office employees spend most of their day with their back unsupported (e.g. Dowell et al., 2001) and that using the backrest reduces the spinal load (Adams, 2006; Harrison et al., 2000; Rohlmann et al., 2001) a proper backrest is important. This stresses also the importance of knowledge of the real office work tasks for designing products. When designing it is important to know, what people do, what they say and what they make (Sanders, 2005). Observing and doing end user research via questionnaires and interviews are, therefore, important methods to improve products. For designers it is important to design the details properly to come as close as possible to actual user needs. For manufacturing, all features that are not needed by the end user could be eliminated to save costs and therefore it is important to know whether these investments have any use for the end-users in a way that provides more comfortable chairs for daily use.

2.5 Conclusion

In conclusion, end-users experience higher comfort, with non-VDU tasks like reading and calling, in using a chair with a range of motion that could reach 124- backrest inclination. Additionally, chairs with a high ease of adjustment are preferred. Chair B had both features and was preferred by 70% of the test subjects. No differences are found for seat design comfort and discomfort, first impression and peak interface pressure. Therefore, when buying a chair, it is important to pay attention to a short use to let end-users notice differences.

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Chapter 3

Usage of office chair adjustments and controls by workers having shared and owned work spaces

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Abstract

In this study two seats were used by workers having shared and workers having owned workspaces. 51 subjects (22 female, 29 male) participated in a six-week experiment in a naturalistic setting. The chairs were different with respect to adjustability options, design of controls and external design. Most of the subjects adjusted the office chairs the first time for seat height, armrest height and backrest inclination. Adjustment times of seat height and armrest height were shorter for chair A. Back rest pressure adjustment takes much time and it is difficult to adjust this without instruction. The workers having shared desks adjust their chair more often and are faster in the adjustment of the backrest pressure compared with workers with an owned workspace. The quality of adjustments of seat height, armrest and backrest pressure was improved by an instruction for 32% of the subjects.

Keywords: office chair, shared workspace, chair controls, adjustment time

3.1 Introduction

Of all EU work, 47% is white-collar work, which is predominantly done in offices and this percentage is still growing [1]. The consequence of a growing service sector is that more people use office chairs. Of course it is of importance that this population can work productive, comfortable and without complaints. A couple of studies have shown that a good adjustable chair in combination with an ergonomic training increases the productivity and reduces musculoskeletal complaints [2], [3]. On the other hand a Dutch-Spanish study showed that the number of persons adjusting their chair is very low. 30-60% of the working population never adjusts their chair [4]. The 30% was in the Spanish group where seats were less complex to adjust. So, a possible explanation for not adjusting could be the complexity of the control system. The question is "what is a good adjustable chair"? A good design of the controls is important, but what is a good design? When the controls are in a logical intuitive position and the adjustment time are low usability increases. But, is that enough? [5]. From the functionality perspective it is important to take the work task into account as different work tasks cause different body dynamics [6], [7], [8], [9], [10] and therefore different tasks might need different chair adjustability options. In this context a study showed that different chair preferences were found in relation to different function types [11].

In this study the user type in terms of work tasks and mobility in combination with the fit with particular adjustment properties was carried out. As there is a number of organizations that move from conventional offices with owned work spaces to more open and transparent offices with shared workplaces [12] the differences between workers using one workstation and users that do not have a fixed work station is becoming of importance. Therefore, in this study these two groups (a group having owned work spaces and a group having shared work spaces) are taken into the study population. The effects of chair characteristics and user type on number of adjustments made, adjustment times and adjustment quality are presented in this paper.

3.2 Methods

The study was carried out in a real office environment of an international consultancy company for Information Technology. Out of the 60 subjects that start the experiment, 51 subjects (22 female, 29 male) participated the whole 6 weeks during experiment. The mean ages were 42.5 years (SD 10.9 years). One group of 34 subjects had an owned workspace and one group of 17 subjects used shared workspaces. Sometimes this is called hotelling. The "owned work space users" had mainly administrative functions and secretary work. About one third of their function consisted of call centre work. The "shared work space users" had mainly consultancy functions. Initially the user type groups were more equal in number, but nine flexible workstations users could not complete the experiment. Due to the consultancy work they were no longer at work in their own office environment.

The two types of office chairs, chair A and B, of this study differed with respect to adjustability options, design of controls and external design (see fig. 1). The original chairs normally meet the European standard, but for this experiment chair A was supplied with fewer options (see table two for adjustability options). So, chair A was seen as the easy adjustable chair and chair B as the more complex adjustable chair. None of the subjects was familiar with the chairs before the experiment. They were used to an office chair meeting the Dutch and European standards. The subjects used each chair for three weeks in a systematically varied order (30 subjects started with chair A and 30 subjects with chair B).

Initial chair adjustments by the subjects were observed. After two weeks of getting used to the chair the subjects were one by one invited to a separate meeting room with their 'own' test chair.

The following measurements were performed:

1. To define user adjustments; seat height, seat depth (chair B only), arm rest height, space between arm rest (chair A only), backrest angle, backrest height (chair A only), use of the dynamic mode and back rest pressure.

2. Time to adjust seat height, armrest height, seat depth and backrest pressure by use of a stopwatch. From a default chair setting (lowest position armrest, seat, backrest, maximum upright and fixed back rest, minimum seat depth and lowest back rest pressure) the subject adjusted the chair in a fixed order to his/her personal location and each subject was encouraged to get comfortable in the chair. This was repeated two times.

3. Chair related body dimensions; lower leg length, upper leg length and height between posterior seat surface and elbow bone (table 1).

4. Quality of the adjustments before and after instructions. This is a combination of chair adjustment and chair related body dimensions.

5. A questionnaire to define user characteristics, work task characteristics, user-friendliness of the chair in terms of adjustability, functionality, task suitability, work related musculoskeletal disorders and comfort.

Figure 1 *The experimental chairs A (left) and B (right)*

Table 1 *Chair related body dimensions of the subjects in centimeters*

	Lower leg length	Upper leg length	Seat surface-elbow height
Mean	47.6	48.2	20.7
Std. Deviation	2.7	3.5	2.5
Minimum	43.0	42.0	16.0
Maximum	55.0	57.0	27.0

At the end of the third week the adjustments the users made were measured again to define whether and how the chair was adjusted in the last week. Then the second chair was presented to the subject and the protocol was repeated.

3.3 Results

<u>3.3.1 Chair adjustments made</u>

No significant differences between chairs are found from the questionnaire in how often the subjects do adjustments their chair. The majority (62%) only adjusted the chair when they received the chair at the start of the three weeks. 16% adjusted it more than once a week. Weekly adjustments were made by 11% of the subjects. Table 2 shows which parts of the chair were adjusted when the subjects received the chair. There are no significant differences between the comparable chair parts of chair A and B in the observed (and questioned) adjustment numbers. Seat height and armrest height are most often adjusted followed by backrest inclination. Space between armrests and the dynamic mode are the least adjusted chair options.

Table 2 *Adjustment of the chair element when subjects received the chair (% yes)*

	Seat height	Seat depth	Armrest height	Inter armrest space	Dynamic mode	Backrest pressure	Backrest inclina-tion	Lumbar support
Chair A	95%	-	83%	10%	15%	18%	70%	-
Chair B	92%	31%	90%	-	21%	33%	42%	28%

3.3.2 Adjustment times

The first time the adjustment time was shorter for chair A compared with chair B concerning armrest height adjustment and seat height adjustment. The second time only the armrest height adjustment time was significantly shorter. The first time adjustments were significantly slower than the second time with exception of the armrest of chair B. The backrest pressure (used in dynamic mode) was very difficult to adjust. In the first attempt 62% of the subjects were not able to find or adjust de backrest pressure of chair A in a proper way. For chair B 36% of the subjects didn't do it in a proper way.

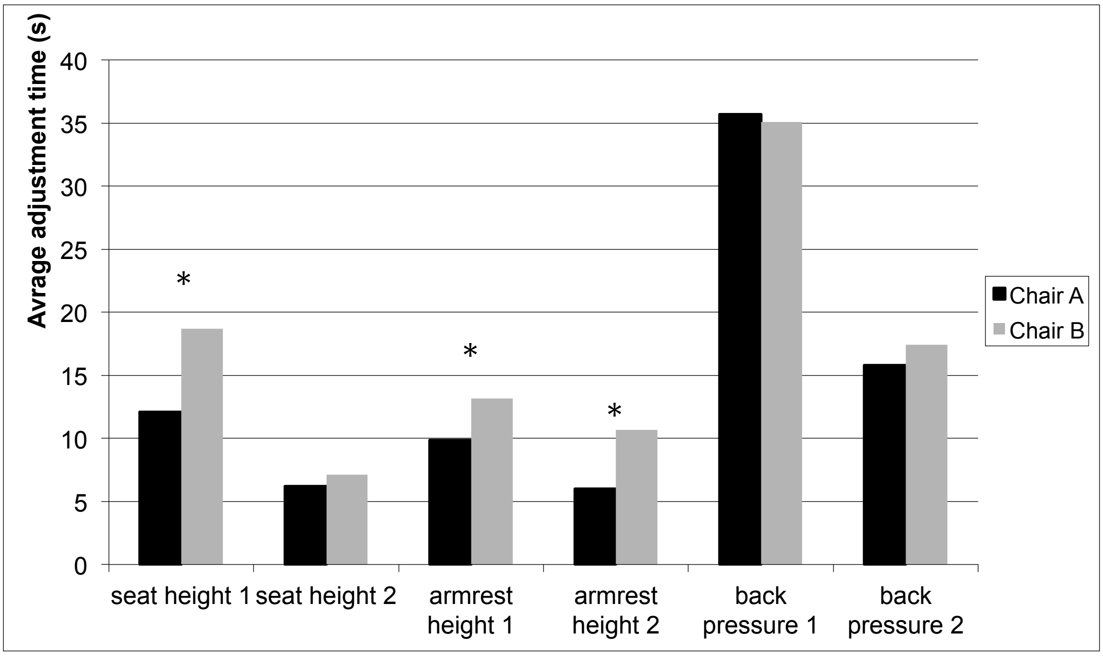

Figure 2 *Average adjustment times (sec) for chair A an B in the first (1) and second time (2) measurements*

3.3.3 User type

Chair use of the experimental chairs for one-workstation users is 85% of the total work time and 65% for the flexible workstations users. Flexible workspace users adjusted their chair significantly more often (weekly - more than once a week) than the one-workstation workers (when receiving chair – weekly). Chair height was adjusted by significantly more (96%) of one-workstation users compared to flexible workspace users (87%). Significantly less one-workstation users workers (8%) changed the chair into dynamic mode compared to flexible workspace workers (39%).

The work tasks of "one work station users" consist significantly more of reading and writing, calling, archiving and filing than the "flexible workspace users". The two user types perform the same level of intensive computer work 4-8 hours a day. Flexible workspace workers value operation of the backrest height control and space between armrest controls lower (on average a little worse) than fixed workers (a little good). Flexible workspace users faster adjusted the backrest pressure of chair A the second time. Lower leg length of flexible workspace users was significantly longer (average 0.49 m) compared fixed (average 0.47 m).

3.3.4 Instruction

After an instruction the average seat height is significantly lower than before for both chairs. 32% of the subjects made after instruction a substantial change in seat height of at least 2 cm in comparison to their initial adjusted seat height. The variation range in comparison to their lower leg length is $-3 < 0 > 3$ to lower leg length. 43% made a substantial change in armrest height after instruction of at least 2 cm in comparison to their initial adjustment. The range is $-2 < 0 > 2$ cm in relation to seat surface – elbow height. The backrest pressure felt for 79% of the subjects comfortable after instruction. For 19% there was no comfortable feeling achieved after instruction.

3.4 Conclusions

Most office chair elements were only adjusted once during use. When subjects do adjust the chair mostly the seat height, armrest height and backrest inclination is adapted. Space between armrests and the dynamic mode are the least used chair adjustment options.

Adjustment times of seat height and armrest height were shorter for the simple chair (chair A). There was no relationship with the number of adjustments, showing that adjustment time was not the most crucial factor. Backrest pressure adaptation takes much time and for many subjects it was very difficult to adjust this without instruction. The shared workspace users are faster in the adjustment of backrest pressure the second time compared with the subjects having an owned workspace.

Differences in adjustment frequencies are also found between worker types. Shared workspace workers adjust more often.

The quality of the initial adjustments of seat height, armrest and backrest pressure was improved by an instruction for 32% of the subjects, showing the importance of instructions.

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Chapter 4

Influences of office tasks on body dynamics using dynamic office chairs

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Abstract

In this study the influence of office tasks on posture, movement, muscular activity and chair position is investigated in a laboratory study. The cross-sectional laboratory research was performed in a simulated office workplace involving seven office tasks and five chairs. Body part postures, muscle activation, body part movements and chair part positions were gathered. This paper reports the findings from 10 subjects, both male and female.

Findings from the experiment demonstrated that the tasks performed exerted strong significant effects on subjects' muscular activity, postures and movement.. The sorting file task was associated with the highest muscle activity, while mouse use was associated with the lowest activity. Error correcting tasks were associated with the most pronounced forward bended posture of the spine. Sorting tasks on the other side showed an upright trunk with substantially flexed head positions.

Keywords: Office Seating, Tasks, EMG, Posture, Physical Activity, (Dis)Comfort

4.1 Introduction

Forty-seven percent of employees in the EU perform white-collar (predominantly office) work, predominantly in offices. As the proportion of white-collar work continues to increase (Parent-Thirion et al., 2007), so does the importance of ensuring that this population can be productive, comfortable and free of symptoms.

The functionality of office chairs is important to accommodate variations in user postures and movements as several studies showed these variations with performing different tasks (Adams et al., 1986, Van Dieën et al., 2001, Dowell et al., 2001, Commissaris & Reijneveld, 2005, Babski-Reeves et al., 2005, Ellegast et al., 2007). Also, users' chair preferences in relation to function type are different with diverge functions (Legg et al., 2002). Therefore it seems that different types of tasks need different chair characteristics. An experiment with a focus on task support of the office chair showed that office workers performing a reading task required a larger back rest inclination range compared with a VDU task (Groenesteijn et al., 2009).

Task specific chair requirements are poorly understood. To improve the match between the characteristics of the task and features of the chair we need to define requirements based on theory, user experiences and physical parameters in the interaction with the task and the office chair. A few experiments are performed where task type is distinguished and physical parameters are specified. According to the study of Luttmann et al. (2003) muscular activity and fatigue, differ per task during sitting. The highest muscular activity in the shoulder region was shown for paper work whereas mouse application showed the highest activity in the lower arm. Physical activity in terms of postural change showed that spending more time in telephoning leads to an increase of extreme spine postures (Benninghoven et al. 2005). This shows that besides the type of task, duration is also an important issue to consider.

The paper of Ellegast et al. (2009) shows that the body posture and the muscle activity of the m. erector spinae and m. trapezius depend more on the tasks performed than on the use of a particular type of office chair. This paper focuses on what the task effects of the specified tasks are on physical parameters using five chairs with different dynamic systems. The selection of tasks performed when using office chairs involves error correcting on paper, typing text data, intensive mouse use, sorting paper files and telephoning. The research question of this study is:

What are effects of different office work tasks like error correcting on paper, typing, mouse use, sorting files and telephoning on postures and movements of body parts and positions of parts of the chair?

4.2 Method

The study consists of a laboratory research, carried out in a simulated computer office workplace (see figure 1) and set up as a cross sectional study with seven office tasks and five chairs. Body postures, muscular activity by electromyography (EMG), body movement and chair movement data were gathered. This laboratory test is part of an extended study with a laboratory experiment and a broader field study where Ellegast et al, (2008) report about. Ten healthy subjects (5 men and 5 women) volunteered to participate in the laboratory study. The mean ages were 35.2 years (SD 12.3 years) for the men and 34.8 (SD 12.7) for the women. Body heights ranged from 1.75 to 1.86 m (mean: 1.82 m) for the men and from 1.62 to 1.68 m (mean: 1.65 m) for the women. Body weights varied from 76 to 100 kg for the men and from 47 to 78 kg for the women. All subjects had performed the majority of their duties VDU workplaces for several years.

Figure 1 *The simulated computer office workplace*

Four chairs selected for their specific dynamic characteristics, labeled A, B, C and E and one reference chair labeled D were used in this study (see figure 2). They were all covered with dark blue textile. The manufacturers and types were blinded. All specific dynamic chairs have features of a conventional dynamic office chair and in addition to that they all come with specific dynamic features that are supposed to facilitate a range of postures and prevent statically or passive behavior of users.

Figure 2 *The experimental chairs: special dynamic chairs A, B, C, E and reference chair D*

During the lab test the subjects performed the following standardized and precisely defined tasks (duration of activity in brackets):

1. Reading and correcting text data on a printed standard text on paper that contains textual faults (10 minutes)
2. Typing words in a Word document with keyboard and mouse. The text (A4 format paper) was presented in a paper stand on the left side of the screen (20 min)
3. An intensive mouse task in a game following and hitting a target on the screen (20 min)
4. Reading and correcting text data continuing of the first task (10 minutes)
5. Typing words continuing the second task (20 min)
6. Sorting paper files on the desk in various document files (10 min)
7. Telephoning performing one call (10 min)

The tasks were for all ten subjects offered in the same order.

Joint body angles and movements of body parts and chair parts were measured with the CUELA system (Ellegast & Kupfer, 2000). Surface electromyography (EMG) was used for measuring the muscle activity of the m. trapezius (right/left) and m. erector spinae (right/left) with the CUELA EMG signal processor for long-term analysis (Glitsch et al. 2006).

From the measured signals, the following body/joint angles were calculated: Head inclination, cervical spine inclination, flexion/extension and lateral flexion of the spine in the thoracic (Th3) and lumbar spinal regions (L1 and transition to L5), trunk inclination and the spatial position of the upper and lower legs (right and left). From the EMG signals percentage of activation was expressed in relation to the Reference Voluntary Contraction (RVC). From the kinematic measurements of all sensors physical activity intensities (PAI) were determined by calculating a sliding standard deviation of the high-passed filtered vector magnitude of the 3D acceleration signals. From the chair signals the angles of seat inclination (in for / backward and sideward directions) and backrest inclination was calculated. For extended analysis descriptions see also Ellegast et al. (2008).

For statistical analysis of the lab study ANOVA for repeated measures was used for comparisons of the, EMG, PAI and chair data. Post hoc LSD was used to compare task by task. The significance level for all statistics was determined at a 0.05 level.

4.3 Results

4.3.1 Muscle activation

There is a main effect of task on all four measured muscles for the medium level (50 percentile). For the peak level (95 percentile) of the left and right trapezius also a main effect of task was found. The most significant differences in EMG between tasks are seen in the right and left trapezius muscles, but also in the erector spinae activity are some significant differences found. The sorting task shows over all muscles the highest muscles activity, which is significantly different for both left and right trapezius from all other tasks. The mouse task shows the lowest muscles activity, which is significantly different from all other tasks in the right trapezius muscle. The first correcting task is for the EMG of the right trapezius different from the mouse task. The first correcting task shows lower muscle activity compared to the sorting task in all measured muscles. The first typing task shows higher muscles activity compared to the mouse task in the peak levels (95 percentile) of the trapezius muscles and in the medium level (50 percentile) of the left erector spinae. The first typing task shows lower muscle activity compared to the sorting task in left and right trapezius muscle. The first correcting task shows also lower muscle activity compared to the telephoning task in the peak level of the right erector spinae. The mouse task shows lower muscle activity compared to all other task in the right trapezius muscles. Lower muscle activity is also seen in the left trapezius muscle compared to the second typing task and sorting. The second correcting and typing tasks show also lower activity compared sorting in both left and right trapezius and at the peak level of the left erector spinae. The sorting task shows higher muscle activity in all muscles compared to telephoning.

4.3.2 Physical activity of body parts

A main effect of task was also found for physical activity intensity of head, thoracic spine, lumbar spine L1 and L5, and left and right thigh and lower leg. There are many significant differences in physical activity intensity between tasks. Among the many differences some are interesting to report to demonstrate the relative differences between tasks in physical activity intensity. Sorting files showed the highest physical activity in the head followed by telephoning. Sorting files showed also the highest activity of thoracic and lumbar spine again followed by telephoning. The correcting and mouse task showed the lowest activity of the head. The correcting and mouse task showed the lowest activity of thoracic and lumbar spine. Telephoning showed the highest physical activity in both upper and lower legs where correcting the first time showed the lowest leg activity. Typing showed also low activity in the legs. There are also significant differences between the first and the second time correcting and typing.

4.3.3 Joint body angles

For the joint body angles also main effects of task were found for all measured angles. And between tasks significant differences in joint body angles are also found in many comparisons. Between correcting the first time and correcting the second time performed there are also significant differences, which is the same task. These p-values of the comparison of the first and second time correcting are between 0.05 and 0.01 where the values between different tasks are <0.01. Among the many differences some are interesting to report to demonstrate the relative differences between tasks. Telephoning shows the highest L5 inclination, which is significantly different of all other tasks. The mouse task shows the second high L5 inclination also significantly of the other tasks. Sorting files shows the least L5 inclination. Both the correcting tasks show the highest cervical spine flexion and head inclination. The sorting task shows also cervical spine flexion and considerable head inclination. The other tasks show cervical spine extension with the mouse tasks with the highest extension and the lowest head inclination. The second time correcting shows the highest lumbar spine flexion closely followed by telephoning and first time correcting. Sorting files shows the lowest lumbar spine flexion. The subjects are sitting pretty upright possibly to overview their paper documents. Correcting, mouse task and telephoning show all comparable high trunk flexion. Sorting files shows the lowest significantly different trunk flexion. All tasks show a little trunk lateral flexion to the left except for some peak values. Correcting shows the highest lateral flexion. The second time correcting shows the highest kyphosis together with the mouse and the telephoning task. Sorting files shows the lowest kyphosis.

4.3.4 Chair part positions

Main effects of task were found for seat pan inclination in forward/backward direction and in sideward directions Telephoning shows the highest backward inclination of the seat pan and is significantly different from the other tasks. Sorting files shows a forward inclination, which is significantly different from the other tasks except for typing. Sorting files shows the most neutral sideward seat pan inclination, which is significantly different from the other tasks with more inclination to the left. Typing shows, together with correcting and the mouse task the most sideward inclination to the left. Telephoning shows the highest backward inclination of the backrest and is significantly different from the other tasks. Sorting files shows the lowest backward backrest inclination and is significantly different from telephoning, correcting and mouse task.

4.4 Discussion

Different office tasks were investigated in a laboratory setting with five different dynamic chairs. The tasks showed many differences in body dynamics and postures between tasks. A summary of the results per task is shown in table 1. The first and second time typing and correcting are despite some differences presented as one as these differences were smaller than differences between tasks.

Table 1 *Summary of results per laboratory task with relative comparison between tasks*

	Influence			
Task	**muscle activation**	**physical activity**	**postures**	**chair positions**
Correcting	- 'medium' activity	- lowest head activity - low leg activity	- highest kyphosis and high trunk flexion - highest head inclination and cervical spine flexion	- close to neutral seat pan inclination - little back rest inclination
Typing	- 'medium' activity	- low leg activity - 'medium' trunk and head actvity	- high trunk flexion and kyphosis - fairly upright position of cervical spine with some head inclination	- close to neutral seat pan inclination - little back rest inclination
Mouse use	- lowest actvity	- lowest head activity - lowest trunk activity	- highest trunk flexion and high kyphosis - highest lumbar spine flexion and high L5 inclination - highest cervical spine extension and upright head position	- high backrest inclination with some backward seat pan inclination
Sorting	- highest activity	- highest trunk and head activity	- least L5 and trunk inclination - high cervical spine flexion and head inclination	- most forward seat pan inclination and side ward inclination to the right
Telephoning	- 'medium' activity	- highest leg activity - high trunk and head activity	- high L5 and trunk inclination - fairly upright position of head and cervical spine	- highest backrest inclination

This study showed that posture variation, as an effect of tasks is large. This is in line with the study Van Dieën (Van Dieën et al., 2001).

The high L5 inclination together with high backrest inclination with telephoning, is supported by Groenesteijn et al. (2009), where subjects preferred a large backrest inclination with a telephoning task.

The significant differences in the same tasks, correcting and typing, for the first and the second time performed in physical activity and joint body angles in the lab study showed that there is also within these tasks variation. These differences are smaller than between different tasks and significant values are less significant than between tasks, but still below the 0.05 significance level.

Because of the systematic order this can be caused by either increased learning or fatigue where the higher physical activity the second time is due to more degrees freedom or a way to compensate fatigued muscles. But this is speculative and further investigation is needed with varied order for founding these speculations.

The position of head and cervical spine is for all tasks highly determined by the target location of the view of the eyes. Tasks with the computer like typing and mouse use have cervical spine extension together with a little inclination of the head. This is in contrast with a target location at the desk which showed cervical spine flexion and head inclination. Telephoning has no direct target location for the eyes view and leaves the most independent posture of the head. Observational studies have shown that office workers usually perform their tasks in upright or forward leaning postures (Dowell et al. 2001). The visual demands of the task and the reach distances can play a role in leaning forward (Lueder, 2004). Reclined postures with substantial engagement between the sitter's torso and the chair backrest account for only about 15 percent of work postures for workers performing a range of office tasks. In this study is specified that reclined postures are related to telephoning. The more reclined postures of conversation and telephoning seem more preferred as Gescheidle, Miller & Reed (2004) found that preferred postures are substantially reclined. Because the task of telephoning is less restricted in posture by input devices, screen and deskwork the subjects are more able to have a preferred posture.

4.5 Conclusion

Considerable effects of tasks on postures and movements of body parts and chair part positions are found with many differences between the task types.

The correction task showed 'medium' muscle activity and the lowest physical activity of the head in comparison. The body posture in this task is a forward flexed spine with the highest kyphosis, head inclination and cervical spine flexion and high trunk flexion. The chair has a little backward backrest inclination and a nearly horizontal seat pan.

The typing task showed 'medium' muscle and physical activity of trunk and head. The body posture with typing is a fairly upright cervical spine position together with a little inclination of the head. The chair positions have a little backward backrest inclination and a nearly horizontal seat pan.

Mouse use showed the lowest muscle and physical activity of the head and trunk. It is a very static task with a body posture that showed the highest trunk flexion, the highest lumbar spine flexion and the highest cervical spine extension head position.

The sorting files task showed the highest muscle activity with high physical activity in the trunk and head and is therefore the most dynamic task. Sorting files showed the least L5 and trunk inclination with cervical spine flexion and high head inclination, and the smallest backrest inclination of the chair.

Telephoning was in between the muscle activation extremes, but still different from other tasks. Telephoning showed the second highest physical activity in the trunk and head and the highest physical activity in the lower legs. The body posture with telephoning showed the most backward position of L5 and trunk together with the highest trunk flexion and kyphosis and a fairly upright position of head and cervical spine. This is in line with the found highest backrest inclination of the chair. This is also a forward flexed spine as in the correction tasks, but with further inclined lumbar spine and assumed different body load by leaning more backward to the backrest.

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Chapter 5

Office task effects on comfort and body dynamics in five dynamic office chairs

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Abstract

In the present study, we investigated the effect of office tasks on posture and movements in field settings, and the comfort rating for chair characteristics and correlation with type of task. The tasks studied were: computer work, telephoning, deskwork and conversation. Postures, movements, chair part inclinations and comfort rating data were collected from 12 subjects.

Computer work showed the lowest physical activity, together with upright trunk and head position and low backrest inclination. Conversation shows the highest activity of head legs and low back together with the highest cervical spine extension. In contrast, deskwork provoked the most cervical spine flexion and showed the second lowest activity. The telephoning tasks showed medium activity and the highest kyphosis. Conversation showed the highest backrest inclination.

Positive comfort relations were found for computer work and a "swing system" chair, for telephoning and an active longitudinal seat rotation, and for deskwork and a chair with a three-dimensionally moveable seat.

Keywords: Office seating and tasks; Physical effects; (Dis)comfort

5.1 Introduction

Forty-seven percent of employees in the EU perform white-collar work, predominantly in offices. As the proportion of white-collar work continues to increase (Parent-Thirion et al., 2007), so does the importance of ensuring that this population can be productive, comfortable and free of symptoms.

The functionality of office chairs is important to facilitate office workers in their jobs. However, the office work comprises not just one task, but a variety of tasks. Several studies showed that the performing of different tasks in office work causes variations in user postures and movements (Adams et al., 1986, Babski-Reeves et al., 2005, Commissaris and Reijneveld, 2005, Dowell et al., 2001, Ellegast et al., 2007 and Van Dieën et al., 2001). Therefore, it is likely that different types of tasks need different chair characteristics to accommodate the variety in postures and movements. An indication was found in the experiment with a focus on task support of the office chair, that office workers performing a reading task preferred a larger backrest inclination range compared with a VDU task (Groenesteijn et al., 2009).

Task-specific chair requirements are poorly understood. To improve the match between the characteristics of the task and features of the chair we need to define requirements based on theory, user experiences and physical parameters in the interaction with the task and the office chair. In the past, a few experiments have been performed where task type was distinguished and physical parameters were specified. According to the study of Luttmann et al. (2003), muscular activity and fatigue differ per task during sitting. Across a variety of office tasks, levels of muscle activation appear to vary a lot with for instance peak levels of activation for paper work in the shoulder region and for mouse work in the lower arm. Others showed that spending more time in telephoning leads to an increase of extreme spine postures in the office (Benninghoven et al., 2005).

It also appears that users' chair preferences in relation to function type differ in divergent functions (Legg et al., 2002). We assume that this is related to a different mixture of tasks with different relative duration of tasks causing different body dynamics during office chair use over the day. To build support for our assumption, we, firstly, want to know more about postures, movements and chair part inclinations per task leading to research question 1:

What are the effects of different office tasks on postures and movements of body parts and inclinations of parts of the chair?

Secondly, we want to learn more about the effect of specific office tasks and its duration in relation to chair comfort. For example, do computer bound workers have a certain chair comfort preference, as it is expected that users adopt more static postures when working on computers compared to tasks like telephoning and conversation. Earlier studies already showed that intensive computer work reduces the opportunities to change posture (Graf et al., 1995, Grieco, 1986 and Waersted and Westgaard, 1996).

Because of the expected variations in body postures across tasks, we expect differences in task-related levels of comfort across chairs with different dynamic systems. The chairs vary in dynamic system from active to passive systems and with one-dimensional to multidimensional movement directions. Research question 2 is:

How does the relative duration of office tasks, namely computer work, telephoning, deskwork and conversation, affect the comfort level across office chairs that differ regarding the dynamic system?

5.2 Methods

5.2.1 General design

In this field study five different office chairs were tested in four German companies in the administration sector, each of the office chairs for one week. From observations, four office tasks were subsequently identified. Postures and movements of body parts, chair part movements and questionnaire data were gathered.

This field test is part of an extended study with a laboratory experiment and a broader field study where Ellegast et al. (2012) report about.

5.2.2 Materials

Four chairs selected for their specific dynamic characteristics, labelled A, B, C and E, and one reference chair, labelled D, were used in this study (see Fig. 1). The chairs were newly purchased for the study and cost between 400 and 1000 Euro. They were all covered with dark blue fabric and the manufacturers and types were blinded. The chairs are within a range of chairs from which German facility departments select their office furnishing.

Figure 1 *The experimental chairs: special dynamic chairs A, B, C, E and reference chair D.*

5.2.2.1 Dynamic characteristics of the chairs

All specific dynamic chairs have the features of a conventional dynamic office chair and, in addition, they all come with specific dynamic features that are supposed to facilitate a range of postures and prevent statically or passive behaviour of users. In the United States the expression "passive ergonomics" is also used for this type of facilities.

Chair A had a seat pan driven by a hidden electromotor, which is activated when a subject is sitting. The seat is rotated along a longitudinal axis alternately 0.8° to the left and 0.8° to the right, five times per minute.

Chair B has a suspension system by which the seat pan can move freely in all directions, independent of the rest of the chair in order to stimulate movement. The firmness of the suspension can be adjusted.

Chair C has a "swing system". Comparable to a pendulum, the seat pan of chair C is suspended by a structure through which a steel rod runs. The seat pan is not fixed in one position, but can rather be moved freely in all directions (rotations with and external rotation point in forward/backward/sideward directions and intermediate directions).

Chair D is a standard dynamic office chair and was used as a 'reference chair' with a synchro system, which means that when the seat pan is rotated around a transversal axis the backrest follows the movement in a fixed ratio.

The specific chair E comes with a three-dimensionally moveable joint that allows the seat pan to move freely in all directions in such a way that it resembles sitting on a ball (rotations with and external rotation point in forward/backward/sideward directions and intermediate directions). There is no rigid connection between seat and base.

All chairs, with the exception of chair C, feature a synchro system for backrest and seat pan.

5.2.2.2 Adjustability options

Besides the dynamic options, the chairs provided different adjustment features. Table 1 shows an overview of the adjustability options of the five chairs. All five chairs are highly adjustable and meet the German and European standards for office chair safety.

Table 1 *Overview of adjustability options for the five chairs. The indication "yes" or "no" states whether the adjustability option is available. The indication "step less" states that the option is available and that within the adjustability range any position is possible. When "steps" are indicated it states that the adjustability range is divided in concrete positions to adjust. Adjustability ranges can vary between chairs, but they are all within the European standards.*

Adjustment options	Chair A	Chair B	Chair C	Chair D	Chair E
Synchro system*	Yes	Yes	No	Yes	Yes
Seat height	Step less	Step less	Step less	Step less	Step less
Seat inclination	11 steps	Step less	No	2 steps	No
Seat depth	7 steps	3 steps	No	7 steps	4 steps
Backrest height	5 steps	Step less	No	7 steps	No
Backrest inclination	Step less	Step less	Step less	3 steps	Step less
Backrest counter pressure	3 steps	Step less	No	4 steps	Step less
Lumbar support	No	Step less (depth)	No	No	Step less (height)
Arm rest height	8 steps	9 steps	10 steps	11 steps	8 steps
Arm rest interspace	Step less	3 steps	Step less	Step less	Step less
Arm rest rotation	5 steps	3 steps	Step less (only fixed in neutral position)	5 steps	3 steps

*Synchro system: both the backrest and the seat are moveable in a fixed ratio.

5.2.3 Subjects

A selection of 12 subjects (4 men and 8 women) based in four different organizations (3 subjects of each company) participated. They were experienced office workers in the administration sector and none of them had physical complaints. The measurements were conducted at their individual workplaces. The mean age of the 12 measuring subjects was 35.3 years (sd 7.5 years) for the men and 36.1 years (sd 7.8 years) for the women. Body heights ranged from 1.81 m to 1.88 m for the men and from 1.58 m to 1.74 m for the women. Body weights varied from 80 to 89 kg for the men and from 52 to 88 kg for the women.

5.2.4 Tasks

During the test the subjects performed their usual daily work. The office work was classified into four categories:

- Computer work with use of keyboard and mouse;
- Telephoning;
- Desk work with writing, reading or filing paper work;
- Conversation like talking and meeting with colleagues.

5.2.5 Procedure

At the start of the experiment, all the subjects were informed about the background and time flow of the study, and the five chairs and their features were presented. After that, the subjects filled out the first questionnaires for each chair, without touching the chair or sitting on it. From then the subjects replaced their regular office chair with the test chairs for one week per chair. The chairs were given out in systematically varied order. All the chairs were individually adjusted at the workplace.

On the day of the physical measurements, first the instrumentation and the measuring station were set up. After the chair was equipped and a first functional test was carried out, the measurement system CUELA was fixed to the subject. The measurements took place at the workstations of the subjects. The duration of each measurement was 90 min during non-standardized office work per chair. The settings of chair and table were not changed.

Daily protocols had to be completed regarding the comfort questionnaires. The final comfort survey of each chair took place at the end of the week.

5.2.6 Measurements

The physical measurements were conducted with three subjects in each company on three different office chairs (reference chair and two specific dynamic chairs that were randomly selected). So altogether there were 6 measurements for each specific dynamic office chair and 12 measurements for the reference chair. The physical measurements took place during several days over the week and varied systematically over the subjects.

Joint body angles and movements of body parts and chair parts were measured with the CUELA system (Ellegast and Kupfer, 2000). This person-centred measuring system consists of movement sensors (Analog Devices ADXL 3D accelerometers 103/203 and muRata ENC-03R gyroscopes) and a miniature data storage unit with a flash memory card, which can be attached to the subject's clothing (Ellegast et al., 2009). In this study, a special version of the system adopted for kinematic analysis at VDU workplaces was used (Ellegast et al., 2007). From the measured signals, the following body/joint angles and positions with their degrees of freedom were calculated:

- Head: sagittal and lateral inclination;
- Cervical spine: flexion/extension;
- Thoracic spine: sagittal and lateral inclination at Th3;
- Lumbar spine: sagittal and lateral inclination at L1 and L5;
- Thigh right/left: spatial position;
- Lower leg right/left: spatial position.

From the kinematic sensors in the lumbar spine at L1 and L5 the percentage of the individual maximum 'lordosis/kyphosis' (% ind.max. lordosis/kyphosis) was evaluated. To normalize the values of the parameter 'lordosis/kyphosis', reference postures were performed at the beginning of all measurements: under guidance of a trainer the subjects performed a maximum lordosis and kyphosis while standing. For that calibration interval the maximum/minimum of the difference of L1 and L5 inclinations were defined as 100% individual kyphosis/lordosis. All postures of the lumbar spinal region are therefore relative to these reference postures (% ind.max. lordosis/kyphosis). By this, positive values were defined as 'kyphosis', negative values as 'lordosis' of the lumbar spinal region. Standing upright in a neutral posture was defined as 0% ind.max. lordosis/kyphosis.

The trunk inclination angle was calculated from the averaged Th3 and L5 sagittal inclination angles. The trunk flexion angle was defined as the difference angle between Th3 and L5 sagittal inclination. The trunk lateral flexion angle was defined as the difference angle between Th3 and L5 lateral inclination.

From the kinematic measurements of the head, the thoracic spine (Th3), lumbar spine at L1 and L5 and lower extremities physical activity intensities (PAI) were determined by calculating a sliding standard deviation of the high-passed filtered vector magnitude of the 3D acceleration signals (time window: 1 s) (Weber et al., 2007).

The data logger of the CUELA measuring system enables the synchronous recording of all the measured data together with the chair parameters at a sampling rate of 50 Hz.

To measure dynamically the adjustments of the office chairs, acceleration sensors (Analog Devices ADXL 103/203) were used for measurement of the backrest inclination and seat pan inclinations (forward and sideward).

Comfort experience in relation to body parts, chair elements and work was measured by a questionnaire consisting of three different parts (expectations at start, each chair after testing days and after one week). This was done for all five experimental chairs. Appendix A shows the questionnaire items with the answering scales (varying from 3-point to 6-point scales).

5.2.7 Analysis

From the measured signals, the following body/joint angles were calculated: Head inclination, cervical spine inclination, flexion/extension and lateral flexion of the spine in the thoracic (Th3) and lumbar spinal regions (L1 and transition to L5), trunk inclination and the spatial position of the upper and lower legs (right and left). From the EMG signals, percentage of activation was expressed in relation to the Reference Voluntary Contraction (RVC). From the kinematic measurements of all sensors, physical activity intensities (PAI) were determined by calculating a sliding standard deviation of the high-passed filtered vector magnitude of the 3D acceleration signals. From the chair signals, the angles of seat inclination (in forward/backward and sideward directions) and backrest inclination were calculated. For extended analysis descriptions see also Ellegast et al. (2012).

The tasks were extracted and classified by observations of the CUELA data. The relative duration per task (summation of times that task was performed) as a percentage of the total task duration of 270 min was calculated for each subject.

From the questionnaire data only the data of the final questionnaire, after a week testing per chair, were used for this study. The comfort score of the subjects per item for each chair was correlated to the relative task duration of the subjects per task.

This paper does not report about the comparison between chairs. The paper of Ellegast et al. (2012) will discuss the instrumental data and the comparison between chairs. Ellegast et al. (2008) discuss the comfort comparison between chairs.

5.2.8 Statistics

For statistical analysis of the instrumental data, a T-test was used for pair wise comparisons between tasks. As not all subjects were measured on each of the five chairs ANOVA was not applicable.

A Pearson's correlation was used to determine correlation of relative task duration and questionnaire items and was tested two tailed. Partial correlations to control for the possible confounders as gender, age and body length and weight were done for significant Pearson's correlations. The significance level for all statistics was determined at a 0.05 level.

5.3. Results

5.3.1 Physical activity intensity (PAI)

Computer work was in all physical activity measures significantly different from the other tasks (see Table 2). The 50th and 95th percentiles (%ile) of the measured body parts all show a lower intensity in physical activity.

Besides the difference with computer work, the telephoning task shows significant higher PAI with the head (50%ile) compared to deskwork. Compared to conversation, telephoning causes significantly less PAI of head (50%ile and 95%ile), thoracic spine (95%ile), L5 (50%ile), and left leg (95%ile of thigh and lower leg).

Deskwork shows besides the differences with computer work and telephoning a significant lower PAI of head (50%ile and 95%ile), L5 (50%ile) and both legs (50%ile and 95%ile), L5 (50%ile). The results are shown in Table 2.

Table 2 *Mean values (standard deviation) over 12 subjects of the 50th and 95th percentiles of PAI values for all tasks (Computer work [1], Telephoning [2], Desk work [3], Conversation [4]), along with the significant statistical results (p values) of the t-test (pair wise comparison).*

	Task				Significant comparison					
Physical activity intensity (PAI)	**Comp [1]**	**Tel [2]**	**Desk [3]**	**Conv [4]**	**1 vs 2**	**1 vs 3**	**1 vs 4**	**2 vs 3**	**2 vs 4**	**3 vs 4**
PAI head (%g)										
50%ile	0.9 (0.2)	1.3 (0.5)	1.1 (0.3)	2.3 (0.6)	<0.001	0.007	<0.001	0.015	<0.001	<0.001
95%ile	4.1 (1.6)	4.5 (1.3)	5.0 (1.3)	8.2 (1.6)	–	0.006	<0.001	–	<0.001	<0.001
PAI thoracic spine (%g)										
50%ile	0.4 (0.1)	0.5 (0.1)	0.5 (0.1)	0.6 (0.3)	0.001	<0.001	<0.001	–	–	–
95%ile	0.9 (0.2)	1.4 (0.7)	1.7 (0.6)	1.8 (0.8)	<0.001	<0.001	<0.001	–	0.018	–
PAI lumbar spine L1 (%g)										
50%ile	0.3 (0.1)	0.4 (0.2)	0.4 (0.1)	0.4 (0.3)	0.009	<0.001	0.001	–	–	–
95%ile	0.8 (0.2)	1.3 (0.7)	1.6 (0.7)	1.6 (1.0)	0.002	<0.001	<0.001	–	–	–
PAI lumbar spine L5 (%g)										
50%ile	0.2 (0.1)	0.3 (0.2)	0.3 (0.1)	0.5 (0.2)	0.006	0.001	<0.001	–	0.012	0.008
95%ile	0.7 (0.2)	1.1 (0.6)	1.4 (0.6)	1.4 (0.6)	0.001	<0.001	<0.001	–	–	–
PAI thigh left (%g)										
50%ile	0.4 (0.1)	0.5 (0.2)	0.5 (0.1)	0.6 (0.3)	0.001	<0.001	<0.001	–	–	0.027
95%ile	1.1 (0.9)	2.0 (1.2)	2.1 (1.1)	2.7 (1.4)	0.001	<0.001	<0.001	–	0.041	–
PAI thigh right (%g)										
50%ile	0.4 (0.1)	0.5 (0.2)	0.5 (0.1)	0.6 (0.2)	0.002	<0.001	<0.001	–	–	0.029
95%ile	1.3 (1.1)	3.3 (4.6)	2.2 (1.1)	3.2 (1.8)	0.028	0.001	<0.001	–	–	0.006
PAI lower leg left (%g)										
50%ile	0.3 (0.1)	0.4 (0.2)	0.4 (0.1)	0.6 (0.4)	<0.001	<0.001	<0.001	–	–	0.042
95%ile	1.7 (2.0)	3.3 (2.3)	3.5 (2.3)	4.9 (2.8)	0.003	0.001	<0.001	–	0.011	0.023
PAI lower leg right (%g)										
50%ile	0.3 (0.1)	0.5 (0.3)	0.4 (0.1)	0.6 (0.2)	0.001	<0.001	<0.001	–	–	<0.001
95%ile	2.4 (3.2)	5.7 (7.0)	4.0 (2.4)	6.3 (3.5)	0.012	0.021	<0.001	–	–	0.001

5.3.2 Joint body angles

The most significant differences in body angles between tasks are seen in cervical spine flexion and head inclination. See Table 3 for significant results.

Table 3 *Mean values (standard deviation) over 12 subjects of the 50th and 95th percentiles of joint/body angles for all tasks (Computer work [1], Telephoning [2], Desk work [3], Conversation [4]), along with the significant statistical results (p values) of the t-test (pair wise comparison).*

Joint/body angles	Task				Significant comparison					
	Comp [1]	**Tel [2]**	**Desk [3]**	**Conv [4]**	**1 vs 2**	**1 vs 3**	**1 vs 4**	**2 vs 3**	**2 vs 4**	**3 vs 4**
Neck flexion (°)										
50%ile	−13 (11)	−6 (16)	7 (13)	−16 (12)	0.045	<0.001	–	0.001	0.004	<0.001
95%ile	8 (13)	13 (14)	26 (13)	5 (14)	–	<0.001	–	<0.001	0.038	<0.001
Head inclination (°)										
50%ile	7 (12)	13 (14)	27 (16)	−5 (9)	–	<0.001	<0.001	<0.001	<0.001	<0.001
95%ile	25 (15)	29 (14)	49 (16)	17 (14)	–	<0.001	0.015	<0.001	0.001	<0.001
Trunk inclination (°)										
50%ile	−8 (8)	−8 (12)	−6 (7)	−13 (9)	–	–	0.009	–	–	<0.001
95%ile	0 (8)	2 (9)	4 (6)	0 (9)	–	0.020	–	–	–	<0.001
Trunk lateral flexion (°)										
50%ile	−2 (2)	−1 (4)	−1 (2)	−2 (3)	–	–	–	–	–	–
95%ile	1 (2)	3(5)	5 (4)	3 (4)	0.023	<0.001	0.013	–	–	–
Lordosis/kyphosis (% ind.max.)										
50%ile	58 (15)	61 (18)	56 (17)	50 (19)	–	–	–	–	0.021	–
95%ile	72 (15)	77 (19)	75 (17)	71 (15)	–	–	–	–	–	–

Computer work shows more cervical spine extension (50%ile) and a little more upright position of trunk lateral flexion (95%ile) compared to telephoning. Compared to deskwork, PC work shows more cervical spine extension and less inclination of the head in means and both percentiles. Also a little less trunk inclination is seen in the 50%ile. The mean trunk lateral flexion is a little more to the left, while the 95%ile is more upright. Compared to conversation, computer work gives more head inclination and a more negative trunk inclination (50%ile). The 95%ile trunk lateral flexion is more upright with computer work.

Telephoning shows cervical spine extension (50%ile) and less cervical spine flexion (95%ile) compared to deskwork. Also head inclination is less with telephoning. Compared to conversation, telephoning shows less extension of the cervical spine and a more negative inclination of the head (50%ile). The 95%ile shows more flexion and inclination. Telephoning shows the highest kyphosis numbers of the trunk in total and is significantly higher compared to conversation.

Deskwork shows the highest cervical spine flexion and head inclination of all tasks and is also significantly higher than conversation. The trunk inclination is least negative for the 50%ile compared to conversation. The 95%ile shows more trunk inclination.

There are no significant differences in L5 inclination, lumbar spine flexion and trunk flexion.

5.3.3 Chair parameters

Significant differences are found for seat pan inclination and backrest inclination (see Table 4). No significant differences are found for seat pan inclination sideward.

Table 4 *Mean values (standard deviation) over 12 subjects of the 50th and 95th percentiles of chair parameters for all tasks (Computer work [1], Telephoning [2], Desk work [3], Conversation [4]), along with the significant statistical results (p values) of the t-test (pair wise comparison).*

Chair parameters	Task				Significant comparison		
	Comp [1]	**Tel [2]**	**Desk [3]**	**Conv [4]**	**1 vs 4**	**2 vs 4**	**3 vs 4**
Seat pan inclination (°)*							
50%ile	0.9 (1.8)	0.7 (2.0)	0.9 (1.8)	0.0 (2.1)	0.042	–	–
95%ile	2.4 (2.1)	2.0 (2.1)	2.4 (1.6)	1.7 (2.0)	–	–	–
Backrest inclination (°)*							
50%ile	−0.4 (2.2)	−1.0 (2.2)	−0.1 (1.9)	−2.5 (3.7)	0.003	0.038	0.001
95%ile	0.9 (2.0)	0.5 (2.0)	1.3 (1.8)	0.6 (1.8)	–	–	–

*Positive values represent forward inclinations.

Conversation is different from the other tasks and shows the lowest values for seat pan inclination and the highest backward inclination. Computer work shows more seat pan inclination for the 50%ile compared to conversation. The mean seat pan inclination with deskwork is also larger than with conversation. The 50%ile backrest inclination is for computer work, telephoning and conversation less backward inclined compared to conversation.

5.3.4 Correlation of task type and duration with comfort values

For each subject the relative task duration per task in relation to the total time (100%) was determined. In Fig. 2 the distribution of the four classified tasks over the total time measured is shown per subject. The mean relative task duration over subjects for computer work is 49% (standard deviation (sd) 22%). The mean task duration for telephoning is 10% (sd 6%), for desk work 30% (sd 21%) and for conversation 12% (sd 9%).

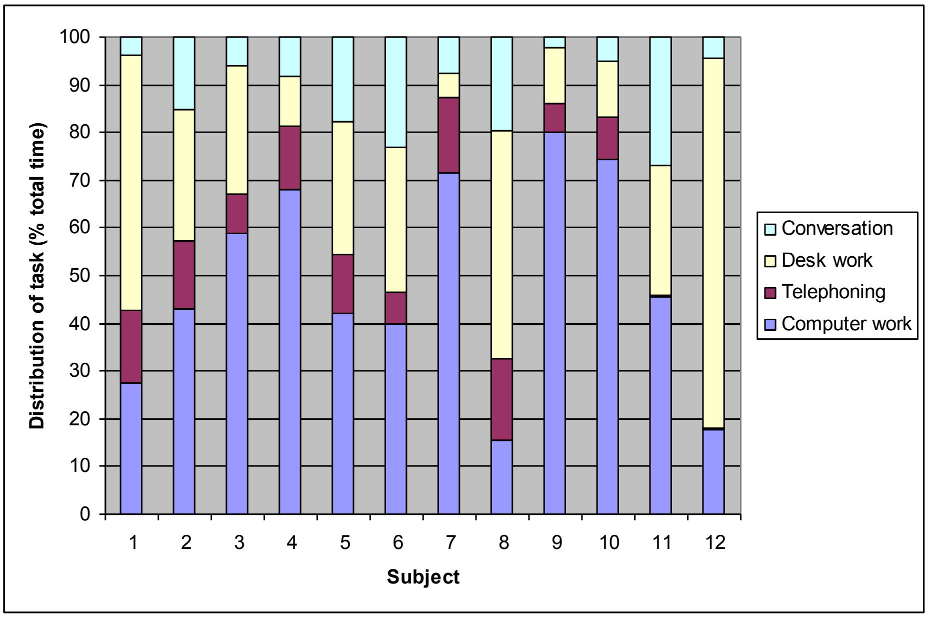

Figure 2 *Distribution of tasks as percentage of the total work time per subject.*

Significant correlations are found between the task duration per task type and specific questionnaire items. All significant Pearson's correlations between relative task duration of computer work, telephoning, deskwork and conversation and questionnaire scores of the chairs are shown in Table 5. Partial correlations found after controlling for possible confounders as gender, age, body length and body weights are also shown. Nine significant partial correlations are found.

Negative correlations are positive for comfort as the scale is from "1 very good" to 6 "very bad".

When subjects perform relatively more computer work, there is a significant correlation with a decrease of mobility awareness score of the seat pan for chair C. This means that subjects with the longest computer work duration have the highest mobility awareness with chair C. An increase of computer work duration is also significantly correlated to overall comfort scores of the backrest and cushion hardness of the backrest of chair C. The subjects with the longest computer work value these comfort items significantly better with chair C.

Subjects with longer telephoning duration value the comfort of chair A on the whole significantly better as an increase of relative telephoning duration is significantly correlated to the comfort scores of chair A. An increase of telephoning is also significantly correlated to the influence in work performance scores of chair A. Subjects with longer telephoning duration value this item more positive.

Table 5 *Correlations between relative task duration of Computer work, Telephoning, Desk work and Conversation and questionnaire scores of the chairs (1 very obvious–4 not at all/1 very good–6 very bad/1 applicable–3 not applicable). Pearson's R is shown for significant correlations and after controlling for the variables gender, age, body length and bodyweight significant partial correlations are shown.*

Questionnaire item	Task	Chair	Mean	R	Significance	Partial	Significance
To what extent is this chair adjustable according to your wishes? (1 very good–6 very bad)	Desk work	E	3.1	−0.641	0.018	−0.698	0.037
How do you assess the comfort of this chair? (1 very good–6 very bad)	Telephoning	A	4.0	−0.602	0.030	–	–
	Desk work	E	3.3	−0.605	0.028	−0.749	0.020
Does this chair assist your physical well-being? (1 applicable–3 not applicable)	Conversation	C	2.5	−0.582	0.037	0.875	0.002
What influence will have this chair on your work performance? (1 very positive–6 very negative)	Conversation	C	3.4	0.748	0.003	0.715	0.030
How much would you like to have this chair as your work chair? (1 strongly willing–6 strongly unwilling)	Telephoning	A	3.1	−0.602	0.029	–	0.030
	Conversation	C	4.8	0.627	0.022	0.717	–
Seat pan							
How do you evaluate the overall comfort of the seat pan? (1 very good–6 very bad)	Conversation	C	3.4	0.594	0.032	–	–
On which level did you perceive the mobility of the seat pan? (1 very obvious–4 not at all)	Comp. work	C	2.6	−0.607	0.028	−06.84	0.042
		D	2.5	0.659	0.020	0.739	0.036
	Telephoning	B	2.1	0.575	0.040	–	–
	Desk work	C	2.6	0.558	0.047	–	–
Backrest							
How do you evaluate the overall comfort of the backrest? (1 very good–6 very bad)	Comp. work	C	4.1	−0.582	0.037	−0.725	0.027
		D	3.4	0.571	0.042	–	–
How do you like the hardness of the backrest cushion? (1 very good–6 very bad)	Comp. work	C	3.8	−0.624	0.023	0.728	0.026
	Desk work	C	3.8	0.589	0.034	–	–

An increase in relative desk job duration has a significant correlation of preferable chair adjustability scores with chair E. The subjects with the longest desk job duration have the most positive experience on chair adjustability with chair E. A significant correlation is also found for comfort of the chair scores. The subjects with the longest desk job value this comfort item significantly better with chair E.

An increase of relative conversation duration is significantly correlated with the physical well-being scores and the work influence scores with chair C. In this case it means that the subjects with the longest conversation duration value these items significantly less applicable and more negative with chair C.

4 Discussion

Five chairs, all fulfilling general ergonomic guidelines, different with respect to dynamic characteristics, were tested in a field setting with various office tasks. Movements and questionnaire data were collected during chair use. The analysis showed differences between tasks in body dynamics and postures. A summary of the results is shown in Table 6.

Table 6 *Summary of results per task, with relative comparison between tasks.*

Task	Influence			
	Physical activity	**Postures**	**Chair positions**	**Comfort**
Computer work	Lowest physical activity in all body parts	- Most upright trunk and head position - Little trunk inclination	- Lowest backrest inclination - Low seat pan inclination	Increase in duration is related to relatively better comfort on mobility awareness and backrest comfort of chair C
Telephoning	'Medium' physical activity	- Highest kyphosis - Second highest head inclination - Little trunk inclination	- Second highest backrest inclination - Low seat pan inclination	Increase in duration is related to relatively better total comfort and work performance support of chair A
Desk work	Second lowest physical activity	- Highest cervical spine flexion and head inclination - High kyphosis	- Lowest backrest inclination - Low seat pan inclination	Increase in duration is related to relatively better total comfort and mobility awareness of chair E
Conversation	- Highest activity of head	- Highest cervical spine extension - Highest trunk inclination	- Highest backrest inclination	Increase in duration is related to relatively worse comfort scores on perception of well-being and work influence of Chair C
	- Highest activity of L5 and legs	- High kyphosis	- Lowest (horizontal) seat pan inclination	

5.4.1 Effects of tasks on postures, movements of body parts and chair movements

Computer work showed the lowest physical activity in all body parts, together with the upright trunk and head position and low backrest inclination. Therefore, computer work is the most static task in this context with a fairly neutral sitting posture. Conversation shows the highest activity of head, legs and L5 together with the highest cervical spine extension. The task seems to allow the subjects more free movements. Deskwork showed the second lowest activity, not so much different from telephoning, and provoked the most cervical spine flexion where the telephoning tasks showed the highest kyphosis. Computer and deskwork showed the lowest backrest inclination where telephoning is higher and conversation showed the highest backrest inclination.

5.4.2 Relation between task and relative duration and comfort preference

Comfort score analysis showed correlations of tasks with chair types. A positive comfort relation is found for computer work and chair C. This means, that subjects with relatively the longest computer work duration rate chair C the highest on mobility awareness and backrest comfort. However, the mean comfort rating is low and in the report of Ellegast et al. (2012) is shown that mean comfort ratings of chair C on many items are low and below the scores of reference chair D. For telephoning, there is positive relation to chair A with regard to total comfort experience and work performance support. Deskwork has a positive relation with chair E with regard to mobility awareness and total comfort. For conversation there was no positive relation found. A negative relation was found with chair C with regard to perception of well-being and work influence. In the report of Ellegast et al. (2012) chair A is rated better in comparison to the reference chair and chair E is comparable to the reference chair. Although the correlations can be meaningful on specific chair items like mobility awareness, comfort of the chair (parts) and work performance support it is also important to assess the total of chair aspects. Preferably, the whole chair exists of parts that support tasks and functionality best.

5.4.3 Posture and dynamics data and comfort preference

The position of head and cervical spine is for all tasks highly determined by the target location of the view of the eyes. Tasks with the computer show an upright trunk and head position. This is in contrast with a target location at the desk which showed cervical spine flexion and head inclination. Conversation showed the highest cervical spine extension and probably took place with a standing person. Telephoning has no direct target location for the eyes' view and shows the most independent posture of the head. Observational studies have shown that office workers usually perform their tasks in upright or forward leaning postures (Dowell et al., 2001). The visual demands of the task and the reach distances can play a role in leaning forward (Lueder, 2004). In this study the results are in line with this, as task restrictions in postures and movements are found especially for computer work and deskwork. But the question in relation to chairs is then: Is there a connection with chair preference? For aspects of Chair C, namely mobility awareness and backrest comfort, a correlation was found with computer work. The static character of the work and the upright posture might be the cause that these aspects were valued higher and are more important for this task. Postures with good back support of the lumbar area contribute to non-appearance of discomfort in the area (Vergara and Page, 2000). The "swing system" of this chair is able to move continuously in all directions. The other chair that is able to move freely in all directions continuously, chair E, has a correlation with desk work for its mobility awareness and total comfort score. Deskwork also restricts the postures, but is less static compared to computer work although still has a low activity level. The specific dynamic characteristics seem to fit and again it is a chair with freely moving seat pan.

Nevertheless, the restricted postures of computer work and deskwork are in general not the most preferred postures. The more reclined postures of conversation seem more preferred; Gscheidle et al. (2004) found that preferred postures are substantially reclined. Reclined postures with substantial engagement between the sitter's torso and the chair backrest account for only about 15 percent of work postures for workers performing a range of office tasks. In this study, reclined postures were specific to conversation. Because the task of conversation is less restricted in posture by input devices, screen and deskwork the subjects are more able to have a preferred posture. This is a possible explanation that there is no positive correlation for the conversation task and a specific chair.

The positive relation to chair A with regard to total comfort experience and work performance support with telephoning is difficult to explain by specific chair characteristics. The positive total comfort is in line with the report of

Ellegast et al. (2012) where chair A is rated better in comparison to the reference chair D.

And finally Carcone and Keir (2007) found that comfort was rated highest in conditions that would not necessarily be considered biomechanically ideal. Therefore, it stays important to value both comfort and biomechanics, as was done in this study.

5.4.4 Low activation

A PAI value of 15–30%g with normal walking in upright position (Ellegast et al., 2008) demonstrates the low PAI values and therefore low activity with sitting and office work. The mean values are below 3%g and the highest peaks (P95) are around 8%g. In the lowest activity task of computer work the activity 50%ile is no higher then 0.9%g and peaks are maximum 4%g. This low activation level is hardly influenced by chair type (Ellegast et al., 2012) so other interventions in workplace design, such as variability of tasks (also other than work station related) and work organizational factors seem more suitable to influence the physical inactivity.

5.4.5 Limitations of the study

Due to too few subjects, functionality is only studied at task level and not at function level, which is a limitation of this study. Most people performing work in the office do not perform one major task, they perform a range of tasks. Parameters like frequency of switching between tasks and the effect of variation and breaks are not studied, but for dynamics over the day it seems important to take this into account as well.

5.5 Conclusion

Considerable effects of tasks on postures and on movements are demonstrated in this field experiment. Computer work is the most static task in this context with a fairly neutral sitting posture. Deskwork showed the second lowest activity, not so much different from telephoning. And deskwork provoked the most cervical spine flexion where the telephoning tasks showed the highest kyphosis. Conversation seems to allow the subjects more free movements with the highest activity of head, legs and low back together with the highest cervical spine extension.

Also indications are found for specific chairs part preferences in relation to specific tasks. Subjects with relatively the longest computer work duration rate chair C the highest on mobility awareness and backrest comfort. For telephoning, there is positive relation to chair A with regard to total comfort experience and work performance support. Deskwork has a positive relation with chair E with regard to mobility awareness and total comfort. For conversation there was no positive relation found. A negative relation was found with chair C with regard to perception of well-being and work influence. Further research is needed to build evidence for the comfort preference of chair characteristics in relation to tasks.

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Appendix A *Questions and scales (laboratory & field).*

	Scale from… to…	Scale 1	2	3	4	5	6
What are your expectations regarding the comfort of this chair?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
What influence might this chair have on your health?	1 very positive–5 very negative	Very positive	Positive	None	Negative	Very negative	–
How much would you like to have this chair?	1 strongly willing–6 strongly unwilling	Strongly willing	Willing	Rather willing	Rather unwilling	Unwilling	Strongly unwilling
Discomfort (evening–morning)	1 none–2 light–3 middle–4 strong	None	Light	Middle	Strong	–	–
How do you assess the comfort of this chair?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How safe do you feel while sitting on this chair?	1 very safe–6 very unsafe	Very safe	Safe	Rather safe	Rather unsafe	Unsafe	Very unsafe
Does this chair assist your physical well-being?	1 applicable–3 not applicable	Applicable	Applicable in parts	Not applicable	–	–	–
What influence will have this chair on your work performance?	1 very positive–5 very negative	Very positive	Positive	None	Negative	Very negative	–
On which level did you perceive the mobility of the seat pan?	1 very obvious–4 not at all	Very obvious	Obvious	Little	Not at all	–	–
How do you like the mobility of the seat pan?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How do you like the overall dynamics and movement of this chair?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How did the chair dynamics influence the exercise of your job?	1 very positive–5 very negative	Very positive	Positive	None	Negative	Very negative	–
To what extent is this chair adjustable according to your wishes?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How do you evaluate the overall comfort of the seat pan?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How do you like the hardness of the seat cushion?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How do you like the uniformity with which the seat pan supports you?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How do you evaluate the overall comfort of the backrest?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How do you like the hardness of the backrest cushion?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad

	Scale from… to…	Scale					
		1	2	3	4	5	6
How do you like the uniformity with which the backrest supports you?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
How do you assess the comfort of the armrests?	1 very good–6 very bad	Very good	Good	Rather good	Rather bad	Bad	Very bad
Did you use the armrests during your working time?	1 always–4 not at all	Always	Most of the time	Just a little	Not at all	–	–
Do you like the look of this chair?	1 yes, very much–6 no, not at all	Yes, very much	Yes	Rather yes	Rather no	No	No, not at all
How long the backrest was flexibly adjusted today? (daily protocol)	1 always–4 not at all	Always	Most of the time	Just a little	Not at all	–	–
Did you adjust the backrest flexible?	1 always–4 not at all	Always	Most of the time	Just a little	Not at all	–	–

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Chapter 6

Activities, postures and comfort perception of train passengers as input for train seat design

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Abstract

Working in the train is a part of new ways of working. However, the ideal working position is unknown. Moreover, the ideal position for leisure and relaxing is also unknown. This article defines what activities train passengers mainly perform and which corresponding postures are seen. Based on the observations on actual train rides, four main activities could be identified: Reading, Staring/sleeping, Talking and Working on laptop. Working on laptop was the activity with the longest duration and talking had the shortest duration. Associated with these four activities, a top eight of different postures were observed. Except for headrest comfort, comfort scores were not significantly different between activities. 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. Nearly for all activities, the majority of passengers preferred adjustability options to fit the seat to the performed activity.

Practitioner Summary

The article is created for insight into activities, postures and comfort of seated train passengers. The results of this study can be used for designing comfortable seating in the transportation industry (train passengers, bus and aircraft seats) and for semi-public spaces to enable optimal support for the user in its activities.

Keywords: train passenger comfort, activities, postures, seat design

6.1 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, Alexander, and Van Hagen (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, Jain, and Holley, 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 are studies regarding postures and activities in 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, Kilincsoy, and Vink (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 our 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:

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;

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.

6.2 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.

6.2.1 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.

6.2.2 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, Kilincsoy, and Vink (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 Branton and Grayson study 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).

6.2.3 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 (10 = high, 1 = low), 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 chair parts (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.

6.2.4 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.

6.2.5 Data analysis

6.2.5.1 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.

<u>6.2.5.2 Duration observation analysis</u>

The following analysis steps were made:

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.

<u>6.5.2.3 Comfort questionnaire analysis</u>

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.

6.3 Results

6.3.1 Observations

6.3.1.1 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 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.

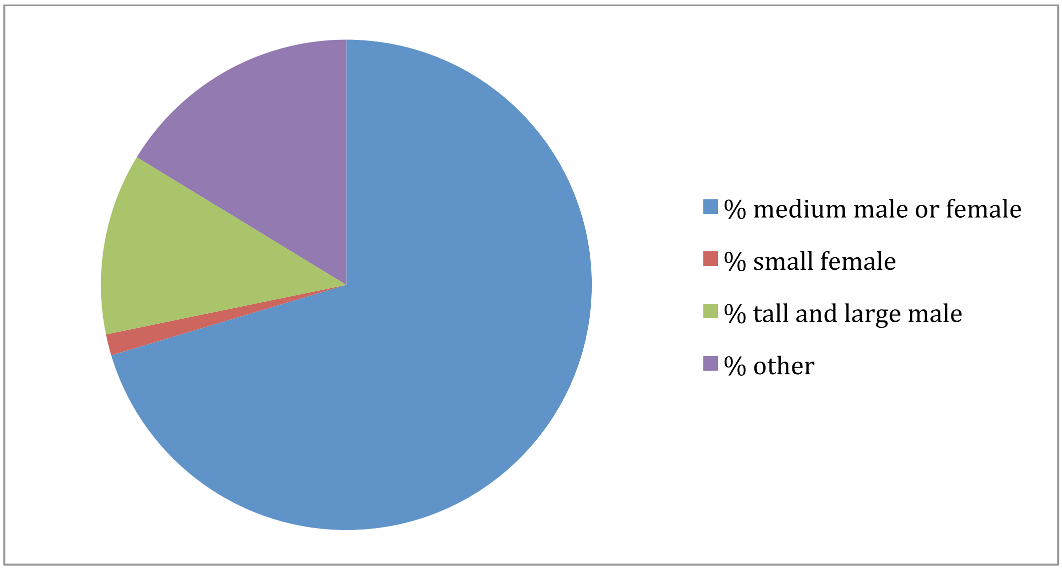


Figure 1 *Distribution of estimated morphology categories (in percentages of total) of the observed population (n = 786). Medium male or female is approximately within the 25th percentiles of length and weight; small female is below the 25th percentiles of length and weight and tall and large male is above 75th percentiles in length and weight. The category other represents the exceptions in the former categories (for example tall in combination with low weight).*

6.3.1.2 Activities momentary observations

Distribution of all momentary observed activities is shown in Figure 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.

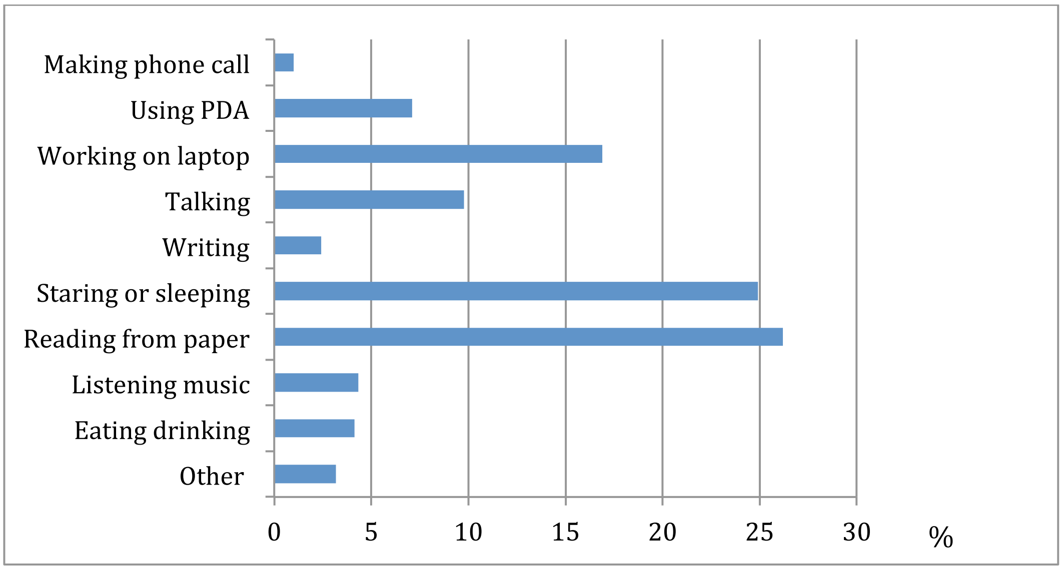


Figure 2 *Distribution of activities (in percentages of total) based on frequencies of 786 short observations.*

6.3.1.3 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.

6.3.1.4 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 3 shows the average duration and the standard deviation for the main activities.

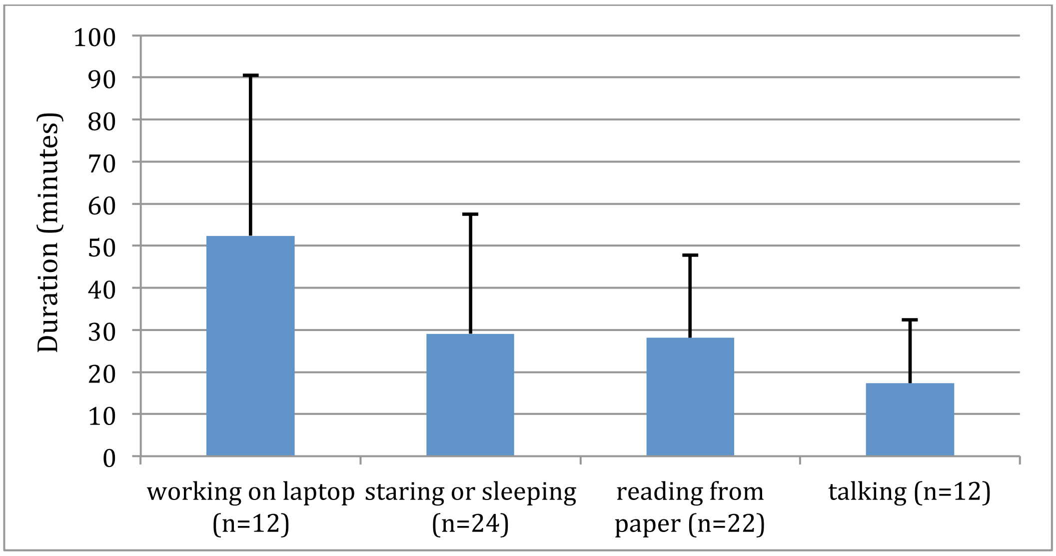


Figure 3 *Average duration (min) and standard deviation of four main activities of observed subjects.*

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.

6.3.2 Perceived comfort and preferred adjustability for main activities

6.3.2.1 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/sleeping, 111 subject were Reading and 25 subjects were Talking.

6.3.2.2 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.

6.3.2.3 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 1.

Table 1 *Percentage of subjects who prefer adjustability options on seat parts for the four main activities.*

	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.

6.3.2.4 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.

6.3.3 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 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 2 *Top eight of observed postures (short description and stick diagram.*

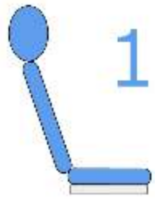
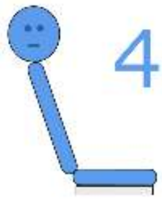
	Body part positions	Stick diagram
1	Head upright Trunk backwards Full seat contact	
2	Head upright Trunk upright Full seat contact	
3	Head forward Trunk upright Full seat contact	
4	Head sideward Trunk backwards Full seat contact	
5	Head forward Trunk backwards Full seat contact	
6	Head sideward Trunk upright Full seat contact	
7	Head sideward Trunk slumped Middle+front seat contact	
8	Head sideward Trunk upright rotated Full seat contact	

Table 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 3 *Main activities, corresponding postures and comfort scores (Question: How do you evaluate your comfort on your seat to practice this activity? Scale 1–10: not comfortable at all–very comfortable).*

Main activities	Postures and comfort notes							
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			

6.4 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.

6.4.1 Activities

The four most observed activities concern both working activities and leisure activities are important to consider for train seat design. A partly comparable study of momentary observed passengers in German trains of Kamp, Kilincsoy, and Vink (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, Kilincsoy, and Vink (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, Jain, and Holley (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.

6.4.2 Postures

For most observed postures, a full comparison cannot be made to the study of Kamp, Kilincsoy, and Vink (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. Also Mörl and Bradl (2013) 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, Chiu, and Poon 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.

6.4.3 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 that 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 be undertaken not to make the trip more pleasant but to achieve satisfaction in other life domains at other times.

6.4.4 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. And 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 touch-screen tablet user configurations, which affect head and neck flexion angles. The study of Franz et al. (2012) showed that the majority of the subjects favoured the headrest with the adjustable neck support.

6.4.5 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.

6.4.6 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, Saran, and Harsha 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.

6.5 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, Jain, and Holley 2007; Gripsrud and Hjorthol's 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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Chapter 7

Using both qualitative and quantitative types of research to design a comfortable television chair

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Abstract

This paper reports on a design and evaluation of a chair in which users can sit comfortably while watching a television screen. The design of this chair is based on requirements that were gathered from three studies with end- users in which their needs and wishes for this chair are explored. These three types of research study show that the chair to be designed should enable users to sit in a large variety of positions and support the body where it requires it. This means that the head, back, arms and legs should be supported in various positions. A full-scale prototype of this chair was built and evaluated with end- users. This evaluation shows that the designed chair enables users to sit in a large variety of positions. A moving arm support and an adjustable feet support contribute to different sitting positions. The designed chair is also rated as comfortable but the position of the head support and the lumbar support need better positioning. The study also shows that the three experiments used to gather end-user information were very valuable to arrive at a better design.

Keywords: chair design; sitting comfort; lounge seat; watching a screen; research for design

7.1 Introduction

This paper presents and evaluates a design for a chair in which users can sit comfortably while watching a television screen. Designing a comfortable television chair is difficult. Despite the frequent use of the term comfort, there is no such thing as a general notion of comfort or discomfort. Slater (1985) defines comfort as a pleasant state of physiological, psychological and physical harmony between a human being and its environment. Richards (1980) stresses that comfort is a state of a person involving a sense of subjective wellbeing, in reaction to an environment or situation. According to Looze et al. (2003)

some issues are generally accepted in the literature:

1. comfort is a construct of a subjectively defined personal nature
2. comfort is affected by factors of various nature (physical, physiological and psychological)
3. comfort is a reaction to the environment.

Several methods can be used to find out the experience, the physiological and psychological effects in reaction to the environment (see Table 1) based on the three experiments: an experiment often described in the literature and two experiments new in the field of comfort research. Tan (2007) described the state-of-the-art regarding seat design and his overview of these two approaches are also missing.

According to Looze et al. (2003) there are many definitions for comfort, but one issue is not really under debate: comfort is a subjective experience. A product in itself can never be comfortable. It becomes comfortable (or not) during its use. Therefore, it is important to involve end-users during the development of this chair.

Having knowledge about the end-user by doing research with real users and studying the context in which the chair is being used will result in a richer, more dependable view on situations in which products are used. Context is defined as those aspects that may influence the experience of a person using a product (Sleeswijk Visser et al., 2005). Therefore, the design for the chair in which the user can sit comfortably while watching a television screen is based on three different studies with end-users (Rosmalen et al., 2009).

Firstly, an observation at users' home is done to discover what position participants use in front of the television and what other activities the participants carry out while watching television.

Table 1 Various experiments used to design or evaluate several designs regarding comfort or discomfort

Table 1 *Various experiments used to design or evaluate several designs regarding comfort or discomfort*

Type of study	*Focus*	*Example of a study*
Interviewing after experiencing alternative designs	Experience	Vink (2005)
Probes to define the optimal comfort experience	Experience	New
Observations on natural postures (assuming that these are comfortable)	Experience	New
Pressure distribution of alternative designs	Physiological	Mergl (2006)
EMG of alternative designs	Physiological	Franz et al. (2008)
Shear force calculation	Physiological	Goossens and Snijders (1995)
Measuring the posture in various designs	Physiological	Park et al. (2000)
Calculating muscle tension in the design	Physiological	Rasmussen et al. (2001)
Measuring spinal shrinkage in various designs	Physiological	Dieën et al. (2001)
Measuring foot swelling in various designs	Physiological	Winkel and Jørgensen (1986)
Rating comfort aspects in the environment	Psychological	Kuijt-Evers et al. (2003)
Locally perceived discomfort in alternatives	Psychological	Hamberg-van Reenen (2008)

Secondly, probes and generative tools are used to discover what people say and think (tacit knowledge), and also what they know, feel and dream about (Sleeswijk Visser et al., 2005) for a chair to watch television in. These techniques are used to find out what aspects and body postures are important to the participants for a comfortable sitting experience and what aspects and body postures could cause discomfort.

Finally, an experiment is done with an existing chair to define comfortable sitting angles of the seat and back rest.

These studies provided first requirements for the design of the chair. The observations showed that people at home often vary their posture and mostly have their feet off the ground. The probes clearly showed again that people like their feet off the ground, but would like to vary and support for crucial body parts is essential in various postures. The experiments gave input for ideal seat pan and backrest angles. Hence, the chair should support a large variety of sitting positions. The seat and backrest angle are fixed (Figure 1). The chair should provide sufficient support for the body where it requires it. The chair should support the head, both arms and the back. Where the backrest is positioned backwards, it should be possible to have the feet off the ground by having a separate feet support still enabling a position for the feet off the floor.

Based on these requirements a concept for a chair in which the user can sit comfortably while watching a screen is developed. A full-scale prototype of this concept is build and evaluated with end-users to ensure a comfortable sitting experience.

The research question of this study is: Does the designed chair, based on three experiments with end-users, enable users to sit in a large variety of positions and is this chair valued as comfortable?

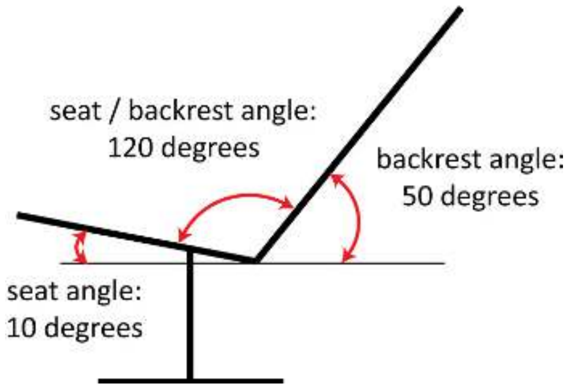

Figure 1 *Suggested seat and back rest angles*

7.2 The design of the chair, the Sslide

Based on the requirements from the user research a concept for a chair in which the user can sit comfortably while watching a television screen is designed. This is the Sslide. The Sslide has six main elements (Figure 2).

Moving arm support: this arm support can slide to create a smaller or wider seat width according to the preference of the user. It has the same height (25 cm from the seat) as the fixed arm support (see number 3 in figure 2) to enable a balanced support for both arms. The distance between the two arm supports can vary from 30 to 70 cm.

Feet support: this is a separate element and can be used in a variation of positions to enable different sitting positions. The user can adjust the position manually.

Fixed arm support: this arm support is fixed to one position and connected to the seat and back rest.

Backrest: this element is fixed in an angle of approximately 50° (Figure 1) and has a fixed lumbar support integrated in the backrest at a height of 18 cm from the seat. The backrest (100-cm wide) is less wide than the seat (115 cm), because at one side the seat is longer to provide room for food, remote controls, drinks or a bag.

Head support: this element is connected to the back support and is adjustable in height. The height ranges from the eye level of the smallest person to the eye level of the tallest person sitting in this chair (from 71 to 89 cm from the seat).

Seat: This element is fixed in an angle of approximately 10° (Figure 1). As it is described, the seat is wider than the backrest. The seat is 45-cm deep and 30 cm from the ground at its lowest point.

Figure 2 *The Sslide, a concept for a comfortable chair to watch a television screen*

7.3 Method of the evaluation of the Sslide

To evaluate the designed chair (the Sslide) a full-scale prototype was built and tested by end-users. This evaluation was performed to discover whether the Sslide enabled different sitting positions, if the moving arm support was understood and used, if the free to position feet support was used, and to find out whether sitting in this chair was valued as comfortable by its end-users.

The experienced comfort and discomfort scores while sitting in the Sslide were compared to the scores of a previous experiment with a reference chair of the Sslide (van Rosmalen, in press). In that experiment three different positions were evaluated to define comfortable sitting angles for the seat and backrest

(Figure 3). The comfort and discomfort experience were measured in each of these positions.

Figure 3 *Three different sitting positions (A, B, C) for the seat and back rest*

<u>7.3.1 Subjects</u>

About 13 students of Delft University of Technology aged between 22 and 26 years old (6 male, 7 female) participated in the evaluation of the Sslide.

<u>7.3.2 Procedure</u>

First an explanation of the chair evaluation was given. Subsequently, the participants were asked to observe the Sslide, with the moving arm support in its smallest position, and mention their first thoughts about the design and possibilities of use. They could touch the Sslide and experiment. Then the participants were asked to adjust the chair to their preference. They watched television in this chair for 36 min. While sitting in the chair the participants could change the position of the moving arm support and feet support. Also different television programmes could be chosen to watch.

The comfort and discomfort experience were measured four times during the experiment by completing a questionnaire; before sitting in the chair, after 12-min sitting, after 24-min sitting in the chair and at the end of the experiment. The television was switched off to concentrate on the questionnaire, and it was turned on again after the completion of the questionnaire. At the end of the sitting session all participants stood up from the chair and were asked to complete a final (fifth) questionnaire. Finally, body measurements were taken.

7.3.3 Materials

A full-scale prototype of the Sslide was used. In contradiction to the design the prototype had a fixed head support (71 cm from the seat) and the moving arm support could only be moved while not sitting on the prototype.

The experiment was performed at the Faculty of Industrial Design Engineering in Delft. A living room was imitated (Figure 4) using dimmed light, the Sslide, a television with a diameter of 90 cm and some sweets and drinks. The 36 min were recorded on video for each participant.

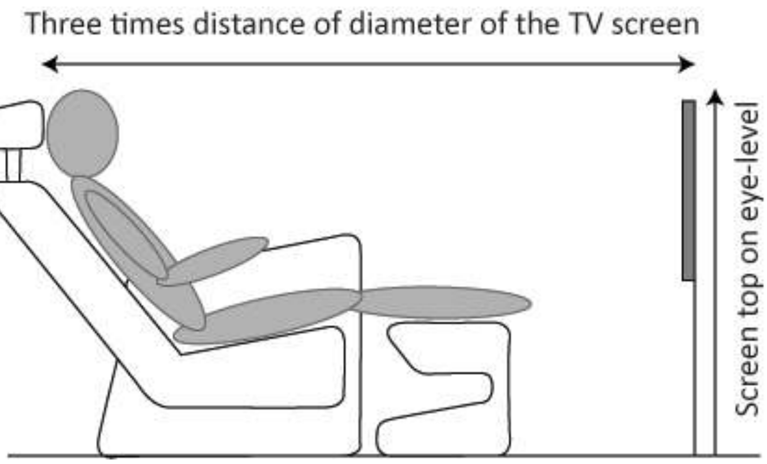

Figure 4 *Schematic representation of the setting of the room*

7.3.4 Measurements

The comfort and discomfort experience of the Sslide were evaluated with a questionnaire making use of the chair evaluation checklist (CEC) and the locally perceived discomfort (LPD) method. The CEC is based on the studies of Helander and Zhang (1997) using a scale from 1 to 7. A high score meant that participants experienced a lot of sitting comfort. The LPD method (Grinten and van der Smitt, 1992) was used to determine the experienced discomfort in different regions of the body; neck, arms, upper back, lower back, upper legs and lower legs. This method uses a Borg Category Ratio Scale from 1 to 10 (Borg, 1990) to define the intensity of discomfort. A high score meant that the participants experienced much discomfort in that region of their body. The participants were asked to put a number in a body map divided into 13 body regions. The method has been used frequently and predicts whether complaints could be found later (Hamberg-van Reenen, 2008). Participants received pictures of the human body with red areas indicating for which part of their body they had to rate the LPD. After sitting in the Sslide the participants were asked to complete a final questionnaire with open-ended questions asking their opinion about the Sslide.

7.3.5 Analysis

The average score of the CEC and LPD of the participants per measuring moment was calculated. For the CEC the total comfort and total discomfort were used (adding all scores of the comfort questions and adding all scores of the discomfort questions). For the LPD a summation of all the regions was used. Additionally, the first LPD score was subtracted from the last indicating the change of the LPD while sitting in the chair. The results of the Sslide were compared to the results from the previous experiment with a reference chair of the Sslide.

A video analysis was done taking screen shots every 4 min. This was done to discover different sitting positions and to evaluate the use of the arm support and feet support. The use of the table has also been observed.

From the results of the final questionnaire a list of recommendations on how to improve the sitting experience of the Sslide was made. Also an overview of the preferred sitting positions of the arm support and feet support has been made.

7.4 Results

7.4.1 Sitting positions

Different sitting positions were observed during the test with the Sslide. Figure 5 shows some examples of the different sitting positions observed in the Sslide.

Figure 5 *Observed sitting positions from the participants while watching television*

7.4.2 The moving arm support

All 13 participants understood the possibilities of the moving arm support and all participants positioned the arm support differently. The preferred position of the arm support is shown in Figure 6. Most participants appreciated the moving arm support.

They mentioned it was 'useful, funny and visually interesting'; however, three participants wondered whether they would keep adjusting the position of the arm support or just have a favourite position after a while. Other participants mentioned that they would adjust the position of the arm support when they changed sitting positions or when other people would use the same chair. Four participants mentioned that they would also change the position of the arm support according to their activity in the chair (watching television, talking to other people, reading, etc.). Three participants mentioned the possibility to sit with two people in the same chair when the arm support is in its widest position, which they would like.

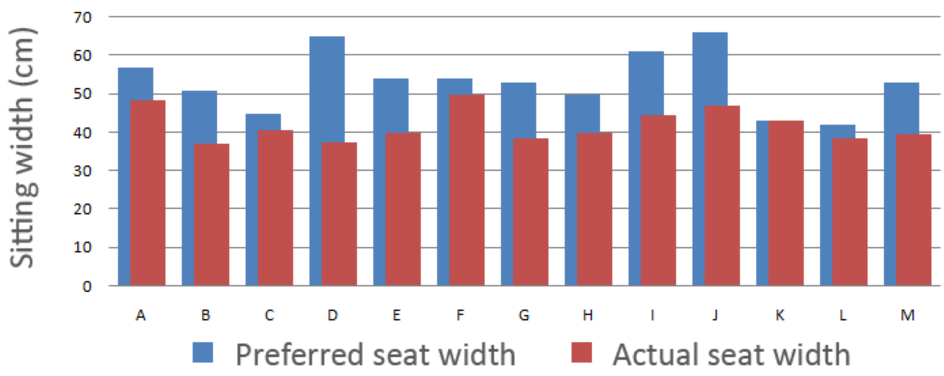

Figure 6 *Difference between actual seat width of the participants and their preferred seat width*

7.4.3 The feet support

Twelve participants used the feet support in a variety of positions. Figure 7 shows the preferred positions of the feet support from the participants. The used position of the feet support differs between and within the participants. While watching television the participants often did not change the position of the feet support but the way they used the support changed. Sometimes they rested both feet on top of the feet support and a few minutes later they had their feet in the support or both feet on the seat. Six participants mentioned that they used the feet support as an extension of the seat and that it was nice to be able to have the feet on top of the feet support and in the feet support. Five participants mentioned the hard edges of the prototype, which they found uncomfortable. Four participants wondered if they would keep adjusting the feet support or if they would find a preferred position and leave the feet support in that position while watching television.

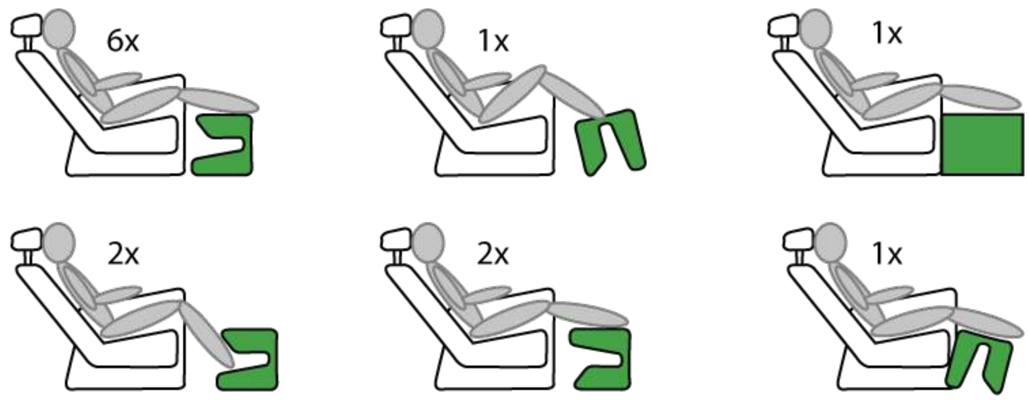

Figure 7 *Preferred positions of the feet support from the participants*

7.4.4 Use of the table

During the test with the prototype the researcher did not pay much attention to the use of the arm support as a location for food and drinks, or to the use of the table. Some statements can be made still. Some of the participants used the arm support as a place to put their drinks, but most often the drinks were placed on the floor. Some participants mentioned that they did not want to place the drinks on the chair because they were afraid of spilling on it. The table was used to place the food or pens and questionnaires.

7.4.5 Opinion about the Sslide

Both positive and negative comments were given about the Sslide. Out of 13 participants six of the participants mentioned that it was nice to have many different sitting positions. Six participants mentioned that the Sslide had a relaxed sitting position; the angle of the backrest was good. Two participants mentioned that the head support was good, whereas eight participants mentioned the opposite by saying that the head support gave less support than expected and the position was too far tilted. Some participants liked a more forward position, whereas others liked a more backward position having the same angle as the backrest (approximately 50°, Figure 1). Five participants preferred a thicker lumbar support in the lower back area and four participants mentioned that the prototype had some hard edges which made the chair less comfortable. Three participants mentioned that the chair was not too soft. Two participants mentioned the need for more support on the side of the back rest of the chair and the head support.

7.4.6 CEC results

The scores of comfort and discomfort of the three positions (Figure 3) of the reference chair of the Sslide (van Rosmalen, 2010) were compared to the scores of comfort and discomfort for the Sslide. The left graph in Figure 8 shows the sum scores of the comfort measurements at the four measuring moments, using the CEC, the right graph in Figure 8 shows the sum scores of the discomfort measurements at the four measuring moments.

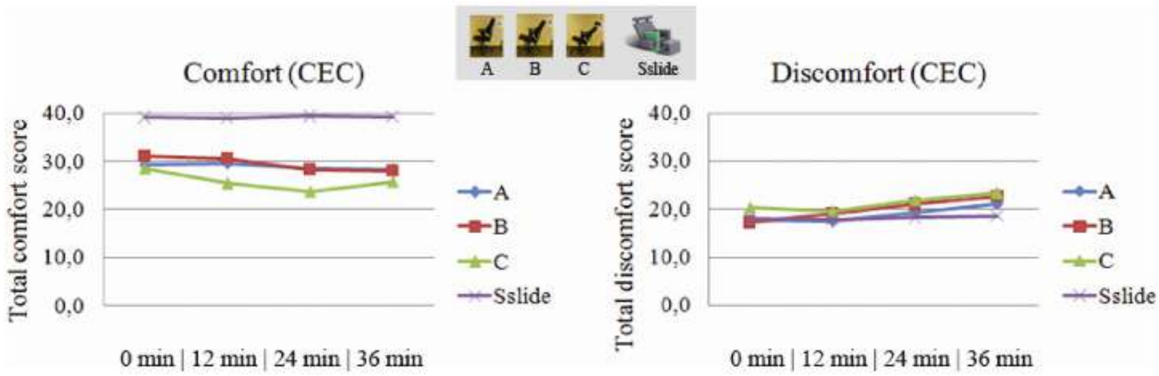

Figure 8 *Results from the CEC from the chair experiment and the prototype of the Sslide*

7.4.7 LPD results

The left graph in Figure 9 shows the sum scores of the LPD for all body regions for the three positions (Figure 3) of the reference chair of the Sslide (van Rosmalen, in press) and for the Sslide at the four measuring moments. The right graph in Figure 9 shows the individual change of the LPD scores per body region for the four positions.

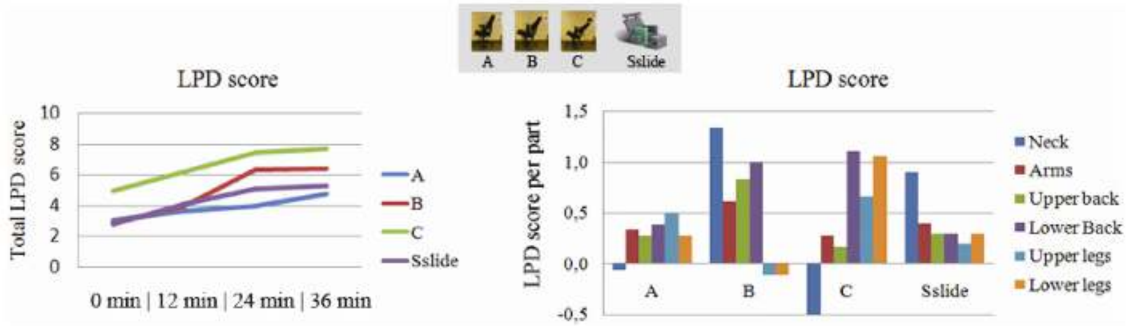

Figure 9 *Results from the LPD from the chair experiment and the prototype of the Sslide*

7.5 Discussion

This paper presents and evaluates a design for a chair (the Sslide) in which users can sit comfortably while watching a television screen. The results of the evaluation of the Sslide are discussed per theme in this discussion starting with the diverse sitting positions.

7.5.1 Diverse sitting positions

The participants frequently changed sitting position during the test, using the moving arm support and adjustable feet support. The participants also mentioned this in the final part of their questionnaire. The chair evokes different sitting positions and also allows different sitting positions as shown in Figures 5 and 7). They show the importance for a chair to provide the possibility of different sitting positions within the same chair, an outcome of two of the three experiments. This corresponds with the ideas of Dieën et al. (2001) that a chair should not enable one ideal sitting position but stimulate variation in posture. Leuder (2004) also mentions the importance of chairs that enable users to dynamically shift between ranges of stable and healthful postures. Konijn et al. (2008) also describe that varying in postures reduces LPD.

7.5.2 Use of the moving arm support

The arms weigh about 10% of the total body weight (Roebuck et al., 1975), when they are not supported well the weight of the arms are carried by the shoulders and spine, which demands muscle tension and is less comfortable for a longer period of time (Laurijsen, 2008; Snijders et al., 1995).

The observations clearly showed the large diversity in positions, which could be solved in the Sslide by a moving arm support. It was found that users changed this, but none of the participants changed the position of the arm support while sitting in the Sslide. This could be caused by the limitations of the prototype, in which the arm support was only movable when the participants were not sitting in the chair. It could also be that users do not prefer to move the arm support once they find an ideal position. The participants did not mention anything about this subject. The participants did mention that they liked the possibility of moving an arm support. More research is needed to discover why the participants did not change the position of the moving arm support while sitting in the Sslide. Research with a prototype in which the arm support is movable while sitting in the chair is recommended.

7.5.3 Use of the feet support

All three experiments pointed towards the need of a feet support, which should be changeable. The participants use the feet support in a variety of positions. The preferred position of the feet support differed among the participants (Figure7). However, none of the participants changed the position of the feet support while watching television. At times they used the feet support and at other times they had both feet on the ground, not using the feet support. Having a fixed feet support would decrease the number of possible sitting positions within the chair. This shows why it is preferable to have a feet support not connected to the chair.

7.5.4 Comfort and discomfort experience

The Sslide is valued as comfortable by the participants. The scores of the CEC are higher for the Sslide than for the reference chair (Figure 8). The experience of discomfort does not differ a lot between the Sslide and the reference chair. However, it is difficult to conclude that the Sslide is experienced as more comfortable compared to the reference chair (Figure 3), because different participants participated in the evaluations of both chairs. These different participants evaluated the chairs on different moments and they could have different perceptions of comfort. To be able to conclude that the design of the Sslide results in a higher score for comfort than the reference chair, another experiment has to be done in which one group of participants evaluate the Sslide and the reference chair.

The LPD scores (Figure 9) showed that participants experienced discomfort in some parts of their bodies. Especially in the neck region and the back regions the participants experienced some discomfort while sitting in the Sslide. The participants mentioned that the position of the current head support was uncomfortable. The participants also differed in their preferred position. The position of the head support should not only be adjustable in height but also be able to move both forward and backward. Some participants mentioned the lack of support on the side of the head support. A head support should support the head in such a way that an equilibrium is generated in which no neck muscle activity is required and the person can relax. That way you have a good head support according to Snijders et al. (1995).

The participants liked the tilted position of the backrest: 'it is a relaxed position to watch a television screen'. But they did have some complaints about the lumbar support.

Although the Sslide had a small lumbar support most participants said the support was insufficient. They prefer a thicker support and it should also be adjustable in height.

It is interesting to see that the input from the three studies used to design the chair was very useful as the aspects that were designed based on these studies are rated positively by many of the end-users. It seems that probes and observations could be helpful in designing comfortable products.

7.6 Conclusion

The aim of this project was to design a chair in which a variety of users could sit comfortably while watching a television screen. The design of this chair was based on the requirements that were gathered from three experiments with end-users in which their needs and wishes were explored. Based on these findings the chair should enable a large variety of sitting positions within the same chair and it should support the body where it is required. Based on these demands the Sslide was developed and tested. A group of 13 end-users evaluated the Sslide. A large variety of sitting positions between and within the participants were found. This evaluation also showed that the moving arm support and adjustable feet support were good solutions for a chair when a variety of people have to sit in a variety of postures. The chair was also rated as comfortable although the position of the head support and the lumbar support need to be improved. It is difficult to conclude whether more comfort is experienced in the Sslide than in the reference chair, because both chairs were not evaluated by the same group of participants. To be able to conclude that the design of the Sslide results in a higher score for comfort than the reference chair, another experiment has to be done in which one group of participants evaluate the Sslide and the reference chair.

Having end-users involved during the development of the Sslide resulted in a design for a chair in which the user can sit comfortably while watching a television screen, as the participants confirmed during the evaluation. This study shows that the input based on end-user research in an early phase of the design was very valuable as the end-users rated especially the aspects based on the previous studies positively. This means that the Sslide complies with the requirements that were generated from previous studies with end-users in which their needs and wishes for this chair were explored. This demonstrates that end-users are of great inspiration and help for the development of chairs.

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Chapter 8

Epilogue

8.1 Epilogue

The studies in this thesis were meant to increase insight in optimal functional seating support for knowledge workers with a diversity of tasks. Therefore, postural behavior and (dis)comfort in current seats were studied in various environments where actual knowledge work and activities were performed. This chapter starts with a discussion of the most relevant results. After that, reflections on the current research and future research are presented. And, finally, practical implications are described.

8.1 Discussion of main results

The objective of this PhD research was to answer the question whether current seat designs optimally support common tasks of knowledge workers in office, mobile and home environments and what the implications are for future chair design. Answers on the different parts of the research question are discussed in the following paragraphs.

<u>8.1.1 Task specific support for common tasks of knowledge workers</u>

The first main result is that the postural and movement behavior of knowledge workers are strongly determined by task characteristics. In several chapters the results showed that different tasks correspond to different postures and movements. In both chapters 4 and 5, many significant differences are found between the tasks in body part positions, chair part positions and the intensity of physical activity of office workers. In the train seat study of chapter 6 also activity corresponding postures could be determined by observations of seated postures. These findings are confirmed by the research of Ellegast et al. (2012) and Kamp et al. (2011) who also reported differences in postures with performing different tasks. The current thesis additionally defines the characteristic postures of specific tasks and activities in chapters 4, 5, 6 and 7. Specific task demands play and important role in the adopted posture. Lueder (2004) reported that the visual demands of the task and the reach distances play a role in leaning forward with trunk and or head. These postures are also reported in chapters 2, 4 and 5 with more computer and or desk bounded tasks. That tasks also strongly influence movement behavior is also reported by Opsvik (2009) who postulates that keyboard, mouse and screen demand active hand/fingers, eyes and brain makes that sitting has become even more static than just the static modus by the sitting itself. In chapter 4 and 5, the computer and more specific the mouse task are found to be the most static tasks. On the other hand, tasks like conversation and as telephoning show more variation in posture and movements. Not connected to input devices, screen and desk these tasks have more freedom of movement and allow more preferred postures. This confirms that the postural and movement behavior of knowledge workers are strongly determined by task characteristics.

With the variety in tasks and the corresponding postures and movements in mind, the big challenge is to support these tasks by an optimal facilitating design of seats. Ideally, the seat design facilitates the variety of postures and movements of corresponding to the variety performed tasks of knowledge workers. In the chapters 2, 5 and 7, indications are found for chair elements that provide a comfortable support in relation to specific tasks. The redesigned office chair in chapter 2 could enable more optimal support for non-computer work tasks, like reading, by a larger backrest inclination. And, in chapter 5, indications are found for specific dynamic chair preferences in relation to the duration of specific tasks, like computer work, telephoning, and deskwork. In chapter 7, the design of the chair was focused on optimal support of one activity with a variety corresponding postures and movements. The evaluation of the designed prototype showed that the prototype chair was rated comfortable in relation to the activity of watching a screen. Also, the adjustable sideways moving arm support and multi applicable feet support were good solutions for both a variety of people and the possibility to sit in a variety of postures with this task. In the context of knowledge work, this activity 'watching a screen' might seem an uncommon activity, but for the future of knowledge work it might be applicable as computer screens are becoming larger and are more intensively used. With new technologies it is no longer needed to use mouse or keyboard as input devices. Kinect input or eye operated computers are already available and might be used in knowledge work context in the future. The adopted postures and the connected design features could be of value for future design of work chairs. Overall, the results of these studies support that chair design matters for optimal task support in the comfort perception of the workers. But, there are also still improvements to be made to support knowledge tasks more optimally. In most chapters there are comfort or posture issues to improve to make the design more applicable to the different tasks.

In chapter 6 and 7, it is shown that with performing just one task different postures occur, and in chapter 6 is also shown that different comfort scores are seen with different postures within one task. It seems that there are more optimal and less optimal posture task combinations. The chair design challenge is to influence the users' posture to improve body part postures that are not optimal. For both reading and watching a screen (chapter 2 and 7) it has been shown that a more reclined backrest is preferable. More specified preferred angles are defined in this thesis in relation to reading and watching a screen, respectively 124 and 130 degrees. There is support in the literature as well for this more reclined position. Gescheidle et al. (2004) described earlier a broader variation range between 20 to 40 degrees backwards (with respect to vertical) for office work. Vos et al. (2006) found that an increased trunk-thigh angle reduces interface pressure. This can be an explanation for experiencing more comfort in these studies. Veen et al. (2013) reported promising results with the design of armrests for holding handheld devices that enabled less neck flexion and a more neutral and comfortable head posture. In conclusion, the design of seats can contribute to the support of postures and comfort perceptions according to performed tasks.

8.1.2 Instruction is important

Besides the design itself, instructions can contribute to improved adjustment behavior leading to improved support. In chapter 3, the adjustment quality was significantly improved according to ergonomic guidelines and anthropometry measures. The importance of this is reported by at least two studies; Amick, et al. (2003) reported that a highly adjustable chair in combination with office ergonomics training had reduced symptom growth over the day. Robertson et al. (2013) state that next to prevention ergonomics training also enhances performance. When the design does not tempt to adopt optimal posture training can contribute to the prevention of muscular skeletal problems and to the performance.

8.1.3 Implications for design of adjustability and chair parts

There are many design challenges left to enable optimal support for current and future tasks and activities. The implications for future chair design that are extracted from this thesis concern improvements of adjustability and specific parts of the chair. Firstly, the adjustability of the current chair designs is discussed.

As knowledge work includes a variety of tasks, the seat design challenge is to facilitate the variety of tasks with their corresponding postures and movements. For optimal task specific support adjustability of the seat is wished. The possibility of making adjustments to different chair parts is also strongly preferred by users in chapter 6 in the context of using train seats. Nearly for all activities, the majority of passengers preferred more adjustability options to fit the seat better to the performed activity. This thesis also reports that people are not tending to adjust their office chair frequently and that only a few of the adjustability options are used. From chapter 3, we know that the majority adjusted their chair only once during a three weeks test time, and that mainly three out of the eight offered adjustability options were used. Vink et al. (2007), found similar results in limited use of adjustability options for reasons like users' unawareness, complexity of the control system and presumed effects. It was reported in both chapters 2 and 3 that more intuitive located and indicated design of the controls reduced the adjustment time. Also, a high ease of adjustment was experienced to be more comfortable. These seem both logical effects, but clear design is not easy to achieve. Understanding the users needs, and the way they use the controls is of great importance. Participation of end users in designing and evaluating design concepts is therefore needed, for establishing optimal control mechanisms. In chapter 7, the prototype seat was designed with much participation of end users, and this lead to two obvious and easy adjustment options. The adjustable sideways moving arm support and multi applicable feet support were good solutions, and can also accommodate both the varieties in user dimensions and posture varieties. In chapter 3, it was also reported that different types of workers used the chair in different ways and have different comfort experiences. In this case, the flex workers adjusted their chair more often and gave lower comfort scores compared to the one-workstation workers. So, when designing future adjustable chairs, it is important to take into account the usage and perception of the designed seat and the actual adjustment behavior.

Secondly, improvement of specific chair parts needs attention, as the evaluated current chairs seem not optimally designed for common knowledge work tasks. Although, there are chair parts in chapter 2, 5 and 7 that have a proper fit with the performed tasks, there is still room for improvement. The headrest and lumbar support are the most striking chair parts to be improved for comfort. Chapter 6 shows a difference in comfort perception between tasks of the headrest design. For reading the comfort score was lowest, compared to the other tasks. So, for this task the headrest was the least suitable. Also, for laptop work the subjects preferred an adjustable headrest for a better fit. In addition, in chapter 7, the participants mentioned that the position of the current head support of the prototype chair was uncomfortable. Adjustable headrests that make a comfortable fit with task and user diversity are a big design challenge. Franz et al. (2012), reported of an advanced headrest design for car passengers that was evaluated as comfortable by the users, but it needed a complex automatic mechanism to adapt it to the user. In Chapter 7, also a less comfortable lumbar support was dicussed. Of this small lumbar support, most participants said the support was insufficient. They prefer a thicker support and it should also be adjustable in height. Considering the variations found over the different work tasks and user diversity, the design challenge is to make a fit for different anthropometry in combination with task diversity and different worker types. Chair design for knowledge work therefore cannot go without adjustability ranges, to cover for the broad variety in functional design requirements. As a consequence, it is inevitable that the dimensioning and usability of the adjustable design features should be strictly taken into consideration.

8.2 Reflections on research

There are many aspects that can affect the comfort, health and functionality of seated knowledge workers. These are not all addressed in this thesis. A selection was made, by focusing on common and current tasks, current chair designs, and studying comfort and health issues while seated. The consequences of these choices are discussed in this chapter.

8.2.1 Focus on common and current tasks

The first research focus of this thesis was studying effects of common and current knowledge tasks. Consequently, less common tasks appearing in the context of knowledge work are excluded, like for example security tasks in a control room. Less common tasks could also affect workers in their comfort, health and performance, and are therefore not of less importance. The focus on current tasks is also limited, as tasks will differ over periods as a consequence of development in work and technology. The here presented tasks will not be the most common tasks anymore at some point in our future. Tablet use, for example, is not part of the research performed, but with the upcoming use of these devices it getting more and more a common task. Recently, Young et al. (2012) have reported that the tilt angle of tablets influences the users' head and neck posture and could therefore provoke risk for work related musculoskeletal disorders (WMSD's).

8.2.2 Focus on current chair design

The second focus of this research has been on evaluation of current chair design. Within current chair design, some examples of current office chairs, current train seat and a prototype chair for watching a screen were studied. This means that the results of this research are not covering for all of the current seat designs. As comfort perception exists in the interaction between the human and the product in within a context (De Looze et al, 2003; Vink and Hallbeck, 2012), this perception is really specific for a product, in this case the chair. Therefore, next to comfort measures more objective measures were taken too. Postures and movement registrations were connected to the tasks, rather than to specify the current chair designs. And, design aspects like angles and dimensioning of chairs could be more generalized as design inputs as well.

8.2.3 Focus on comfort and health issues while seated

The focus has also been on risk prevention, in relation to sitting from a biomechanical and functional comfort point of view. Broader health issues related to more sedentary behavior of Western societies was not the focus of this thesis, but have become more topical over the last years. Ryan et al. (2011), report both long duration sitting and uninterrupted sitting in office work, often longer than current recommendations advice (Atlas and Deyo 2001, Chartered Society of Physiotherapy 2005, Owen et al. 2009). The study of Netten et al. (2013) confirms this. Several studies show the importance of alternating seated postures (e.g. Lueder, 2004: Nordin, 2004). The dynamic chair systems of chapters 4 and 5 enable posture variety and therefore less static behaviour. The tested dynamic chairs do not influence significantly distinguishable movement behaviour by itself, as was found in the connected study of Ellegast et al. (2012). The chairs enable the posture and movement varieties following the performed tasks. The users experience comfort according to the dynamic system, and indications are found in chapter 5 for preferred dynamic systems in relation to specific tasks. Lengsfeld et al. (2000) also states that a dynamic concept is preferable from the lumbar spine kinematics point of view. But as sitting by itself is a health risk (Hendriksen et al., 2013), dynamic chairs are not covering for prevention of sedentary behavior, as total sitting duration should be reduced a well.

8.3 Future research directions

From this thesis general research suggestions on the design of chairs are extracted next to more focused research directions. General future research suggestions are on usability to enable healthy behavior, and optimal functionality. Design that evokes this, by seducing the user in optimal postures or even 'smart' design that automatically facilitate the optimal support of unaware and more task-oriented user, could be of great value. Research on 'smart' design concepts with participation and evaluation of users could provide an evidenced basis for this. More specified future research directions are suggested in the following three paragraphs.

8.3.1 New tasks, new seat concepts in varied environments

As work tasks keep changing due to development of new technologies and new organization of knowledge work, different corresponding postures, movements, and task related comfort perceptions would occur in the future. Therefore, research on future common tasks remains important as input for design. Different tasks using modern devices like tablets, smart phones, or other input forms like eye operating/ scrolling or kinect input techniques, will give new design challenges for optimal seating support. In addition, new seat concepts could be evaluated in the context of different tasks and with different devices. Especially new seat concepts that focus on reduction of WMSD's, like neck or shoulder complaints from biomechanical, physiological and comfort points of view are important, to reduce the risk for knowledge workers. With the number of mobile workers still increasing, seats in mobile environments like airplanes, cars, buses and in lounge/ waiting areas, are of special interest. Amongst others Kamp et al. (2012) and Franz et al. (2013) did perform research on this topic, but there are still questions remained for different types of transport with different tasks performed.

8.3.2 New societal and design trends

New societal and design trends call also for new research questions. Due to the globalization user populations could be more diverse regarding, amongst others, diverse anthropometry and cultural diversity. This will affect dimensions, adjustability, usability and comfort perceptions of seats. On the other hand, there is the trend of more customization and specialized products that interact with a small and specified user group, or even one single user. With new technologies, for example 3D scanning and 3D printing, manufacturing of customized products is made possible. One important research question in this context is, which critical inputs of users or user groups are needed to come to an optimal customized, or otherwise global, design.

8.3.3 Prevention of sedentary behaviour

Designs that enable optimal seating support is important for the functionality and prevention musculoskeletal health risk, but interventions on long-term sitting are important for vitality and prevention of other health risks like diabetes for example. Interventions could focus on awareness and changing the user behavior, to interrupt sitting more often and to shorten the total sitting duration. A promising start is made by the study of Goossens et al. (2012) who reported that both instruction and feedback have an effect on behavior of office workers. Also Epstein et al. (2012), had promising results with real time feedback on sitting behavior with good ergonomic equipment and education on how to use it. The determination of both postures and tasks can be helpful too. The study of Huang et al. (2012) showed examples of posture and task determining seat technologies. Next to sitting devices that promote frequently taking a sitting break, there are also workstations that enable standing or exercising during knowledge work. Use of sit-stand desks was associated with less time seating, while ergonomics awareness did not enhance the effect (Straker et al., 2013). Commissaris et al. (2014) described the effect of a standing and three dynamic workstations on task performance, showing that there are other ways of performing knowledge work than just static sitting. Groenesteijn (2013), reported positive results on both physical and mental health perception without loss of work performance by use of an exercise workstation called Oxidesk. First steps are hereby made in this field of stimulating physical activity during work, but there are still many future research challenges left.

8.4 Implications for practice

The final goal of this thesis was to create input for functional seat design to optimally support knowledge workers. The research of this thesis was focused on the essentials of optimal seating support in biomechanical and functional way, with different types of tasks performed. The acquired insights can supplement the current ergonomic guidelines for knowledge work chairs and can be an aid for the design of chairs for current and future tasks in offices, public transport and home settings. The relevance for industry and designers of this design input is that there could be focused essential design features that enable comfort and functionality, based on research evidence.

The implications for practice are described in two parts. First, the input needed for designing or evaluating seats to obtain the right requirements, and secondly the design specifications that resulted from this thesis.

8.4.1 Process input for designing and evaluating

Based on the most striking results of this thesis, inputs for designing and evaluating seats are formulated. One of the results of this thesis is that the performed task (or activity) is leading in posture and movement behaviour. Consequently, in the process of seat designing the designer should focus on task characteristics in terms of postures and movements, to facilitate optimal support. Another result is that different worker types make use of the chair in different manners and have different comfort experiences. Therefore, user characteristics of the worker type like habits and knowledge of good postures, movements and seat adjustment should be a designing input too. Also user characteristics in terms of physical dimensions are important input, as learned from other studies. Considering the variations found, the design challenge is to make a design fit for tasks with the corresponding diversity in postures and movements for worker types with divergent anthropometry, skills, habits and preferences. Furthermore, the environment should be part of the considerations too. To achieve or evaluate a seat design that covers for all the mentioned variations, the following points can be an aid:

- Consider the tasks performed by the target users and define the tasks characteristics of the target users. This could be required by interview or questionnaires, and additionally more securely by observations.
- Define the corresponding postures. Data of corresponding postures and movements of common knowledge worker tasks, studied in this thesis, is described in chapters 4 and 5. For other, not described tasks, configured observations or posture registration techniques can

contribute to insight in type, frequency and duration of postures and movements.

- Define the target users' dimensions. This can be required by use of databases or by specific anthropometric measures when adequate data is not available.
- Consider the worker type, habits and (adjustability) skills by questionnaires, interviews and observation of skills.
- Define the workplace or environments in terms purpose, users and facilities.
- Obtain comfort requirements of the contemplated user group. This could be required by qualitative methods, like for example the probes techniques used in chapter 7 of this thesis. In case of evaluations of current seats also more quantitative measures could be used.

The above points are completely focused on the design inputs from the functional perspective of seating. Other design issues like the affective and technical inputs are not of less importance, but were not the focus of this research thesis.

8.4.2 Design specifications from this thesis

Different design specifications could be extracted from the results. For many tasks and activities the majority of workers preferred adjustability options, to fit the seat to the performed task/activity. The adjustability is preferred, at least for seat height, backrest angle, armrest height, headrest height, and lumbar support height, according to dimensions of users and tasks characteristics. Secondly, the adjustability should be really easy to adjust, and automatic or 'smart' design could guide the unaware and task-oriented user.

Some specific dimensions in relation to tasks are reported and could be used in defined cases. When there are specific cases with reading or watching a screen, consider the backrest angle to be more reclined. For reading, a more open angle up to 124 degrees is preferable. For watching a screen without the use of input devices like keyboard and mouse, an angle of 130 degrees with respect to the horizontal is preferred, but with a seat angle of 10 degrees to reduce shear forces. Based on the results of chapters 4 and 5, postures and movements are defined for computer work, typing, mouse use, deskwork, correction work, sorting files, telephoning and conversation. These data can be used as design input. Depending on the aim whether to make a specific seat design that facilitates one or a few comparable tasks or a chair that accommodates all knowledge workers tasks, the data can be translated in dimension ranges. The prototype of chapter 6 is an example with adjustment options that can accommodate variety in user and postures for a specific task.

For the practise of seat design, there is still a challenge in designing comfortable headrests and lumbar supports, as these seat parts were perceived as less comfortable in relation the performed tasks. Furthermore, the usability and comfort of controls for chair adjustments influences the comfort perception and the use of the seat, and are therefore important design issues.

8.5 Final comment

In this PhD thesis experiments are performed to increase insight in optimal seating support to design better seats for knowledge workers. All experiments were performed with subjects performing various tasks and using various seats. It showed that the task strongly influences the users' posture and movements. For example, the posture while reading and watching a screen needs a more reclined backrest and telephoning and conversating generates much movement variation asking for a more dynamic seat and backrest. Support of various tasks is required as knowledge work includes a variety of tasks. A multi adjustable seat design is then preferred to facilitate the large variety of task corresponding postures and movements. It also showed that the design of the controls has a large effect. The time to adjust a seat with more intuitive controls was significantly reduced. Additionally, the experiments show that instruction is needed as it influences the way the seat is adjusted and improves the seating posture. Variation in user habits and knowledge on good postures and adjustment options is important to address in the design or seat selection process. Finally, the headrest is the chair part that is a large design challenge for more comfortable design supporting different positions with different tasks. For future research and design smart systems that can detect and adjust to the task corresponding posture and movements are promising. These smart systems could automatically facilitate the optimal support of the knowledge worker in their tasks.

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Summary

Summary

How are you seated? Assumed that you sit while reading this summary, think of how you are seated. Where are you sitting? What kind of seat are you using? Which seat parts do you actually use? How is your body posture? Do you move frequently or are you mainly sitting still? Does the seat provide you comfortable support or do you perceive discomfort? Are you slipping off the seat or are you steady? Does the seat fit with your body dimensions? Is the seat adjustable? Is there a risk, concerning the fact you will sit for a while during this task, for neck/shoulder/back pain? Does the seat provide support in such a way that your task 'reading from paper or screen' is optimally facilitated? All these questions about interactions of the user with the seat, with the task performed and in a given environment; that is where this thesis is about. The final goal of this research project was to create input for functional seat design to optimally support knowledge workers in their common work tasks.

Due to the global growth of employees working in the service sector more work is done seated, and predominantly performed in offices. With the development of information and communication technology New Ways of Working are also upcoming trends, and these workers are no longer bounded to traditional offices and traditional 'nine to five' workdays. Many of these workers are seated for many hours during the day, with restricted options in working postures and with low physical effort. This way of working can induce discomfort and health complaints, mainly in the neck and shoulder regions, with reduced work performance as a possible consequence. Therefore, optimal seating support is important to facilitate this large group of workers in such a way that their work performance is enhanced by minimal discomfort and risks on Work related Muscular Skeletal Disorders (WMSD) risks, and maximal comfort. The currently performed work tasks and current work environments play an in important role in how the seat is used, but they are not yet addressed in relevant research, and current standards and guidelines. There is a lack of knowledge on the most common work tasks and their effects on working postures, and what the consequences are for optimal seat design in varying environments. The research objective is to gain more knowledge on chair design in relation to actual knowledge work and activities, (dis)comfort and postural behaviour, to provide insight in optimal functional seating support. The project contains research after the most common work tasks performed by knowledge

workers in different settings like offices, trains and a home setting with actual or prototype seats. The results can be an aid for the design and evaluation of chairs for current and future tasks in offices, public transport and home settings.

Whether a redesigned office chair can enable more optimal support for specific office work tasks, was subject of research in **chapter 2**. Design differences in controls, seat pan cushioning, and backrest inclination of the original chair and the redesigned chair were evaluated in relation to two types of knowledge work tasks, i.e. computer task and non-computer tasks. The redesigned chair was preferred by 70% of the subjects in relation to the tasks they performed. They experienced higher comfort, with non-computer tasks like reading and calling, when using a chair with a larger range of motion that could reach 124 degrees-backrest inclination. Additionally, the redesigned chair was experienced to have a higher ease of adjustment and more comfortable. Also, significantly less time was required with this chair to adjust the armrest height and to switch into the dynamic mode, because of more intuitive design. These results gave the indication that chair design matters for optimal comfortable task support.

The behaviour of different worker types in interaction with chair designs is investigated in the following **chapter 3**. Two worker types, namely flexible workspace users and one work station users, were observed and questioned on their adjustment behaviour in their natural office environment and with their actual tasks. Flexible workspace users adjusted their chair significantly more often, also with short use of the chair, and were faster with some adjustments compared to the one-station workers. Flexible workspace workers seem also more critical and value operation of some the controls lower in comfort than the fixed workers. The frequency of adjusting the chairs was low. Only a few participants adjusted the chair more than once a week. Better-indicated and intuitively located design of the controls reduced the adjustment time. Instruction improved the adjustment quality for all subjects and with both the experimental chairs.

Effects of tasks on more objectively registered measures, like postures, muscle activity and movement variation, were studied in a laboratory setting first. The outcomes of **chapter 4** show considerable effects of the performed tasks on postures and movements. In comparison, many differences are reported between correction work, typing, mouse use, sorting files and telephoning. The performed tasks had very different characteristics in movement intensity, muscle activity, body postures and chair positions. For chair design, this evokes that all these task-connected characteristics ideally should be supported by the chair to optimally enable the knowledge worker the in variety of work tasks.

In **chapter 5,** the study on objectively measured task characteristics was continued in a field setting where office workers performed their actual work tasks. Besides the objective measures, perceived comfort was questioned. The comfort analysis was aimed on a possible connection of tasks (duration) with specific chair features. The considerable effects of performed tasks on both postures and movements outcomes were confirmed in this study; the categorized tasks as computer work, deskwork, telephoning and conversation had different characteristics in postures and movements. Indications were reported for specific comfort preferences in relation to the different tasks related to the mainly distinguishing dynamic characteristics of the chairs. Further research should demonstrate how task characteristics and connected comfort preferences are related to specific chair features.

Tasks and activities performed in a mobile environment during train travels were investigated in **chapter 6**. Both work and leisure of nearly 800 passengers were recorded using current train seats with corresponding postures and comfort perception. The mainly observed activities of these passengers were reading, staring/sleeping, talking/conversation and working on a laptop. Working on a laptop had the longest average duration compared to the other activities. Corresponding to these four activities, a top eight of observed postures could be extracted. Per activity, different postures were observed. But also, some similar postures were observed corresponding to different tasks. Except for the headrest comfort, the comfort perception was not significantly different between activities. In the top eight posture-connected comfort scores there is an indication that comfort scores varied with the combination of posture and activity. Another result was that for nearly all the performed activities the majority of passengers preferred more adjustability option to fit the seat better to the performed activity. The results of this study can be used for designing comfortable seating in the transportation industry (train passengers, bus and aircraft seats) and for semi-public spaces to enable optimal support for the user in its activities.

Chair design for one specific task or activity with the aim to optimally support this, was focus of the study reported in **chapter 7**. The development of a comfortable television chair that could support the variety of observed postures and the variety in anthropometry was explained. Evaluation of the designed prototype chair showed that the adjustable designed chair parts, like the sideways moving arm support and multi adjustable feet support, could accommodate the observed varieties. The chair was also perceived as comfortable in relation to the activity of watching a screen. Still, there were some design features that could be improved according to the activity, like the position of the head support and the lumbar support shape and position. This shows the relevance of doing research on usability and comfort in different stages of the design process. The results on adopted postures with this activity and the connected chair features could also be of input used for future work situations, without input devices as mouse and keyboard. New technologies like Kinect and eye operated computers make no longer use of such devices and users can move more freely and varied, like the subjects of the current study.

The last chapter of the book is a reflection on the performed research and on optimal design for knowledge work. In **chapter 8**, an interpretation is made of the research findings in the context of the question whether current seat designs optimally support common tasks of knowledge workers. Two main subjects are discussed. The first one is: 'Task specific support for common tasks of knowledge workers'. From the studies was learned that postural and movement behaviour are strongly determined by task characteristics. Furthermore, the design of seats can contribute to more optimal support of postures and comfort perceptions according to performed tasks. Some specific design features are extracted from the studies in this thesis, to enable comfortable and more neutral postures.

The second main subject discussed is: 'Implications for design of adjustability and chair parts'. Adjustability of chair parts and the usability in this context was a topic in several chapters. The overall conclusion was that the usability of the design and the actual adjustment behaviour, evaluated with different worker types of the contemplated user population, is very important for comfort and the quality of adjustments. Improvements of specific chair part needs attention, as the evaluated current chair design seem not optimally supported for the common knowledge work task in this thesis. What is learned from the evaluation of the current chair design is that improvements could be made for a better match with tasks for adjustability, usability, and the design of chair parts specifically headrest and lumbar support.

From this thesis four future research directions are classified. The first one, more general about designs, is about the usability to enable healthy behaviour and optimal functionality. Secondly, the ongoing developments in knowledge work tasks, work organization and new seat concepts will lead to different corresponding postures, movements, and task related comfort perception compared to current. Therefore, research on future common tasks remains important as input for design. Thirdly, new societal and design trends call also for new research. Global design for very diverse users versus customized design for a specific group or individual calls for critical design inputs to create an optimal fit with the contemplated user (group). At last, sedentary behaviour and the prevention of long-term and frequent sitting for prevention of health risks calls for new research. The challenge here is to create awareness and to change the user behaviour.

Implications for practise as final part of the epilogue are described in two parts: 'Process input for designing and evaluating' and 'Design specifications of this thesis' The designing and evaluating process input is formulated to obtain the right requirements for an optimal design from the functional perspective. Several points are made to consider and define user-, tasks-, and environmental characteristics and the interactions when designing or evaluating seat design. Variation in user habits and knowledge on good postures and adjustment options is important to address in the design or seat selection process. Also, methods to obtain data are suggested.

Design specifications that are extracted from this thesis are about adjustability, usability, and specific dimensions. For example, the posture while reading and watching a screen needs a more reclined backrest and telephoning and conversating generates much movement variation asking for a more dynamic seat and backrest. Support of various tasks is required as knowledge work includes a variety of tasks. A multi adjustable seat design is then preferred to facilitate the large variety of task corresponding postures and movements. More intuitive design of the controls has a large effect. Additionally, the experiments show that instruction is needed as it influences the way the seat is adjusted and improves the seating posture. Finally, the headrest is the chair part that is a large design challenge for more comfortable design supporting different positions with different tasks. For future research and design smart systems that can detect and adjust to the task corresponding posture and movements are promising. These smart systems could automatically facilitate the optimal support of the knowledge worker in their tasks.

Samenvatting

Stoelontwerp in het kader van kenniswerk

Samenvatting

Hoe zit u? Ervan uitgaande dat u zit terwijl u dit leest, sta (zit) dan eens stil bij hoe u eigenlijk zit. Waar zit u? Wat voor stoel heeft u? Welke stoelonderdelen benut u daadwerkelijk? In welke houding zit u? Beweegt u regelmatig of zit u juist veel stil? Ervaart u een comfortabele ondersteuning of juist discomfort? Zit u stabiel of glijdt u langzaam onderuit? Past de stoel u qua lichaamsafmetingen? Is de stoel instelbaar? Is er, gezien het feit dat u waarschijnlijk nog wel langer zit, een mogelijk risico op dat er pijnklachten in nek, schouders of rug gaan ontstaan? Biedt de stoel u een optimale ondersteuning voor de leestaak die u nu uitvoert? Al deze vragen, die gaan over de interactie tussen de gebruiker en de stoel, met de daarbij uitgevoerde taak in een specifieke omgeving; daar gaat dit proefschrift over. Het doel van dit onderzoeksproject was om input te creëren voor functioneel stoelontwerp om kenniswerkers optimaal te kunnen ondersteunen in hun werkzaamheden.

Door de wereldwijde toename van werknemers in de dienstverlenende sector wordt steeds meer werk zittend verricht, vooralsnog voornamelijk in kantoren. Samen met de ontwikkelingen in informatie en communicatie technologie èn opkomende trends als Het Nieuwe Werken, zijn deze werknemers niet meer uitsluitend gebonden aan het traditionele kantoor en werkdagen van 9 tot 5. Veel van deze werknemers zitten echter veel uren per dag in een beperkt aantal werkhoudingen en met weinig fysieke inspanning. Deze manier van werken kan discomfort en klachten veroorzaken, met name in de nek- en schouderregio. Als mogelijke consequentie geeft dit een afname van de werkprestatie. Daarom is het van belang om deze grote groep werkenden te faciliteren met een optimale zitondersteuning, die het discomfort en het risico op werk gerelateerde klachten beperkt en optimaal comfort biedt. De huidige taken en de huidige werkomgevingen spelen een belangrijke rol in hoe de stoel wordt gebruikt. Echter, in relevant onderzoek en huidige richtlijnen is daar nog weinig aandacht aan besteedt. Er ontbreekt nog kennis over de effecten van huidige werktaken op werkhoudingen en welke consequenties dit heeft voor een optimaal stoelontwerp. De onderzoeksdoelstelling is het verwerven van meer kennis over stoelontwerp in relatie tot kenniswerkactiviteiten, houding en bewegingsgedrag en(dis)comfort teneinde inzicht te verkrijgen in optimaal functionele zitondersteuning. Dit project omvat onderzoek over de meest

voorkomende werktaken van kenniswerkers in verschillende werkomgevingen, zoals kantoren, treinen en in een thuissituatie. Daarbij werd gebruik gemaakt van bestaande ontwerpen of prototype stoelen. De resultaten van dit onderzoek kunnen gebruikt worden bij het ontwerp en de evaluatie van zitondersteuning voor huidige en toekomstige kenniswerktaken in kantoren, openbaar vervoer of thuiswerkplekken.

Hoofdstuk 2 richt zich op de vraag of een herontwerp van een kantoorstoel meer optimale ondersteuning biedt. Verschillen in bedieningsknoppen, het zitkussen en de hoek van rugleuning van de originele stoel en het herontwerp, zijn geëvalueerd bij computertaken en niet-computer gebonden taken. 70% van de proefpersonen gaf daarbij de voorkeur aan het herontwerp met betrekking tot de uitgevoerde taken. Ze vonden het herontwerp comfortabeler bij de niet-computer gebonden taken, zoals lezen en telefoneren, met een grotere maximale rugleuninghoek van 124 graden. Tevens, werd meer bedieningsgemak en comfort ervaren bij de herontwerp stoel. Daarbij was ook minder tijd nodig om de armleuningen en de dynamische modus in te stellen, door een meer intuïtief design. Deze resultaten indiceren dat het stoelontwerp bijdraagt aan optimale taakondersteuning in de beleving van werknemers.

Het gedrag van verschillende typen werknemers in interactie met het stoelontwerp is onderzocht in **hoofdstuk 3**. Twee typen werknemers, te weten werknemers die gebruik maken van flexibele werkplekken en werknemers met een vaste werkplek, zijn geobserveerd en bevraagd naar hun instelgedrag bij twee typen stoelen. Het onderzoek vond plaats in hun eigen werkomgeving en met hun eigen werkzaamheden. Werknemers met flexibele werkplekken stelde de stoelen daarbij vaker in, ook voor kortdurend gebruik, en waren sneller met een aantal instellingen in vergelijking tot de gebruikers van een vaste werkplek. De werknemers waren ook kritischer in hun beoordeling van het comfort van de stoelen. Over het algemeen stelden de gebruikers in het algemeen hun stoel weinig in. Slechts enkelen veranderden meer dan 1 maal per week de instellingen en men gebruikte dan slechts een paar van de instelopties. De insteltijd werd wel korter als de bedieningsmiddelen beter aangeduid werden en meer intuïtief gelokaliseerd waren. Een persoonlijke instructie verbeterde de kwaliteit van de instelling voor alle proefpersonen bij beide stoelen.

Het effect van werktaken op meer objectieve maten zoals lichaamshoudingen, spieractiviteit en bewegingsvariatie is in eerste instantie onderzocht in een gesimuleerde kantooromgeving. De uitkomsten in **hoofdstuk 4** laten aanzienlijke effecten zien van de uitgevoerde taken op houdingen en beweeglijkheid. Er werden, ten opzichte van elkaar, veel verschillen gevonden tussen type werkzaamheden zoals correctiewerk, muisgebruik, sorteren van dossiers en telefoneren. De taken hadden zeer verschillende karakteristieken in bewegingsintensiteit, spieractiviteit, lichaamshoudingen en stoelposities. Voor een goed functioneel stoelontwerp betekent dit, dat al deze taakkarakteristieken ondersteund moeten worden om kenniswerkers optimaal te faciliteren in hun werkzaamheden.

In **hoofdstuk 5** is deze studie voorgezet in een veldstudie waarbij kantoormedewerkers hun werkzaamheden uitvoerden in hun eigen werkomgeving. Naast de meer objectieve maten werd ook comfortvragenlijst afgenomen. De comfortanalyse had als doel te onderzoeken of er een verband is tussen specifieke stoelkenmerken en specifieke taken. Wederom werden aanzienlijke verschillen gevonden tussen taken op houdings- en bewegingsmaten. De gecategoriseerde taken als computerwerk, bureauwerk, telefoneren en overleggen hadden sterk uiteenlopende houdings- en bewegingskarakteristieken. Er zijn indicaties gevonden, dat een aantal voorkeuren voor specifieke dynamische stoeleigenschappen gerelateerd kunnen zijn aan specifieke taken en hun duur. Er is echter nog meer onderzoek nodig om taak specifieke comforteisen te kunnen verbinden aan stoelkenmerken.

Effecten van taken en activiteiten die in een mobiele omgeving, namelijk in een trein, plaatsvonden zijn het onderwerp van **hoofdstuk 6**. Naast werkzaamheden zijn ook ontspanningsactiviteiten van bijna 800 treinreizigers geobserveerd met bijbehorende houdingen en comfortscores. De meest voorkomende activiteiten van de reizigers waren: lezen, staren/slapen, converseren en laptopwerk. Laptopwerk werd daarbij gemiddeld het langste gedaan in vergelijking tot de andere activiteiten. Bij deze geobserveerde activiteiten werd een top 8 aan meest voorkomende houdingen bepaald. Per activiteit werden verschillende houdingen geobserveerd, maar er werden ook vergelijkbare houdingen gevonden die terugkwamen bij verschillende activiteiten. In comfort scores werden nauwelijks verschillen gevonden tussen de activiteiten, behalve voor het comfort van de hoofdsteun. Wel werden er indicaties gevonden dat de comfortscores behorende bij de vergelijkbare houdingen verschillend waren in combinatie met de verschillende activiteiten. Daarnaast werd gevonden dat de meerderheid van de treinreizigers voor bijna alle activiteiten meer instelopties wilden, om de stoel beter te kunnen afstellen op de uit te voeren activiteit. De uitkomsten van deze studie kunnen worden gebruikt voor stoelontwerpen voor openbaar vervoersvormen als treinen, bussen en vliegtuigen, maar ook voor stoelen in publieke ruimten om optimale ondersteuning te kunnen bieden aan de gebruiker met deze activiteiten.

Een stoelontwerp voor een specifieke taak of activiteit met als doel optimale ondersteuning hiervan, was de focus van **hoofdstuk 7**. De ontwikkeling van een comfortabele stoel voor televisiekijken, die variatie in geobserveerde houdingen en variatie in lichaamsafmetingen van gebruikers kan ondersteunen, is hier uiteen gezet. Evaluatie van het prototype ontwerp met gebruikers liet zien dat de verstelbare onderdelen, zoals de zijwaarts verplaatsbare arm steun en de meervoudig verstelbare voetsteun, de geobserveerde variaties goed ondersteunden. Het prototype stoel werd tevens comfortabel gevonden bij het kijken naar een beeldscherm. Er waren echter ook ontwerpaspecten die verbeterd konden in relatie tot deze activiteit, zoals de positionering van de hoofdsteun en de vorm en locatie van de lumbaal steun. De bevindingen van deze studie over de houdingen en de typerende stoelkenmerken bij deze activiteit kunnen ook input geven voor toekomstige werkplekken, waar muis en toetsenbord niet meer gebruikt worden. Nieuwe technologieën, zoals Kinect besturing of oogaansturing van computers, maken het mogelijk meer vrije houdingen met het lichaam aan te nemen, zoals de proefpersonen van deze studie deden.

Het laatste boekhoofdstuk reflecteert op de onderzoeken en optimaal stoelontwerp voor kenniswerk. In **hoofdstuk 8** zijn de bevindingen geïnterpreteerd in de context van de onderzoeksvraag of huidige stoelontwerpen gebruikelijke werktaken van kenniswerkers optimaal ondersteunen. Daarbinnen worden twee onderwerpen besproken. Het eerste onderwerp is: 'taak specifieke ondersteuning voor gebruikelijke taken van kenniswerkers'. Uit de onderzoeken blijkt dat houdings- en bewegingsgedrag sterk beïnvloed worden door taakkenmerken. Tevens kan het ontwerp van stoelen bijdragen aan meer optimale ondersteuning van houdingen en comfort, in relatie tot uitgevoerde taken en activiteiten. Uit deze studies komen een aantal specifieke ontwerp aspecten naar voren die comfortabeler zijn en meer neutrale houdingen bieden.

Het tweede onderwerp dat besproken wordt is: 'Ontwerp implicaties voor instelbaarheid en voor stoelonderdelen'. Instelbaarheid van stoelen en de bruikbaarheid daarvan is in verschillende hoofdstukken aan bod gekomen. De conclusie daarbij was dat de bruikbaarheid van het ontwerp en het instelgedrag, dat verschilt per type gebruiker, erg belangrijk is voor het comfort en de kwaliteit van instellen. Ook het verbeteren van specifieke onderdelen verdiend aandacht, daar huidige stoelontwerpen geen optimale ondersteuning bieden voor huidige werktaken van kenniswerkers. Uit het huidige onderzoek is gebleken dat een betere ontwerpmatch met werktaken gerealiseerd kan worden op het gebied van instelbaarheid, bruikbaarheid en het ontwerp van onderdelen, met name hoofdsteun en lumbaal steun.

In dit proefschrift worden vier richtingen aangegeven voor toekomstig onderzoek. De eerste is algemeen en gericht op verbetering van de bruikbaarheid en optimalisatie van de functionaliteit. De tweede richting gaat over de ontwikkeling in kenniswerktaken, werkorganisatie en nieuwe zitconcepten die er toe zullen leiden dat er nieuwe houdingen, bewegingen en taak gerelateerde comfortpercepties zullen ontstaan. Vanwege die ontwikkelingen blijft het belangrijk om dit te onderzoeken om daarmee nieuwe ontwerpinput in te leveren. De derde richting betreft nieuwe maatschappelijke en ontwerptrends die vragen om nieuw onderzoek. Zowel 'global design' voor een breed spectrum aan gebruikers als 'customized' design voor een specifieke groep gebruikers of individuen vraagt om de specifieke ontwerpcriteria om te komen tot de optimale passing met de beoogde gebruikers. Als vierde en laatste richting wordt sedentair gedrag en de effecten van langdurig en frequent zitten genoemd. De potentiele gezondheidsrisico's hierbij vragen om nieuw onderzoek ter preventie. De uitdaging is hier om naast bewustzijnsverhoging de benodigde gedragsverandering te faciliteren vanuit een goed ontwerp.

De epiloog eindigt met aanbevelingen voor de praktijk en zijn beschreven in twee delen: 'Input voor het ontwerp- en evaluatie proces' en 'ontwerpspecificaties uit dit proefschrift'. De input voor het ontwerp- en evaluatieproces is geformuleerd om de juiste vereisten te bepalen voor een optimaal stoelontwerp. Verschillende stappen worden benoemd om gebruikers, activiteiten/taken, omgevingskarakteristieken en de interactie te definiëren bij ontwerp en/of evaluatie. Variatie in gewoonten en kennis van gebruikers over een goede werkhouding en instelmogelijkheden is belangrijk om te specificeren in zowel het ontwerp- als selectieproces van zitondersteuning. Tevens worden methoden benoemd om de juiste gegevens te verwerven.

De ontwerpspecificaties uit dit proefschrift gaan over instelbaarheid, gebruiksgemak en specifieke dimensionering bij de verschillende activiteiten. Bijvoorbeeld dat activiteiten als lezen of naar een scherm kijken een grotere rugleuninghoek behoeven, terwijl telefoneren of converseren meer vragen om een dynamische instelling van zitting en rugleuning gezien de bewegingsvariatie die hierbij gevonden is. Door de variatie aan taken van kenniswerkers, biedt een optimaal ontwerp, idealiter ook ondersteuning aan de diverse taken. Een meervoudig instelbaar ontwerp is nodig om de taakvariatie met de bijbehorende houdingen en bewegingen te faciliteren. Intuïtief ontwerp van de bedieningsmiddelen heeft daarbij een groot effect op comfort en gebruiksgemak. Van bedienings- en gebruiksinstructie is aangetoond dat het bijdraagt aan de kwaliteit van de instelling. Tot slot zijn er nog een aantal ontwerpuitdagingen aan te gaan. De hoofdsteun is een uitdagend element om de verschillende taken en houdingen comfortabel te ondersteunen. Voor toekomstig onderzoek en ontwerp lijken 'smart systems' veelbelovend om taak specifieke houdingen en bewegingen detecteren en automatisch en direct de kenniswerker te faciliteren in hun werkzaamheden.

About the Author

About the Author

Liesbeth Groenesteijn was born on November 18th 1972 in Baarn, the Netherlands. After completing secondary school at the Griftland College in Soest in 1990, she moved to Amsterdam to study Physiotherapy at the Amsterdam University of Applied Sciences. She graduated in 1994 and worked for five years as a physiotherapist in several private practises in the Netherlands, and in three hospitals whereof two in the United Kingdom. In 1997 she started studying at the Faculty of Human Movement Sciences of the VU University Amsterdam where she graduated with a specialisation in Ergonomics. Subsequently, she started working in 2000 as a researcher and consultant in ergonomics and innovative work environments at the Netherlands Organisation for Applied Scientific Research TNO. Here she worked on various projects related to physical workload and design of work environments in relation to wellbeing and performance of employees. In 2007 she started a PhD project, in combination with her job at TNO, at the Faculty of Industrial Design Engineering of the Delft University of Technology. The results of this project are presented in this thesis.

Together with Bart Visser she has two sons. Liesbeth's favourites leisure time activities are travelling, cooking/enjoying good food, and outdoor activities like hiking, speed skating and tennis.

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