Supporting seat design for Smartphone use during travel

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Supporting seat design for Smartphone use during travel

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Summary

Summary

Many passengers traveling by train, bus or other vehicles pass the time by using their smartphones. The literature confirms that using smartphones is now train passengers' main activity. The limited space for movement on the armrest, which a person shares with their neighbour, and the fact that they must keep their neck bent while using their smartphone certainly leaves room for improvement. Studies have confirmed the experience of discomfort, especially in the neck, shoulders, arms and back, which could even lead to musculoskeletal disorders. This study aims to develop background information to improve the vehicle seat environment to comfortably use a smartphone.

To develop background information for passenger vehicle interiors, a literature review on seat comfort during smartphone use was conducted (Chapter 2). The literature review showed that smartphone use is one of the main activities' passengers performed. Holding a smartphone in both hands and laying the arms on the armrests was the most common posture, resulting in frequent discomfort in the neck, back, shoulders and arms. Neck flexion is the most important problem caused by smartphone use. Some papers mentioned that arm support could reduce neck flexion and neck discomfort. However, the proper height of the armrest needs future research. The duration of holding the smartphone should be reduced because a long period of smartphone use increases discomfort. The backrest angle also influences smartphone use comfort. An angle of 120 degrees is best for comfortable smartphone use in an aircraft seat. For other vehicles, studies are still needed. In addition, the activities, postures, anthropometric data and needs of passengers should be considered.

Passengers filled out a questionnaire that asked about their travel purposes, activities, postures and needs related to smartphone use during a train trip (Chapter 3). Its aim is to answer the research question 'How many passengers use a smartphone and what activities are performed on the smartphone?' In this study, the four main activities performed on a smartphone were listening to music, watching videos, reading, and texting. Participants used both hands for texting, while they held the phone in the right hand for reading and watching videos. The passengers preferred to use their smartphones with an arm support. However, in this study, a high armrest discomfort score while using the mobile phone was recorded. Based on this study, it might be interesting to examine using a smartphone holder for watching a video, while for texting, an improved armrest might be explored.

In Chapter 4, the train passengers' needs for the seating environment were collected. Context mapping and co-creation techniques were used to answer the research question 'What are the passengers' needs regarding the vehicle interior for using a smartphone?' In this study, sessions were arranged for groups of students, employees, and older people. The student and employee group mainly used the smartphone during a long-distance train trip, while the older people did other activities. The results showed that the younger group and the employee group mainly used their smartphones for listening to music, watching videos, reading and texting, while the older people group were doing other activities such as gazing out of the window, reading and working on a laptop. While listening to music on the phone, they did not hold their phone in their hands, and their postures were comparable to other activities. The main posture for watching a video and reading was holding the smartphone in the right hand. For Texting, they typed on the phone using both hands. However, the participants tried to find support for their arms, such as the armrest or the lap. Even some parts of the window could help reduce arm discomfort. This means that the passengers need support for their arms to increase comfort while using a smartphone. In future interior design, smartphone use support should be considered.

The research also showed that not only the armrest improvement is needed, but also the facilities to charge and the Wi-Fi. It is also important to take special groups of passengers into account, such as the disabled.

Chapters 5, 6 and 7 discuss design aspects of the environment to increase smartphone comfort. Chapter 5 showed that an arm support reduces neck discomfort. It was interesting that a difference between expected and experienced discomfort was recorded. Chapter 6 defines the most comfortable trunk angle while using a smartphone while lying down. The experiment was set up with 52 participants. It showed that between 120 to 142 degrees of trunk angle provided the best comfort score. However, for the neck and upper back, the discomfort was relatively high, which still needs to be addressed. In Chapter 7, the comfort and discomfort of a specially designed armrest in the smartphone chair was studied. The neck showed the highest discomfort while using a smartphone without support, while in the case of using the smartphone with support, neck discomfort decreased. However, discomfort of the upper arms increased probably due to the high level of arm support. The recommendation is to make the height of the armrest adjustable.

Chapter 8 provides recommendations on the height levels of the arm support while the passengers are using a smartphone with both hands while reading and texting on the phone. This study found that the height level of the armrest should be adjustable between 18.4-29.5 cm. above the seat pan. If it cannot be adjusted, 24.3 cm. is advised. In addition, while passengers are watching a video on the phone, a smartphone holder is preferred. The height of the holder on the backrest in front of the person should vary between 63.1-87.5 cm. above the seat pan. Future steps could be the design and mechanism of the armrest or another tool that can hold the smartphone. This should be tested with end-users. A problem that also needs to be studied is the duration of holding the smartphone. In this thesis, various solutions are described for vehicle interiors to improve body posture, but the literature review indicates that next to maintaining good posture, the duration of holding a smartphone should also be limited.

Samenvatting

Veel passagiers die per trein, bus of andere vervoermiddelen reizen gebruiken de mobiele telefoon. In de literatuur zijn er studies die aantonen dat het zelfs de meest voorkomende activiteit in de trein is. De beperkte ruimte op de armleuning, die ook vaak gedeeld wordt met degene die naast je zit en het feit dat je nek gebogen is wanneer je de mobiele telefoon gebruikt vragen om een verbetering. In de literatuur wordt tijdens het gebruik van de mobiele telefoon gesproken over discomfort in de nek, schouders, armen en rug. Dit kan zelfs tot klachten aan het bewegingsapparaat leiden. Het doel van dit proefschrift is om informatie te verzamelen, die gebruikt kan worden bij het ontwerpen van voertuiginterieuren, waar de mobiele telefoon comfortabel gebruikt kan worden.

Om informatie te verzamelen voor het ontwerpen van voertuiginterieuren, is een literatuuronderzoek naar comfort tijdens het gebruik van een mobiele telefoon uitgevoerd (hoofdstuk 2). Uit het literatuuronderzoek blijkt dat smartphonegebruik één van de belangrijkste activiteiten is van passagiers. De mobiele telefoon wordt vaak vastgehouden met beide handen, waarbij de armen op de armleuningen liggen, wat resulteert in ongemak in de nek, rug, schouders en armen. Nekflexie is een belangrijk probleem dat wordt veroorzaakt door smartphonegebruik. In sommige artikelen werd vermeld dat een armsteun nekflexie en daardoor nekklachten zou kunnen beperken. De juiste hoogte van de armleuning behoeft echter nader onderzoek. De duur van het vasthouden van de smartphone is ook een risicofactor voor klachten en moet worden verkort. De hoek van de rugleuning heeft ook invloed op het gebruikscomfort van de smartphone. Voor comfortabel smartphonegebruik in een vliegtuigstoel is een hoek van 120 graden te prefereren. Voor andere voertuigen zijn nog weinig studies beschikbaar. De literatuur geeft ook aan dat rekening moet worden gehouden met de activiteiten, die op de mobiele telefoon worden gedaan en met de houdingen, antropometrische eigenschappen en behoeften van passagiers.

In hoofdstuk 3 van dit proefschrift vulden treinpassagiers een vragenlijst in waarin werd gevraagd naar de reden van hun reis, activiteiten, houdingen en behoeften met betrekking tot het gebruik van de mobiele telefoon. Hierbij was de onderzoeksvraag ‘Hoeveel passagiers gebruiken een smartphone en welke activiteiten worden er op de smartphone uitgevoerd?’. Hieruit kwamen vier belangrijke activiteiten die op een mobiele telefoon worden uitgevoerd: naar muziek luisteren, video’s kijken, lezen en sms’en. Deelnemers gebruikten beide handen om te sms’en, terwijl ze de telefoon in de rechterhand hielden om te lezen en video’s te bekijken. De passagiers gaven er de voorkeur aan om hun smartphones met armsteun te gebruiken. In dit onderzoek werd echter een hoge score voor ongemak van de armleuningen gevonden tijdens het gebruik van de mobiele telefoon. Op basis van dit onderzoek blijkt dat het interessant is om het gebruik van een smartphonehouder voor het bekijken van een video te onderzoeken, terwijl voor het sms’en een verbeterde armleuning nodig is.

De wensen van treinreizigers inzake het interieur zijn onderzocht in hoofdstuk 4. Hierbij werden ‘context mapping’ en co-creatietechnieken gebruikt. De onderzoeksvraag was: ‘Wat zijn de behoeften van de passagiers met betrekking tot het voertuiginterieur voor het gebruik van een smartphone?’. In dit onderzoek werden sessies georganiseerd met groepen studenten, werknemers en ouderen. Uit de resultaten bleek dat de jongere groep en de werknemersgroep hun smartphones vooral gebruikten om naar muziek te luisteren, video’s te kijken, te lezen en te sms’en, terwijl de groep ouderen andere activiteiten deed, zoals uit het raam kijken, lezen en werken op een laptop. Wanneer de deelnemers naar muziek luisteren, houden ze hun telefoon niet in hun handen en zijn de houdingen vergelijkbaar met andere activiteiten. De meest voorkomende houding bij het bekijken van een video en het lezen is het vasthouden van de smartphone in de rechterhand. Voor sms’en zijn beide handen aan de telefoon. De deelnemers probeerden echter steun te vinden voor hun armen, zoals de armleuning of op schoot. Sommigen gebruikten delen van het raam om het ongemak in de armen te verminderen. Dit betekent dat de passagiers behoefte hebben aan ondersteuning van hun armen om het comfort tijdens het gebruik van een smartphone te vergroten. Bij het toekomstige interieurontwerp moet hiermee rekening worden gehouden. Uit het onderzoek bleek ook dat niet alleen de armleuning van belang is, maar ook de faciliteiten om op te laden en de Wi-Fi. Verder bleek dat het belangrijk is om rekening te houden met bijzondere groepen passagiers, zoals gehandicapten, omdat die speciale voorzieningen nodig kunnen hebben.

In de hoofdstukken 5, 6 en 7 worden ontwerpaspecten van de omgeving bestudeerd om het smartphonecomfort te vergroten. In hoofdstuk 5 is aangetoond dat een armondersteuning minder nekdiscomfort geeft. Interessant bij deze studie was dat een verschil in verwachte en ervaren discomfort werd waargenomen. In hoofdstuk 6 is de meest comfortabele romphoek bij liggend gebruik van een smartphone bestudeerd. Aan dit experiment deden 52 deelnemers mee. Hieruit bleek dat liggend een romphoek tussen 120 en 142 graden de beste comfortscore opleverde. In deze positie is nog een aanvullende oplossing nodig voor de nek en de bovenrug, omdat discomfort daar relatief hoog is. In hoofdstuk 7 werd het comfort en ongemak van een bestaande speciaal ontworpen armleuning van de smartphonestoel bestudeerd. Het grootste ongemak werd gemeten bij gebruik van een smartphone zonder ondersteuning, terwijl bij gebruik van de smartphone met ondersteuning de nekklachten afnamen. Het ongemak van de bovenarmen nam echter toe bij de armondersteuning, waarschijnlijk omdat deze te hoog was voor een deel van de populatie. Het advies is daarom om de hoogte van de armleuning verstelbaar te maken.

Hoofdstuk 8 bevat aanbevelingen over de hoogte van een armleuning wanneer passagiers de smartphone met beide handen gebruiken, zoals dat gebeurt tijdens het lezen en sms'en. De hoogte van de armleuning moet verstelbaar zijn tussen 18,4 en 29,5 cm boven de zitting. Indien niet verstelbaar, is 24,3 cm aan te raden. Wanneer passagiers een video bekijken op de telefoon is een smartphonehouder aan te raden. De hoogte van de houder op de rugleuning voor de persoon is dan tussen 63,1-87,5 cm. boven de zitting. Een aanbeveling is om in de toekomst een ontwerp te maken voor een armleuning en hulpmiddel dat de smartphone kan vasthouden dat is gebaseerd op deze richtlijn. Dit moet dan wel weer worden getest met eindgebruikers. Een probleem dat nu nog onderzocht moet worden, is hoe de duur van het smartphone gebruik beperkt kan worden. In dit proefschrift worden verschillende oplossingen beschreven voor het interieur van voertuigen om de lichaamshouding te verbeteren, maar uit het literatuuronderzoek blijkt dat naast het behouden van een goede houding ook de duur van het vasthouden van een smartphone beperkt zou moeten worden.

Contents

Chapter 1
Introduction

Chapter 1. Introduction

1.1 The situation of passengers and smartphone use

Since the launch of the smartphone in 2007, smartphone use has increased dramatically. From 2016 to 2021, the number of smartphone users worldwide increased from 3.6 to 6.4 billion. In 2021, 4.32 billion people accessed the internet via mobile devices(1). Some even use a smarphone more than 7 hours per day (2) to access email, calendars, internet browsing, reading, texting, listening to music and using social media (3). People use smartphones everywhere at home, in the office, in restaurants and in their cars. The smartphone is used in public transport as well (see Figure 1.1).

The International Air Transportation Association (IATA) reported in 2017 that 82% of airplane passengers accessed digital information via their smartphones while travelling by air (4). In addition, passengers have frequently used a smartphone on other forms of public transport (5). Kilincsoy and Vink (6) observed 345 passengers who travel in first- and second-class trains in the Netherlands. They found that 48.3% used smartphones on the train. A study in 2011 observed 3.8% using a smartphone (7). In a study in 2014, the percentage was 12.1% (8). The studies did not exactly follow the same observation method, but the trend is clear. All intercity trains in the Netherlands provide free Wi-Fi for passengers (9). Passengers used smartphones to look for real-time information on train schedules more than the local displays on platforms (10). Smartphones made it easier for passengers to buy tickets, potentially increasing user satisfaction with the rail system (11). Travelers demanded not only pre-trip information for planning, but also information during journeys such as punctuality, connections, and platform location (12).

Kamp (7) found that passengers were reading, talking, discussing and relaxing on the train. Three years later, Groenesteijn (8) reported that the main activities of train commuters were staring, sleeping, relaxing and watching. In 2018, Kilincsoy and Vink, (6) observed passengers on a train. Their main activities were smartphone use (48.3%), relaxing (staring or sleeping) and reading from paper. Using a smartphone for a longer period of time results in unnatural postures. The unnatural postures could be partly caused by a traditional seat design based on older activities. This influences comfort and discomfort and might even result in musculoskeletal injuries in the long run (13). When people use a smartphone, they usually stress their upper body (14). This can cause neck flexion, eye strain and pain in the shoulder and upper and lower arm, including the wrist and fingers because the smartphone is held for a long period in one position, leading to static loads (15).

Some studies suggest a solution for the static load. For instance, Liu (16) reported that for aircraft seats, passengers mention that they wanted a better armrest for using their smartphones.

Figure 1.1: Some examples of smartphone use in an airplane (left) and in a train (right)

To summarize, smartphone use has increased, including while people are travelling. The static load associated with smartphone use could result in discomfort and musculoskeletal problems. To prevent this, adaptations of the environment might be helpful. This PhD thesis focuses on improving the travel environment. However, information about how to improve the environment is still limited. How passengers use mobile phones, what their needs are and how mobile phone use influences posture are all unknown. Additionally, comfort and discomfort data gathered while people are using smartphones in the transport systems are scarce. Having these data might be helpful in formulating adequate solutions. This project aims to gain insight into the needs of passengers, their different body postures, and people's (dis)comfort in the context of smartphone use in transport modes. This could form a basis for design solutions to improve (dis) comfort when passengers are using a smartphone. These results might be applied to passenger seat environments to increase comfort during a long trip. The aim is to eventually create a Guidelines for improving seat comfort for smartphone use in transport systems.

The research question of this PhD is:

'How can the seat environment be improved so that passengers can comfortably use a smartphone while traveling?'

1.2 Comfort Definitions and Models

Before answering the research question, the concept of the experience of comfort and discomfort is explained. Comfort is 'a pleasant state or relaxed feeling of a human being in reaction to its environment', while discomfort is 'an unpleasant state of the human body in reaction to its physical environment', as described by Vink and Hallbeck (17). Thus, comfort is more related to a human being's feelings, while discomfort is an unpleasant state of the human body.

Figure 1.2 illustrates that comfort and discomfort are not each other's opposites. Zang (18) state that based on research, discomfort experiences are influenced more by physical factors, while comfort is more affected by psychological aspects and by expectations, well-being and emotions.

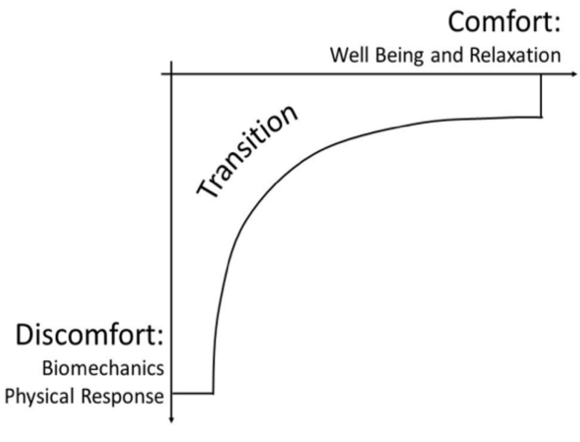

Figure 1.2: Relationship between comfort and discomfort, with discomfort on one axis and comfort on another axis (18).

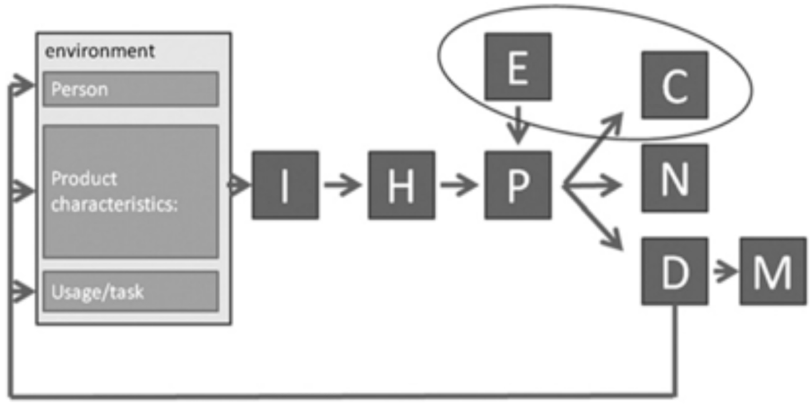

Figure 1.3: Comfort Model by Vink and Hallbeck (2012) (17). (P: Person, U&T: Usage & Task, Pr: Product Characteristics, I: Interaction with the environment, H: Body effect, P: Perceived effects (comfort (C) discomfort (D)), E: Expectation).

Figure 1.3 presents another comfort model by Vink and Hallbeck. Many studies in the field have cited this study. The interaction (I) within an environment is caused by the contact between the human and the product and its usage. This can result in internal human body effects (H), such as tissue deformation, body posture change and muscle activation. The perceived effects (P) are influenced not only by the human body effects, but also by expectations (E). These are interpreted as comfortable (C), or one feels nothing (N) or it can lead to feelings of discomfort (D). Discomfort may also lead to musculoskeletal disorders (M). However, (19) separates the process towards discomfort and the process leading to comfort. Their model illustrates that the physical environment directly influences discomfort, while comfort is not only influenced by the physical environment, but also by psychosocial factors. This model might be helpful in finding causes of comfort and discomfort. However, in all these models, variations in external forces and duration are not taken into account, while comfort and discomfort change over time even if nothing in the environment changes (20). Naddeo (21) modified the model further and added psychosocial effects and added the methods to measure various factors. In this PhD thesis, the comfort model of Figure 1.3 will be used, and comfort and discomfort will be considered different entities.

1.3 Research Focus and Approach

This Ph.D. project focuses on studying the use of devices that connect to the World Wide Web (like the smartphone). Based on data about how the devices are used, including the recording of body postures, designs and Guidelines are developed to increase passenger comfort during smartphone use (22). The research will consist of several studies and experiments that gather knowledge as a backbone for a theory on comfort during smartphone use to answer the main research question.

‘How can the seat environment be improved so that passengers can comfortably use a smartphone while traveling’?

Vink and Hallbeck’s comfort model has been applied, as Figure 1.4 shows. The eight aspects influencing comfort and discomfort are studied: the Context of smartphone use (including usage/task), Person (body sizes), Product Characteristics (seat), Internal Human Body Effects (e.g., joint angles), Perceived Effects, Expectations and effects on Comfort and Discomfort.

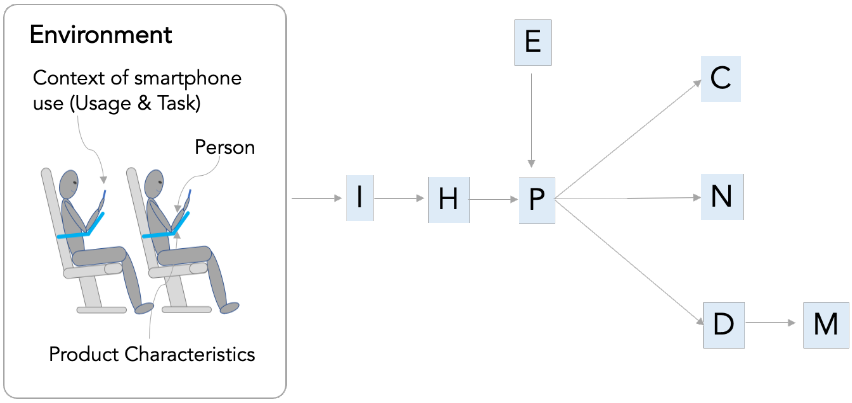

Figure 1.4: Framework of the study "supporting seat design for Smartphone use during travel", based on the Comfort Model by Vink and Hallbeck (2012)

This Ph.D. project explores the context of smartphone use (Usage & Task; U&T). It aims to understand how passengers use smartphones while they are traveling, including what tasks are performed and how. Specifically, it examines how these tasks influence the body effect (H) and how it relates to the perceived effect (P) by the passengers, resulting in comfort (C) and discomfort (D). In addition, the different human body sizes (Person; Pe) and the seat elements (Product Characteristics; Pr), such as the headrest, backrest, seat pan, leg room and armrest, all play a role and will be examined in this study. Moreover, the context of use is studied, including the psychological state and situation, for example, with regard to the expectation (E) towards seat comfort and privacy and the overall journey. These are related to how passengers perceive comfort and discomfort.

These aspects will be studied with methods such as observations, questionnaires, interviews, measurements and co-design. Sub-research questions are formulated to gain insights into specific factors influencing (dis)comfort. The sub-questions are as follows:

1. What is described in the scientific literature?
2. How many passengers use a smartphone?
3. What activities are performed on the smartphone?
4. What are the passengers' needs regarding the vehicles' interiors for using a smartphone?
5. What is the difference between expected comfort and experienced comfort and the association between discomfort in the head/neck region and recorded neck angle?
6. What is the best trunk support angle for comfortable smartphone use on a bed?
7. Does body posture support during smartphone use influence productivity, comfort and discomfort?

After investigating these five sub-research questions, we hope to shine a light on the main research question:

'How can the seat environment be improved so that passengers can comfortably use a smartphone while traveling?'

1.4 Relevance of this Research

This research is conducted at the Department Human-Centered Design at the Faculty of Industrial Design Engineering, Delft University of Technology, The Netherlands. It is related to the societal challenge 'Mobility' and the disciplinary perspective theme 'People' of the faculty.

The main contribution of this project is to develop a Guidelines for designing an innovative seat for smartphone use in transport systems. To develop the Guidelines, the activities of passengers, the needs of the passengers while using smartphones, anthropometric data and advice for an adapted seat design supporting smartphone use are studied.

These Guidelines support designers and seat manufacturers to design future seats that might increase passengers' comfort while using smartphones. Also, the transportation industry might use the Guidelines to select the seat for a train, airplane or bus. The study aims to increase the passengers' comfort by improving the body postures assumed while using a smartphone.

1.5 Thesis Outline and Methodology

A literature review, a passenger observation study and four experiments are conducted to answer the five sub-research questions and thereby the main research question. Figure 1.5 presents the different studies and the relevance of the studies.

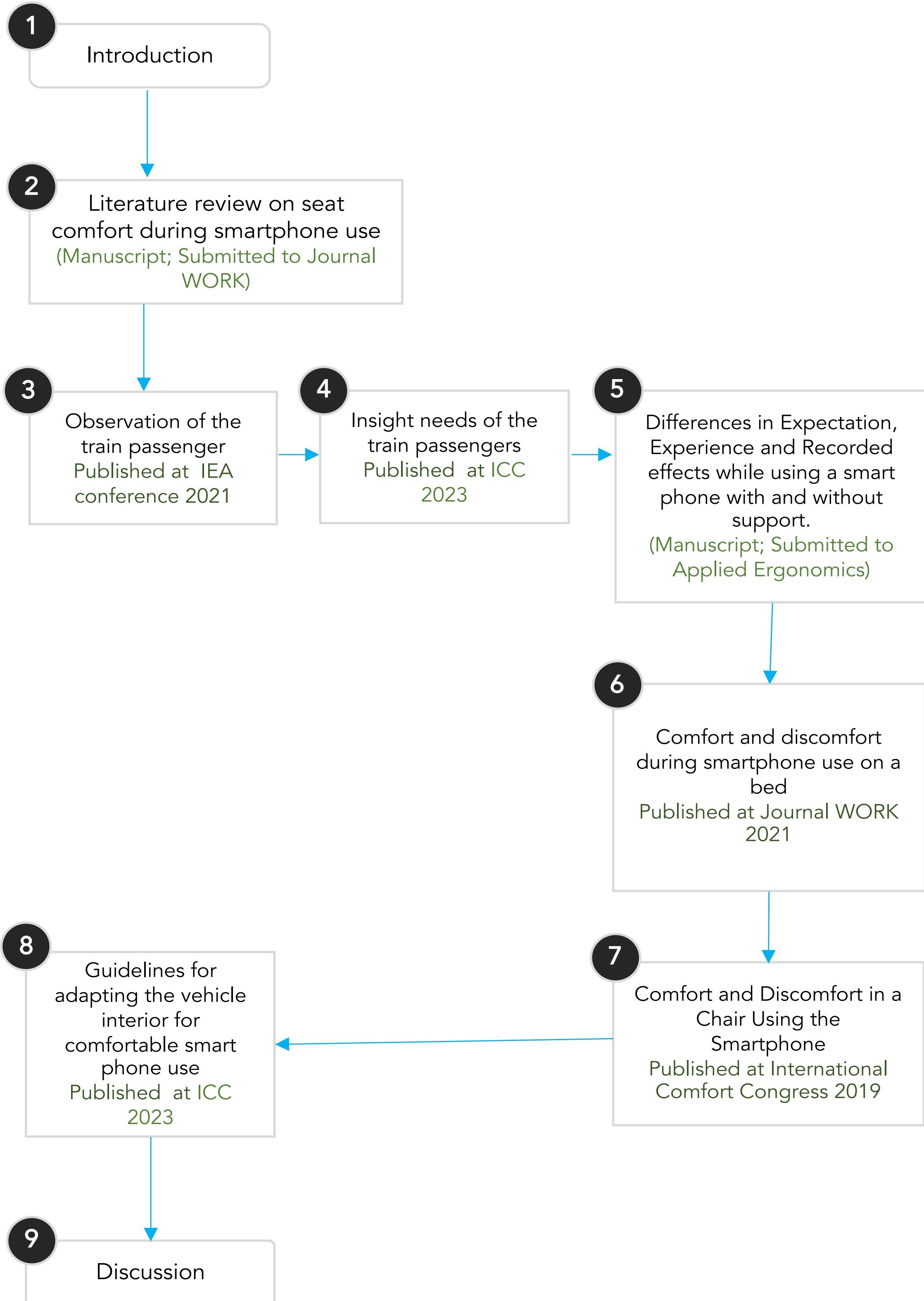

Figure 1.5: The thesis outline.

Chapter 1 presents the overview of this thesis. The background, problems, actual situation, research gap, aims, related theories, framework, relevance and outline of the research are reported.

A literature review was conducted to determine what has been published on the relationship between vehicle interiors, seat design, smartphone use and its effect of humans in terms of comfort and discomfort. This is described in **Chapter 2**. We studied activities, anthropometrics, seat elements, postures and perceived effects (comfort and discomfort experiences) of smartphone use. Additionally, availability of information on the relationships between smartphone use, activities, anthropometry and corresponding postures, comfort and discomfort were investigated.

In **Chapter 3**, passengers are observed on a train. Kilincsoy and Vink (6) and Kamp (7) observed passenger activities on trains. However, the activities of the passengers in the 2018 study were drastically different compared with the earlier study, and Kilincsoy and Vink's study (2018) was rather superficial and yielded no data on activities passengers performed on their smartphones. Thus, new knowledge was needed to define which part of the interior should be optimized. The three main research questions for this study are: 1) how much can smartphone use be observed in train passengers in Thailand in 2021? 2) what activities are performed on smartphones? and 3) how are such activities linked to posture change and perception of comfort or discomfort?

To understand the context of needs of the passengers while they are using smartphones, in **Chapter 4**, context mapping and co-creation sessions were performed. The experiment used the sub-research question 'What are the passengers' needs for smartphone use regarding the vehicle interior? By interviewing the participants and letting them map their context, an indication was gathered on the passengers' needs for the seating environment. Then the participants were invited to co-create a new seat environment to support their comfort experience while they are traveling.

Figure 1.6: some examples of smartphone holders

In many situations, smartphone holders can be found (see Figure 1.6) that could be a solution to reducing discomfort. However, not much research has been done on the effects of smartphone use. Therefore, in **Chapter 5**, a study is done on the effect of smartphone holders. In the literature, a difference is sometimes shown between expected and experienced effect. For instance, Bouwens (23) showed that expectation is influenced by visual impression. A cushion around the neck in the form of a collar is perceived as uncomfortable (expectation), but after sitting for two hours with the collar in an airplane seat, the comfort score was much better. Therefore, in this study, expected comfort and experienced comfort were measured and it was checked whether a difference was found. The research question for this chapter is, 'What is the difference in seat comfort and discomfort expectation and experience between two conditions (with and without a smartphone holder) while using a smartphone?' Twenty-four participants were asked to use their smartphones in train seats with and without smartphone holders and to rate the expected and experienced comfort by mentioning factors in the seat that influence comfort.

In some vehicles, it is possible to sleep lying flat, like night trains and business-class aircraft seats. However, using a smartphone while lying flat might not be the optimal position. Therefore, a study was done in which passengers held their smartphones in different positions while lying down. This is described in **Chapter 6.** The research question for this chapter is, 'What is the best trunk support angle for comfortable smartphone use on a bed?' It is hard to predict the outcome because in theory, a flat position might put too much strain on the neck because it is bent, and a fully upright position might result in too much stretching of the hamstring muscles. The experiment and results are described in this chapter.

At the faculty of Industrial Design Engineering, a special smartphone chair was developed with an arm support. This offered the opportunity to study smartphone use in this seat, which could give insight into how arm support is experienced. Therefore, a study was set up with the research question, 'Does body posture while using a smartphone influence productivity, comfort and discomfort?' The experiment and the results of this experiment are described in **Chapter 7.**

In **Chapter 8**, a Guidelines is developed for a seat for smartphone use in transport systems based on the knowledge developed in **Chapters 2-7**. This study shows a Guidelines that is especially focused on the armrest, which could support the elbows during smartphone use.

In the last chapter (**Chapter 9**), the main research question is answered, and an overview of the main results is given. Also, limitations of the current research are discussed, and suggestions are made for future research.

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Chapter 2

Literature review on seat comfort during smartphone use

Introduction

As noted, the number of smartphone users is continuously increasing. Using smartphones for a long period of time influences the upper body and can cause discomfort in the neck, shoulders, arms and upper and lower back, which might lead to musculoskeletal disorders (1). This chapter searches the literature for factors influencing comfort and discomfort during smartphone use. The comfort model (2) is used to organize the literature studies. The protocol of the literature review follows the PRISMA approach published by (3). It identified 50 articles. The main findings are described in this chapter.

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Chapter 2. Literature review on seat comfort during smartphone use

2.1 Abstract

BACKGROUND: Smartphone use in public transport systems increased from 8% to 48% from the years 2014 to 2018. Smartphone use while seated could cause discomfort, especially in the upper limbs, back and neck, and could lead to musculoskeletal disorders (MSDs). However, seats are often not designed for this activity. **OBJECTIVE**: This systematic review summarizes smartphone use with attention to the activities done, durations, postures, characteristics of the human body, and discomfort experience with special attention for vehicle seats. In addition, potential improvements of the seat are reviewed. **METHOD:** In all, 185 articles were collected from the Scopus and Pub-Med databases. The abstracts were screened by two researchers and then compared and discussed based on a set of inclusion criteria. Forty-five publications met the criteria, and five were added because the authors were familiar with them. **RESULT:** The literature shows that the smartphone is often used with two hands, sometimes with the elbows on an armrest. Smartphone use influences discomfort, which mainly occurs in the neck and back. Using a smartphone with proper arm support at the correct height might prevent neck and back pain. **CONCLUSION:** Many papers state that neck bending should be prevented, and smartphone usage time should be limited. Some studies mention that the preferred angle of the backrest for smartphone use is 120 degrees in an aircraft seat and an arm support should be added. In future studies, redesigned seats should be tested by smartphone users. The redesign can be based on the recommendations in this paper.

2.2 Keywords:

smartphone use, activities, posture, seat comfort, passenger, seat design.

2.3 Introduction

From 2016 to 2021, the number of smartphone users worldwide continuously increased from 2.5 to 5.2 billion. The Global Digital Report (4) showed that internet usage via a mobile device jumped from 26% in 2014 to 66% in 2021. Wi-Fi access has been introduced on public transport as well. Many Dutch trains now have Wi-Fi and power supplies for mobile devices (5). NS train (6) reported that 75.6% of the travellers in public transport or cars are using smartphones. (7) found that 48.3% of train passengers in The Netherlands were using a smartphone while traveling. According to a recent study in Thailand (8), this percentage was even higher, 57.4%, in 2021.

This growth in the use of mobile computing devices might have comfort and health implications. When people use a smartphone, they usually stress their upper bodies(9), resulting in neck flexion, eye strain and pain in the shoulder (1). The upper and lower arm, wrist and fingers could potentially be overused by holding the smartphone for a long time (1). The head is bent forward when people use a smartphone on their laps, which could increase neck pain, or the smartphone is held higher, which puts strain on the arms. Perhaps it would be preferable to use a smartphone while holding the arms on an armrest and with a more upright head position. Some studies report as much as 7 hours of mobile device use during the day (10). When people used a smartphone for a long time, they reported more pain and fatigue (11).

To prevent these problems, at least to some extent, it might help to redesign the vehicle interior of public transport systems like trains. Unlike desktop computing, there is not much literature on discomfort and health effects associated with the use of mobile computing devices, especially while traveling. To support the redesign of vehicle interiors (like trains, cars, and airplanes), background information on affected areas in the human body, activities performed during smartphone use and postures might be helpful.

The main goal of this study was to review what is known in the scientific literature on smartphone use in vehicles. We searched for activities, anthropometrics, seat elements, postures and perceived effects (comfort and discomfort experiences) of smartphone use. Additionally, we examined whether there is information on the interrelationships between smartphone use, activities, anthropometry and corresponding postures, comfort, and discomfort.

2.4 Methods

In this systematic review, we followed the method of PRISMA published by (3). We used the Scopus and PubMed databases. Both articles and conference papers were selected. The papers were included when they meet all three of the inclusion criteria. 1) The articles describe an experiment, observation, survey questionnaire, interview or co-creation session related to comfort, discomfort, activities or postures while using a smartphone on the seat. Additionally, 2) information was gathered on seat elements that are connected to smartphone use. Also, 3) the publications should be available in English and published between the years 2011 to 2022. Publications that are not related to the passenger's seat comfort or the effect of smartphone use are excluded.

Search terms were related to five aspects in the comfort and discomfort model proposed by (2) (Figure 1.3 in chapter 1). These aspects are Person (anthropometry, head, back, hip, thigh, arm, hand, fingers, leg, body), Usage/task (activities, smartphone, cell phone, mobile phone), Product characteristics (seat), Interaction with the environment (posture, position), and Perceived effect (comfort perception, experience, comfort, discomfort).

Search title terms were: "((head OR back OR hip OR thigh OR arm OR hand OR fingers OR leg OR body) AND (activities OR smartphone OR cell phone OR mobile phone) AND (posture OR position) AND (comfort OR discomfort OR perception OR experience))". In addition, search terms "((anthropometry AND activities AND seat) AND (posture OR position) AND (comfort OR discomfort OR perception OR experience))" were used. Additionally, the combined search terms "((head OR back OR hip OR thigh OR arm OR hand OR fingers OR leg OR body) AND (smartphone OR cell phone OR mobile AND phone) AND (posture OR position) AND (comfort OR discomfort OR perception OR experience))" were included. Figure 2.2 shows the results of the article screening process.

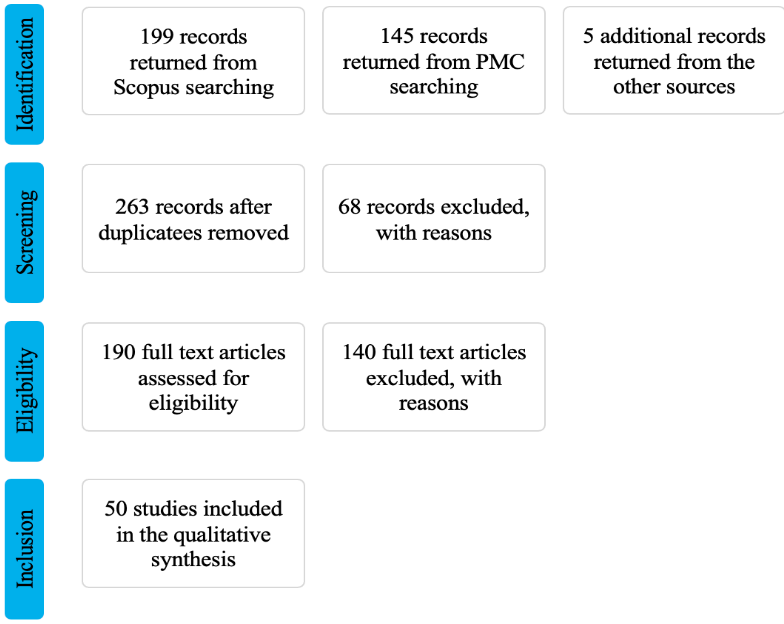

Figure 2.2: The results of article searching process.

The total identification process found 344 related articles from Scopus and PubMed. The authors added five papers that did not come up in the search but seemed relevant. This resulted in 263 articles. After screening,190 papers met the inclusion criteria. From this list, the relevance of the articles was checked. In all, 140 papers were excluded that did not mention 'seat' or 'smartphone use'. Review papers were excluded as well. Two researchers came to the same conclusion. This resulted in a total of 50 articles being included in the analysis. The studies are categorized according to the model (Figure 1), and the discomfort/complaints mentioned in the papers are counted per body region.

2.5 Results and Discussion

Twelve conference papers and 38 articles published in peer-reviewed scientific journals are found (see Table 2.1). The selected papers are divided over 6 different areas: 2.5.1. The activities and duration of smartphone use (usage/task in the model of Figure 1.3); 2.5.2. The effects related to human body dimensions (person in Figure 1.3); 2.5.3. The interaction with the environment (vibration) (interaction with the environment (I) in the model of Figure 1.3). 2.5.4 The internal human body effects (postures)**.** 2.5.5 The relationship with seat elements (e.g., the headrest and the armrest, the backrest and the seat pan, and the seat space) (Product characteristics in the model of Figure 1.3); and 2.5.6 Other improvements made to support smartphone use (intervention, which is the feedback loop from D (discomfort) to usage/task in Figure 1.3). The papers are presented in Table 2.1, below, summarizing the type of paper it is according to the categorisation described above, as well as the scope and focus of each study and the resulting main findings or recommendations for design.

Table 2.1: The papers studied, including their resulting findings and design recommendations.

Remarks: *; repeat articles, c; conference papers, s; peer-reviewed scientific papers.

No./ type	Authors/ environment	Subjects	Activities studied	Main findings/ recommendations for design
2.5.1 The activities and duration of smartphone use (usage/task)				
1 (s)	Ahmed et al., 2021(12)/sitting students	113 participants	Using a smartphone	The participants were using a smartphone for 3-5 hours per day. Inappropriate neck/thumb postures should be avoided.
2 (s)	Canaria et al., 2019(13)/classroom seat	101 online questionnaires/ 30 posture studies	Using a smartphone	Students use smartphones 4-7 hours per day. Non-neutral wrist and neck angles should be avoided while using a smartphone.
3 (s)	Damasceno et al., 2018 (10) /high school students	150 students	Using a smartphone	The students were using a smartphone more than 7 hours per day. There was no association between texting and neck pain in 18-21-year-old young adults.
4 (c)	Guzman-Sarmiento et al., 2020 (14)/ students	285 students	Typing/texting, checking email, surfing the WWW, graphic work, playing games, photo, watching a movie/TV, reading a book, listening to music, other	The students were using a smartphone more than 5 hours per day. Reducing exposure time and improving posture is advised.
5 (s)	Groenesteijn et al., 2014(9)/train passengers	786 observations/ 48 momentary observations/ 350 questionnaires	Non-smartphone activities: working on laptop/staring or sleeping/reading from paper/talking/writing/ listening to music/eating or drinking and phoning/ using Personal Digital Assistant (PDA).	The majority of passengers preferred adjustability options to fit the seat to the performed activity.
6 (s)	Hiemstra-Van Mastrigt et al., 2016(15)/aircraft	18 experiments, 114 questionnaires	Non-smartphone activities: upright sitting/ eating and drinking/ reading/sleeping or relaxing	The seat design should support the activities performed by the passengers.
7 (s)	Kamp et al., 2011(16)/train	743 train passengers	Non-smartphone activities: sleeping/ relaxing/watching reading/talking/eating or drinking/working using large electronic devices and using small electronic devices	Watching, talking/discussing and reading were most observed. Surprisingly, differences in head, trunk, arm and leg postures were not significant when using small electronic devices. The passenger’s seat should be designed to facilitate the activities.
8 (c)	Kilincsoy et al., 2018(7)/train	354 train passengers	Staring/sleeping, reading from paper, laptop, coffee/eating, music/ smartphone, tablet, talking, standing, writing, and others.	48% of the passengers use a smartphone. This implies the need for new Guidelines for train interior design.
9 (s)	Liu et al., 2019 (17)/ aircraft	27 healthy participants	Non-smartphone activities: sleeping and resting/reading/eating or drinking/talking and using small electrical devices/ watching video in flight/	Suggestions for seat design should be based on supportability, adjustability, affordance, and aesthetics.

No./ type	Authors/ environment	Subjects	Activities studied	Main findings/ recommendations for design
10 (c)	Ospina-Mateus et al., 2017(18)/sitting children	60 questionnaires for parent of children.	Gaming on computer and smartphone	The children use the computer, smartphone or tablet for 3 hours per day. The safest positions are sitting at a desk and standing, and the greatest risk is in the area of the neck-trunk.
11 (s)	So et al., 2017(6)/ sitting students	285 students	Typing/texting, checking email, surfing, graphic work, playing games, photo, watching a movie/ TV, reading a book, listening to music, other	The students were using ICT around 7.38+_5.2 hours per day. Reducing the exposure time and improving poor postures are needed to improve comfort.
12 (s)	Tapanya et al., 2021(19)/gaming seat	24 healthy participants	Using a smartphone with and without a newly designed arm support	The participants were using the smartphone around 7.19+_2.98 hours per day. The arm support reduces neck and shoulder muscle activity during smartphone use.
13 (c)	Udomboonya nupap et al., 2021 (8)/train	606 observations, 119 questionnaires	Listening to music, Texting, or typing, Texting, watching video, and reading from a smartphone.	Most passengers hold a smartphone with both hands, or with the right hand. The thigh support and the armrests need improvement.
14 (c)	Veen et al., 2012 (20)/car	26 rear seat passengers	Using laptop, tablet, book	EMG of the shoulder muscle was sometimes high, neck bending was seen. It was advised to create arm support for holding computer devices.
15 (s)	Woo et al., 2016 (21)/sitting with a smartphone	503	Using a smartphone and other computer activities	The participants were using a smartphone for more than 5 hours per day. The median nerve in the carpal tunnel was rotated, deformed and displaced during smartphone use.
16 (s)	Yalcinkaya et al., 2020 (22)/university students	63 young participants (18-25)	Using a smartphone and other computer activities	The young participants were using a smartphone between 3.6-4.2 hours per day. There was a fair relationship between the daily calling time on the smartphone and potential neck pain and disability.
2.5.2 The effects related to human body dimensions (Person)				
*	Canaria et al., 2019 (13)/classroom	101 online questionnaires/ 30 posture studies	Using a smartphone	Leaning the arm on the table and holding the smartphone at eye height level could help reduce neck flexion.
17 (s)	Sharafkhani et al., 2021 (23)/aircraft seat	29	Reading books/talking to friends/sleeping/ daydreaming/using laptop, phone or tablet for work and leisure.	Analysis in relationship to anthropometric measurements indicated that especially tall participants and those who were sitting in the middle seat may have performed space-constrained exercises more frequently.
*	Veen et al., 2012 (20)/car seat	26	Using laptop, tablet, book	In a car seat, the viewpoint at eye height results in close to neutral neck angles.

No./ type	Authors/ environment	Subjects	Activities studied	Main findings/ recommendations for design
18 (s)	Yoshimura et al., 2017/sitting and sleeping	23	Sleep after smartphone use	The viewing distance of smartphones in the sitting position ranged from 13.3 to 32.9 cm. among participants. In the lying position, it ranged from 9.9 to 21.3 cm., which resulted in better sleep.
2.5.3 The interaction with the environment (vibration)				
19 (c)	Amore & Qiu, 2019 (24)/car seats	12	Sitting on the car seat	There is a main effect of both vibration magnitude and sitting configuration (activity done) on comfort and protection.
20 (s)	Bhiwapurkar et al., 2016 (25)/train seat	30	Sitting on the train seat	The seat-to-head-transmissibility response registered maximum head motion in lateral direction with a single peak at 2 Hz. An additional peak was reported near 6 Hz in forward lean postures.
21 (s)	Desta et al., 2011 (26)/sitting at table with backrest relevant for travelling	12	Sitting on the seat	In terms of discomfort level and experimental data sets indicate that the human body resonance frequency or discomfort zone is around 5 Hz.
22 (s)	Guo et al., 2022 (27)/driver seat	20	Sitting on the car seat	In seat design, an appropriate lumbar support should be considered in case of vibration. This can help reduce fatigue in the lumbar muscle,
23 (s)	Singh et al., 2019 (28)/sitting without backrest	1	Sitting on the seat without backrest	At 2.8 Hz, maximum deformation of 5.6 cm. occurred at the head segment and with the increase in natural frequency, it started diverting to lower arms. At 18.7 Hz, maximum deformation (12.4 cm.) occurred at lower arms.
2.5.4 The internal human body effects (postures)				
24 (s)	Jin et al., 2019 (29)/ sitting standing	14 healthy men	Using smartphone and smartwatch	The tasks that require more time (typing and calling) should be performed on a smartphone, while the shorter tasks (application setting, message checking) could be allocated to a smartwatch.
25 (c)	Lee et al., 2016 (30)/students	16 healthy young students	Standing/sitting on the chair/sitting on the floor	Using a smartphone while standing for a short period could reduce the neck flexion angle.
*	Liu et al., 2019 (17)/ aircraft seat	27	Sleeping and resting/ reading/using small electrical devices/ watching videos in flight/ eating or drinking/talking with other	The most observed posture for passengers using a smartphone is head: free of support, trunk: against the backrest, arms: on the armrest, legs: both feet on the floor.
26 (s)	Nurwulan et al., 2015 (31)/standing and moving	20 college students	Normal stance/normal stance with texting/ tandem stance/tandem stance with texting	Using mobile phones impairs postural stability of the college students.

No./ type	Authors/ environment	Subjects	Activities studied	Main findings/ recommendations for design
*	Ospina-Mateus et al., 2017 (18)/ gaming	60	Gaming	Neck and trunk flexion should be avoided during smartphone use.
27 (s)	Elserty et al., 2020 (32)/students	420	Reading, studying, using social media (such as Facebook), all of the previous, other	Using proper postures and taking a break of at least 20 minutes could help to reduce muscle fatigue from smartphone use.
28 (s)	Thumser & Stahl, 2013 (33)/phoning	21 (19-57)	Phoning	Holding a phone to one ear restricts the range of spontaneously generated head movements and narrowed the range of gaze, influencing performance.
29 (s)	Vera et al., 2020 (34)/reading	24	Reading on a smartphone	Reading increases intraocular pressure, which is higher in the supine than in the sitting position.
*	Udomboonya nupap et al., 2021 (8)/train seat	606	Traveling by train and using smartphone	The most observed posture by train passengers was Posture 1 (head: free of support, trunk: against the backrest, arms: up on armrest, legs: free, both feet on the floor), followed by posture 2, the passenger held the smartphone only with the right hand. Posture 3 (head: free of support, trunk: against the backrest, arms: up on armrest, leg: crossed) (see Figure 2). All four postures are free from headrest, and arm support is missing.
30 (s)	Zhang & Dong, 2020 (35)/sitting	13	Using a smartphone	Recording a bad posture using a smartphone and warning helps improve the posture.
31 (s)	Frey et al., 2021 (36)/office seat	28	Sitting on the seat	Dynamic sitting resulted in lower pain ratings, decreased calf circumference, lower average seat pressure, and greater seat contact area.
2.5.5 The relationship with seat elements (Product characteristics)				
1) Backrest and seat pan				
32 (s)	Cappetti & Manso, 2021 (37)/kitchen chair.	17/4	Sitting on the seat	Considering the seat pan curve and cushion form could help to reduce stress at the articular joint of pelvis and hip. An adjustable front of seat pan could reduce stress at the knee joint.
*	Guo et al., 2022 (27)/ride seat	20	Sitting on the seat	In case of vibration, the seat design should have an appropriate lumbar support. This can help to reduce lumbar fatigue.

No./ type	Authors/ environment	Subjects	Activities studied	Main findings/ recommendations for design
33 (s)	Kumar & Saran, 2014 (38)/train seat	30	Reading and vibration	Vibration magnitude has the largest effect on reading. Reading while leaning on the table and with the book on the table showed the highest reading difficulty compared with leaning on the backrest with the book in hand. The reduction in reading performance is higher in the 'without backrest' posture compared to that 'with backrest' posture, in both vertical and lateral directions of vibration.
*	Liu et al., 2019 (17)/ aircraft seat	27	Sleeping and resting/ reading/using small electrical devices/ watching video in flight/ eating or drinking/talking with other	Support and privacy protection functions of headrest and backrest are needed. Adjustability is one of the most mentioned points in the answers to the questions by passengers.
34 (c)	Parida et al., 2019 (39)/car seat	51(23-60)	Using laptop/using smartphone/general reading, window gazing, sleeping	Backrest angle for laptop use is 94°, for smartphone use it is 100°, general reading and window gazing it is 120° and for sleeping, it is 150°. Seat pan angle while using laptop 9°, using smartphone 8°, general reading 10°, window gazing 10°, and sleeping 30°.
35 (s)	Pei et al., 2020 (40)/ aircraft seat	15	Sitting on the seat	120° angle of backrest and 34" seat pitch had increased comfort compared with more upright and less pitch. However, no smartphone use.
36 (s)	Smulders et al., 2016 (41)/business class aircraft seat	3 interviews/10 participants	Writing/eating and drinking/sleeping/ watching in-flight entertainment/listening to music/playing, working on a smartphone, tablet/ reading book/working on notebook	Backrest should be 110° for writing/ eating/drinking; 120° for mobile phone/tablet/reading book, 126° for listening to music.
37 (s)	Udomboonya nupap et al., 2021 (42)/sunbed	52	Using a smartphone	Using a smartphone lying on a sunbed showed highest comfort at 120° to 142° backrest angles.
38 (s)	Wang et al., 2019 (43)/experimental seat	36	Sitting on the seat	A 100° and 110° backrest recline were associated with an average seat pan angle of 6.2+-3 degrees for a comfortable position (preventing shear force).
39 (s)	Wang et al., 2018 (44)/experimental seat	36	Sitting on the seat	Guidelines for the seat contour and backrest contour for an aircraft seat are presented based on recordings. A relationship between the seat pan and backrest angle was found.
2) Armrest Headrest				
*	Canaria et al., 2019 (45)/classroom seat	101 online questionnaires/ 30 posture studies	Using a smartphone	Leaning the arm on the table and holding the smartphone at eye level could help reduce neck flexion.

No./ type	Authors/ environment	Subjects	Activities studied	Main findings/ recommendations for design
40 (s)	Ciaccia & Sznelwar, 2012 (45)/aircraft seat	6	Resting/reading	The armrest was massively used in reading, and participants frequently used the environment such as windows and side ledge to support mainly their head and limbs.
41 (s)	Kuo et al., 2019 (46)/test collar	41 healthy young subjects	Using a smartphone	A cervical collar could reduce the neck and head angles during smartphone use.
*	Liu et al., 2019 (17)/ aircraft	27	Sleeping and resting/ reading/using small electrical devices/ watching videos in flight/ eating or drinking/talking with other	Passengers mentioned that the armrests are too hard and narrow. The armrests need to be wider and more inclined.
42 (s)	Smulders et al., 2019 (47)/television seat	21	Watching IFE	Head position was more upright while watching IFE without headrest compared with the same condition with headrest.
43 (c)	Tan et al., 2013 (48)/aircraft seat	No	No activities were studied.	Head and neck cushion supporting the neck on both sides controlled by air pressure sensors and solenoid valve increased passenger head and neck comfort.
*	Tapanya et al., 2021 (19)/gaming seat	24	Using a smartphone	Arm support helps reduce neck load and shoulder muscle loading and fatigue during smartphone use
*	Veen et al., 2012 (20)/car seat	10 (age 18-67)	Typing/playing games/ reading on tablet	During tablet use, neck flexion is significantly less with armrests compared to without armrests for all tasks. Armrests should be cushioned with 3.0 cm. polyether foam. Height of upper arm support was 36.0 cm. and of lower arm support 38.0 cm. (24° between upper and lower arm).
44 (s)	Veen et al., 2014 (49)/car seat	26	Using laptop, tablet, book	Appropriate armrests or other support should be developed to reduce neck bending and shoulder activity at the same time.
45 (c)	Udomboonyanupap et al., 2019(50)/seat	24	Texting	A too-high arm support that restricts movement can lead to more discomfort than no arm support.
3) Seat space				
*	Liu et al., 2019(17)/ aircraft	27	Sleeping and resting/ reading/using small electrical devices/ watching videos in flight/ eating or drinking/talking with others	Future design should avoid a restricted seat space.

No./ type	Authors/ environment	Subjects	Activities studied	Main findings/ recommendations for design
*	Pei et al., 2020 (40)/ aircraft seat	15	Sitting on the seat	A 120° backrest angle and 34-inch seat pitch is more comfortable than a standard one
*	Veen et al., 2012 (20)/car seat	26	Using laptop, tablet, book	Enough legroom is needed to increase comfort.
2.5.6 Other recommendations for smartphone use				
*	Ahmed et al., 2021(12)/students sitting	113 participants	Using a smartphone	Proper warning should be provided while using a smartphone in abnormal postures for a long period.
46 (c)	Campos et al., 2014 (51)/screen design	13	Experiment on finger and thumb angle	Horizontal screen touching is less comfortable than vertical. A preferred thumb touchscreen area is defined to design touch screen control buttons.
47 (s)	Hiemstra-van Mastrigt et al., 2015 (52)/gaming in car	6	Active seating/gaming	Participants felt more fit and more refreshed during active seating.
48 (s)	Hiemstra-Van Mastrigt et al., 2016 (15)/aircraft seat	18 participants, and 114 questionnaires	Upright sitting/eating and drinking/reading/sleeping or relaxing	A sitting break by walking through the plane and serving food reduces discomfort.
49 (c)	Pope-Ford et al., 2017 (53)/children	9	Gaming	Parents should be careful to prevent MSDs and ocular symptoms.
*	Sharafkhani et al., 2021 (23)/aircraft seat	29	Reading books/talking to friends/ sleeping/ hard-wearing/ using laptop, phone or tablet for work and leisure	Exercise could help to decrease discomfort while sitting for a long time.
50 (s)	Tang et al., 2021 (54)/sitting and standing	25	Using a smartphone	Prism glasses can help to reduce the neck extensor muscle activity and neck flexion while texting on the phone
*	Woo et al., 2016 (21)/students	503	Using a smartphone and other computer activities	Smartphone users should get a training program to help people hold proper postures and monitor phone time during smartphone use.
*	Yalcinkaya et al., 2020 (22)/students	63 young participants (age 18-25)	Using a smartphone and other computer activities	Long smartphone calling affects cervical joint repositioning in university students. Design configuration and accessories would be helpful for posture and comfort during smartphone use.
*	Zhang and Dong, 2020 (35)/sitting	13	Using a smartphone	A warning system could help to reduce smartphone usage time.

2.5.7 The relationships found in the literature.

1) The activities and duration of smartphone use (usage and tasks)

Train passenger activities have changed over the last 10 years. In 2011, the main activities were reading, talking and relaxing (16). Three years later, (9) found that staring/sleeping, relaxing and watching were the main activities performed by the train passengers, but the use of mobile devices was observed as well. Eight percent of the observations consisted of mobile device use. (7) reported that smartphone use is the main activity train passengers performed in 2018 (48% of the time), followed by staring/sleeping and reading a book. (17) found that aircraft passengers were mainly sleeping, using small electrical devices (33% of the time) and reading from paper. In 2021, (8) showed that train passengers were using smartphones 57% of the time while traveling. The four main activities performed by train passengers on a smartphone are listening to music, Texting, watching a video and reading on the phone. To increase passenger comfort, (16), (9), and (15) suggest designing the seat based on activities that are performed.

In addition to the fact that passengers use their smartphones during travel, people also use them in daily life. The studies in Table 2.1 show that 4 studies report around 7 hours of smartphone use per day, while 5 studies mention between 3-5 hours per day. The studies point out that this is a lot of hours.

2) The effects related to human body dimensions (Person)

Three papers mention that the smartphone should be held at eye level. (13) mention that neck flexion decreased when the user propped the arms on the table to hold the smartphone at eye level. However, lower arm height and upper arm height vary considerably, which might not solve the issue for everyone. (49) developed an armrest in such a way that for 9 out of 10 participants, who varied a lot in anthropometrics (height 157 cm. to 190 cm), discomfort was reduced, and the head was 10 degrees closer to the neutral position (more upright). The distance between the eye and the screen could also help reduce neck flexion. Additionally, the distance itself affects sleep quality. Sitting users who had their smartphone further away from their eyes were compared with lying users (55). Using the smartphone before sleeping in a sitting position resulted in better sleep. (55)mention that most studies advise 30-50 cm. distance between the eyes and the smartphone, but their study recorded a distance of 20.3 cm. while sitting, which was better than while lying down (16.4 cm.). Variation of posture is important to reduce discomfort. However, (23) showed that in an aircraft seat, tall people and passengers in the middle seat have fewer opportunities to vary their posture or do exercises.

3) The interaction with the environment (Vibration)

Five articles concern vibration (see Table 2.1). Vibration certainly influences performance and comfort during smartphone use. According to these papers, reading performance decreases with vibration, and more vibration both in lateral direction (relevant for trains) and vertical direction (relevant for cars) means more discomfort. A backrest (38)and good lumbar support (27) could help reduce the effects.

4) The internal human body effects (Postures)

Ten papers concerned posture and smartphone use. The most observed postures of train and aircraft passengers and (8) using a smartphone are shown in Figure 2.3: Head: free of support, Trunk: against the backrest, Arms: on the armrest, Legs: both feet on the floor, followed by passengers holding the smartphone with the right hand only, and followed by resting the smartphone on the lap.

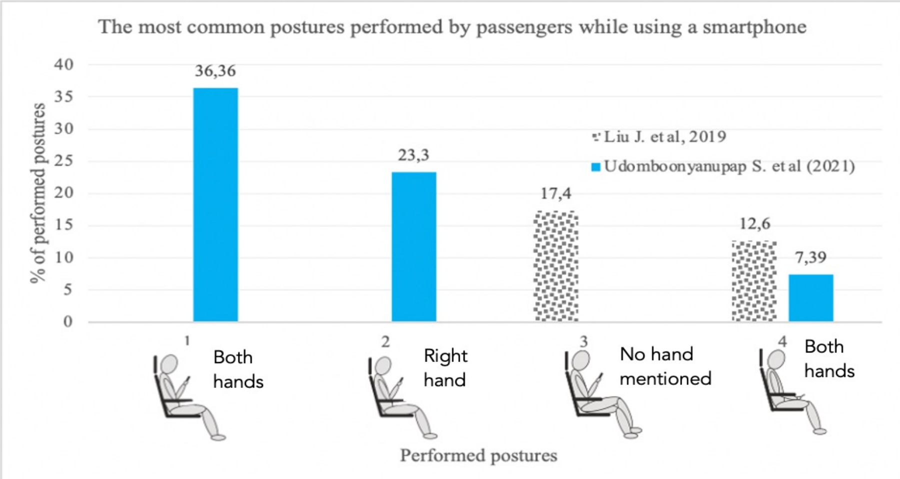

Figure 2.3: The most observed postures performed by passengers while using a smartphone.

As mentioned, these papers also state that neck flexion should be avoided. Three papers investigated preventing bad posture. The first, (35) recommend having a warning when there is bad posture to help users improve their posture. The second, (56) suggests that taking a break of at least 20 minutes from smartphone use can reduce muscle fatigue. The third, (30), suggests using the smartphone while standing for a short period, which could reduce the neck flexion angle. There is also a relationship between texting and postural stability. During texting, stability is impaired (31). If possible, the seat and backrest should be dynamic to vary posture (36).

The other three papers on posture state (1) that holding a smartphone to one ear for too long should be avoided because it restricts the range of spontaneously generated head movements (2) that reading increases intraocular pressure. Vera (34) which is higher in the supine than in the sitting position (another paper states that smartphone use should be done sitting instead of lying down) and (3) that tasks that require more time (typing and calling) should be performed on a smartphone, while the shorter tasks (application setting, message checking) could be done on a smart watch

2.5.8 The relationship with seat elements

1) Backrest angle and seat pan

Thirteen papers explore the backrest and seat pan in relationship to sitting and smartphone use. The preferred backrest angle while sitting varies between 100 and 120 degrees. Two papers, both on aircraft seats (40), and(41), suggest 120 degrees for smartphone use. One paper on car seats (39) suggests 100 degrees. (39) also proposes a seat pan angle of 8 degrees. When listening to music with the smartphone, the angle is 126 degrees (41). When lying on a sunbed, the preferred backrest angle for smartphone use is between 120 and 142 degrees(42). In case of vibration, a lumbar support is advised to reduce fatigue(27). Due to the vibration influence, reading performance on the phone is higher with than without a backrest Kumar & Saran, (2014). A contoured seat is also advised (37). One paper by Wang (44) showed that the seat pan angle is dependent on the backrest angle to prevent shear forces in the thighs and buttock. A seat pan should be soft in the front of the seat to avoid pressure (57). Two papers also advise adjustability of the seat pan and backrest(58), and (17).

2) Arm and neck support

Four papers observe that smartphone users use an armrest(45), (13), and (20). Three other papers advise providing a support for the arm (17), (20), (49) and (19) since this reduces neck flexion. Two cases mention that arm support helps relax the shoulders (20), and (20). Armrests should not be too high and restrict movement because this increases discomfort(50). Armrests are sometimes too hard or narrow. One study recommends that the armrest should be padded with 3.0 cm. polyether foam(50).

One paper suggests the need for a head support (48). Another tested the effect of a cervical collar (13), which resulted in less discomfort during smartphone use. Also, a neck cushion supporting the neck on both sides controlled by air pressure sensors increased head and neck comfort (48).

3) Seat space

Most papers implicitly mention that space is needed for smartphone use for instance, the paper that shows that the distance from the eyes should be long enough(55). Three papers explicitly mention that enough space is needed for smartphone use(17), (20), and (20). One paper proposes the dimensions of the for-aft space: for an aircraft seat, a 34-inch pitch is preferred (40).

2.5.9 The other recommendations made to support smartphone use.

The other ten papers made recommendations for smartphone users. Four mention that for smartphone use, training(40), education (53), an active seat (52), or exercises, (23) should have positive effects on discomfort. One paper reports the positive effects of taking a break by walking through the plane in a long-haul flight(15). Two papers mention that a warning system for overly long smartphone use or having bad posture is advisable(12), and (35). Two papers advise using accessories, (22), and(54). Tang (54) also mentions prism glasses to prevent neck bending. One paper has advised on the position of touchscreen buttons and activities that fit to the human body, (51).

1) The perceived effects (comfort and discomfort)

Thirty articles out of fifty publications reported neck pain or discomfort could affected by a smartphone use, and twenty-seven papers mentioned back problems or discomfort related to smartphone use. Moreover, head, arms, hands, and shoulders are also often mentioned (see Figure 2.4).

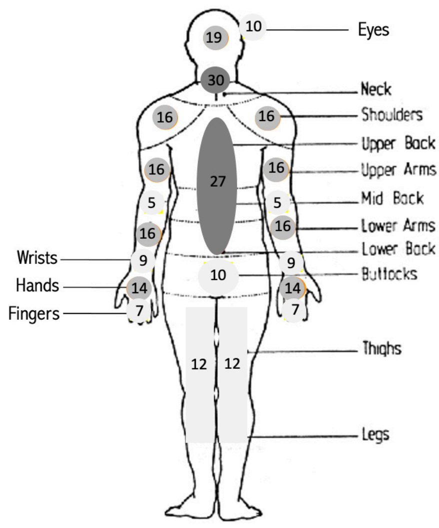

Figure 2.4: The articles that mentioned the body part discomfort during smartphone use. Modified from a technique for measuring postural discomfort (59).

The discomfort is dependent on activities and postures. For instance, listening to music while using a smartphone gives more freedom for body postures and might result in fewer complaints. Future study should indicate the activities performed on a smartphone, for example, texting, reading or watching the video. However, eyes and fingers should be focus.

2) Synthesis: Guidelines for seat improvements in the context of smartphone use.
The passenger's comfort experience could be increased by redesigning the seat elements. However, in the design process, the activities, anthropometry and corresponding postures performed in the seat should be considered. The angle of the backrest depends on the activity. For most smartphone activities, an angle of 120 degrees seems preferable in an aircraft seat (41), and(40), but further research is needed, especially for applying it to other vehicles. Wang (44) state that when the backrest is reclined, the seat pan angle should be adapted to avoid the passenger sliding out of the seat (shear force). This phenomenon was also described by (60) The appropriate seat pan angle for smartphone use seems to be between 5 degrees (43), and 8 degrees(39), which also should be studied further.

Stability while using a smartphone could be improved by an arm support (31). If the arm support is at the right height, it could also bring the smartphone closer to eye height, which reduces neck flexion. Passengers have complained that the armrests are too hard and narrow. Veen (20) show that heightened arm support reduces neck flexion and increases comfort. However, (50) show that the armrest should not be too high or restrict freedom of movement, which could also increase discomfort. More research is needed to define the ideal armrest for vehicles. It is clear from the literature that using a smartphone for a long period can increase muscle fatigue and neck discomfort. (12) and (35) suggest issuing a warning when a smartphone is used for a long period in awkward postures. Breaks and variations of posture have shown positive effects on discomfort in several studies.

2.6 Conclusion

This literature review on seat comfort in the context of smartphone use showed that it is one of passengers' main activities while they are travelling nowadays. Their most frequently observed postures are both hands on the phone and laying the arms on the armrests. Discomfort during smartphone use is most often found in the neck, followed by back, shoulders and arms. Some studies show that an arm support reduces neck flexion and neck discomfort, which is potentially a good solution and needs further research on the preferred height. However, the duration of smartphone use should be reduced by taking breaks. Vibration in cars and trains influences the passenger comfort experience as well. Slight evidence is available that a lumbar support and a backrest reduce the influence of vibration. The preferred angle of the backrest for smartphone use is 120 degrees in an aircraft seat. Limitation of this study is the articles selection process, that includes a lot of articles related to the effects of smartphone use for the users. However, only a few papers related to the smartphone use of the passengers, and the design improvement. Next publication of the literature review should be added the methods for example, screening the articles by the experts on that field. Further research is needed on this point, especially for other vehicles. In future studies, redesigned seats should be evaluated. The redesign can be based on the first design directions mentioned in this paper. In addition, the performed activities, anthropometric data and behaviour of passengers should be taken into account.

2.7 Acknowledgement

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Chapter 3
Passenger Activities, Postures, Dis (Comfort) Perception, and Needs During Train Travel

Introduction

The literature review in the previous chapter showed that there is limited knowledge on postures and activities of smartphone users while travelling. Damasceno (1) found that people used a smartphone more than 7 hours per day and they were using the smartphone while waking up, at home, traveling to work, working, dining, and traveling back to their house. Kilincsoy & Vink (2), and Liu (3) reported the increase in percentages of smartphone use on the train and in the airplane. These activities result in comfort and discomfort experiences of the passengers. However, to improve the vehicle environment more data are required. Data are needed, for example, on the activities performed on the smartphone, the related postures, and the needs. This chapter reports on the observation of the postures, activities, and needs of train passengers.

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Chapter 3. Passenger Activities, Postures, Dis (Comfort) Perception, and Needs During Train Travel

3.1 Abstract

This study aims to collect data on the activities, postures, dis(comfort), and needs of train passengers. Observations in the trains and questionnaires completed by train passengers were used. The online questionnaire was completed using the smartphone of the passengers during the train trip. The most often observed activity of the passengers was using a smartphone while travelling. They used a smartphone to listen to music, chat or type, look at a video or picture, and to read. Most passengers reported that they hold a smartphone with both hands and used a smartphone with the right hand. The thigh support and the armrests of the seat showed the lowest comfort and certainly have room for improvement. Future research could be considered for the design of a seat to increase passenger comfort while using a smartphone.

3.2 Keywords: Train, Smartphone, discomfort, Activities, Posture

3.3 Introduction

From 2016 to 2020 the number of smartphone users worldwide continuously increased from 2.5 to 3.5 billion. The Global Digital Report (4) showed that internet usage via a mobile device has jumped from 26% in 2014 to 48% in 2019. Smartphones can be used in many locations, for example in bed, on the airplane, and on the train. Observations by Kilincsoy and Vink (2) in the train in the Netherlands showed that smartphone use increased from 12.1% in 2014 to 48.3% in 2018 and the activities that are done using the smartphone differed in duration. Honan (5) described that smartphone use influences the neck flexion, eye strain, and pain in the arm, wrist, and fingers. More pain and fatigue were reported when the smartphone was used for a long period (6). This might lead to Musculoskeletal disorders (MSDs) or a Smartphone Syndrome. The smartphone is also used on trains and facilitating smartphone use by reducing neck flexion might be a way to attract more passengers on the train apart from creating more comfort. There are other papers studying postures and activities on the train: (7), (8), (9), (2). However, the way of working with information and communication technology possibilities have been changing drastically. For example, previous studies by (2) and (10) observed passenger activities on the train. Both studies collected several activities: sleeping, reading, talking or discussing, and others. However, the activities of the passenger in the 2018 study on the train changed drastically. Thus, new knowledge on postures and activities is needed to optimize train interiors to facilitate that the traveller can both work and relax optimally. However, more background knowledge is needed to define which part of the interior should be optimized. The 3 main research questions for this study are: 1) How much smartphone use can be observed in train passengers in Thailand? 2) What activities are performed on the smartphone? 3) How is it linked to posture change and dis(comfort) perception?

3.4 Methods

To answer above mentioned questions train passengers were observed and asked to complete questionnaires. This study followed the study by (9). The observation focused mainly on the percentage of passengers using a smartphone, while the questionnaires were used to collect the performed activities and tasks while using a smartphone. The researchers collected the data in a sprinter train starting at Nakhonratchasima train station in Thailand. A pilot test was conducted with 40 paper questionnaires and 18 online questionnaires using a mobile phone. Of the questionnaires, 19 copies were returned of the paper version and 11 were completed. All 18 persons who joined the online questionnaire returned their questionnaire completed. For this reason, the online questionnaire was selected. Based on the pilot nine self-reported postures were defined and a tenth 'other' was added (figure 3.1). Five researchers were trained, and sessions started by explaining the project objective and benefit to the passengers. Then an observation of how many people used a smartphone was recorded by five trained researchers using an observation form. The main characteristics of the ride were noted (three inputs): train, class, and railway carriage number. Then the total number of passengers in the carriage, and number of passengers who use a smartphone were noted by the observers. Then the researchers asked the train passengers to fill in their performed activities, posture, dis(comfort) experience, and their needs in the online questionnaire. They sat on the seat and conducted their normal activities while completing the comfort questionnaire on their smartphone. The global and local discomfort scores were collected using a CR-10 scale (11). In each body part, they could rate discomfort on a scale of 1-10 (1= No discomfort at all, 10= Extreme discomfort) using a local discomfort map by (12) (figure 2.4, Chapter 2). The first part of the questionnaire provided the consent form, in which the participants could read about the project objective and make their decision to participate or not. After that, they completed the questionnaire and uploaded it by clicking a submit button.

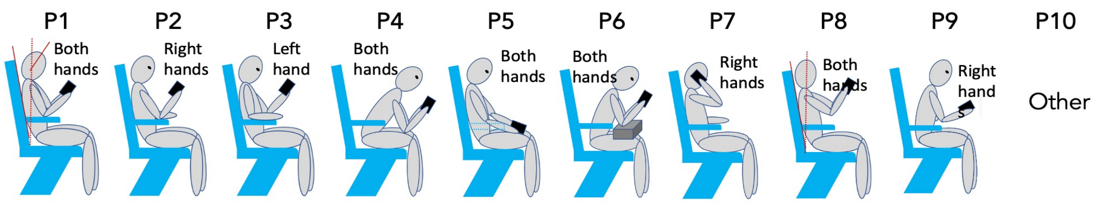


Fig 3.1: The postures corresponding to smartphone use.

3.5 Results and Discussion

3.5.1 Observation results of the main activities performed by the train passengers.

The observation could answer the research question on which percentage of train passengers use a smartphone. The researchers collected the overall number of train passengers, then the number of people who use a smartphone were recorded on the observation form. The results showed that from 606 train passengers 57.43% were using a smartphone during the trip. This is a 9.13% increase in smartphone use from the last publication by (2) as shown in figure 3.2.

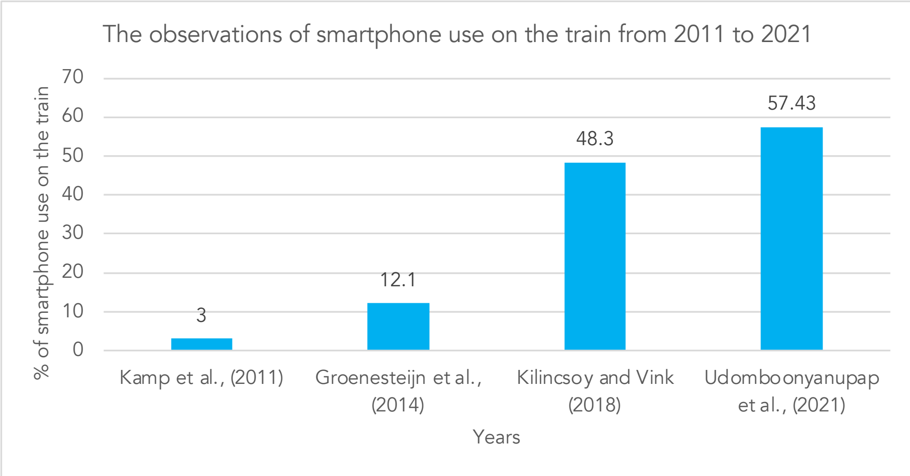
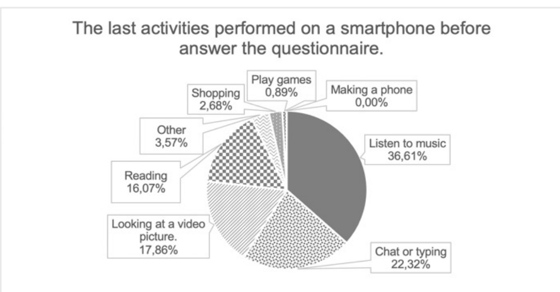


Fig. 3.2: Smartphone use in the train in several studies from 2011 to 2021.

3.5.2 The questionnaire on activities, postures, dis(comfort), and needs of the train passengers.

The questionnaire was completed by 119 passengers who used a smartphone on the train. There were more female than male passengers in the study population (61.2% female, 37.3% male, and 1.5% considered themselves as others). Their reported average height was 164 cm, which varied from 150 cm to 183 cm. The weight varied from 40 kg to 100 kg, with an average of 64 kg. The ages of the participants varied from 18 to 67 years (average 31 years). Their jobs were of type low-intensity for 64.3%, followed by moderate-intensity 27.0%, and 8.7% high-intensity. 47.97% of passengers travelled by train to visit their family, while 20.27% and 18.24% stated that their trip was for holiday and commuting purposes respectively.

1) Main activity of the train passengers.
Of the passengers, 88,9% reported mainly using the smartphone during train travel, while the remainder reported mainly doing other activities. The last activities of the passengers using the smartphone (Figure 3.3) was listening to music (36.61% of the time), Texting or typing (22.32%), looking at a video or reading (17.86%, 16.07% respectively). For the questions what the passengers did on the smartphone for the whole trip, it was listening to music for 24.41% of the time, 18.90 % Texting or typing on the screen. Looking at a video or picture was 16.93% of the passengers and reading 13.39% as presented in figure 3.4.



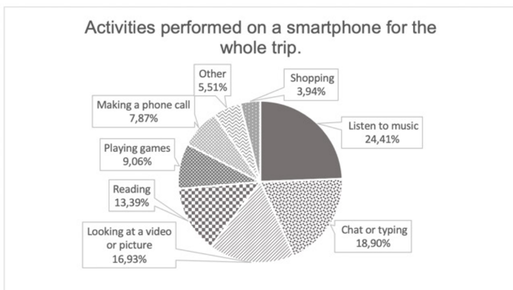


Fig. 3.3: The last activities performed on a smartphone before answering questionnaire (in percentages of the 88.9% of passengers)

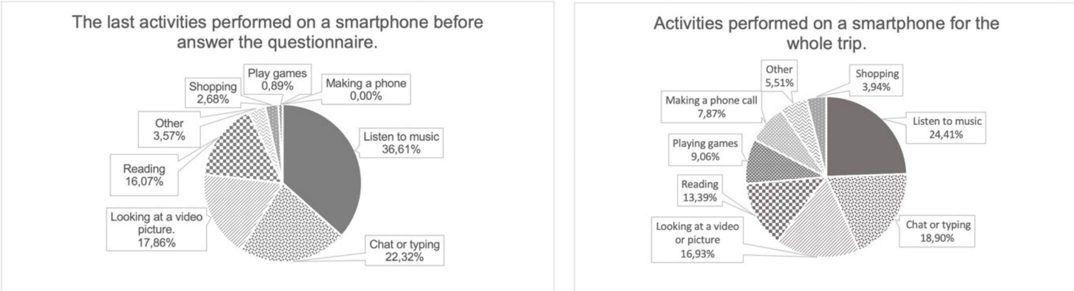


Fig. 3.4: activities estimated by the passengers over the whole trip (in percentages of the 88.9% of passengers)

The average duration for the main activity was approximately 98 minutes. However, they performed the tasks on a smartphone for 30 to 120 minutes. The minimum time was 10 minutes and the maximum 420 minutes. The travel time for the whole trip was on average 6.48 hours and the duration varied from 2 to 12 hours.

<u>2) The postures while using a smartphone on the train.</u>
The ten postures during smartphone use that participants reported are listed in figure 3.1.

Participants then self-reported

- their last posture before completing the questionnaire and
- their posture as estimated for the whole trip.
- The percentages of these are shown in figure 3.5. The two most common postures were:
- using both hands to hold their device and using the arms support, at 26.3%, and 36.4%, respectively.
- holding the smartphone in the right hand, and using the armrests, at 30.5% and 23.3%, respectively.

Other postures were used for lower percentages.

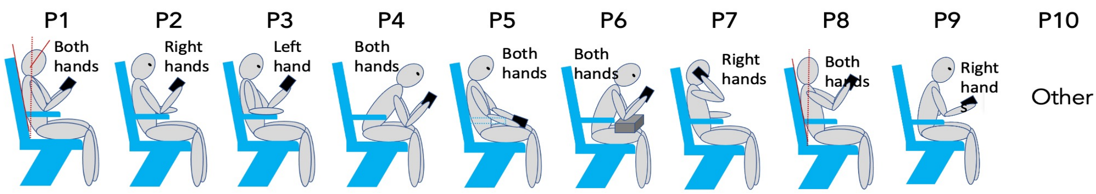


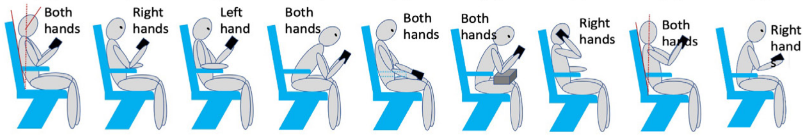
Fig. 3.5: Self-reported last posture before answering the questionnaire and estimated posture during whole trip while using a smartphone on the train.

Table 3.1, below, shows the self-reported activities and corresponding postures of the train passengers. Of these, 20% held a smartphone with the right hand and used the armrests when listening to music. 10% held the device with both hands and put their elbows on the arm supports for Texting or typing. They assumed the same posture at 5.83% for listening to music, and 5.00%, for reading.

Table 3.1: The self-reported postures and

performed activities of train passengers (%).

Postures / Main activities	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
	Both hands	Right hands	Left hand	Both hands	Both hands	Both hands	Right hands	Both hands	Right hand	Other
Listening to music	5,83	20,00	1,67	1,67	1,67	0,00	1,67	2,50	1,67	2,50
Texting or Typing	10,00	1,67	2,50	1,67	1,6	1,67	0,00	2,50	0,83	0,00
Looking at a video	2,50	4,17	2,50	0,00	2,50	0,83	0,0	2,50	0,00	0,83
Reading	5,00	2,50	1,67	0,00	2,50	0,0	0,0	0,00	0,00	0,83
Playing games	0,00	0,83	0,00	0,00	0,00	0,	0,00	0,00	0,00	0,00
Other	1,67	0,83	0,00	0,00	0,00	0,00	0,00	0,83	0,00	0,00
Shopping	1,67	0,00	0,83	0,00	0,0	0,00	0,00	0,00	0,00	0,00
Making a phone call	0,00	0,00	0,00	0,00	0,00	0,00	3,33	0,00	0,00	0,00



3) Seat comfort experience.

The overall comfort and discomfort experience while using a mobile device on the train was 5.47 and 5.70 on a scale from 1 to 10 respectively. The seat pan was rated with the highest comfort score: 6.01, The upper backrest and lower backrest followed, with a score of 5.66 and 5.54, respectively. The lowest scores were 4.41(thigh support), and 4.89(Armrest), and 4.99(headrest), respectively (Figure 3.5).

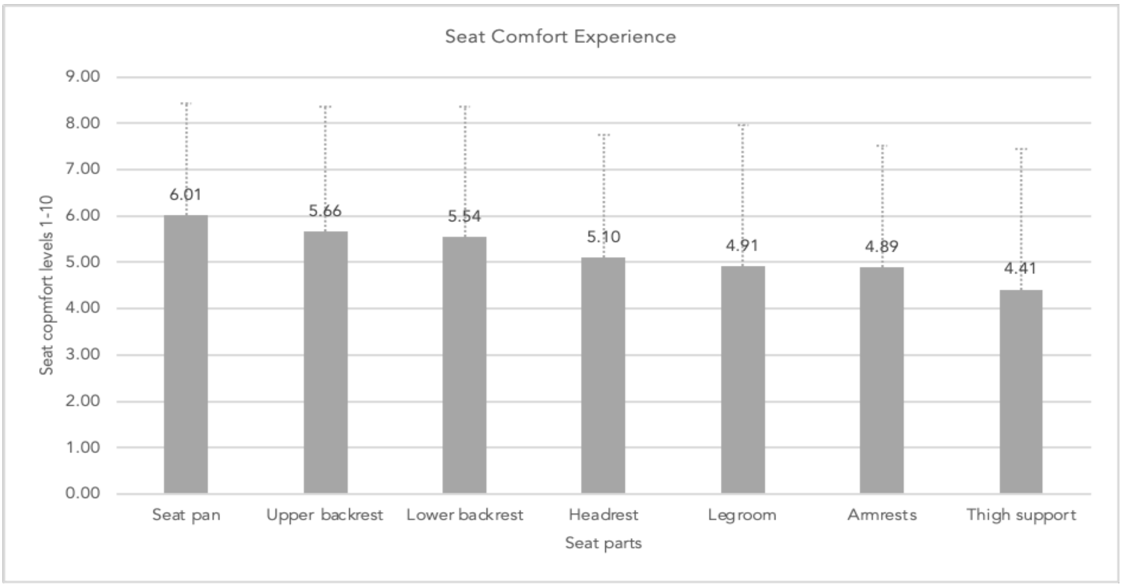


Fig. 3.5: Seat comfort experience during train travel.

4) Dis(comfort) perception.

The train passengers' discomfort ratings per body part showed that the upper back and middle back had the highest scores (5.61), followed by the buttocks, the right fingers, the lower back, and the right upper arm (5.58, 5.46, 5.40, and 5.38, respectively). Figure 3.6 illustrates the comparison of discomfort between the left and the right body parts. The Wilcoxon signed-rank test showed a significant difference for the shoulder, upper arm, hand, and fingers ($P<.05$). The right side showed a higher level of discomfort than the left side.

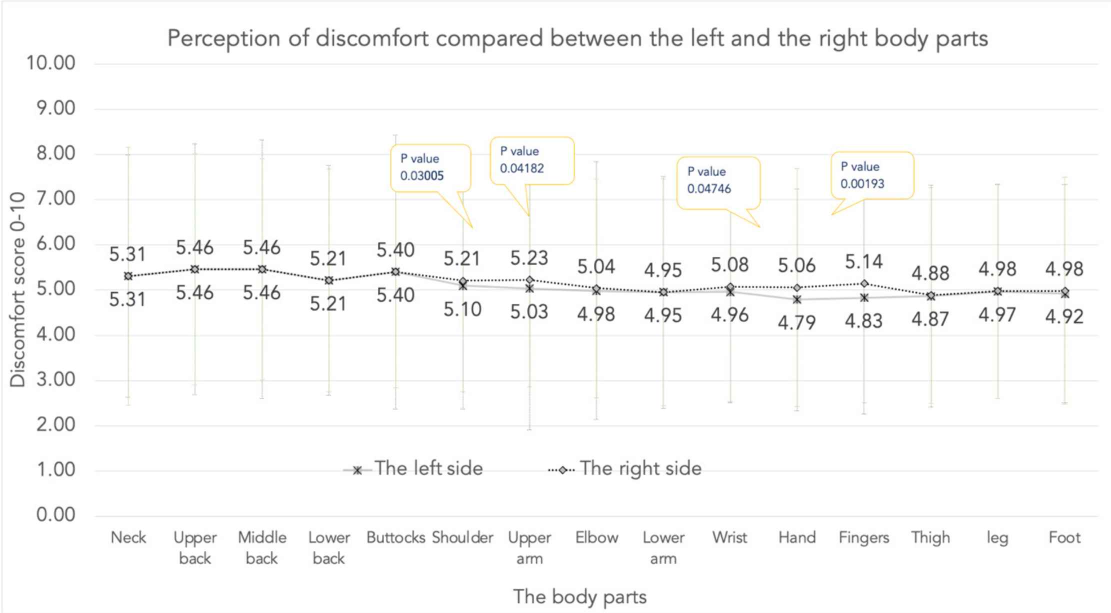


Fig. 3.6: Discomfort per body part for left and the right side of the human body.

5) The train passengers' needs related to comfort during smartphone use.

On the general question "Which improvements are needed for comfortable smartphone use?", the Wi-Fi and charger score highest. 21% of the passengers preferred to have Wi-Fi and a charger. 18% mentioned that they needed a better seat pan, for example by increasing the softness and the width of the seat or changing the cover material to reduce slipping while seated. 17% mentioned the cleanness inside the train and physical problems like maintaining the same posture over time. Also, passengers mentioned improvement of the armrests such as by installing armrests between the two seats and improving the width and softness of the armrests. Additionally, the high level and the size of arm supports was mentioned by 15% of the passengers. Finally, 12% preferred to have a headrest, and 12% needed more legroom.

3.6 Discussion

Kamp (10) found three main activities while people travel by train: reading, talking/discussing, and relaxing. Seven years later (2)observed these three activities: smartphone use, staring/sleeping, and reading from paper. Groenesteijn (9) found 3 main activities staring/sleeping, relaxing, and watching. The corresponding postures of the last study are presented in figure 3.7. Although smartphone use was not one of the main activities, the passengers held the smartphone with both hands or in the right hand and used an armrest. This result is comparable with a previous publication by (13), who found that 46.1% of the subjects use a smartphone with both hands, and 36.2% hold a mobile phone in the right hand.

In this study, the main self-reported activity was using a smartphone. It could have been influenced by the rapid change of information and technology leading up to 2020. However, the other activities that did not relate to smartphone use were the same as previous publications, for example, sleeping, watching or observing, and relaxing. But there were some decreases in percentages, for example in sleeping, shopping, and eating on the train.

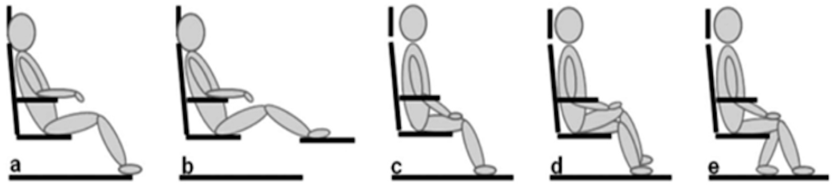


Fig. 3.7: Significant postures for sleeping (a and b), relaxing (a) and watching (c/d/e), studied by Groenesteijn et al. (2014).

The result of smartphone use is that upper back and middle back have the highest discomfort score. Another study (14) showed that passengers using a smartphone on the airplane mentioned the highest discomfort in the neck. An explanation could be that the heights of the participants were completely different. The average height of this study was 164 cm., while in the airplane study it was 175 cm. Moreover, the main activities in this train study were listening to music (36.6%) and then neck flexion is not needed most of the time.

The results of this study indicate that comfort can also be linked to the armrests. For the two main postures observed, passengers used armrests while holding the devices. Gustafsson (15) have reported ergonomic recommendations for texting on a smartphone. A forearm support was preferred while typing fast on a small device, to avoid the neck bending forward. Van Veen (16) reported that discomfort decreases significantly for the neck with forearm support, but that arms and hands were not significantly different. A reason for this finding was that participants were able to adjust the height level of the arm support to fit their anthropometry and bring the screen closer to eye height.

Thigh support of the train seat of this study was also an issue. It was too high, and the seat pan was too long. When passengers were sitting on the seat, and they tried to put their feet on the floor it created more pressure on the thighs. This result is in alignment with (17), who reported that when there is too much load at the front of the seat, discomfort increases. Moreover, (18) found that out of all body parts in the buttock, the area contacting the front area of the seat pan had the highest sensitivity levels, significantly higher than other areas in the buttock.

3.7 Conclusion

The main activity observed among 606 train travellers is using the smartphone. The smartphone is self-reported to be used for listening to music, Texting, looking at videos, pictures, and reading. Passengers reported two main body postures during a train trip in which they used a smartphone. The most frequent style reported was with both hands holding the device with both thumbs typing (36.4%) and one thumb typing while the same right hand holds the device (23.3%). In the seat, the thigh support and the armrests showed the lowest comfort score. These results might be useful for new ideas for train seat design that increase the passenger comfort, given the change in activities.A limitation of this study was that some passengers preferred to sleep or were unwilling to answer the questionnaire. In future research it would be ideal to observe the duration of all of the other activities as well.

3.8 Acknowledgement

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Chapter 4
Train Passengers' Needs for the Seating Environment.

Introduction

Chapter 3 showed the observed postures and activities passengers assume while using a smartphone. It also mentioned that discomfort is high. In this chapter, co-creation sessions were organized to gather information on the needs of passengers and ideas to improve the environment in the vehicle. Insights into the needs are gathered by using context mapping and co-creation.

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Chapter 4. Train Passengers' Needs for the Seating Environment.

4.1 Abstract

The number of train passengers using smartphones is continuously increasing, which directly influences their comfort on long-distance train journeys. In this study, data are gathered to improve the train passengers' seating environment. Thirteen experienced train travellers were invited to participate and were separated into groups of students, employees and older people, respectively. First, the problem was explored followed by a co-creation session in which ideas were generated to improve smartphone use in the vehicle interior. The results showed that the younger group and the employee group mainly used their smartphones for listening to music, watching videos, reading and texting, while the older people group were doing other activities such as gazing out of the window, reading and working on a laptop. The smartphone was mainly held in the right hand. Participants held the smartphone in both hands while texting. The co-creation showed that passengers need more support for smartphone use, like an arm support and a holder. This research is useful for train, car, bus and airplane seat suppliers to create new designs for the passengers' comfort that fit the performed tasks.

4.2 Keywords: Train passenger, comfort, seat, activities, postures

4.3 Introduction

Passengers frequently use smartphones while travelling by public transport (1). Previous studies found that train passengers were using smartphones during their trips. Over time, smartphone use has increased from 3.8% to 12.1% to 48.8% and 57%, respectively (2), (3), (4), and (5). However, the activities passengers do on their smartphones differ. Activities could be listening to music, texting, watching videos and reading on the phone (5) which might cause upper body discomfort (6). The train seat is not designed for heighty smartphone usage. Many studies recommend that the passenger seat design should be based on the passengers' activities and corresponding postures e.g.,(7). The question is what the passengers' needs are regarding the interior. This study aims to gain insight into the needs of the train passengers based on their activities, including the use of smartphones. These data might be used to design a comfortable train seat, which might attract more passengers.

4.4. Methods

To understand the train passengers' needs, generative design approaches are applied in this paper. Generative techniques like context mapping can be a rich source of information for designing a product Stappers & Sanders, (2003). Three sessions were organized with groups of 4 to 5 participants: a student group (18-25 years old) of 4 persons, an employee group (25-60) of 5 persons, and a group of older people (>60 years)) of 4 persons. They were invited based on the difference in use of time during the journey, as studied by (8). Rüger et al. showed that age is the aspect correlated to the activities passengers perform during long-distance train trips.

After an introduction, the participants signed an informed consent form. Then the respondents were asked to take a seat in a simulated train interior and imagine they were on a train journey, to recall their last journeys and to express their needs regarding the interior. A mock-up of a train interior was built in which participants could sit and indicate their needs, which were gathered by interviewing the participants. To express their opinions, they could place green stickers on the parts of the interior that had good comfort and pink stickers on the parts that had lower comfort. Then, the researcher distributed a toolkit that included picture stickers of travelling activities (as shown in figures 2 and 3). First participants recalled the purposes of their long-distance train trips using these pictures. The second phase concerned the activities they performed during a long-distance train trip, again using the pictures. The third phase is about recalling the purposes and details of their smartphone activities specifically, as in (5). In a fourth phase, participants recalled the purposes and details of other activities not done with a smartphone like sleeping, talking/discussing, reading a book, watching/window gazing, working using large electronic devices e.g., a laptop, eating/drinking, standing, writing or other activities. The fifth phase was about the body postures corresponding to the activities. The results from the first session were then summarized and discussed with the participants. After these sensitizing activities, the participants were asked to co-create in small group discussions how to improve the interior or specific seat parts to increase their comfort (Figures 4, 5 and 6). After the sessions, the research team used descriptive statistics to analyse the data from the first part, for example, data on the percentages of the travel purposes, activities performed on the train and corresponding postures. The second part of the analysis included the data from the co-creation, which were analysed by means of theme analysis (9).

4.5 Results and Discussion

4.5.1 The train passengers' needs for the seating environment while using the smartphone.

The student and employee groups stated that their activities as train passengers were mainly using the smartphone, at 61.7% and 57.9% of the time, respectively, while the older people were mostly doing other activities (74.4% of the time) on the train, as Figure 4.1 shows.

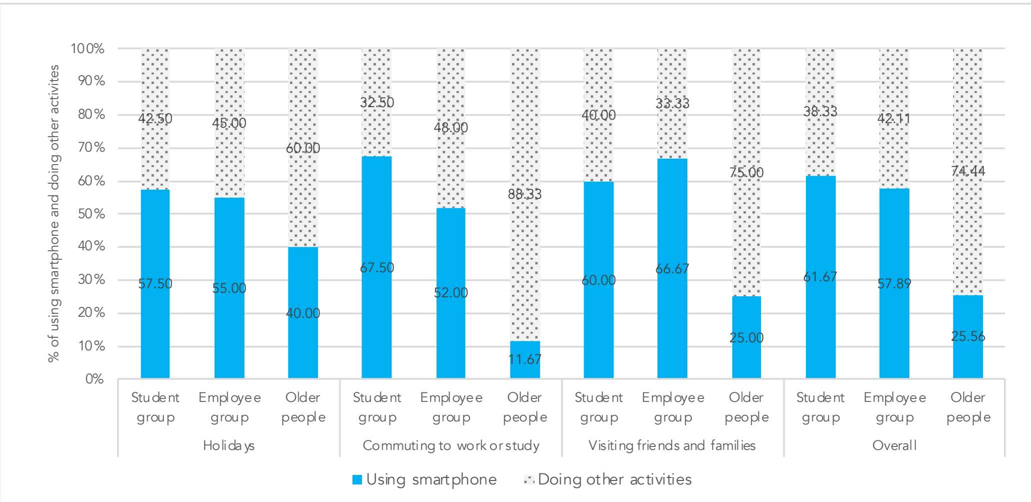

Figure 4.1: The main activities of the long-distance train passengers in percent of their total time spent on the train.

The high percentage of smartphone use aligns with other studies that also showed a high percentage of smartphone use (4) and (5). Indeed, the use of journey time was different for different age groups, as (8) also found. Figure 4.2 shows that the students report mainly using a smartphone for listening to music (25.7%), followed by watching videos, reading and texting

(24.8%, 21.8% and 12.6%, respectively). The main smartphone activities of the employees are reading, watching videos and texting (48.5%, 25.6% and 13.4%, respectively). Older people use a smartphone on the train for less time: 25.6% (Figure 4.1). They mainly use a smartphone for texting (32.6%), reading (30.5%) and making phone calls (22.5%) (Figure 4.2).

Older people were doing other activities while traveling by train (Figure 4.1). Figure 4.3 shows that gazing out of the window, reading from a book, and working on a laptop were the 3 main activities at 41.16%, 22.22%, and 14.62% of the time, respectively.

The postures were influenced by the performed activities. When the passengers were listening to music, their self-reported postures were very different and comparable to no smartphone use activities. Sometimes they placed the smartphone on their lap, sometimes in their pocket and sometimes, they held it in their right hand while selecting the music. Passengers mainly held the smartphone in their right hands while watching videos, followed by putting it on their laps, holding it with both hands, or using their knees to support their elbows. They also held it in their left hands, both hands or with their right hands and used their left hands to support their right hands. The positions that the passengers performed while using a smartphone for reading are holding it by either hand, followed by holding it by both hands and propping one of the arms or hands up on the windowsill. Holding a smartphone in one hand with the head looking down at the phone was observed as well. When the train passengers were texting on the phone, they were mainly holding it with both hands and using the armrest to support their elbows. Sometimes they held the smartphone in the right hand without using the armrest. The main postures observed in this study correspond to those described in the literature, such as (10) and (5), who found that when people use a smartphone, their head was free of support, their trunk against the backrest and their arms placed on the armrests.

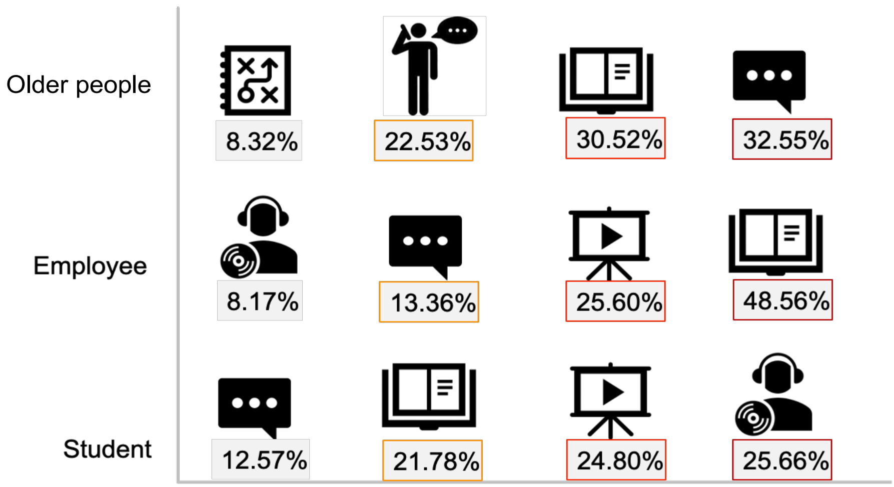

Figure 4.2: Smartphone activities of the long-distance train passengers in percent of their total time spent on the train.

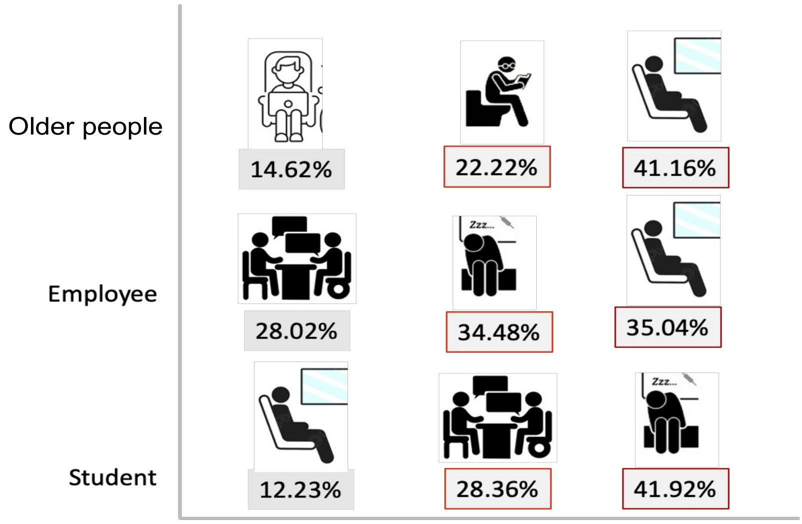

Figure 4.3: The other activities of the long-distance train passengers in percent of their total time spent on the train.

The students suggest that a smartphone stand on the backrest area could help them while they are watching videos (Figure 4.4), while the employees and the older people suggested a special arm support for the elbows that can help them improve comfort while reading (Figure 4.5, and 4.6). This result has similarities to (11) study, who found that passengers used the armrests while using the smartphone. Other studies by (10), (12), and (13) also advise support for the arms at that level to reduce neck flexion.

Figure 4.4: Suggestion to improve the smartphone stand by the students.

Figure 4.5: The special arm support suggested by the employee

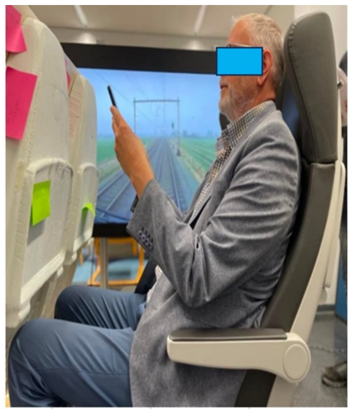

Figure 4.6: A higher arm support suggested by the older people.

4.5.3 Train passenger needs for the seating environment while doing the other activities.

The other activities performed in the session such as gazing out of the windows and sleeping also needed interior improvements (Figure 4.3). When the participants gazed out of the window, they were reclined with their backs on the backrest and their heads rotated toward the window side of the train. An adjustable backrest is preferred for this. The other activity they preferred was sleeping. For this activity, passengers would like to recline their backrest as much as possible, which is why they need an adjustable backrest. Sometimes their heads were unstable because the headrest is too wide. (2) and (3) also showed that the passengers prefer to have their head and trunk supported by a headrest and a backrest. For sleeping and window gazing, the arms are in a natural posture passenger did not use the armrest often because they did not have anything in their hands.

4.6 Conclusion

This research focused on train passengers' need for the seating environment. The student and the employee groups mainly used a smartphone during train trips. The different activities such as watching videos, reading and texting on the phone influenced their posture. The passengers mainly held a smartphone in their right hands while watching videos or reading. While texting, they were typing on the phone with both hands. When they used the smartphone to listen to music, they assumed many postures because the smartphone did not dictate their posture. The participants tried to use the armrest and the wall of the train or windowsill to support their arms while using the smartphone. This means they need some parts or equipment that can help them hold the smartphone to improve their comfort. However, to prevent neck flexion, often a higher position of the supporting environment is needed for the elbows. This research could be used as input to design a seat to improve passenger comfort while using a smartphone in the train, automotive car, bus or coach. The small number of participants might be a limitation of this study. However, the data align with other studies. Also, the imbalance between men and women in each group might have influenced the results, such as the height level of the armrests. This means that designs based on this study certainly needs to be tested. Also, special groups of passengers like wheelchair users or visually impaired passengers might have other needs that require attention.

4.7 Acknowledgement

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Chapter 5
Differences in Expectation, Experience and Recorded Effects while Using a Smartphone with and without Support.

Introduction

As discussed in the previous chapters, smartphone use on trains and airplanes has dramatically increased. Those chapters have also identified room for improvement in the vehicle interior to support smartphone use. This study concerns an improvement in the interior that is tested with end-users. Earlier research found that comfort experiences could be different when evaluated before or after use e.g., (1). Therefore, in this paper, attention is paid to the difference in (dis) comfort that is experienced after using the product and the expectation based on first sight. This could also help enrich the theoretical background of the (dis)comfort experience.

This chapter has submitted to *Applied Ergonomics* journal.

Chapter 5. Differences in Expectation, Experience and Recorded Effects while Using a Smartphone with and without Support.

5.1 Abstract

This paper concerns the difference between expected comfort and experienced comfort and the association between discomfort in the head region and recorded neck angle. Twenty-four participants were asked to use their smartphone with and without a holder in a train seat and then to rate their expected and experienced comfort. Participants mentioned that the headrest should be softer, the armrest should be adapted, the backrest should give more support and the seat pan should be softer. This experience was significantly different from the expectations based on first sight. It shows that tactile experience adds information influencing comfort, but also the behaviour of performing the task in the seat is important to giving a good comfort score. The experience of use is also needed to increase the quality of the suggestions for improvement. This study strengthens the theory that comfort expectations and comfort might differ from experienced comfort. It also strengthens the theory that there could be a relationship between experienced neck comfort and recorded neck angles.

5.2 Key words: expectation, passenger comfort, smartphone, discomfort, neck flexion

5.3 Introduction

In applying ergonomic interventions, there is often a difference in expectation, experience and effects. An example of a difference between expectation and experience is described in Bouwens's study(1). To improve comfort while flying, participants were given various neck cushions. The expectation of a neck collar was that it would be uncomfortable, but after sitting for two hours in an airplane seat with the collar on, the participants scored their comfort as much better. Effects of ergonomic interventions could also differ from the experience. A pertinent example of a difference in user experience and recorded effects is the use of a winch in scaffolding. The scaffolders had the feeling that the process was going slowly as they stood waiting while the winch brought the scaffold elements upwards. In the old situation, the scaffolders had worked hard transporting protruding scaffolding parts upwards manually. Recordings showed that the productivity was in fact higher with the winch (2). This last example focuses on performance by ergonomic intervention. According to (3), ergonomics focuses on two closely related outcomes: performance and well-being. Well-being is related to health. Regarding health, differences between expectation, experience and effects have also been described in the literature. For instance, (4) asked 58 women in 28 occupations to give an estimate of their physical exertion and physical activity in tasks that they did, and no correlations could be found with the measured average heart rate during those tasks. On the other hand, (5) showed that workers were able to define their experienced discomfort level, which above a certain level predicted musculoskeletal injuries. These studies show that users have difficulties making predictions based on first impressions. After experiencing the situation, the relationship with recorded effects is clearer. It seems that feeling discomfort in body parts is more clearly related to complaints and that experiences like physical effort are harder for humans to estimate.

In this paper, two hypotheses are studied:

1. expected effects of an ergonomic intervention are different from experienced effects; and
2. local perceived discomfort is associated with recorded effects.

In this study, the two hypotheses are studied in an increasingly common activity: smartphone use.

5.3.1 (Dis)comfort.

The experience of (dis)comfort is influenced by various factors (6). The environment influences our comfort (e.g., sound or seat hardness). In addition, our physical state, our history/past experiences and expectations play a role in experiencing comfort or discomfort (7). A product is not comfortable by itself; comfort experience depends on the way the user interacts with the product in combination with expectations (7). This means theoretically that it is hard for people to predict their comfort without having interaction with the product.

5.3.2 Smartphone use

Smartphones have become an inseparable part of our daily lives. Smartphones are used for many different purposes, such as talking to someone, texting, listening to music, reading, or watching videos. The number of smartphone users worldwide has continuously increased. The Global Digital Report (2019) showed that internet usage via a mobile device jumped from 26% in 2014 to 48% in 2019. These technologies are used in public transport as well. Kilincsoy and Vink (8) showed that 48.3% of train travellers used a smartphone, and (9) reported that 57.4% used a smartphone.

This growth in the use of mobile computing devices might have comfort and health implications. When people use a smartphone, they usually stress their upper body (10). The upper and lower arm, wrist and fingers could potentially get overused by holding the smartphone for a long period of time (11). The head is bent forward when people use a smartphone on their lap, which could increase neck discomfort and eventually pain compared with holding the smartphone at eye level. Using the smartphone for an extended period of time can lead to more pain and fatigue, as (12) described.

Redesigning the environment might help prevent these problems to some extent. Some studies report subjects using mobile devises as much as 7 hours per day (13). Unlike for desktop computing, there is not much literature on discomfort and health effects associated with long-term mobile phone use, especially while traveling, which is the environment chosen for this study. To support the redesign of vehicle interiors (like trains, cars and airplanes), design Guidelines could be helpful.

The main goal of this research is to study comfort expectations, experience and recorded postures while performing various activities on a smartphone in a train. The research question is, 'What is the difference in vehicle seat (dis)comfort expectation and experience between two conditions (with and without a smartphone holder) while using a smartphone, and what is the effect on posture?'

5.4 Materials and Methods

To answer the research question, posture, seat comfort, expectation and discomfort perception were recorded while passengers were using a smartphone with and without a holder. Four different activities were performed on the smartphone in a long-distance highspeed train seat.

Postures were recorded using a video camera, while comfort and discomfort experiences and expectations were determined using questionnaires.

5.4.1 Subjects

Twenty-four participants (13 female and 11 male) aged between 22 and 55 years from Europe, Asia, and South Africa were recruited. Their height varied from 155 to 191 cm. They were experienced train travellers and had sustained no musculoskeletal disorders or injuries in the last 6 months.

5.4.2 Experimental setup and stimuli

Long-distance second-class train seats were installed in a mock-up of a train interior with astandard distance between two rows of seats of 97.1 cm. pitch including 4.0 cm. of the backrest, simulating the train environment (for other dimensions, see figure 5.1). The seat width was 46.5 cm. The setup was a within-subjects design with two conditions: Condition A: Using a smartphone without support, and Condition B: Using a smartphone with a smartphone holder.

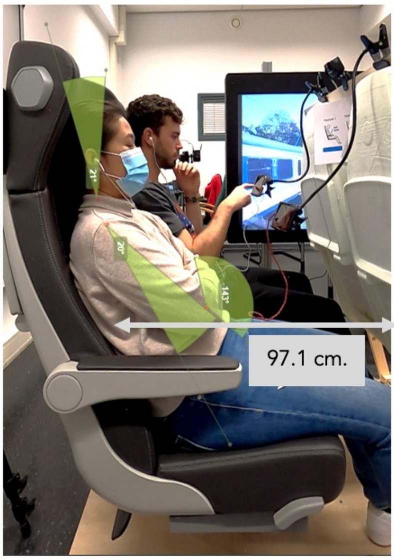

Figure 5.1: The seat setup layout with a smartphone holder. The distance from the front of the seat to the back of the seat in front was 97.1 cm.

5.4.3 Apparatus

<u>1) Smartphone holder</u>

A flexible smartphone holder suitable for 5-15 cm.-wide device was used. Dimensions were 62 by 7 by 11 cm. The research was approved by the ethical committee of the TU-Delft.

<u>2) Camera systems</u>

Four GoPro (hero 9) cameras were placed around the seat. One camera was positioned at the left and one at the right side of the seat row to estimate the neck flexion, the upper arm and lower arm angles in the sagittal plane. Two other cameras were installed in front and behind the passenger to check posture. The camera recorded in 2.7k linear mode (2704 X 2028 pixels) with 30 frames per second. Before starting the experiment, the cameras were calibrated following the procedure by Open CV. Markers were placed on the C7 of the neck, on the middle of the shoulder and on the lateral epicondyles of the elbow to identify angles.

5.4.6 Experimental protocol

After arriving at the lab, the participants were informed on the protocol and signed the informed consent. They were then asked to complete a prequestionnaire (time not included in the test period), which also consisted of questions on their expectations. Then they were asked to take a seat.

Twelve participants started without a smartphone holder, and 12 started using their smartphone with support. The participants were asked to perform four activities: listening to music, texting, watching a video, and reading on the phone because these were the most observed activities in a previous study (9). Six subjects started listening to music while the others started reading. Each activity lasted 15 minutes. After each activity, participants were asked to complete the second questionnaire on their smartphone. After completing the first round of the test, the participants took a break for 30 minutes. During the break, their anthropometry was measured, as Table 5.1 shows.

In the second, third and fourth round of the experiment, the subjects followed the same protocol with other activities. At the end, they completed a final questionnaire.

5.4.7 Measure

<u>1) Anthropometric measurement</u>

Fourteen anthropometric measurements were taken. Twelve were as described by (14). Two items were added, numbers 8 and 13 in figure 5.2, because these might be relevant for smartphone use. The 5th, 50th and 95th percentiles of the participants were calculated.

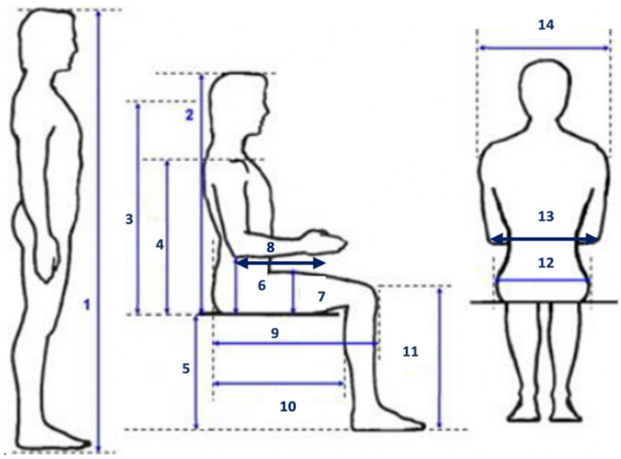

Figure 5.2: Anthropometric measurements taken in the experiment.

<u>2) Seat comfort experience</u>

The questionnaire consisted of questions on passengers' comfort and discomfort expectations, which they completed before sitting in the mockup train seat. The participants had to rate the headrest, upper backrest, lower backrest, seat pan, thigh support, armrest, legroom, and overall seat comfort experience in the questionnaires. A CR-10 scale (15) was adapted to the seat comfort questionnaire with a scale of 1-10 (1=No comfort at all, 10= Extreme comfort). The differences in scores between the two conditions were tested using the Wilcoxon paired signed rank test ($p<.05$).

3) The expectation and experience comfort.

To compare the expectation before the experiment and the experience after finishing the test questionnaires, before and after tests were compared as well. Again, the Wilcoxon paired signed rank test ($p<.05$) was used.

4) The correlation on expectations and seat comfort experiences.

The Spearman's rank correlations were used to compare the seat comfort experience of each seat part with the expectations of the participants. The correlation coefficient and p-value were calculated to understand the relationship of the two factors.

5.5 Results and Discussion

The participants mainly commuted by train once a week per month. In all, 96.4% mentioned that they used a smartphone while travelling. The four performed activities the participants mentioned were listening to music, texting, watching videos and reading, which they reported as 28%, 25%, 23%, and 20%, respectively. This aligns with a previous study (9).

5.5.1 The anthropometry data

Table 5.1 shows the anthropometric data and weight of the 24 participants.

Table 5.1: Anthropometric data of the 24 participants referred to in figure 5.2.

ItemS	Smallest	P5	P50	P95	Tallest
(0) Weight (kg.)	43,50	61,18	66,50	71,82	87,00
(1) Height (cm.)	155,00	165,32	169,70	174,08	191,00
(2) Sitting height (cm.)	71,10	79,69	82,35	85,01	100,00
(3) Sitting eye height (cm.)	61,50	69,89	72,25	74,61	88,60
(4) Shoulder height (cm.)	45,30	52,18	54,25	56,32	68,50
(5) Popliteal height (cm.)	39,00	44,01	45,50	46,99	53,00
(6) Elbow rest height (cm.)	13,70	17,91	19,40	20,89	27,00
(7) Thigh clearance (cm.)	6,80	8,56	9,50	10,44	14,50
(8) Lower arm height (cm.)	3,40	28,52	31,65	34,78	45,00
(9) Buttock knee height (cm.)	48,20	53,01	54,70	56,39	63,50
(10) Buttock popliteal height (cm.)	36,90	39,82	41,85	43,88	59,30
(11) Knee height (cm.)	42,00	47,01	48,70	50,39	57,00
(12) Hip breadth (cm.)	31,50	34,36	36,75	39,14	54,00
(13) Elbow breadth (cm.)	35,00	39,26	41,15	43,04	52,00
(14) Shoulder breadth (cm.)	33,10	35,86	37,40	38,94	47,00

The maximum elbow breadth (52.0 cm.) is wider than the shoulder breadth (47.0 cm). Molenbroek (16) also mention that elbow breadth is widest and is a critical anthropometric measure for seat width. A seat width of 50.0 cm. (19.7 inch) is preferable because elbow-to-elbow breadth is 50.0 cm. for p95 males. (17)also showed the importance of seat width. An 18-inch-wide seat (45.72 cm.) was significantly more comfortable than a 17-inch-wide seat (43.18). This increase in 1 inch of seat width (2.54 cm.) is more effective in improving comfort than increasing the pitch by 1 inch (17). Our seat width was 46.5 cm. (18.3 inch), which is rather comfortable, but might still lead to elbow contact with the other passengers.

5.5.2 Seat comfort experience

1) Overall seat comfort experience while using a smartphone with and without support.

Figure 5.3 presents an overview of the comfort experience of using a smartphone supported and unsupported, averaged over the four activities. The Wilcoxon signed rank test shows that the comfort in the head rest area was significantly higher with a smartphone support compared to without support ($p < 0.05$), probably because in the supported situation, the head is more upright, which makes the person better able to use the headrest. However, the other body parts showed no significant difference between the two conditions.

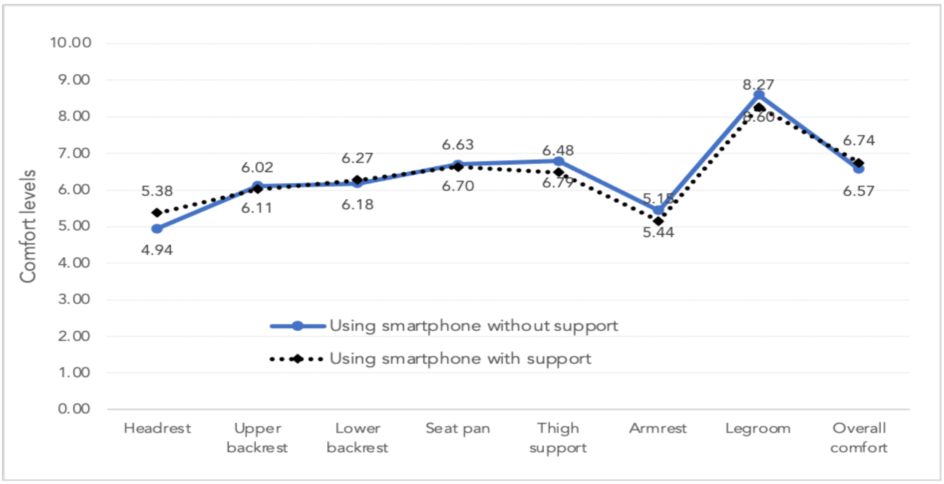

Figure 5.3: A comparison of comfort using a smartphone with and without support.

Table 5.2: The difference in seat comfort experience while using a smartphone with and without support.

Seat comfort experience	P-value				
	All activities	Listening to music	Reading	Watching video	Texting
Headrest	**0.0375**	0.5000	**0.0392**	**0.0166**	0.3085
Upper backrest	0.3632	0.2579	0.1446	0.2946	0.0139
Lower backrest	0.1587	0.0516	0.2119	0.1977	0.1611
Seat pan	0.4841	0.1736	0.1788	0.4641	0.3897
Thigh support	0.0764	0.1112	0.4841	0.0749	0.4207
Armrest	0.0630	0.4721	**0.0048**	0.3446	0.1210
Legroom	0.0808	0.5821	0.4841	0.2676	0.2327
Overall comfort	0.0793	0.5938	0.1170	**0.0066**	0.0606

Figure 5.3 and Table 5.2 show that overall seat comfort while watching videos is significantly higher while using a smartphone with a holder than without support, while using a smartphone for reading, watching, and other activities with a holder resulted in higher comfort in the headrest area than using a phone without support. However, using a smartphone for reading without holder showed significantly higher comfort than with the holder. This means, that the smartphone holder could help to improve comfort on the neck watching a video and while reading. However, to covered all of the performed smart phone activities an additional adjustable armrest is recommended.

5.5.3 Expectation and experience

There were significant differences between the expected comfort at first sight and the score after experiencing the situation, as Figure 5.4 shows.

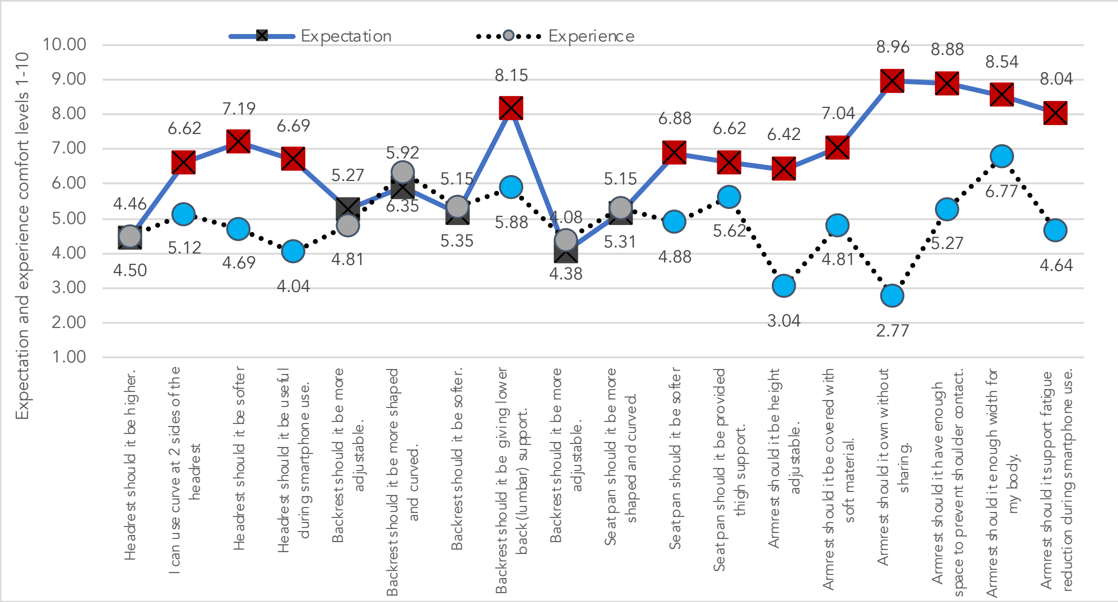

Figure 5.4: Expectation and experience of comfort while using a smartphone on a train seat. Black/grey is not significantly different, while red/blue is significantly different.

The headrest comfort was rated higher in expectation than after experiencing the headrest, which was true for the backrest and armrest as well. Participants mentioned that the headrest should be softer and more adapted to smartphone use and a head side support is needed. This is hard to determine by visual inspection, the experience is needed. Also, the backrest should give more support in the lumbar region, which is also hard to estimate based on first impressions. After experiencing the seat, participants said the seat pan should be softer as well. The armrest also shows differences between expectation and experience. In this case, the visual inspection is not sufficient to judge the softness and whether there is contact with one's neighbour.

The suggestions the participants made after experiencing the seat mainly concerned the armrest. Six aspects related to arm support were mentioned: the height of the armrest should be adjustable, it should be covered with soft material, each passenger should have their own armrest, there should be enough space to prevent shoulder contact, the armrest should "allow space (width) for my body" and the armrest should give support to reduce fatigue during smartphone use.

These suggestions cannot be made by visual inspection or first impression. People need to experience the seat and actually do the activities to come to useful conclusions for redesign. The expected comfort is in this case is hard to define. On the other hand, expectations might still influence the outcome of the comfort experience. As we are used to soft paddings on armrests, participants perhaps expect the paddings to be soft. Also, context plays a role. For example, (18) study showed that the price of the ticket influences the comfort rating, but here participants did not mention price. Also, in Naddeo (19) experiment, participants rated a mattress as more comfortable when they were told it was very expensive than when they were told the exact same mattress was cheap. According to (3), ergonomics focuses on two closely related outcomes: performance and well-being. Well-being is related to health. Regarding health, differences between expectation, experience and effects have also been described in the literature as found in this paper.

5.4.4 Recorded neck angles

As was stated above, comfort in the area around the headrest was significantly higher with a smartphone support compared to without support. This aligns with the recorded neck angle. With the smartphone holder, the neck was closer to neutral (more upright), which might create less discomfort, especially for watching a movie and reading (see figure 5.5). This also aligns with the questionnaire data. The direct correlation between upper trapezius muscle activity, neck angle and perceived discomfort in smartphone use has been reported before (20).

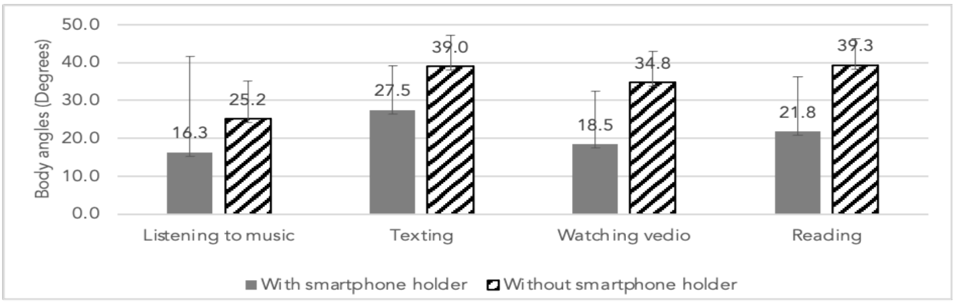

Figure 5.5: Comparison of the neck angle between four activities while using a smartphone with and without support.

5.4.5 Other comments

After experiencing all conditions, most participants preferred to use the smartphone holder for all activities (68%). Thus, 32% preferred not to use a smartphone holder. There were 12 suggestions related to the stability of the smartphone holder. The holder wobbled when other passengers moved. This might also be hard to notice based on expectations alone. It is a relevant finding because the train vibration might be even stronger than the laboratory setting. An unstable holder annoyed the subjects, because, for instance, it was uncomfortable to turn the page while reading. For texting, the smartphone holder is really uncomfortable because the hard plastic clamps dug into the reader's hand and also did not let them hold their phone in the way they were used to. It slowed down their typing speed, and their wrists and fingers hurt. The holder also needed to be easier to adjust. However, a smartphone holder was experienced as positive for watching videos. Some window-seat passengers complained about inconvenience during ingress and egress. Also, some felt that a neighbour could see what they were doing on their phones.

Participants also had other suggestions for improving the smartphone support. For example, as was already mentioned, participants suggested modifying the smartphone stand by connecting it to the tray table or seat structure. Also, connecting it to the back of the seat in front of you was mentioned as desirable. It is far from the eyes but very stable, and it can be used to watch videos, make videocalls and charge the phone. There could be a second small phone holder on the side of the seat, which is useful when typing. This stimulates the passenger to change their posture, which would be beneficial as well.

5.4.6 Reflection on expectation, experience, and recording

The participants' suggestions would probably not be as rich if they were based on expectations alone. The quality of the outcomes was clearest when the participants experienced both conditions, showing the importance of user research in a condition that closely resembled reality. Most ideas for improvement were influenced by the fact that the participants could really feel and experience the seats. This strengthens the theory that comfort, and discomfort expectations might differ from experienced comfort and discomfort. Additionally, this study confirms that it is important to take behaviour into account in comfort research, as (6) stated.

The hypothesis: This study adds evidence that the expected effects of an ergonomic intervention are different from the experienced effects.

There was a relationship between the recorded effect (in this case, neck flexion) and the (dis) comfort in the head region in this study. This link between discomfort and body posture has been reported previously e.g., (21). This study adds evidence that the hypothesis 'local perceived discomfort is associated with recorded effects' might be true.

5.6 Conclusions

This study shows that the headrest could be softer, the armrest could be adapted, the backrest could give more support and the seat pan could be softer. This experience was significantly different from the expectations based on first sight. It shows that tactile experience adds information influencing comfort, but also the behaviour of performing the task in the seat is important to giving a good comfort score.

5.7 Acknowledgements

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- the student assistants.
- the participants.

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Chapter 6
Comfort and Discomfort while Using a Smartphone in Bed

Introduction

People use a smartphone while sitting on the sofa, lying on a bed or riding on a train or an airplane. Using a smartphone for a long period could lead to musculoskeletal disorders mainly in the neck, upper and lower back, shoulders and arms. Besides seats, also beds are installed in trains, airplanes and ships. This paper focuses on smartphone use on a bed. Such use is not preferable because the literature review showed that intraocular pressure is higher in the supine than in the sitting position (1), but in practice, people will use their smartphones in bed. In those cases, a good backrest angle is preferred. This is the topic of this chapter.

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Chapter 6. Comfort and Discomfort while Using a Smartphone in Bed

6.1 Abstract

BACKGROUND: The number of smartphone users is immense. People can always do more with a smartphone. Smartphones are used everywhere, including in bed and on sofas. The awkward postures taken in these situations affect comfort and discomfort. In designing a bed, it might be useful to know which position is comfortable for smartphone use on it. OBJECTIVE: The objective was to define the most comfortable trunk angle for smartphone use on a bed. METHODS: To study comfort and discomfort, 52 participants were asked to use a smartphone on a bed. The trunk angle of this bed was adjusted to 6 positions, from flat to upright. For each angle, comfort and discomfort were recorded. RESULTS: The results showed that the participants prefer a trunk angle range around 120 and 142 degrees. At the best trunk angle, 29% of the participants felt comfort in the legs, 25% in the upper back and 16% in the shoulders. However, in this position, 36% also mentioned discomfort in the lower back and 24% in the neck. CONCLUSIONS: For smartphone use, a bed is preferable that enables a trunk angle of around 120-140 degrees. For the legs, this is comfortable. However, for the neck and upper back, the problem of discomfort still needs attention.

6.2 Keywords: Comfort, Discomfort, Posture, Smart phone, Bed

6.3 Introduction

In 2018, 40-50% of train passengers were using their smartphones at the moment they were observed (2). This is an enormous increase compared with observations in 2011 (3). In the recent study, 5% were listening to music, while others were watching a movie or series, texting, web browsing, or checking email or the train time schedule. In marketing and research, much attention has been paid to optimizing the systems and mechanisms of smartphones to increase productivity (4), and (5). New versions of smartphones are introduced frequently. The number of iPhones sold from Q3 2014 to Q3 2018 is 40 million per quarter, as reported by Apple Worldwide (6). Presumably, newer models have more features, which may stimulate users to use the smartphone even more. The relationship between smartphone comfort and body posture is seldom mentioned. Yet improving posture might be more effective in increasing productivity than introducing new smartphone features. Vink (7) showed that improving posture to fit the task can improve productivity. People use smartphones in many locations: on the sofa, in conference rooms, in the workplace or on the bus, train or airplane and they use them in bed (8). US study, 50% of respondents reported frequently using their smartphones in bed. This might be an issue because it may lead to uncomfortable postures. Some beds are adjustable and can be inclined. The Semi-Fowler's position is used in hospitals, in which the upper part of the bed supports the trunk at 30 degrees. The Semi-Fowler's position is more effective than a supine position in supporting the hemodynamic stability of patients with head injuries (9). In designing the bed in a new aircraft (the Flying V), see (10) in which smartphones could be used, we found a gap in knowledge about which angle passengers preferred for trunk support when they are using their smartphones. This knowledge might be relevant in other environments such as submarines, trains, or capsule hotels where smartphone use in bed might be increasing. The research question is: 'What is the best trunk support angle for comfortable smartphone use on a bed?' A flat position might put too much strain on the neck, and a fully upright position might result in too much stretching of the back or hamstring muscles. This paper aims to identify the appropriate trunk position for smartphone use on a bed.

6.4 Methods

To answer the research question, 'What is the best trunk support angle for smartphone use on a bed?', an experiment was performed.

6.4.1 Participants

Thirty men and 22 women of different nationalities (European, American and Asian), all with higher educations, participated in the study. The height of participants varied from 153 to 197 cm. The average height was 175 cm, and their ages were between 22 and 30 years.

6.4.2 Protocol

The research started with the introduction of the experiment and signing of an informed consent. Four research staff instructed the participants and monitored whether the groups followed the protocol. The participants were separated into 13 groups of 4 persons each. In the first 15 minutes, the first person of each group settled on a sunbed and took 6 positions (2.5 minutes/ positions) (different backrest angles of 177, 162, 142, 120, 99 and 75 degrees since these are the angles of the sunbed). The participants used their own smartphone for some tasks they could define themselves, and at the end, they answered an online questionnaire while still on the bed. One staff member was the timekeeper who managed the timing of the experiment and adjusted the reclining mechanism. In each position, which lasted a few minutes, a second staff member sent a message to the timekeeper who then asked the first person to score their comfort in an electronic questionnaire on a smartphone. Questions regarding discomfort were also completed. A third staff member took a lateral picture of the first person to check their posture. The fourth staff member managed the whole process and checked to make sure everything was done correctly. All four participants of each group took all positions and experienced all angles. Twenty-six participants were asked to start with the flat position (177 degrees), and the other 26 were asked to start in the upright position (75 degrees).

6.4.3 Questionnaire

An online questionnaire was used to evaluate each angle of trunk support. The questionnaire is illustrated in Appendix 1. Each participant was asked to rate their comfort on a 7-point Likert scale (1 = no comfort at all, 7 = extreme comfort). Another 7-point Likert scale to assess discomfort was used as well. It was adopted from (11). After scoring each position, the participant was asked to take the most comfortable position and selected their most uncomfortable body area using a number from the body maps, as shown in figure 6.1. After that, they were asked to identify most comfortable area. The participants could select more than one part of the body for both comfort and discomfort.

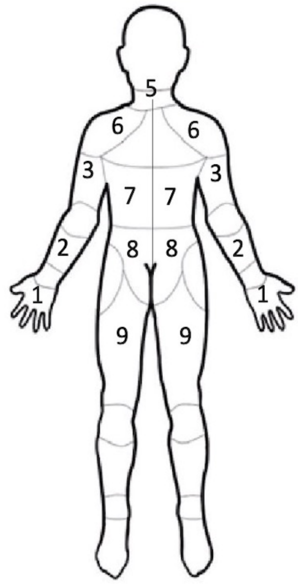

Figure 6.1: The body map.

6.4.4 Analysis

The analysis consisted of calculating the mean and standard deviation of the comfort and discomfort score, plotting these data on a graph for each angle of 177, 162, 142, 120, 99 and 75 degrees, respectively. An Independent-Sample Kruskal-Walli's test was used to compare the participants' comfort during smartphone use at each angle. With this, we could answer the research question as to the best trunk support angle for smartphone use on a bed. The data in the body map showed the percentage of people mentioning comfort and discomfort in the different regions. This gave an impression of where comfort and discomfort are experienced. It also tested whether the way the participants use the smartphone was related to the preferred position.

6.5 Results and Discussion

6.5.1 Results for the back support angle

All 52 participants used the smartphone with 6 different backrest angles. For 26 of them, the order of angles was 177, 162, 142, 120, 99 and 75 degrees, and for the other 26, it was from 75 to 177 degrees. Figure 6.2 shows the angles.

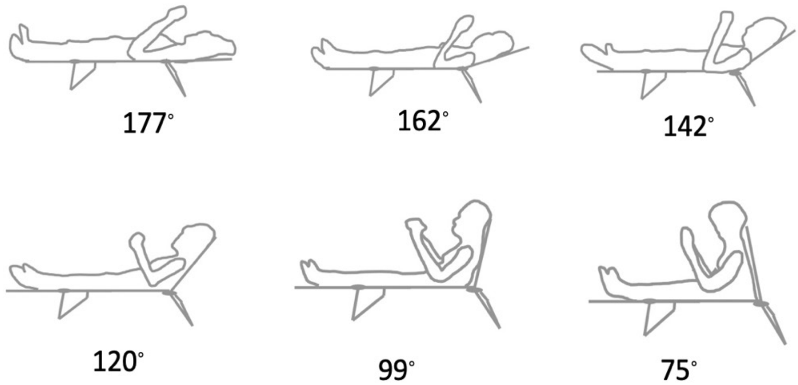

Figure 6.2: The different angles at which the participants used the smartphone.

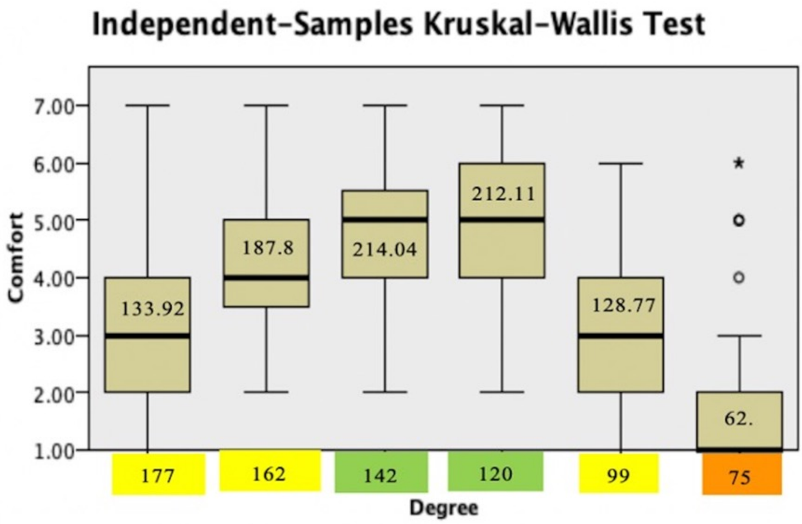

Figure 6.3 Comfort levels separated by angle of back support.

The comfort results (Figure 6.3) were analysed using an Independent-Sample Kruskal-Walli's test. This method is a nonparametric test that can be used to compare two or more independent samples of equal or different sample sizes. It compares the median between the groups of data for different conditions. In this case, the sample sizes were always the same: all participants tested all angles in different orders to control for order effects. The samples were the participants, and the conditions were the angles. The results showed that the angles of 142 and 120 degrees differed most from all the other angles. The participants reported greatest comfort in these angles. There was no significant difference between these two angles. The next preferred angles were 162, 177 and 99 degrees. These again did not differ from each other, but they did differ significantly from the 75, 142 and 120 degrees of angles. Average comfort levels were rated at 4.8, 4.8, 4.4, 3.3, 3.2 and 1.8, respectively (an extremely high comfort level is 7, and no comfort at all is 1). Based on these data, the answer to the research question regarding the best trunk support angle is that the users prefer the area between 142 and 120 degrees.

Figure 6.4 shows the preferred angle given by the 52 participants. Some participants preferred a number of angles, but among them too, 120 and 142 are the preferred angles.

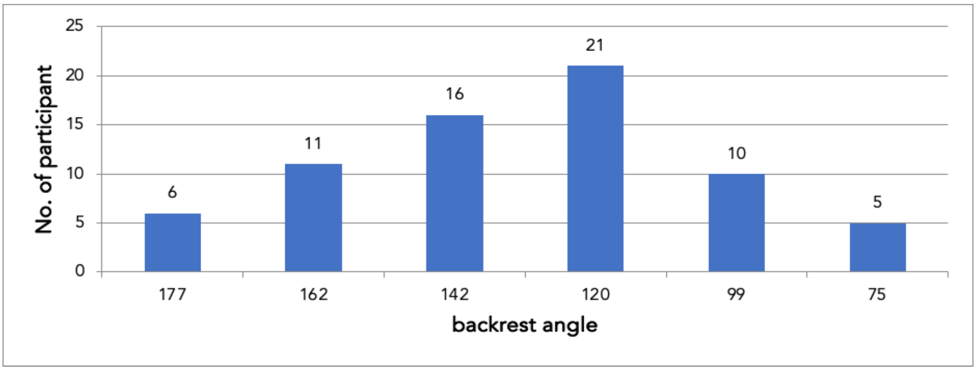

Figure 6.4: The number of participants voting for a specific angle.

6.5.2 Results for (dis)comfort felt by body region when the participants take the best of the six positions.

When the 52 participants were in their preferred position, 29% felt most comfort in the legs. The percentages of participants who felt comfort in the upper back and shoulders region were 25% and 16%, respectively. The percentage reporting comfort for the other regions was lower. In all, 0%, 3%, 6% and 8% felt comfort in the hand, lower arm, lower back and neck, respectively, when using the smartphone on a bed (see Figure 6.5).

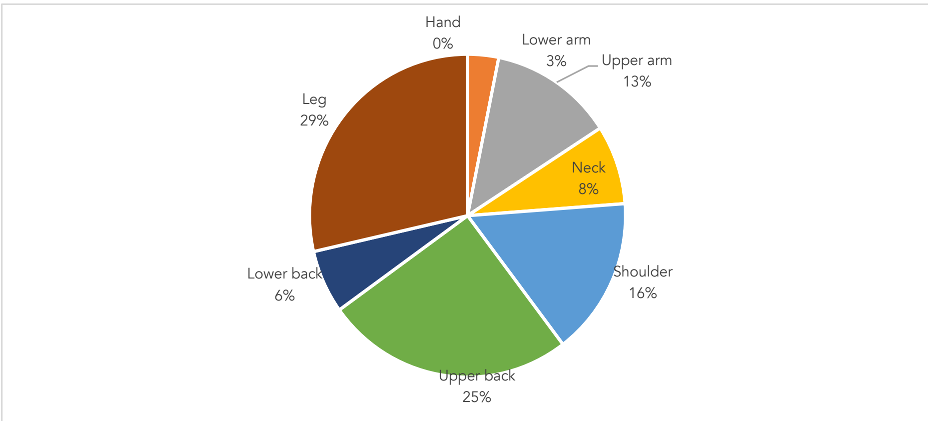

Figure 6.5: The percentage of participants reporting comfort for the different regions.

Discomfort for the best out of the six positions was highest in lower back and neck. In all, 36%, 24%, 10%, 9% and 8% of the participants reported discomfort in the lower back, neck, upper back, shoulder and lower arm, respectively. The number of persons reporting discomfort in the hand, upper arm and leg while using the smartphone on a bed was low (<6%) (see Figure 6.6).

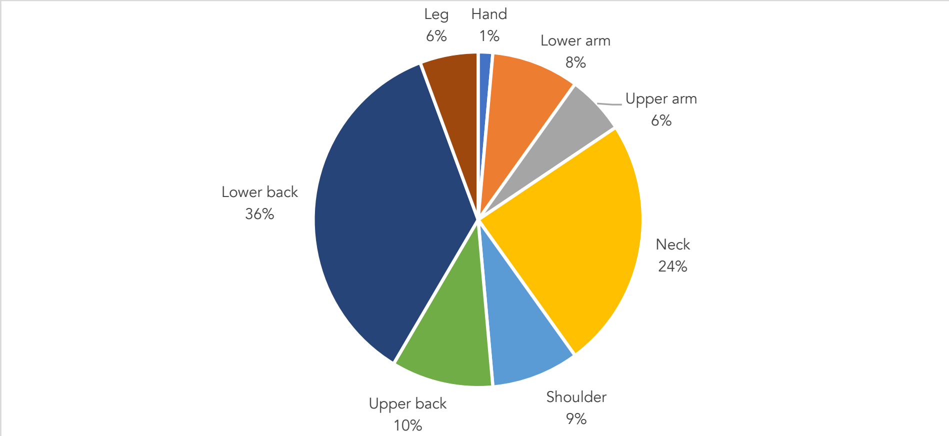

Figure 6.6: The percentage of participants reporting discomfort for the different regions.

6.5.3 Results for hand position during smartphone use

Figure 6.7 shows that most of the participants preferred to use the smartphone with two thumbs (63%). Another 31% mention that they operate the smartphone using only one finger. A remaining 6% of the participants used the smartphone in a different way. There were no significant differences between using a smartphone with two thumbs or one finger for each of the different trunk angles.

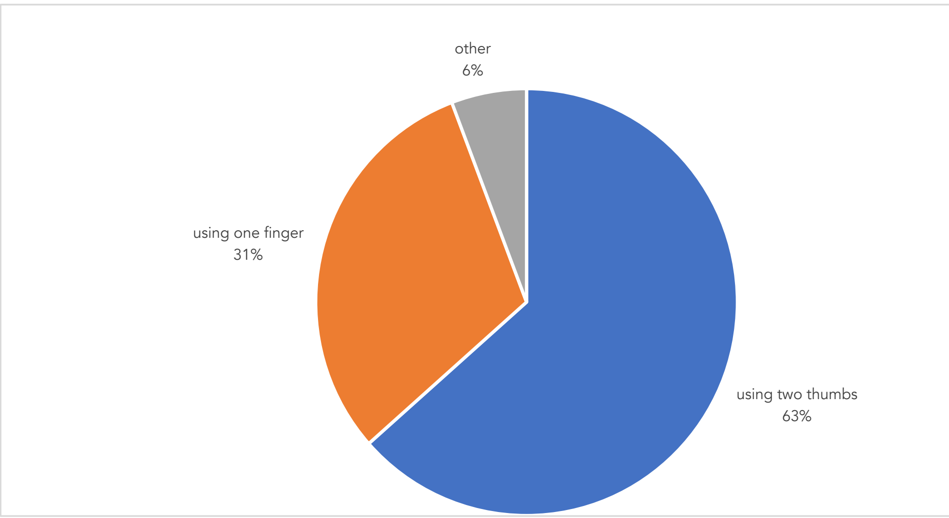

Figure 6.7: Results of hand position during smartphone use.

6.6 Discussion

In answering the research question 'What is the best trunk support angle for smartphone use on a bed', there is not one preferred angle, but a range of angles in which the comfort is higher. The participants experienced high comfort when using the smartphone in a bed with a backrest angle at around 142 to 120 degrees. Groenesteijn (12) mention that an adjustable backrest is preferred so that support can be adapted to the characteristics of the human and the task. They found a preferred backrest angle of 132 degrees for reading in an office chair. Of course, this is not lying on a bed, but the results are similar. Probably the position of the arms and neck plays a large role in determining the most comfortable backrest angle. This certainly needs further research. Of all the participants, 35% report comfort of the legs in this position, and 27% and 19% felt comfort in the upper back and shoulders, respectively. The discomfort recordings showed that 36% and 24% of the participants felt discomfort in the lower back and neck, respectively. It is clear that the leg position is comfortable. Rosmalen (13) report that while watching television, people like to have their feet off the floor and at a higher level. Probably humans like to have their feet off the floor or their legs at a level not much below their pelvis, and this may have contributed to comfort in our study too. Cicolini (14) found a progressive decrease in blood pressure rates when the body position changed from sitting to the Fowler and from the Fowler to the supine position. It appears that having the feet at a higher position is not only more comfortable, but also decreases blood pressure. There may be a relationship.

A problem that still needs to be solved in the 'best' position is discomfort in the lower back and neck. Lower back discomfort might be caused by the fact that the bed gives no support there or because of stretching of the hamstrings. Neck discomfort is probably caused by neck flexion, which has been found in other studies as well,(15). A shortcoming of our study is that the participants only used the smartphone for a few minutes. It could be that longer use leads to other preferences. Sammonds (16) and Smulders (17) showed that sitting longer in one position leads to higher discomfort ratings. This might be true for the supine position or Semi-Fowler position as well.

6.7 Conclusion

Regarding the research question 'What is the best angle of trunk support for smartphone use on a bed', the 52 participants preferred a trunk angle of around 142 to 120 degrees. In particular, the leg position is comfortable, but a reasonable percentage of participants also experienced upper back comfort. The participants prefer this angle but still have some discomfort. More than one-third experienced discomfort in the lower back and a quarter discomfort in the neck, which needs attention.

6.8 Acknowledgement

The research work reported here was made possible by The Royal Thai Scholarship.

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Chapter 7
Comfort and Discomfort in a Chair Using the Smartphone

Introduction

Using a smartphone for a long period result in discomfort in the upper body and could lead to musculoskeletal disorders (1). Studies by Ciaccia (2), Canaria (3), and Veen (4), reported that smartphone users preferred to use an armrest because it reduces neck flexion. In addition, using an arm support helped relax the shoulders (5), and (6). Based on these problems, (5) developed a special seat that supports the arms and encourages the neck to assume a position close to neutral. The study in this chapter was set up to answer the question 'Does using this special seat improve body posture while one is using a smartphone and thus influence productivity, comfort and discomfort?'

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Chapter 7. Comfort and Discomfort in a Chair Using the Smartphone

7.1 Abstract

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

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

7.3 Introduction

A survey among 1,500 office workers in the UK and Australia found that nearly half the employees use a smartphone or mobile in the workplace (abc.net.au, Dec 2012). Much effort is devoted to optimizing the systems and mechanisms of smartphones to increase productivity e.g., (7), and (8). A few milliseconds of improvement seem very important. However, the relationship between smartphone productivity and body posture is seldom considered, while the effects could be larger than milliseconds. The users of smartphones are often not aware of their body posture. The question is whether they have tacit knowledge of the body postures that improve smartphone productivity, which is the theme of this study. Body posture research concentrates mostly on the relationship between musculoskeletal complaints or emotions. For instance, a literature review by (9) concluded that workers who adopt unusual or restricted postures are at higher risk of musculoskeletal complaints and often exhibit reduced strength and lifting capacity. Regarding emotions, (10) found that a more slumped-over body posture may infer greater helplessness. However, research on the relationship between body posture and productivity is scarce. A search in 'science direct' on the terms 'body posture' AND 'productivity' in title, keywords or abstracts returned 8 papers published between 1996 and December 2013. Only four consider human productivity. One of these four showed a significant difference in productivity between two assembly workstation layouts (11). The layout influenced body posture, and productivity increased through more economical use of hand movements. In computer work, the number of studies on body posture and productivity is also limited. Some studies, which do not primarily focus on productivity, also measured performance effects. Moffet (12) showed that the number of typed characters was significantly higher using a screen positioned closer to the eyes. Sommerich (13) found differences in productivity between using a stand-alone notebook computer along with inexpensive peripheral input devices. Participants were more productive with a mouse than with a pointing stick. However, effects on productivity of other postural changes were not found. The changes in parts of the human body in space were small, but significantly different. In a pilot study, Commissaris (14) showed that various office work postures influenced productivity. For instance, an asymmetric posture with the back bent sidewards reduced productivity for a VDU task.

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

To test the assumed effect of large body posture changes on productivity, an experiment was performed. In this study, productivity is defined as typing performance. First, pilot tests were performed to improve the test set-up and the questionnaires. For instance, letters in the pilot texts shown on a paper were too small to read, and type size in the smartphone was enlarged in the real test because we did not want to measure readability. Pilot tests were also done in developing an armrest chair (see Figure 7.1) to design the ideal smartphone chair to support the arms adequately.

Figure 7.1: Various stages in the development of the armrest chair for supporting working with a handheld device. Left: one of the first drawings, middle: the first test version, right: the final prototype.

7.4 Methods

The two research questions, 'Does body posture during smartphone use influence productivity?' and 'Does body posture during smartphone use influence comfort and discomfort?', were answered via an experiment. The research team members were provided with materials and a method to answer the question.

7.4.1.Participants

Thirteen men and 11 women of various nationalities (European, American and Asian) participated in the study. They were all participating in, or had completed, higher education. Their average age was 25.2 years (20 to 40 years), and their average height was 1.74 m, varying from 1.58 to 1.89 m.

7.4.2. Measurements and protocol

A pilot test was set up to simulate the planned experiments. One participant participated and followed the planned protocol that was set up by the research team (see Table 7.1).

Table 7.1: The protocol of the smartphone seat experiment.

Introduction and observation for 10 minutes	Start typing text scenario 1 for 15 minutes, send an email	Rest (change posture) for 5 minutes	Start typing text scenario 2 for 15 minutes, send an email	Answer comfort and discomfort questionnaire

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

When each participant arrived, the first 10 minutes were spent explaining the research protocol, and the participant completed an informed consent. The participants were invited to observe the previous participant while that person was sitting in the chair typing.

The 24 participants were asked to type a text as quickly as possible on their own smartphone for 15 minutes in each chair. The chair was presented in two different conditions: with and without armrests. The texts were different in each condition but had the same type of words. To prevent order effects, the sequence of the seat use was systematically changed. The participants had to read the texts they were asked to type from a screen in front of them at the appropriate eye height. Video recordings were made to see if the participants used the same typing method in all chair conditions (e.g., using both thumbs in typing, using the right finger, etc.). The participant typed this text on their own smartphone and had to send the typed text via an email to the researcher. Twelve participants started in the chair with armrests, and the others started typing in the chair without armrests. Finally, the participants were asked to rate the perceived comfort and discomfort for each condition on a 7-point Likert scale (1 represents the lowest comfort and discomfort, 7 represents the highest comfort and discomfort) after typing. See Figure 7.2 of sitting in a chair with and without an armrest.

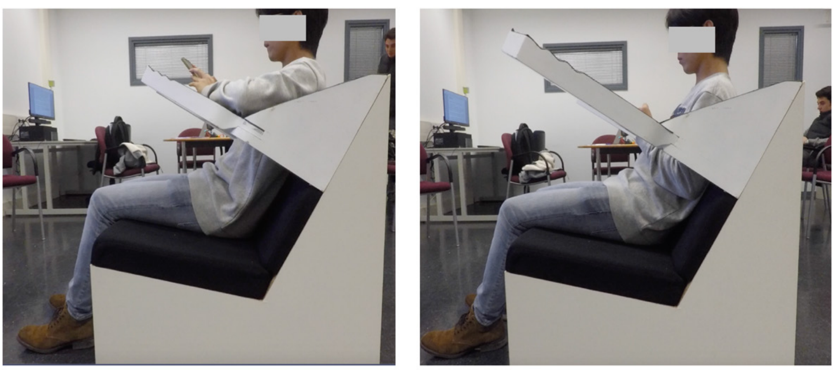

Figure 7.2: A chair with and without armrests

7.4.3 Questionnaire

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

7.4.4 Posture recording

The posture of participants when they used a smartphone while typing in the chair with and without armrests was analysed by scoring the angles by using the Kinovea software (15) and then evaluated on ergonomic risk by RULA. The participants used the same posture of the upper limb in the left and right side.

7.4.5 Analysis

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

7.5 Results

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

7.5.1 Smartphone productivity in two different chairs with and without armrests.

Productivity is expressed as words counted and averaged for each condition over the 24 participants. The productivity was lower when participants used the smartphone chair with armrest support than when they used it without support (see table 7.2). However, the difference was not significant, p-value 0.18406. There were significantly more mistakes, spaces and wrong letters when participants used the smartphone chair with the armrests than without, (p-value 0.00001).

Table 7.2: Word count, mistakes, spaces and wrong letters.

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

7.5.2 The results of postures

The results from RULA showed that when the participants used the smartphone with the arm support, the risk of posture-related complaints was higher than when they used the smartphone in the chair without the armrests at a significant level, p-value 0.00001 (table 7.3).

Table 7.3: The average RULA score separated by part of body.

Posture	Upper arm	Lower arm	Wrist	Wrist Twist	Neck	Trunk	Leg	RULA Score
Chair with armrests	5	2	2	1	2	1	2	5
Chair without armrests	1	2	2	1	2	1	2	4
Significance Level	Significant	Not sig	Not sig	Not sig	Not sig	Not sig	Not sig	Significant

The RULA score is shown in table 7.3. Column A shows the arm and wrist scores based on the observations, and column B the neck, trunk and leg in the RULA form (16). The results of the RULA score are the same on the left and right side of the body. None of the body parts were significantly different. The only significant difference was in the upper arm: the score was higher in the chair condition with the armrest than without the armrest.

7.5.3 The results of comfort and discomfort

The participants evaluated their comfort and discomfort after sitting in the chair with and without the armrests and typing the text for 15 minutes in each chair. The lowest comfort is found in the neck while using the smartphone without support. While using arm support, the neck comfort score (3.75) is better than without support (3.46) (Table 7.4). While upper arm comfort when using the chair with armrests was lower than without armrest due to the fixed height level of the armrest is too height.

Table 7.4: Comfort experience and RULA score compared between using smartphone with and without armrest.

Part of body	Minimum RULA score (1)		Average comfort experience		Maximum RULA sore (7)		P-Value
	With armrest	Without armrest	With armrest	Without armrest	With armrest	Without armrest	
Total body	1	2	3.75	4.00	7	7	0.43
Neck	1	1	3.75	3.46	6	7	0.41
Upper back	1	2	4.42	4.29	7	6	0.49
Lower back	2	2	4.63	4.29	7	7	0.30
Upper arm	**1**	**2**	**3.33**	**4.21**	**6**	**7**	**0.02**
Lower arm	1	2	3.83	3.75	6	7	0.45
Wrist	1	2	3.83	4.17	6	7	0.16
Leg	3	3	4.96	4.96	6	5	0.50

The discomfort score (Table 7.5) in the neck while using a smartphone without support is also high (4.54) and higher than with support (3.67). In addition, the total body, neck, upper back, lower back, lower arm, wrist, and leg discomfort between the chair with and without armrests was not significantly different (P-value 0.05). The participants' discomfort when using the smartphone on the chair with armrests was higher than when using the smartphone without arm support.

Table 7.5: Discomfort experience and RULA score compared between using smartphone with and without armrest.

Part of body	Minimum RULA score (1)		Average discomfort experience		Maximum RULA sore (7)		P-value
	With armrest	Without armrest	With armrest	Without armrest	With armrest	Without armrest	
Total body	1	1	3.67	3.75	7	6	0.48
Neck	1	1	3.67	4.54	7	7	0.75
Upper back	1	1	3.25	3.63	6	6	0.29
Lower back	1	1	2.92	3.17	7	6	0.25
Upper arm	**1**	**1**	**3.79**	**3.71**	**7**	**6**	**0.049**
Lower arm	1	1	3.71	4.04	7	6	0.36
Wrist	1	1	3.25	3.54	7	6	0.39
Leg	1	1	2.63	2.58	5	6	-**

Remark : *means that the body part in table 7.4 and 7.5 showed a significant difference.

** The data in this part were the same level, which means comparison with the Wilcoxon test is not possible

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

7.6 Discussion

Answering the research question 'Does body posture during smartphone use influence productivity?', the results illustrated that productivity of word count is different between the participants using the smartphone in the chair conditions with and without armrests, but not at a significant level for all recordings. The errors such as mistakes, spaces and wrong letters were significantly fewer when the participants used the smartphone without armrests than with armrests. This aligns with (17) study, which found that postural discomfort might have an effect on typing performance. The error rate did not increase progressively with the work duration. It did increase with Borg scale ratings, but there was a not significant work interval effect. However, the authors mentioned that the test time was for 2 hours. Pan (18) reported that 2 hours may not be a long work duration. In addition, they tested 6 participants, and a large sample size was recommended in further studies. A pilot study by Commissaris (14) showed that various office work postures influenced productivity. For instance, an asymmetrical posture with the back bent sidewards reduced productivity for a VDU task. Regarding the second research question, 'Does body posture during smartphone use influence comfort and discomfort?', the study showed that there is no significant difference between most of the body parts regarding the comfort level.

The total body, neck, upper back, lower back, lower arms, wrist, and legs were not significantly different between the chair conditions with and without armrests while using a smartphone. Only the upper arms showed a clear significant lower comfort score in the condition with armrests. Also, the discomfort during smartphone use with armrests was significantly higher than without. According to the results of RULA, there is no difference between the left and right side of the upper body. The posture during smartphone use in the chair without armrests has a significantly lower risk than with armrests, according to the RULA evaluation method. Notably, the upper arms showed a significant difference because of the height at which the armrests were installed without adjustability at 55cm height from seat level. While the results of comfort and discomfort between two chair conditions showed a significant difference only in the upper arm, other body parts were not significantly different. Still, the results showed low comfort and high discomfort scores, for example, in the neck, lower arm and wrist. Similarly, (5) reported on neck, arms and hand comfort and discomfort in a comparison between using a tablet in a chair with and without armrests. The results of their Wilcoxon Signed Ranks test showed that comfort of the neck region increases significantly while sitting in a chair with armrests, but the arms and hands were not significantly different. Moreover, discomfort decreases significantly for the neck, but arms and hands were not significantly different. They were able to adjust the height level of the arm support to fit the participants' anthropometry. This might have been a crucial element. Albin and McLoone (19) reported that as the tilt angle of a tablet increases, the neck flexion decreases significantly. Therefore, perhaps in a future design, the height of the arms should be made adjustable to prevent the shoulders being lifted and improve the position of the neck. A limitation of this study is that the armrest limited freedom of movement and forced the participants into an unnatural posture. With more freedom, comfort scores may have been different. However, the comfort score of the arms aligns with the RULA scores, showing that the chair needs to be improved.

7.7 Conclusion

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

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

7.8 Acknowledgement

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Chapter 8

Guidelines for adapting the Vehicle Interior for comfortable Smartphone use.

Introduction

In several of the previous chapters, it has been suggested that for texting with two hands, arm support should be added. It is also suggested that current armrests are often too low, resulting in neck flexion. The literature is clear that neck flexion should be avoided to prevent discomfort in the neck and musculoskeletal injuries in the long run. As shown in chapter 7, an armrest should not be too high either, as this affects productivity negatively. This chapter develops Guidelines based on observations of how people sit while using smartphones, in combination with anthropometric data.

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Chapter 8. Guidelines for adapting the vehicle interior for comfortable smartphone use.

8.1 Abstract

Passengers often use smartphones while traveling in trains, airplanes, or buses, and perhaps in the future, they may use them in automated cars. Ideally, future designs should support smartphone use to prevent discomfort. People often use smartphones with both elbows on the armrests. However, the armrest height could be too low and cause neck flexion. This study researches the appropriate height level of the armrest while using a smartphone, in order to develop Guidelines for this. Participants performed four main smartphone activities: listening to music, texting, watching videos and reading on the phone in a train seat. The anthropometric data and the neck, trunk and elbow angles were recorded. Based on these data, the height level of the armrest was calculated. The results show that the height level of the armrest should be adjustable between 184-295 mm above the seat pan. If there is no possibility of making it adjustable, 243 mm is advised. Future steps could be the design and mechanism of the armrest or another tool that can help hold the smartphone, but tests are still needed to confirm the proposed Guidelines for new height levels of the armrest.

8.2 Keywords: Comfort, seat, armrest, smartphone, passenger

8.3 Introduction

Smartphones have become an inseparable part of our daily lives. People use them for many different purposes, such as talking to someone, texting, listening to music, reading or watching videos (1) and (2) showed that 48.3% of train travellers used a smartphone. The recent study in 2021 (1) reported that 57.4% used a smartphone. This growth in the use of mobile computing devices might have comfort and health implications. When people use a smartphone, they usually stress their upper body (3). The upper and lower arm, wrist and fingers could potentially get overused due to holding the smartphone for a long period of time (4). People bend their heads forward when they hold their smartphones on their laps, which could increase neck discomfort and eventually cause pain. In contrast, holding the smartphone in front of one's head and resting one's arms on an armrest would result in a more upright position of the head. Some studies have reported people using mobile devices for as many as 7 hours a day (5). Using the smartphone for an extended period of time can lead to more pain and fatigue, as (6) described. Redesign of a vehicle's interior might help prevent these problems to some extent. Anthropometric data could be helpful in defining the ideal armrest support height. However, previous armrest Guidelines are based on the height level of the armrest measured by the elbow height above the seat pan with a 90-degree angle. "Generally, Office Chair armrests should be positioned at the same height as the point of your bent elbow to allow a straight lower arm position"(7). However, passengers' back posture while traveling is more reclined. Also, the upper arm is not vertical, and the elbow is not at a right angle to it. The angle of the trunk and elbow influence where the armrest should be positioned to support the elbows. In the literature, it has not yet been reported what the armrest height should be to support smartphone use. The main goal of this research is to study the elbow and neck postures of passengers while they are performing various activities on a smartphone whilst seated. The results should then serve to provide Guidelines for interior design supporting comfortable smartphone use.

8.4 Method

Thirteen females and 15 males aged between 22 to 25 years volunteered to take part in the experiment. Their height varied from 155 to 191 cm. They were from Europe, Asia, and South Africa. They had sustained no musculoskeletal disorders or injuries in the last 6 months. Their elbow rest heights at 90 degrees were 17.91(P5) to 20.89(P95) cm, respectively. After arriving at the lab, the participants were informed of the protocol and signed the informed consent. They were then asked to sit in the train seat. Fourteen participants sat in the seat and used the smartphone to perform four activities: listening to music, texting, watching videos and reading on the phone. These were the most observed activities in a previous study (1). The other 14 passengers started by reading, followed by watching, texting and listening to music. All participants performed each activity for 15 minutes. After completing the test, the anthropometrics were measured, as Table 8.1 shows. During the session, the body angles were video recorded laterally on 2 sides of the seat, such as the neck, trunk and upper arm angles. The video camera recorded the angle between the trunk and the elbow and the neck angles. For each activity, pictures of the postures were recorded while the participants were holding a smartphone at the 1-, 7.5- and 15-minute marks (using Kinovea program version 8.5) (8), as figure 8.1 shows. The position of the armrest was recorded as well. Based on these data, the elbow height was calculated using the equation ((shoulder sitting height*sin (angle)) - (elbow sitting height* sin(angle)). From DINED (9) the P5 and P95 percentiles of shoulder sitting height (532 to 664 mm) and the elbow sitting height (203 to 301 mm) were derived. Then the P5 and P95 of the armrest height were calculated. Descriptive statistics (percentages) were used to explain the neck flexion and the armrest used.

Figure 8.1: The trunk, elbow and neck angles calculations.

8.5 Results

This research aims to develop Guidelines for armrest design to increase comfort for passengers using a smartphone. A previous publication provided in the DINED database showed the values of the height of the elbow and the trunk for the angles of 90 degrees to the horizontal Dirken (9) in DINED, undated. However, the passengers in the train seat using the smartphone had different angles than 90 degrees. This experiment was conducted with the four main activities (listening to music, texting, watching videos and reading) that people holding a smartphone on the train seat usually do(1). Table 2 shows the angles of the trunk and upper arm. The activity listening to music is not seen as relevant for defining the armrest height because the elbows are usually not on the armrests. For video watching, a holder on the backrest of the seat in front is preferred. Therefore, the armrest height determination is based on the other two activities, texting and reading. The sinus of the maximum and minimum trunk angle varies between .69 and .98. The sinus for the upper arm varies between .56 and .98. The p5 sitting shoulder height (Dutch adults 20-60 mixed 2004) is 538 mm and the upper arm height is 335 mm. This means that for these smaller persons (p5) and largest angles, the armrest height should be .69x538-.56x335=184mm. For the tallest persons (p95) and smallest angles (close to vertical), the armrest height should be .98x664-.98x363=295mm. Therefore, the armrest needs to be adjustable between 184 and 295mm (figure 8.2). It is interesting to see that for all activities, the average trunk angle is approximately the same. That is true for the upper arm angle as well. The average trunk angle for all activities is around 62 degrees, and the average upper arm angle is 55 degrees. Combining this with the p50 person height, the average armrest height is 243 mm.

Table 8.1: The recorded angles of the trunk and upper arm of the 28 participants.

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

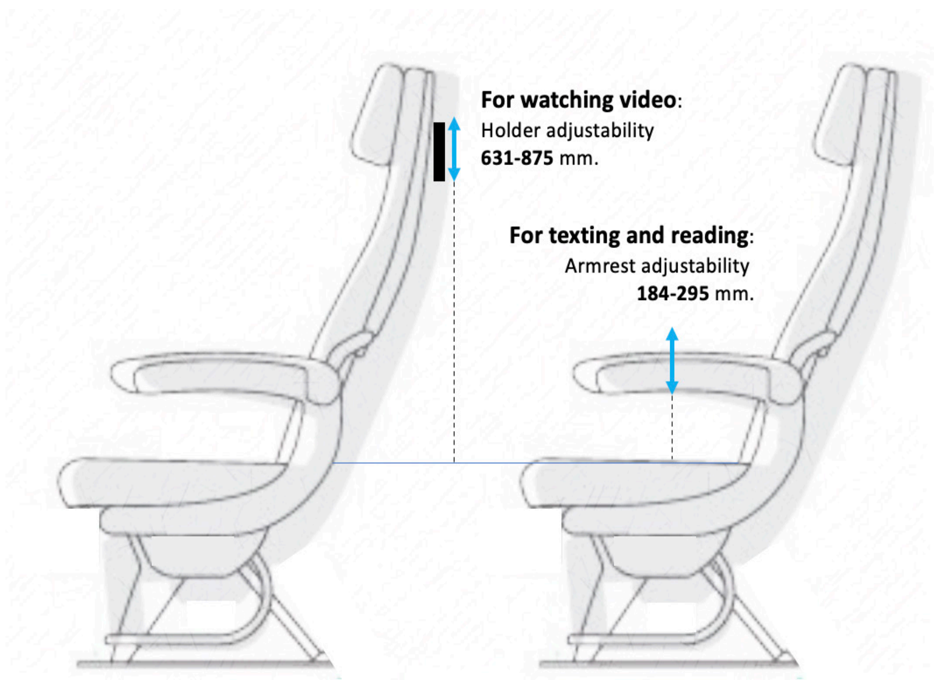

Figure 8.2: Guidelines for adapting the interior design for comfortable smartphone use.

For watching videos, a smartphone holder should be set up at eye height. The measurements of people globally, as referenced in the DINED database, show that the 5th and 95th percentiles of the eye height levels above the seat pan are 631 and 875mm, respectively. Thus, an average eye height level of the smartphone holder for a watching activity could be 753 mm (see discussion).

8.6 Discussion on the Guidelines

Based on these data, the Guidelines for the environment of smartphone use differ depending on the activity. For listening to music, no Guidelines are needed because the smartphone is not linked to the eyes and hands and thus can be placed anywhere. For video watching, the hands are not linked to the smartphone. Perhaps the Guidelines should be based on (10) study, in which a viewpoint (the middle of the screen) between 0-15 degrees under the horizontal line through the eye is defined based on the studies of (11) and (12). Suppose we use 0 degrees; then for a 30" pitch (760mm) aircraft seat and a smartphone with a height of 75 mm, the lowest point of the holder should be at the height of 718 mm above the seat pan for p5 and 872 mm above the seat pan for p95 (DINED, 20-60 male and female). The 753 mm in our study might be optimum.

For the tasks of texting and reading, where the hands are on the smartphone and people have to watch the screen, the armrest should be adjustable to between 184-295 mm above the seat pan. If it cannot be adjusted, an armrest height of 243 mm above the seat pan is recommended.

These Guidelines are based on the observations of 28 participants. Anthropometric data of other persons in DINED in combination with literature. This means that verification is needed. Performing future empirical research to test the Guidelines in practice and comparing these with other conditions are recommended. Another limitation of this study is that privacy is not considered. It might be that postures are different when one is trying to prevent one's neighbour from following one's smartphone activities. The seat design in our case had only one armrest between two seats, and the elbow breadth was rather wide, which could have influenced the postures. Future studies should enquire how to design the arm support itself. For example, its hardness could also influence comfort. The dimensions of the armrest, the mechanism of adjustment and cover and cushion materials should be studied.

8.7 Conclusion

Vehicle interiors can be improved to prepare for smartphone use. In this paper, a set of indicative Guidelines developed based on observations, anthropometric data and literature. These Guidelines are a first indication to help improve the interior. For video watching, the height of the holder on the backrest in front of the person should be adjustable between 631-875 mm above the seat pan. For texting and reading, the armrest should be adjustable between 184 and 295mm. The average trunk angle for all activities is around 62 degrees, and the average upper arm angle is 55 degrees. Combining this with the p50 person height, the average armrest height could be 243 mm.

8.8 References

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Chapter 9
Discussion and Conclusion

Chapter 9. Discussion and Conclusion

This PhD thesis aims to answer the main research question: **How can the seat environment be improved so that passengers can comfortably use a smartphone while traveling?** This thesis studied seat elements and the environment influencing the passengers' comfort while using a smartphone. Data are gathered from the literature and experiments. This chapter reflects on the results of the different chapters linked to the main research question. Limitations will be described, suggestions are made for future research, and tips and Guidelines for designers are given.

9.1 Overview of the results and main findings

To answer the research question, first the literature was studied (**Chapter 2**). In all, 185 articles were collected from the Scopus and Pub-Med databases. The abstracts were screened by two researchers, then compared and discussed based on a set of inclusion criteria. Forty-five publications met the criteria, and five were added because the authors were familiar with them, and they did not show up in the databases. The literature shows that the smartphone is often used with two hands and sometimes with the elbows on an armrest. Smartphone use is associated with discomfort, which mainly occurs in the neck, back and arms. To improve the neck, back and arm positions during smartphone use, neck flexion should be reduced. With the elbows on the armrest, the correct armrest height can position the smartphone at the correct height for texting and Texting. Most studies in the literature were conducted in the laboratory, at home or in offices. The number of studies on smartphone use while travelling is limited. Therefore, this PhD set out to conduct observations of travellers and their smartphone use.

In **Chapter 3**, observations in trains and questionnaires completed by train passengers were used to study how many passengers use smartphones, what activities passengers do while travelling and which postures can be observed. Out of 606 observed train passengers, 57.4% used a smartphone during the trip, which was an even higher percentage than in the study of (1), who observed that 48.3% of the train passengers were using a smartphone while traveling on a train. The passengers used a smartphone to listen to music, chat or type, look at a video or pictures, and read. Most passengers reported that they hold a smartphone with both hands. Also, using the smartphone with the right hand was observed frequently. They used their thighs and the armrests of the seat to support their elbows, but this appeared to provide the lowest comfort. There is certainly room for improvement. Future research could be considered to redesign the seat to increase passenger comfort while using a smartphone.

In **Chapter 4**, data are gathered to improve the train passengers' seating environment. Experienced train travellers first explored the problem, followed by a co-creation session in which ideas were generated to improve smartphone use in the vehicle interior. The co-creation showed that passengers need more support for smartphone use, like an arm support and a holder. In **Chapter 5**, the effect of a smartphone holder in a train was studied. The participants performed several smartphone activities, and postures and comfort and discomfort were recorded with and without a smartphone holder. The results showed that the holder significantly decreased the neck flexion and the lower arm angle while using a smartphone and reduced discomfort in the neck while passengers were watching a movie and reading. However, the holder did not improve discomfort for all activities. Texting on the phone presented significant discomfort in the upper body with a holder compared to texting without a holder. This study showed that to improve the comfort for train travellers, a study was needed to determine which activities were easier when using the smartphone holder and at which height the armrests should be positioned. This study also contributed to theory on comfort generally because a difference was found between expected and experienced (dis)comfort. This shows that experiencing the tasks and haptic information is needed to gather user information about the use of a product or environment.

In **Chapter 6**, another contextual aspect of smartphone use in public transport was studied. Since some public transport features beds, 52 participants were asked to use the smartphone on a bed. The trunk angle of this bed was adjusted to 6 positions from flat to upright, and for each angle, the comfort and discomfort was recorded. The results showed that for smartphone use on a bed, it is preferable to have the trunk angle between 120–140 degrees. Based on these studies, the recommendation is for beds to have the backrest adjustable to 120-140 degrees.

Chapter 7 presents the results of an experiment studying the effect of an arm support on smartphone use. A chair with a special arm support that supports the upper and lower arm was tested by 24 participants. The number of spelling mistakes users made in the chair without armrests was lower than when they sat in same chair with armrests ($p< 0.05$). The upper arm in the condition with an arm support showed higher discomfort and lower comfort ($p< 0.05$). The chair used in the experiment was not adjustable, which also limited freedom of movement. Therefore, it is advised to have a height-adjustable armrest and to give the user more freedom of movement.

In **Chapter 8**, Guidelines are developed for situations in which two hands are used (e.g., texting or Texting). Train, car, bus, or airplane interior designers or seat suppliers are advised to add a smartphone holder for watching videos and reading and to make the armrests adjustable for texting and Texting. The armrest height is now often too low, which might cause neck flexion. Based on joint angles and anthropometrics, the height level of the armrest was calculated. The results show that the adjustable height level of the armrest should be between 184-295 mm above the seat pan. Future steps could be the design and mechanism of the armrest, or another tool that can help hold the smartphone and evaluate the effects on comfort.

9.2 Reflection on methods

In this PhD study, several methods are used to answer the research question, 'How can the seat environment be improved so that passengers can comfortably use a smartphone while traveling?'

Observations were used in a study on passengers' activities, postures, dis(comfort) and needs while travelling by train. Advantages of this method are that they encouraged the researchers to find the actual situations in the train bogies. This method helped screen many train passengers without interrupting their activity and privacy. However, the limitation of the observations is that the data do not cover a person's whole trip. Another disadvantage of this method is that the researcher can have some influence when observing. It can help to check whether the researcher's perspective was correct by examining additional data. That is why this research uses mixed methods: observation as well as a questionnaire. Kamp (2) used the observation method as well to observe the activities of the train passengers. Groenesteijn (3) observed the activities of passengers during a train trip, noted the main postures, and then added questionnaires of selected passengers that affirmed the findings of their observations. Kilincsoy and Vink (1) observed train passengers' activities, and the results are comparable to those of our study. These references support what observations can add to valuable field data of the train passengers.

Next to observations, questionnaires were used to gain insights into the passengers' needs. Advantages of this method are that data are gathered on the way passengers perceive smartphone use, but it also helped the researchers understand more about the passengers' activities, postures and needs while traveling by train. Disadvantages are that the data are subjective and reflect only what passengers experience. Questionnaires were also used for the comfort studies and while researching smartphone use with and without an arm support. Questionnaires have been used similarly before e.g., (4), (5), and (6)and provided valuable information. In addition, comfort and discomfort questionnaires were used here during smartphone use on a bed, identifying a preferred backrest angle. Using comfort and discomfort questionnaires digitally on the participants' own smartphone was better than a paper questionnaire because the analysis is quicker, and the chance is smaller that mistakes are introduced (no need to type the data from the forms to a SPSS file). However, the size of the smartphone screen is limited, restricting the use of some questions. In all cases, researchers need to prepare the questionnaire, and a pilot study is advised. A pilot test that was conducted in this PhD study yielded valuable information to improve the questionnaires. Also, testing the digital version before starting the experiment is advisable. Hiemstra-van Mastrigt (7) also used a digital questionnaire and gained valuable data about activities while sitting in an aircraft seat.

Considering measurements related to comfort, Song and Vink (8) conducted a literature review of used methods. Three measurements are most frequently seen: anthropometrics, body angles and pressure/force. The anthropometrics and body angles are recorded in this PhD thesis as well.

Comfort and discomfort are influenced by the interaction between the human, tasks and seat characteristics. Anthropometrics plays a role as well. That is why anthropometric measurements were often done to collect the participants' size and body dimensions related to the seat dimensions. For this study, care was taken to have a variation in sizes of the subjects because human size influences postures in a seating environment. The anthropometric dimensions were recorded in a standardized way based on (9), which makes comparison with the literature possible. These dimensions are also needed to arrive at design Guidelines because the seat should fit the body dimensions.

Apart from anthropometrics, observation and questionnaires, the body angles of the participants were measured while using the smartphone on the smartphone chair, bed and train seat. The video camera was also used to collect data on the interaction between the human and the tasks (all the activities performed on the train such as listening to music, watching, texting and reading). Furthermore, data were gathered on seat characteristics like angles and armrest heights, especially because the armrest height needed improvement for comfortable smartphone use. In recording body angles, marks were used as a reference before recording. These marks were helpful while using the posture analysis program (Kinovea) (10) to analyse the anthropometric data. Recording this data required a lot of storage space. Consequently, the data transfer process and the storage space needed to be prepared before setting up the study. Adnan (11) tested the reliability of the Kinovea system to analyse the HD video and found that the average variances are less than 10%, which was important for interpreting the data.

Also, Stappers and Sanders (12) context mapping techniques were used, which help participants generate new knowledge. The process starts with creating context awareness by recalling the experiences of the users. The group of users engaged in our study were supported in this way in expressing their emotions, concerns and feeling around the context (13). In this study, this method allowed the passengers to recall their trip of the long-distance train in the mock-up of the second-class train seat. After that, the researchers provided a tool kit and encouraged the participants to discuss the context of smartphone use in a long-distance train trip. The participants were stimulated to discuss their problems, experiences and needs for improvements. However, this method requires considerable effort in preparing the tool kit and gathering the right data to answer the research questions. The support of experienced co-creation researchers was needed to make the session successful. To solve those questions, (13) reported that experience from the practice of context mapping researchers is needed.

Lastly, interviews were used in this study. For instance, after the co-creation session, interviews were used to let the participants explain their design preferences and experiences after experiencing the products such as the smartphone holder and the special design of the armrest. Advantages of the interview process are that open answers are possible and there is space for ideas that researchers might not think of in advance. It also helps researchers gain insight into the experience and needs of the participants beyond the context. However, the researchers need to prepare the main questions and prevent the discussion from straying into irrelevant areas.

9.3 Application of the research

This research provides recommendations for designers to improve seat comfort for train passengers who prefer to use their smartphones during their trip. However, the results could be applied to other transportation modes such as airplanes, buses, cars, boats and future vehicles, like, for instance, the Flying V and the hyperloop, if similar dimensions are at issue there. Also, home furniture might be designed using the knowledge presented in this thesis.

9.4 Limitations and future work

Of course, this study has limitations. One difficulty was that the research was conducted during the COVID-19 pandemic, which limited the number of participants and the distance between them, because sometimes they had to use mouth caps. The observation on the train could not be conducted in Europe and other countries because of COVID-19 restrictions. The smartphone use in the train was only done in Thailand, where the situation allowed measurements at that time. Because the train is not the most important transportation mode in Thailand, the percentages of people using smartphones in other countries might be different. The smartphone use activities are now based on the questionnaire completed by the participants. Future observations of the activities might give more precise percentages. On the other hand, the design solutions will probably not differ.

The smartphone holder was investigated because watching videos was the main activity performed. (Actually, listening to music also occurred frequently, but the performed postures did not need any specific attention because users are free to choose their position.) The smartphone holder was tested in the lab, and it does improve posture. However, other positions could be even more beneficial, and further research is needed to optimize the smartphone holder position, while also taking the lateral vibration of trains into account. For texting, the armrest Guidelines developed here could be used. However, more research is needed to validate whether discomfort is really reduced, and comfort is really improved. An issue arising from the literature review in Chapter 2 that also needs attention is the fact that the duration (height of use) of the smartphone plays a role in causing complaints. That means that next to creating a seat environment that stimulates good posture, a time limit should be added. This topic is not addressed in this PhD thesis, but it certainly needs attention in future research.

9.5 Final Statement

This research shows that train passengers do use smartphones during travel. The main activities that were performed on the phone were listening to music, watching videos, reading and texting. As (14) mentioned in their comfort model, the task (activities performed on a smartphone) influences the users' postures, which was seen in our study as well. Defining the task as 'smartphone use' is not enough because the different activities done on the smartphone ask for a different environment. People adopt postures in interaction with the seat elements, which were designed for other activities than smartphone use. However, the duration of the activities and the postures play a big role in the perception of comfort and discomfort, as also found by (15). Future seat design should consider not only activities and postures, but also anthropometrics and other needs related to the main performed activities of the users.

Guidelines for the design of the seat elements to support comfortable smartphone use should also include a special armrest for reading and texting activities. For watching videos on the phone, the design should include an element or holder that can help position the smartphone at the right spot. Regarding the neck angles that were recorded while using a smartphone, too much neck flexion was recorded and mentioned in the literature as well. In this situation, the headrest adaptation does not help reduce the neck angle. Armrests and smartphone holders are more effective. That is why a special armrest, and a holder should be considered to reduce arm discomfort and increase comfort of the neck simultaneously.

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Publications

List of Publications

1. Udomboonyanupap S, Boess, S., Song, Y., & Vink, P. Sumalee Literature review on seat comfort during smartphone use. Work. 2024 (Manuscript, under review)

2. Udomboonyanupap S, Boess, S., & Vink, P. Passenger Activities, Postures, Dis(Comfort) Perception, and Needs During Train Travel. Lecture Notes in Networks and Systems. 2021;220.

3. Sumalee Udomboonyanupap, Stella Boess, Peter Vink, Train Passengers' Needs for the Seating Environment. In: Proceedings of the 4th International Comfort Congress, 2023, Amberg, Germany, page 69-73. Accessible at https://9b4fc83a-6fd0-4bd0-a6d9-9fb1220e9922.usrfiles.com/ugd/9b4fc8_56fcb6bc98394f729459b54f541acace.pdf

4. Udomboonyanupap S, Boess, S., & Vink, P. Differences in Expectation, Experience and Recorded effects while using a smart phone with and without support. Applied Ergonomics. 2024 (Manuscript, under review)

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1. Peter Vink, Shabila Anjani, Sumalee Udomboonyanupap, Golnoosh Torkashvand, Thomas Albin, Symone Miguez, Wenhua Li, Christian Reuter & Amalia Vanacore (2021) Differences and similarities in comfort and discomfort experience in nine countries in Asia, the Americas and Europe, Ergonomics, 64:5, 553-570, DOI: 10.1080/00140139.2020.1853248

2. Xinhe Yao, Yufei He, Sumalee Udomboonyanupap, Norbert Hessenberger, Yu Song & Peter Vink (2023) Measuring pressure distribution under the seat cushion and dividing the pressure map in six regions might be beneficial for comfort studies of aircraft seats, Ergonomics, 66:10, 1594-1607, DOI: 10.1080/00140139.2022.2157495

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Presentations

1. Sumalee Udomboonyanupap, 2019. Comfort and discomfort during smartphone use on a bed. International Comfort Congress 2019. Delft University of Technology, August 29-30, 2019.
2. Sumalee Udomboonyanupap, 2019. Comfort and Discomfort in a Chair Using the Smartphone. International Comfort Congress 2019. Delft University of Technology, August 29-30, 2019.
3. Sumalee Udomboonyanupap, 2023. Train Passengers' Needs for the Seating Environment. 4th International Comfort Congress, 2023, Amberg, German, September 6-7, 2023
4. Sumalee Udomboonyanupap, 2023. Guidelines for adapting the vehicle interior for comfortable smartphone use. 4th International Comfort Congress, 2023, Amberg, German, September 6-7, 2023
5. Sumalee Udomboonyanupap, 2020. Discomfort perception per body part while using a smartphone in an aircraft seat. Joint Conference of the Asian Council on Ergonomics and Design (ACED) and the Southeast Asian Network of Ergonomics Societies (SEANES) – "Convergence: Creating Ergonomic Breakthroughs Through Partnerships," 2-4 December 2020. (Online)

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About the author

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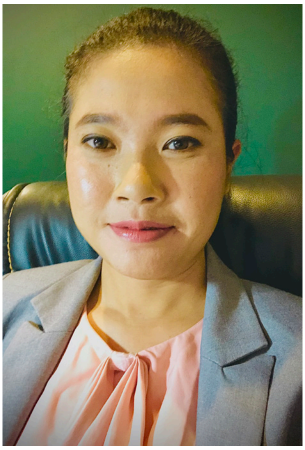

Sumalee Udomboonyanupap was born in Nakhon Ratchasima, Thailand. She started the PhD project at Delft University of Technology in 2019 in the field of Applied Ergonomics and Design, supported by the Royal Thai Scholarship. This scholarship was provided following the requirements of The Ministry of Higher Education, Science, Research and Innovation, and Suranaree University of Technology, Thailand.

After she graduated in the field of Occupational Health and Safety from Khon Kaen University, she worked in the position of Safety officer at Advance Agro Public Company Limited. After that, she continued to her Master's degree. She also joined the Occupational and Safety team at Hitachi Global Storage Technology (Thailand) Ltd, where she helped to reduce discomfort and improve productivity together with the employees for more than 5 years. During that time, she completed the Master degree in Safety Engineering at Kasetsart University. She aimed to use her knowledge and experience to create more impact. That is why after completing the Master degree she followed her own plan by starting in the position of lecturer at Suranaree University of Technology, where she can follow her passion.

In her future career she hopes to inspire the students, employees, and entrepreneurs to apply ergonomics knowledge to improve their jobs or products. She also hopes to apply the knowledge to develop new materials from agricultural products in Thailand and Asian countries to serve the needs of everyone in the world. She aims to help them have comfort in their daily life and especially help people in developing areas increase their incomes and quality of life.