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DOI
10.4233/uuid:306dd9f8-fab9-4f1f-8c1a-1a208e815c21

Publication date
2018

Document Version
Final published version

Citation (APA)
Bouwens, J. (2018). *Design Considerations for Airplane Passenger Comfort*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:306dd9f8-fab9-4f1f-8c1a-1a208e815c21

Design Considerations for Airplane Passenger Comfort

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Design Considerations for Airplane Passenger Comfort

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus, prof. dr. ir. T.H.J.J. van der Hagen,
voorzitter van het College voor Promoties,

in het openbaar te verdedigen op
dinsdag 25 september 2018 om 15.00 uur

door Joyce Martina Antonia BOUWENS
Ingenieur Industrieel Ontwerpen
geboren te Bergen op Zoom

Dit proefschrift is goedgekeurd door de

promotor:	prof. dr. P. Vink
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Samenstelling van de promotiecommissie:

Rector Magnificus	Voorzitter
Prof. dr. P. Vink	Technische Universiteit Delft
Dr. U.W. Schultheis	General Motors, USA
Dr. ir. S. Hiemstra-van Mastrigt	Technische Universiteit Delft

Onafhankelijke leden:

Prof. dr. ir. R.H.M. Goossens	Technische Universiteit Delft
Prof. dr. G. Konieczny	Hamburg University of Applied Sciences, Duitsland
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Cover design:	Foek Le
Layout:	Joyce Bouwens
Printing:	Ipskamp Printing

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Chapter 1: General Introduction

Section 1.2 and 1.3 are adapted from the following publication:

Bouwens, J. (2017). Passenger comfort goes beyond anthropometrics. How environmental factors in the aircraft cabin interior influence comfort experience. *Tijdschrift voor Human Factors [Dutch Journal of Human Factors]* *42*(4), 6-9.

1.1 Aircraft passenger comfort

1.1.1 Passenger diversity and expected growth

Between 1980 and 2016, the number of passengers travelling by airplane increased from 0.6 billion to 3.7 billion globally (The World Bank, 2017). Passenger numbers will likely continue to grow at approximately 3.7% annually, resulting in 7.2 billion passengers by 2035 (IATA, 2016). Airplane passengers can be distinguished by nationality, gender, age, anthropometrics, income and other factors. The composition of passengers is also subject to change; the number of people aged 60 and above is growing faster than the number of people from other age groups (United Nations, 2015), and the share of Asian passengers will increase considerably, with China as the single largest market by 2035 (IATA, 2016). It can be assumed that all of these passengers are seeking a comfortable experience when travelling by airplane, however it is less clear what the most important factors are when improving the passenger experience.

1.1.2 Passenger journey

In this thesis, the passenger journey is defined as the journey between two airports. Between these two points, passengers spend time at the airport (e.g. at check-in, security control and shopping) and in the airplane (e.g. boarding, during take-off, sleeping, eating and landing). Vink et al. (2017) suggested that an unpleasant experience could make a person more aware of comfort in the subsequent event. So, it seems that all stages of the passenger journey are connected. Comfort in this context (and in this thesis) has been used as a generic term to mean both comfortable (associated with feelings of relaxation and well-being) and discomfortable experiences (related to pain, soreness and numbness) which, according to Zhang et al. (1996), need to be assessed separately. Since little is known about the impact of the stages in a passenger journey on comfort, more research is needed to identify the high and low comfort peaks in a passengers' flight.

1.1.3 Stakeholders in aircraft cabin design

Three stakeholder groups can be identified that can influence perceived comfort in the airplane cabin environment: manufacturers (i.e. Zodiac Aerospace), airlines and cabin occupants (Space et al., 2000). Aircraft and cabin interior manufacturers design system performance in the airplane and thereby influence, through this design, the airplane's physical environment. Airlines affect this physical environment through seating configurations, in-flight service and safety and maintenance procedures. Cabin occupants (flight attendants and passengers) influence cabin environment comfort through their individual activities.

In Figure 1.1, environmental comfort factors are sorted for each stakeholder involved. Stress, fear, health status and eating habits are examples of personal factors. According to Space et al. (2000), it is not only the passenger (cabin occupant), but also the airline that is responsible for these personal factors. Factors such as air quality and humidity are part of airplane system performance and are attributed to aircraft and cabin interior manufacturers. Cabin service and operational procedures are factors that are the responsibility of the airlines. Seat design, noise and lighting are examples of factors belonging to the physical environment of the airplane, the design of which is a shared responsibility of the airlines and the aircraft interior manufacturers. Since aircraft interiors strongly correlate with the willingness of the passenger to fly with the same airline again (r=0.73) (Vink et al., 2012), the design of the cabin interior is a key precondition for airlines to remain competitive in the market (Hall et al., 2013). Therefore, aircraft manufacturers and airlines are looking for the best aircraft cabin design to attract customers.

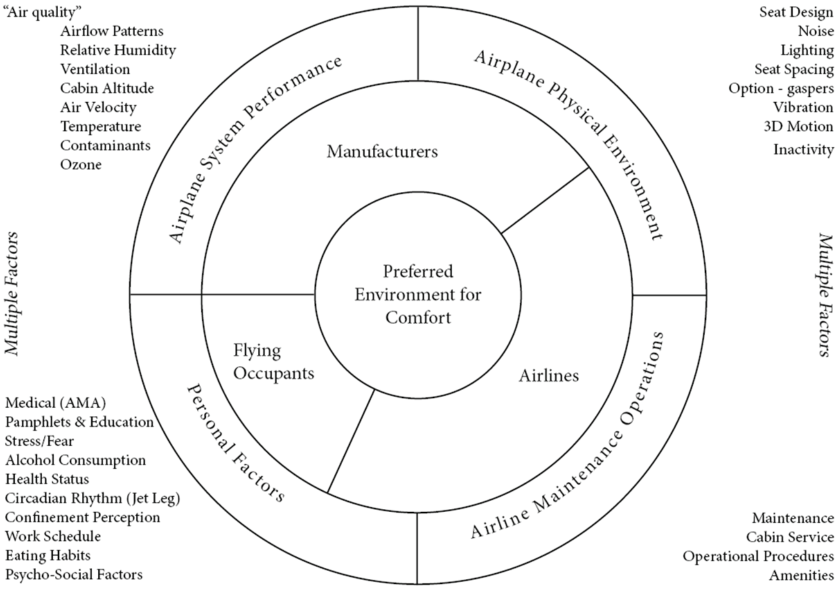

Figure 1.1: Airplane cabin environment wheel (Adapted from Space et al. (2000, p. 194))

1.1.4 Environmental components associated with passenger comfort

The airplane cabin environment wheel (see Figure 1.1) suggests that there are many factors that influence the preferred environment for comfort (Space et al., 2000). Dumyahn et al. (2000) listed extrinsic (environmental) components associated with passenger comfort as well as a set of intrinsic factors (see Table 1.1) that affect comfort. The intrinsic factors correspond with the personal factors mentioned by Space et al. (2000) (e.g. anxieties, health status). The extrinsic factors that directly affect passenger comfort (Dumyahn et al., 2000) are related to the physical environment of the airplane (Space et al., 2000) (e.g. noise, vibrations, lighting). Therefore, it can be inferred that a good design of the aircraft interior benefits passenger comfort.

Table 1.1 Extrinsic (environmental) and intrinsic (personal) factors of airplane passengers that influence comfort (adapted from Dumyahn et al. (2000, p. 6))

Extrinsic (environmental)	Intrinsic (personal)
Temperature	Metabolism and Activity
Relative humidity	- Age
Air velocity	- Gender
Radiant heat	Climatization
Temperature gradient	Insulation
Turbulence	- Clothing
Noise	Odor & Irritation Sensitivity
Vibrations	Health Status
Lighting	Anxieties
Ergonomics	Atopy
Odorants	Cognitive functioning
Irritants	

1.2 Aircraft interior

Extrinsic factors (Dumyahn et al., 2000) and the airplane's physical environmental factors (Space et al., 2000) can be classified into six main themes: smell (odorants), light (lighting), vibrations (turbulence, vibrations, three dimensional motion), noise (noise), climate (temperature, relative humidity, air velocity, radiant heat, temperature gradient) and physical ergonomics

(ergonomics, seat spacing, seat design). The following subsections provide an overview of the academic literature regarding the effect of environmental factors on the comfort perception of airplane passengers.

1.2.1 The effects of smell on comfort perception

The olfactory system, which is responsible for the sense of smell, can distinguish 20,000 different odors and has direct connections to the amygdala and the hippocampus, two brain regions that are implicated in emotions and memories (Abrahams, 2007). Perception of different odors can vary from person to person, based on age, gender and cultural background (Cardello & Wise, 2008), resulting in affected mood, physiology and behavior (Herz, 2009), cooperation and interaction (Cardello & Wise, 2008).

Despite this variance, common perceptions of smell were also found in academic literature. Curtis and Biran (2001) described "disgust" as a primal mechanism, because of which the odor of feces is universally loathed. Jellinek (1998) suggested that the smell of eucalyptus improves memory, that orange and peppermint improve concentration and reduce stress, and that rose and rosemary activates that body, whereas lavender and sandalwood deactivate the body.

Although the environmental conditions (mild hypoxia, dry air, low pressure) in the airplane cabin may cause an impaired sensitivity of smell (Burdack-Freitag et al., 2011; Kühn et al., 2009), passengers still complain regarding the odors that result from being in close quarters while aboard an airplane (Vredenburgh et al., 2015). Although each passenger reacts differently to odors, a bad odor in an airplane will have a significant influence on the comfort perception of the majority of individuals (Vink & Brauer, 2011).

1.2.2 The effect of light on comfort perception

The retina, located at the innerwall of the eye, contains photoreceptors that are sensitive to light of different colors. The brain utilizes and interprets the signals from both eyes to construct a three dimensional image of the environment (Abrahams, 2007; Clarkson, 2008).

Light is defined by its color (temperature) and intensity. Its effect on human beings has been studied extensively. For example, the sleep-wake cycle is synchronized by outdoor light from the sun (Abrahams, 2007). The sunset has a red glow, which activates the production of melatonin that leads to sleepiness. The sunrise on the other hand, consists of bright blue light that supports the production of cortisol in the brain and makes people alert (see Figure 1.2). Utilizing these light colors in the airplane cabin may help reduce jetlag (Zee & Goldstein, 2010).

Figure 1.2: Sunset and sunrise (Image source: Pixabay)

Psychological effects of light color and intensity have also been studied. For example, Schauss (1979) indicated that pink light has a sedative effect on people and should be used in any situation where sudden aggression is likely. However, Bakker (2014) found that color's effect on people is highly dependent on its context and Pellegrini, Schauss, & Miller (1981) found that the tranquilizing effect of pink may be temporary. Applying blue light in the airplane cabin will improve the behavioral alertness of the flight and cabin crew (Brown et al., 2014). Blue light also improves the perceived air quality for passengers, while yellow light makes the temperature of the environment feel warmer (Winzen et al., 2014). The "ideal" cabin lighting, however, highly depends on the in-flight activities performed by the passenger (Clarkson, 2008). Lighting in the airplane cabin is mostly functional; lights are turned on during boarding and during service (meals, shopping) and dimmed during a night flight when passengers tend to sleep. The cabin crew considers this lighting to be adequate (Lee et al., 2000).

1.2.3 The effect of vibrations on comfort perception

Vibrations are continuous quick, slight shaking movements that can occur in all directions. In vehicles, for example, vibrations can be caused by engines and weather conditions (turbulence). Vibrations that are perceived by the body are a source of discomfort and physical stress that passengers should be protected from (DeHart, 2003; Mansfield, 2005; Oborne, 1977; Vink & Brauer, 2011).

Passengers in the airplane cabin will be exposed to vibrations during their flight. These vibrations peak during take-off, landing and as the result of turbulence, and cause discomfort for airplane passengers. The more vibrations, the more discomfort, and for this reason aircraft manufacturers should attempt to minimize vibrations.

1.2.4 The effect of sound on comfort perception

Sound is defined by volume (dB) and tone (frequency in Hz). The human hearing range lies between 20 and 20,000 Hz, wherein people are most sensitive to frequencies between 2 and 5 kHz (Slater, 1985). A volume of 0 dB is the hearing threshold for a child, and 150 dB corresponds with the volume of a rock concert when standing in front of the sound box. The brain is responsible for the perception of sound waves, which affect human behavior and performance. Noise is a type of sound characterized by its annoying nature.

Airplane passengers are exposed to a wide range of noises during flight, with origins ranging from aircraft engines to conversations of fellow passengers to crying babies, which people find difficult to ignore (Lewis et al., 2016). The level of noise awareness also depends on the flight experience of the passenger; novice flyers may become more alarmed by and attentive to sudden changes in the aircraft's acoustic environment than experienced flyers (Västfjäll et al., 2003).

Sound levels across all flight phases and aircraft types range from 37.6 to >110 dB(A) with a median of 83.5 dB(A) (Zevitas et al., 2018). Cabin noise can cause increased awareness of symptoms such as fatigue, concentration problems, swollen feet and headaches (Mellert et al., 2008), but can also cause differences in comfort experience and mood (Pennig et al., 2012). Both low frequency (80-135 Hz, > 82 dB) and high frequency noise (described as "shrill" and "bright") can result in annoyance among airplane passengers (Mixson & Powell, 1985; Pennig et al., 2012). Despite these reported effects, passengers are not always aware of the effects of noise – when recalling flight experiences, only 0.9% of airplane passengers mentioned noise, whereas 79% mentioned comfort and service (Vink et al., 2012). However, sound can also benefit comfort. A study by Kruithof et al. (2014) demonstrated that music has a positive effect on comfort experiences.

1.2.5 The effect of climate on comfort perception

Climate consists of environmental temperature, humidity and atmospheric pressure. Thermoreceptors in the skin provide feedback about external temperatures. When the environmental temperature rises or falls, the body uses various mechanisms to ensure it maintains a comfortable equilibrium. Humidity is the amount of water vapor present in the air. High humidity leads to a reduced ability of the body to cool itself through perspiration and can also lead to difficulty breathing, while low humidity levels can lead to dry skin, cracked lips and excessive thirst. Atmospheric pressure determines how dense air is and indicates the amount of available oxygen.

The climate in the airplane cabin is centrally configured. Airplanes are pressurized to counteract low atmospheric pressure at high altitude (Abrahams, 2007). The temperature in an airplane cabin varies from 20 – 31.7 degrees Celsius (Pang et al., 2014), the relative humidity in the aircraft cabin is 15% (an ideal indoor house climate is 30-60%) and the atmospheric pressure is approximately 760 hPa (atmospheric pressure values at sea level hover around 1000 hPa) (Burdack-Freitag et al., 2011). Since indoor climate conditions can only work when occupants are offered sufficient means for creating their own comfort (de Korte et al., 2015; Kuijer & de Jong, 2012), it is suggested that passengers should be able to control temperature (Pasut et al., 2013) and air supply (Jacobs & De Gids, 2006) on an individual level.

1.2.6 Effect of physical ergonomics on comfort perception

According to the International Ergonomics Association (2018), physical ergonomics is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity. Most of the activities passengers perform during a flight are done while seated, and therefore the main point of physical interaction with the aircraft interior is the airplane seat.

Hiemstra-van Mastrigt et al. (2017) studied the relationships between human, seat and context variables in order to predict passenger comfort and discomfort. They concluded that although much research has been done to determine the relationship between anthropometrics and pressure variables, no comprehensive conclusion could be drawn due to significant differences in research design. It was also suggested that additional variables, such as personal space, need to be taken into account. This is in line with the findings of Kremser et al. (2012), who studied the effect of seat pitch on comfort experience, and found that a seat pitch between 34 and 40 inches results in the maximum sense of perceived well-being on the part of airplane passengers.

Typically, multiple passenger classes can be found on most aircrafts. These include first class, business class and (premium) economy class. These classes differ in terms of seats, but also in terms of seat configuration and associated legroom. According to the study of Vink et al. (2012), however, the correlation between class and comfort experienced is very low (r=0.111), which might be the result of expectations of the passenger (e.g. they expect higher levels of comfort in a higher class).

Taken together, it seems that environmental elements, in the airplane interior need to be considered when designing for passenger comfort. However, further research is needed to investigate the contribution and importance of these elements on passenger comfort.

1.3 Design for passenger comfort

From Section 1.2, it seems that the "ideal" environment depends on individual preference, the performed activity and the expectations of the passenger.

1.3.1 Individual preferences

Facilitating control over environmental factors on an individual passenger level is necessary to optimize comfort (Hedge, 2017). This is in line with the findings of Ahmadpour et al. (2014), who indicate that besides physical and psychological well-being, proxemics (the passengers' concern for having a level of autonomy or control over personal affairs and immediate space) is the third most prominent factor for comfort experience in the airplane cabin. Based on this, Hedge (2017) suggested design improvements, such as personal light controls, headphones or earbuds, temperature controls and seat controls. However, more research is needed to investigate the effect of having control over the aircraft environment on passenger comfort.

1.3.2 Performed activities

Comfort is often studied in relation to a specific activity (e.g. seat design in the context of knowledge work (Groenesteijn, 2015)); however, the activity itself also affects comfort (Hiemstra-van Mastrigt et al., 2016). Hiemstra-van Mastrigt et al. (2016) found that walking is the most refreshing activity in an airplane, especially on long-haul flights, and therefore she suggested that comfort could be improved by stimulating passengers to move in their seat. Although concepts that facilitate in-seat movement have been validated in other fields (e.g. active car seating systems (Hiemstra-van Mastrigt et al., 2015), dynamic work stations (Groenesteijn et al., 2016)), little is known about facilitating in-seat movement in the aircraft cabin and its effect on passenger comfort.

1.3.3 Passenger expectation

Several comfort models (De Looze et al., 2003; Vink & Hallbeck, 2012) describe expectations as an important comfort factor. Nevertheless, evidence that suggests passengers have the ability to predict their perceived comfort is scarce, since only a few studies have described the relationship between expected and actual comfort. More research is needed to investigate the relationship between expected and perceived comfort.

1.4 Aim of this thesis

The aim of this thesis is to investigate how to provide airplane passengers with a comfortable flight experience by designing airplane cabin elements that meet their individual needs.

Based on the knowledge gaps identified above, more research is needed to determine whether comfort experience is culturally dependent, to identify the high and low comfort peaks in a passenger journey and learn about the effect of environmental factors on comfort. Furthermore, additional research is needed on the effect of passengers' expectations, control and behavior on comfort. Based on this, the following research questions are investigated in this thesis:

- What are the high and low comfort points in a passenger journey?
- Can a hierarchy of environmental factors in relation to in-flight activities be created in order to prioritize design efforts of cabin interior manufacturers?
- How are features of the airplane seat perceived by passengers from different cultural backgrounds?
- Are there differences between expected and experienced comfort?
- What is the effect of autonomy/control on passenger comfort perception?
- Can in-seat passenger movement behavior contribute to passenger comfort?

1.5 Outline of this thesis

The studies carried out in this thesis are categorized into two parts: (I) Context and (II) Aircraft Seats and Environment.

Context factors were studied by means of questionnaires among experienced aircraft travelers. Chapter 2 investigates how passenger comfort evolves over time during a flight journey. In Chapter 3, the importance of the environmental factors on comfort perception are presented, while Chapter 4 investigates the importance of seat features as perceived by different nationalities.

The second part of this thesis investigates the aircraft seat and the environment of the aircraft interior through experiments. Chapter 5 investigates the effect of expectations on comfort perception. In Chapter 6, the effect of control on comfort is researched, and Chapter 7 studies the effect of in-seat movement behavior on passenger comfort.

In the general discussion (Chapter 8), the research questions are answered and the limitations of the studies and implications for future airplane cabin design are discussed. Table 1.1 shows an overview of the publications that are part of this thesis.

Chapter 1: General Introduction

Part I: Context (questionnaires)

Chapter 2:	High and low comfort peaks on a passengers' flight
Chapter 3:	Ranking of Environmental Factors
Chapter 4:	One Seat a Million Perceptions

Part II: Aircraft Seats and Environment (experiments)

Chapter 5:	Expected versus experienced neck comfort
Chapter 6:	Being in Control of Noise Levels improves the Aircraft Seat Comfort.
Chapter 7:	Effect of In-seat Exercising on Comfort Perception of Airplane Passengers.

Chapter 8: General Discussion and Conclusions

Figure 1.3: Visual outline of this thesis

Table 1.1: Overview of publications part of this thesis

Chapter	Article title	Journal	Status
1	Passenger comfort goes beyond anthropometrics - How environmental factors in the aircraft cabin interior influence comfort experience	Tijdschrift voor Human Factors [Dutch Journal of Human Factors]	Published
2	The high and low comfort peaks in passengers' flight	WORK	Published
3	Ranking of human senses that contribute to passengers' aircraft interior comfort experience.	Conference paper First International Comfort Congress, Salerno Italy, June 2017	Published
		International Journal of Aviation, Aeronautics and Aerospace	Published
4	Relative importance of different airplane seat features for perceived comfort and in-flight activities by different nationalities	Ergonomics in Design	Under review
5	Expected versus experienced neck comfort, A study identifying the difference between the expectations and experiences of comfort associated with the use of travel pillows in an airplane seat.	Human Factors and Ergonomics in Manufacturing and Service Industries	Published
6	Being in control of noise levels improves the aircraft seat comfort.	Aviation Psychology and Applied Human Factors	Under review
7	Effect of in-seat exercising on comfort perception of airplane passengers.	Applied Ergonomics	Published

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Chapter 2: The high and low comfort peaks in passengers' flight

2

This chapter has been published as:

Bouwens, J.M.A., Tsay, W.J., Vink, P. (2017). The high and low comfort peaks in passengers' flight. *Work, 58*(4), 579-584.

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Abstract

BACKGROUND: Knowing the high and low peaks in comfort during a flight could be useful in prioritizing aircraft interior improvements.

OBJECTIVE: The first objective of this study was to identify whether there are differences in comfort experiences during different phases of a flight. The second objective of this study was to identify similarities between recalled and real time reported comfort experiences.

METHODS: 149 participants were asked to rate the comfort in the different phases of their last flight on a scale from 1-10. Additionally a combination of a self-reporting design probe and generative interview was used to investigate the appraisal patterns of emotions in nine passengers.

RESULTS: The 149 subjects reported the highest comfort after take-off and arriving at the destination, the lowest while stowing the luggage and during the cruise flight. The qualitative long haul inflight study showed after take-off and while arriving at the destination the most positive emotions and during the cruise flight there is a negative experience phase.

CONCLUSIONS: Suggestions are given to improve the cruise flight phase, by for example stimulation of movement or better service.

Keywords: comfort experience, air travel journey, live reporting versus recall of experiences

2.1 Introduction

The growth of world air travel has averaged approximately 5% per year over the past 30 years and air traffic will double in the next 15 years [1]. It is important for airlines to obtain a share in this growing market. Designing a comfortable interior is one way to acquire a market share, since this can attract passengers. Dependent on the length of flight, 20-40% of air passengers name the cabin environment as the most important factor in their choice of an airline [2]. Vink, Bazley, Kamp and Blok demonstrated a correlation (r=0.73) between comfort of the aircraft interior and "fly again with the same airline" in a study among 10,032 passengers [3].

Having said that comfort is an important factor, prioritizing design efforts in order to create better comfort is difficult. Knee space has the highest correlation with comfort [4], which corresponds with the finding of Kremser, Guenzkofer, Sedlmeier, Sabbah and Bengler [5] that seat pitch is an important design factor. Increasing leg room seems to offer the obvious solution to improve comfort, however Lewis, Patel, Cobb, D'Cruz, Bues, Stefano et al. showed that by using a VR entertainment system, passengers can be distracted from discomfort caused by a lack of knee space [6]. In addition, Hiemstra-van Mastrigt showed that interaction with other people could also distract from discomfort [7].

The seat is also often mentioned in relation to comfort [8]. Next to legroom and seat there might be other improvements conceivable. McMullin studied the experienced comfort of the same seats with 2 different ceilings in the Boeing 737 . It appeared that 78% of the passengers feel there is greater comfort in the same seat in the new Dreamliner sky interior [9], which indicates that humans are often not aware of the environmental characteristics that exactly cause positive experiences.

Ahmadpour, Lindgaard, Robert and Pownall showed that the seat plays an important role in the overall comfort experience [8], but a later study showed that passengers' first part of the flight determined their overall comfort [10]. An older study found that comfort perception during the flight correlates with comfort experience preceding the flight (r=0.407) [11]. This indicates that also during the flight comfort experiences at different moments in time might be important. The fact that comfort experiences varies over time have been described before. Discomfort increases during the workday [12] and discomfort experiences increases significantly within the first two hours of sitting in a business class seat [13]. Theoretically, this pattern in discomfort or comfort in time could help prioritizing the aspects that need attention. When after the flight certain phases of the journey are remembered for its low comfort or high discomfort, these should be a starting point as input for design, since negative experiences could be a decisive factor in booking your next flight and therefore taken as input for design.

The question is whether the comfort and emotions noticed during the flight correspond with the recalled comfort experience after the flight. In this study the following research questions are researched:

- Do passengers remember differences in comfort experience during different phases of their last flight?
- What do passengers report during different phases of their flight as the emotional experience in real time recording?
- Is there a similarity between both patterns?

2.2 Method

To answer the first research question 149 participants (students, 21-33 years old) in 2014 and 2015 were asked to rate the comfort on a scale from 1-10 in the different phases of their last flight. The following 10 phases were distinguished: before the flight at the airport, stowing hand luggage, taxiing, taking off, just after taking-off, in cruise, preparing for landing, landing, taxiing and at the airport of arrival. The comfort rating of the cruise phase of the flight was indicated by activities respondents performed during their flight. Nine activities were pre-defined: watching a movie, food being served, garbage collected, reading, sleeping, gaming, listening to music, walking through the plane and being bored. Information was also gathered on the length of the flight. To see if there are difference in comfort in the different phases of the flight a t-test for paired comparison ($p<.05$) was done between the phases following each other chronologically. Also, a difference was made between the short (<6 hours) and long haul flights (>6 hours) following Hiemstra-van Mastrigt [7], and a t-test ($p<.05$) was done to see whether differences in comfort scores could be found between the two lengths of the flights. To find out whether differences in activities score differently on comfort, they were analysed pairwise with a t-test.

To answer the second research question, a more in-depth qualitative approach was used. A combination of a self-reporting design probe and a generative interview was used to investigate the appraisal patterns of emotions in the passengers' in-flight journey. First, a design probe, in the form of either a physical booklet or a digital file (according to their convenience), was filled out by 9 frequent flyers during their long haul (6-12 hours) flight. Passengers' self-reported experiences, documented in the probe gave insights on the activities and feelings of the passengers during different stages and events in the flight. The feelings and emotions for each stage was indicated by the passenger picking a corresponding facial expression [14] and writing down the reasons why they are feeling in such way. After the flight, a generative interview was done to map out the emotional timeline for each passenger. The passenger also elaborated on the reasons of the peaks in comfort perception. Lastly, the individual emotion-based timelines were compared and collective patterns among the 9 experience reports were identified. Passengers' concern for the high and low comfort peaks were also mapped out.

The third question is answered by comparing both trend lines.

2.3 Results

From the 149 participants, 68% were from the Netherlands, 17% from Asia (China, Taiwan and South Korea), 9% was from other EU countries and 6% from the rest of the world. The average flying time of the participants was 5.9 hours, 90 participants had a flight shorter than 6 hours (average flying time 2.52 hours; SD=1.11) and 59 participants flew 6 hours or more (average 11.2 hours, SD=2.52).

In figure 2.1 the comfort scores at the different times in the flight are shown. The lowest scores are found during hand luggage stowage and during cruise. The highest scores are found just after take-off and arriving at the destination airport. These two lowest and two highest scores are significantly different from the adjacent phase.

Comparing the different activities, it is clear that the activity gaming is done by a small group of flyers, while sleeping is done by the majority (see fig. 2.2), and the comfort experienced during these activities vary (see fig. 2.3). Figure 2.3 shows that sleeping and being bored have the lowest comfort scores. These scores are significantly lower from the other activities (t-test for paired comparison, $p<.05$). The highest scores (significantly higher than the other scores) are found when the garbage is collected, while watching In Flight Entertainment (IFE), when listening to music and while the food is being served.

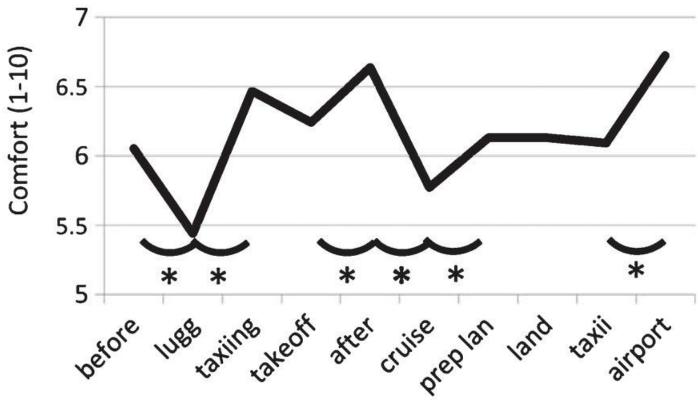

*Figure 2.1. Average comfort scores at the different phases during a flight. *means significantly different from the adjacent phase (t-test for paired comparison, $p < 0.05$).*

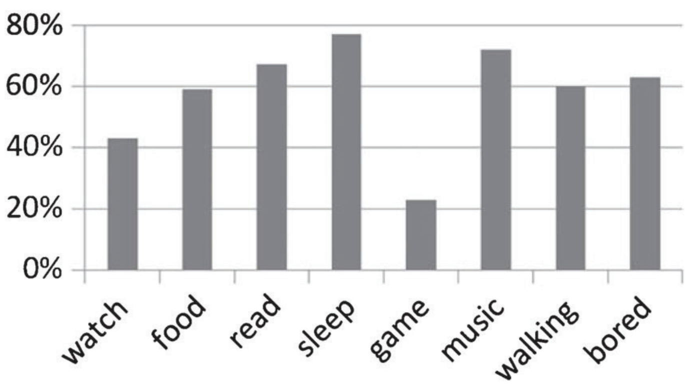

Figure 2.2. Percentage of the participants that watch IFE, have food served, read, sleep, game, listen to music, walk through the plane during cruise flight and are bored during a flight

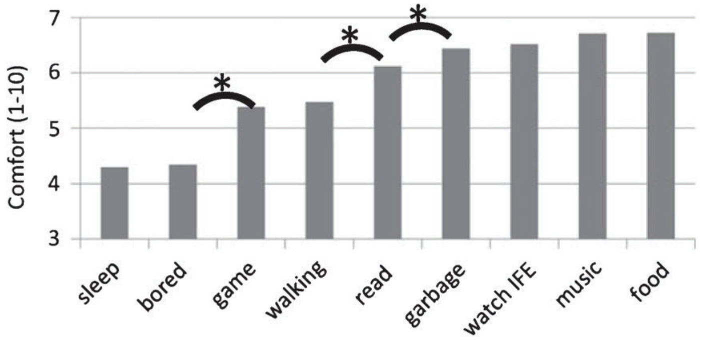

*Figure 2.3. Average comfort scores at the different activities during a flight.*means significantly different from the adjacent phase (t-test for paired comparison, p < 0.05).*

Figure 2.4 shows that the comfort scores at a short flight are similar to the long haul flight. The only two significant differences are found while gaming and listening to music. The comfort scores are higher during a short flight.

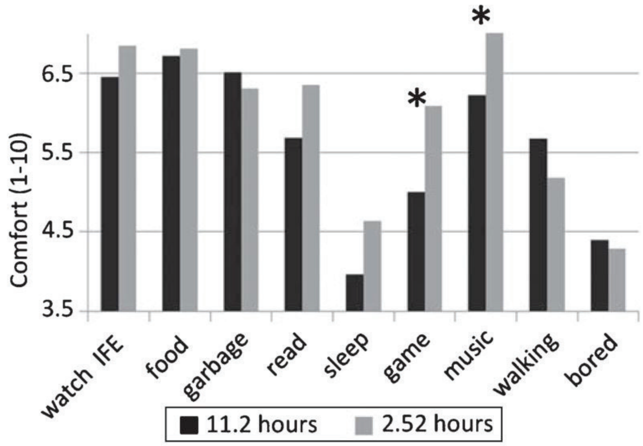

*Figure 2.4. Average comfort scores at different activities during a short and long haul flight. *means significantly different(t-test, p < 0.05)*

In figure 2.5 an overview of the qualitative real time reported emotions is presented. This graph shows that there are differences between the 9 participants, although all of them have relatively positive emotions right after boarding, while settling themselves before the take-off. In the following in-flight phases, two general patterns can be observed. First, a general pattern

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of combination of extreme high and low emotion peaks can be found during food and drink services (the stages with black background which includes drink/snack service or the two full meal services). Secondly, the stages in between food and drink service were reported negative. This includes the stage before the 1st full meal service and during the cruise flight. During the cruise flight all participants rate their emotion level scale negatively. The participants unanimously consider the stage before landing and the landing itself as positive.

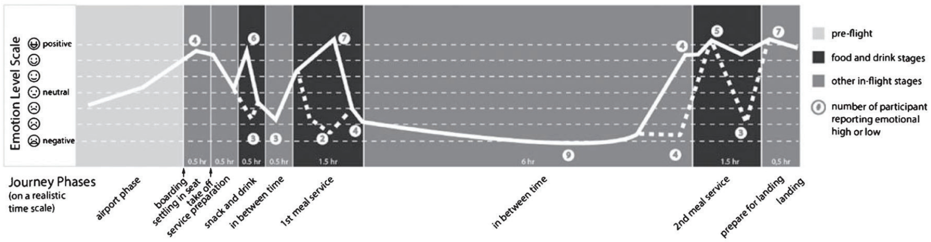

Figure 2.5. A map of the emotional timeline of nine passengers recorded during the flight. The solid line shows the overall emotion level participants have during different stages of the flight and the dashed line shows the outliers. The numbers in the bubbles represent the amount of participants that reported their emotions similarly.

Figure 2.1 and 2.5 are useful in answering the third research question. The cruise flight, which is usually the longest part of the flight showed significantly lower comfort and the most negative emotions. The period after boarding and before taking off and the period of arriving at the destination both have a high comfort and positive emotions.

2.4 Discussion

The first research question regarding the recall of previous comfort experiences can be answered by this study. In different phases of the flight, differences in comfort experience were shown. The highest comfort was between take-off and the cruise flight period and arriving at the destination and the lowest comfort was experienced while stowing the luggage and during the cruise flight. It shows similarities with the answers to the second research question. Real time recording of the emotions show that during the long haul flight, ‘after boarding but before take-off’, ‘meal service stages’ and ‘arriving at the destination’ were experienced as positive, while the long cruising time is perceived negative. Ahmadpour, Kühne, Robert and Vink also showed that the real-time emotional recordings and retrospective evaluations of comfort were not significantly different [15].

In this study not all answers were similar. The period "after boarding but before taking off" is reported as a positive through real-time reporting, while stowing carry-on luggage has low comfort scores in the retrospective study. Perhaps the whole process of boarding and settling down in passenger's seat is seen as positive and the stage of luggage stowing is only a small element in it, with minimal influence on the total experience. However Ahmadpour, Robert and Lindgaard also found a significant correlation between overall comfort and carry-on luggage room for long haul flights [10] and Vink, Bazley, Kamp and Blok also reported a correlation of .33 between luggage stowing and overall comfort [3].

In the qualitative in-flight research, food and drink services (including the first drink/snack service and the two full meal services) were reported as a combination of positive and negative experiences. The positive perception of food and drink services found in the quantitative retrospective study is also rather high. From the in-depth insights of the qualitative reporting, it suggests that food and drink service provides passenger something to do and it distracts them from boredom and the discomfort of lack of leg room. Also VR can distract from a situation with low discomfort [6]. In the retrospective study it is shown that under the same conditions the comfort is rated significantly higher while gaming, walking through the plane, reading, when the garbage is collected, while watching IFE, when listening to music and while the food is being served, probably also because it distracts from the situation.

On the other hand, in the real-time reporting, some passengers expressed that although they appreciate the food service, they also experience negative emotions of feeling overwhelmed by the abundant objects (e.g. food tray, fold down table, personal items etc.) and multiple activities (e.g. watching a movie, being served by flight attendant, and eating a meal at the same time) during this period. This explains the combination of positive and negative experiences.

Sleeping and boredom have the lowest comfort recordings from both the retrospective research and real-time reporting. This makes sense since sleeping upright is not ideal and can even lead to health risks [16].

Some drawbacks of this study are that a relatively young population is studied and the majority of participants is from the Netherlands. Age and difference in cultures do play a role in the emotional experience and comfort [17]. Accessing overhead bins, using in-flight entertainment systems and in- and egress are for instance problems mentioned by elderly. The hand luggage issue was mentioned by the relatively young people in this study as well, but boarding and IFE scored relatively good.

This study also did not explicitly relate the different aspects to the overall comfort (like [8] and [3]). Also first impressions of the cabin environment (within the 12.8±4.5 minutes of a short and 31±19.5 minutes of long flights) highly determines passengers' overall comfort experience [15]. So, apart from paying attention to the cruise flight and luggage, it might be useful to see what the elements in this phase are. Passengers associate the seat and the cabin temperature both with positive and negative emotions, while IFE is only considered positive and the neighbour as negative [8].

The data is analysed statistically with multiple pairwise t-tests, comparing consecutive phases of the flight. This method might lead to a chance of error when comparing comfort experience of activities in all different (not adjacent) phases due to using multiple t-tests.

This study suggests that airlines should invest in improving the passenger comfort experience during the cruise phase of the flight. This can be done by improving the possibility to sleep, overcoming boredom and adjust the service provided by the flight attendants to the liking of the passengers [18] [3]. Moreover, opportunities could be in two directions, improving the in-seat experience or innovation in cabin spaces outside of the seat to encourage passengers to get out of their seat occasionally during the long cruise. For the latter [7] showed that walking in the plane of flights longer than 6 hours during cruise flight was seen as the most refreshing activity.

2.5 Conclusion

149 young travellers reported the highest comfort after their flight after take-off and arriving at the destination. The lowest comfort was experienced while stowing the luggage and during the cruise flight between the two meals. It shows similarities with the qualitative long haul inflight study as after take-off and while arriving at the destination the most positive emotions were recorded and during the cruise flight there is a negative experience phase.

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Chapter 3: Ranking of Human Senses in Relation to Different In-flight Activities Contributing to the Comfort Experience of Airplane Passengers.

3

Section 3.1 and 3.2 are adapted from the following publication:

Bouwens, J., Hiemstra- Van Mastrigt, S., Vink, P. (2017, June). Ranking of human senses that contribute to passengers' aircraft interior comfort experience. *First Comfort Congress, Salerno, Italy.*

This chapter has been published as:

Bouwens, J., Hiemstra-van Mastrigt, S., & Vink, P. (2018). Ranking of Human Senses in Relation to Different In-flight Activities Contributing to the Comfort Experience of Airplane Passengers. *International Journal of Aviation, Aeronautics, and Aerospace, 5*(2).

3.1 Introduction

When booking a flight, passengers seek comfort and are willing to pay higher prices in exchange for increased seat comfort (Airbus, 2013). A pleasant and comfortable experience also increases the likelihood that customers will return to an airline for future travel (Vink et al., 2012). Based on this, it makes sense for some airlines to invest in the design of a comfortable airplane interior. Many factors influence passengers' comfort, such as expectations and environment (De Looze et al., 2010; Vink & Hallbeck, 2012). According to Krist (1993) and Bubb et al. (2015), comfort is established through six factors: anthropometry, climate, sound, vibrations, light and smell. These factors have been applied to airline travel in the following subsections.

Anthropometry

Anthropometry is the scientific study of measurements of the human body. When designing products such as aircraft seats, anthropometric data can be a valuable source of information. For instance, a study by Hiemstra-van Mastrigt (2015) comparing the dimensions of economy class aircraft seats to anthropometric measurements from a database demonstrated that current seats are not suitable for up to 21% of passengers due to the distance between armrests, which is too narrow to accommodate the hip width of some passengers. If the dimensions of the aircraft seat, such as width of the seat or the seat pitch (distance between two seats), are not well suited to the passenger, this will have an effect on the individual's perceived (dis)comfort.

Climate

Ranging from 20°C to 27°C on intercontinental flights and 21°C to 31.7°C on continental flights, the temperature in an airplane cabin varies significantly (Pang et al., 2014). A self-controlled heated and cooled office seat contributes to maintaining neutral body temperature, however the perceived comfort is higher when using a heated seat in a cold environment than when using a cooled seat in a warm environment, as suggested by Pasut (2013). Therefore, providing passengers with the right means to control their body temperature might contribute to a better comfort experience.

Noise

Aircraft interior sound levels depend on different factors, such as flying speed, altitude, and seat position (Quehl, 2001). The sound level (75 dB) inside an aircraft at cruise flight altitude (Ozcan & Nemlioglu, 2006) mainly originates from the aircraft engines and does not cause permanent hearing loss (Mixson & Powell, 1985) or reach the discomfort threshold (Slater, 1985). However, the noise levels in the aircraft cabin can result in annoyance (Mellert et al., 2008). Despite this, Quehl (2001) has suggested that annoyance caused by sound is based on individual preferences. Therefore, providing passengers with the right means to cancel or control the environmental noise (earplugs, noise cancelling headsets) might contribute to a better comfort experience.

Vibrations

Compared to other vehicles such as trains and cars, passengers in an aircraft at cruise flight altitude experience minor vibrations unless turbulence occurs. For instance, when passengers travel by train they experience significant lateral movement, which affects activities such as writing, eating and drinking (Bhiwapurkar & Saran, 2010; Corbridge & Griffin, 1991; Khan & Sundstrom, 2007; Khan & Sundström, 2004; Krishna Kant, 2007; Nassiri et al., 2011). In comparison, the vibrations experienced by most aircraft passengers are sufficiently minor that they do not affect most in-flight activities.

Light

Light and color are well-studied environmental factors that influence human beings. In the literature review by Sokolova and Fernández-Caballero (2015) it was found that color influences emotions and is applied in numerous fields (e.g. psychology, medicine, design and architecture). Although the authors indicated that there are global trends in color perception, the use of specific colors for different socio-demographic groups (i.e. cultures and ages) should be exercised with caution, since people might react differently to the same stimuli. For example, kids like the colors yellow and red, but when they grow older this preference will change to blue or green (Sokolova & Fernández-Caballero, 2015). This should also be considered in the design of lighting in the airplane cabin, since the composition of passengers is diverse.

Smell

Majid and Kruspe (2018) found that hunter-gatherer tribes in the tropical rainforest of the Malay Peninsula could name odors as easy as colors. However, the reduced importance of recognizing smells in modern (and sedentary) life has led to a reduced ability to communicate about smell using words (Engen, 1982; Majid & Kruspe, 2018). Despite its decreased importance, people do react to smell; odors can affect mood, physiology and behavior (Cardello & Wise, 2008; Herz, 2009; Holland et al., 2005). Therefore, it is important to be aware of this when designing airplane cabin interiors.

Although many studies have been conducted focusing on individual factors, the relationship and hierarchy between different human senses remains under-examined in scientific literature. Research by Quehl (2001) on the effects of aircraft interior sound and vibration on passenger comfort demonstrated that the sound pressure level contributed to approximately 70% of the comfort evaluation while the vibration magnitude contributed to about 30%. This was in line with the commonly reported dominance of noise in relation to subjective annoyance responses.

To indicate their relative significance, Bubb et al. (2015) proposed a generic hierarchical model of six discomfort sensations. In descending order, these are anthropometry, climate, sound, vibrations, light and smell. This model is established based on a study by Krist (1993). In this study participants were asked to indicate relevant factors that contribute to comfort experience. Anthropometry was mentioned most often by the interviewees, followed by climate, sound, vibration and light. Although smell was not mentioned by any of the participants, Bubb et al. (2015) suggested that smell must be a factor that contributes to comfort as well, because there is a direct connection between smell and the part of the brains that is responsible to emotion. Bubb et al. (2015) attributed the fact that smell is not mentioned by the participants to the unawareness of the participants, since they never experienced the effect of smell on comfort. Based on this, he suggested a hierarchical model, presented in a pyramid (see Figure 3.1). The base layer (smell) is most important, followed by other factors such as vibrations and climate. However, since the factors closer to the top of the pyramid were mentioned more often, Krist (1993) reasoned that it is less likely that these factors are accomplished yet.

In addition to this set of six environmental factors, more comfort factors have been described, such as expectations and time (Bazley, 2015). However, for the sake of manageable research not all factors influencing comfort are taken into account here, and only the influence of the six environmental factors smell, light, vibration, noise, climate and anthropometry are evaluated. The research question of this study is:

- What is the order of importance of the environmental factors as contributors to aircraft interior comfort experience, based on passenger expectations?

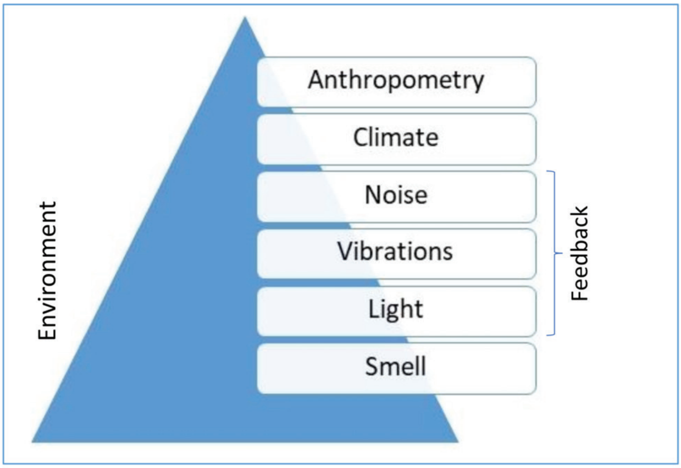

Figure 3.1. Hierarchy of environmental comfort factors represented in a pyramid (adapted from Bubb et al. (2015)). The environmental factors are ranked from most important (base of the pyramid) to least important (top of the pyramid).

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3.2 Study 1: Evaluation of Environmental Factors

3.2.1 Method

In a questionnaire, respondents were asked to rank six different human senses: climate, vibration, light, noise, anthropometry and smell. These senses were presented to participants as 15 different "word pairs," and respondents were asked which element, according to their expectations, is the most important in experiencing a comfortable aircraft interior. For each of the environmental element pairs (Table 3.1) participants were asked to indicate which factor was more valuable to them. Respondents were recruited at the faculty of Industrial Design Engineering at Delft University of Technology. In total, 183 respondents between 19 and 64 years old (mean: 30.5, SD: 12.8), of which were 114 female and 66 were male (3 unknown), with flight experience completed the questionnaire. The scores for each environmental factor were analyzed with a Friedman test (IBM SPSS Statistics 24), and significance was accepted at $p<0.05$. When significance was found, a Wilcoxon signed rank test (IBM SPSS Statistics 24) was used to determine between which elements differences occurred. For the Wilcoxon signed rank test significance was accepted at $p<0.05$. Additionally, respondents were allowed to provide comments on the questionnaire.

3

Table 3.1. Environmental factors (each factor occurs five times)

Element 1	Element 2
Climate	Noise
Vibration	Light
Light	Climate
Noise	Light
Anthropometry	Smell
Smell	Climate
Vibration	Anthropometry
Light	Anthropometry
Noise	Vibration
Vibration	Smell
Noise	Smell
Anthropometry	Noise
Climate	Vibration
Smell	Light
Anthropometry	Climate

3.2.2 Results

The Friedman test found a statistically significant difference between the environmental factors, $\chi 2(5, N=183) = 193.43$, $p<0.001$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p<0.01$. The average importance of anthropometry was 3.46 (SD=1.54), noise 2.91 (SD=1.38), smell 2.91 (SD=1.65), climate 2.69 (SD=1.50), and vibrations 1.91 (SD=1.50), and light 1.11 (SD=1.2). There were no significant differences between noise and smell (Z=-.022, p=0.982) and smell and climate (Z=-1.238, p=0.216). However, there were significant differences between anthropometrics and noise (Z=-.3220, p=0.001), climate and vibrations (Z=-4.583, p<0.001), and vibrations and light (Z=-5.002, p<0.001) (see Figure 3.2).

The element of anthropometry was, on average, indicated between 3 and 5 times as more important for experiencing aircraft interior comfort. The three elements of noise, smell and climate were indicated as more important approximately 3 times, the element of vibration twice and the element light just once. Three significant differences were found between anthropometry and noise, smell and climate, climate and vibrations and vibrations and light.

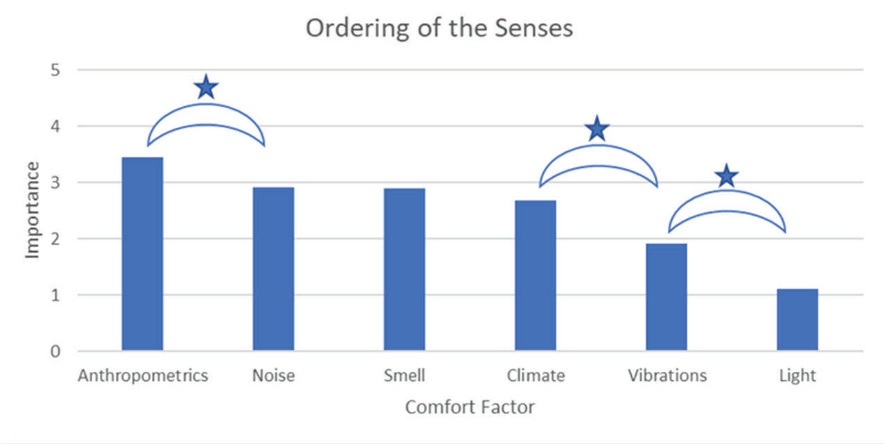

*Figure 3.2. Ordering of the human senses from most important (5) to least important (0) for experiencing aircraft interior comfort (n=183, the asterisk * indicates significance p<0.05).*

In 16% of the comments by respondents it was mentioned that their choice of most important factor is dependent on the situation. For example, one of the comments on climate stated, "Does climate refer to warm or cold air?" With regard to smell, one participant commented, "I hate a bad smell more than I love a nice smell."

3.2.3 Discussion

This study illustrates that it is possible to create a hierarchy of environmental factors related to expected impact on comfort experience. The respondents indicated anthropometry as the most important factor, followed by noise, smell, climate, vibrations and finally light. This order differs from the discomfort pyramid proposed by Krist (1993) and Bubb et al. (2015). However, the respondents stated that the context of the factors was unclear, since the importance of each factor might depend on the performed in-flight activity (e.g. "I prefer a different temperature while sleeping than while walking"). Moreover, the factors were insufficiently explained (e.g. "Does climate refer to warm or cold air?"). Therefore, in order to provide reliable results, this study required repetition with a questionnaire that was clear and unequivocal, and which clarified context by adding an in-flight activity.

3.3 Study 2: Evaluation of Environmental Factors in Relation to In-flight Activities

The study described in Section 2 of this article was repeated after improving the research design based on the feedback from respondents.

3.3.1 Method

In a questionnaire, respondents were asked to rank six environmental factors of an airplane cabin for two activities, namely *sleeping* and *watching the in-flight entertainment (IFE)* screen. A general explanation of each factor was provided as follows:

- Seat: Adjustable seat to match personal body measurements
- Temperature: Manipulate temperature to personal preference
- Noise: Possibility to reduce cabin noise
- Vibrations: Control vibrations caused by the airplane
- Light: Control the intensity and color of the light
- Smell: Possibility to reduce bad odors in the airplane cabin

These senses were presented as 15 different "word pairs," and respondents were asked which factor, according to their expectations, is the most important in experiencing a comfortable aircraft interior for two different activities, sleeping or watching IFE. The survey was completed 168 times by respondents that did not participate in the first study. Respondents were recruited at the faculty of Industrial Design Engineering at Delft University of Technology. One response was not evaluated because the participant indicated that he did not have flight experience. The other 167 respondents were between 19 and 61 years old (mean: 26.6, SD: 9.0), of which were 98 female and 69 were male. The number of times each element was indicated as more important was recorded for each activity, and these scores were analyzed with a Friedman test (IBM SPSS Statistics 24). Significance was accepted at $p<0.05$. When significance was found, a Wilcoxon signed rank test (IBM SPSS Statistics 24) was used to determine where differences occurred between elements. For the Wilcoxon signed rank test significance was accepted at $p<0.05$.

3.3.2 Results

Figure 3.3 and Figure 3.4 show the ranking of comfort aspects when sleeping and watching IFE.

There was a statistically significant difference in importance of each environmental factor, $\chi2(5, N=167) = 263.00$, $p<0.001$ for the activity sleeping. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p<0.01$. The average importance of the seat was 4.09 (SD=1.07), noise 2.86 (SD=1.29), temperature 2.80 (SD=1.38), light 2.01 (SD=1.34), vibrations 1.31 (SD=1.41), and smell 1.69 (SD=1.60). There were no significant differences between noise and temperature (Z=-0.464, p=0.643), light and smell (Z=-1.628, p=0.104) and smell and vibrations (Z=-1.961, p=0.050). However, there were significant differences between the seat and noise (Z=-7.135, p<0.001), and temperature and light (Z=-4.451, p=0.643).

For the activity watching IFE, a significant difference in importance of each environmental factor was found, , $\chi2(5, N=167) = 219.04$, $p<0.001$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p<0.01$. The average importance of the seat was 3.65 (SD=1.12), noise 3.43 (SD=1.42), temperature 1.87 (SD=1.37), light 2.47 (SD=1.16), vibrations 1.80 (SD=1.61), smell 1.45 (SD=1.64). There were no significant differences between the seat and noise (Z=,-1.374, p=0.170) temperature and vibrations (Z=-0.523, p=0.601), and vibrations and smell (Z=-1.788, p=0.074). However, there were significant differences between noise and light (Z=-6.065, p<0.001), and light and temperature (Z=-3.577, p<0.001).

The results for IFE and sleeping appear rather similar, except for temperature and light. Temperature was found to be more important than light for sleeping, while light was ranked as more important for IFE than temperature.

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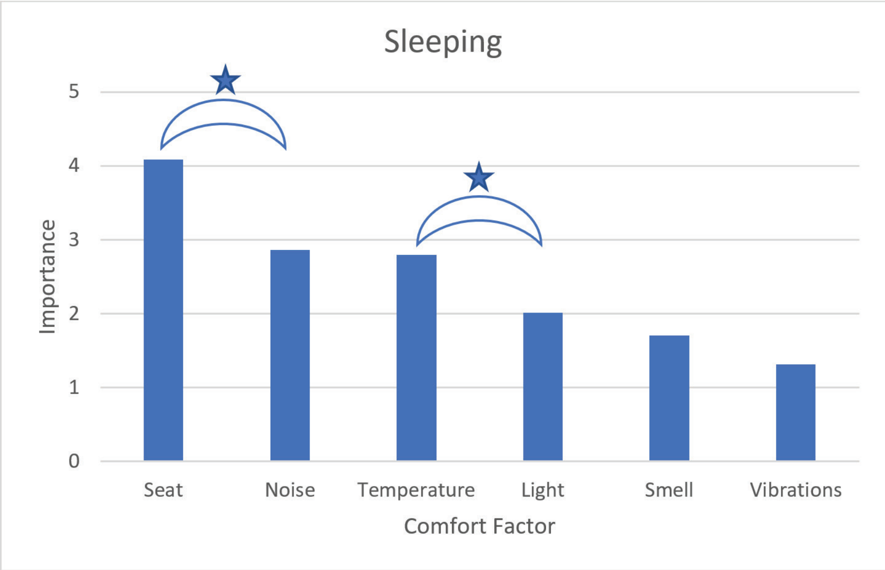

*Figure 3.3. Ordering of the human senses from most important (5) to least important (0) for experiencing aircraft interior comfort while sleeping (n=167, the asterisk * indicates significance p<0.05).*

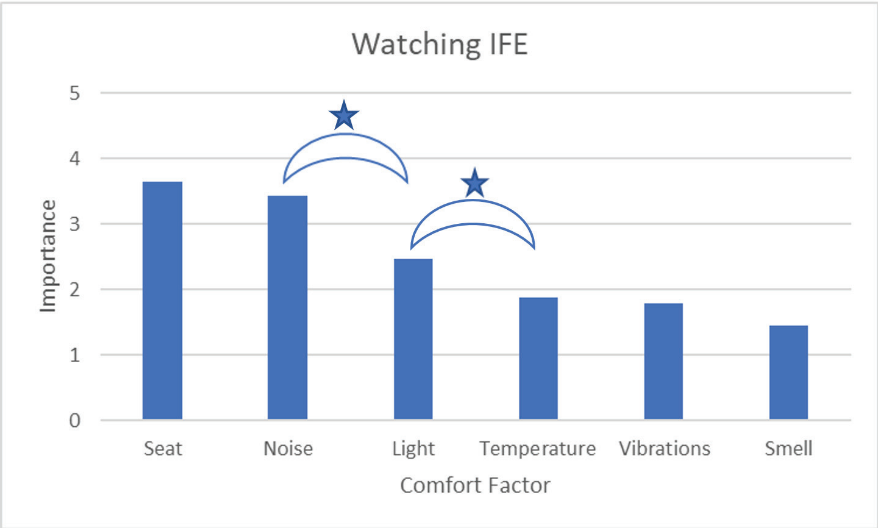

*Figure 3.4. Ordering of the human senses from most important (5) to least important (0) for experiencing aircraft interior comfort while watching IFE (n=167, the asterisk * indicates significance p<0.05).*

3.4. Discussion

The results of the second study suggest that for the in-flight activities of watching IFE and sleeping, airplane passengers consider different human senses important (see Figure 3.5). Nevertheless, the seat (anthropometrics) is considered the most important factor for both activities. The first study shows anthropometry as the most important factor, noise as falling in the mid-range and vibration in the top, least important area. However, other factors appear to take different positions within the comfort pyramid. Therefore, it is possible that the way a factor is interpreted plays a role in the score it receives. The absence of light while sleeping has a different effect than watching a movie in the dark.

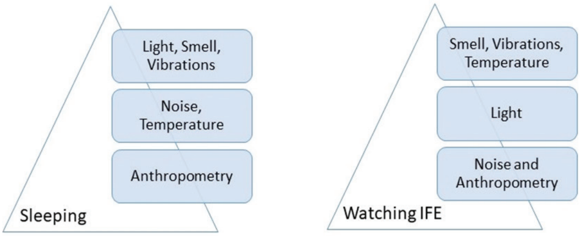

Figure 3.5. The two new comfort pyramids for sleeping and watching IFE on the right (based on the outcomes of this research). The most important environmental factors are placed at the base, and the less important factors are placed at the top.

Anthropometry's importance is also seen in other studies. Kuijt-Evers (2007), for instance, demonstrated in hand tool research that while working with a screwdriver, the appearance of the tool (related to visual system) has almost no influence on comfort while the anthropometry (tool fit to the hand) has a strong influence.

There are some similarities between the findings of Krist (1993) and Bubb et al. (2015), since anthropometry is mentioned most in both studies. However, the position of this factor in the pyramids is different. Expectations and emotions influence passenger comfort (Ahmadpour et al., 2014; De Looze et al., 2010; Vink & Hallbeck, 2012), and might have influenced this order. For example, since passengers expect to have limited personal space in the airplane seat, they consider this aspect much more important than light or smell (since they have never experienced problems with these factors in the past). Also, passengers are not always aware of the influence of some of the environmental factors. For instance, noise does affect the human comfort experience unconsciously. A study by Mellert et al. (2008) found, for example, that more physical complaints were reported in a noisy airplane cabin. Similarly, the design of the airplane cabin ceiling affects the perceived seat comfort, air quality and temperature (McMullin, 2013). Therefore, passengers might consider some factors less important when in fact these factors have a considerable effect on actual comfort experience.

Although the outcomes of this research suggest a hierarchical order of factors that might give direction to prioritizing design efforts, Vink et al. (2016) discuss that optimizing every single element in the environment in order to optimize comfort is neither possible nor wise. Lewis et al. (2016) suggest that people can be distracted from sources of discomfort by a virtual environment. This technique appears to be more effective for distracting people from discomfort caused by restricted space than noise disturbances (such as a crying baby). Although rather counterintuitive, negative associations people might have with certain factors, such as noise, can also have positive side effects. For example, the presence of background noise is considered positive by train riders, as it masks other sounds like conversations between other passengers (Khan, 2003).

In the second questionnaire the environmental factors were clarified by providing definitions. Even though this was a major improvement on the initial questionnaire, respondents may still have interpreted the definitions differently (e.g. adjustable seat to match personal body measurements might refer to the adjustability of the width and/or the recline function). Therefore, more research is needed in order to define design requirements for each environmental factor that lead to an improved comfort experience. Future research is also needed to quantify the relationships between different factors of the comfort pyramid, and to research the generalizability of the outcomes to other fields (e.g. comfort of offices, car interiors).

3.5 Conclusion

This study indicates that different in-flight activities require different environmental properties in order to facilitate passengers' comfort during their flight. The results from the second study (n=167) suggest that a hierarchy of any comfort-related environmental factors depends on the performed in-flight activity.

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Chapter 4: Relative Importance of Different Airplane Seat Features for Perceived Comfort and In-Flight Activities by Different Nationalities

4

This article is under review at Ergonomics in Design.

Nijholt, N., Bouwens, J.M.A., Vink, P., (submitted). Relative Importance of Different Airplane Seat Features for Perceived Comfort and In-Flight Activities by Different Nationalities.

Abstract

Airplane passengers often mention the design of the airplane seat as an important factor for experiencing comfort. However, an airplane seat consists of many features (e.g., cushion, headrest) that might be valued differently. Yet it is unknown if the geography (country of origin) of the passengers plays a role in valuing seat features, which can also be subject to the any in-flight activity performed. By questioning 247 experienced airplane passengers from America, Europe, and Asia, we found that seat features are valued differently for distinct in-flight activities but that the dissimilarities among the geographical groups are rather small.

Keywords: airplane seat, geographical background, seat design, airplane passengers, sitting comfort, seat elements

4.1 Introduction

The distances people are bridging are increasing, and so is the time people spend in airplanes. The need for comfort is therefore more important than ever. However, with more than 879 million passengers worldwide in 2014 (Eurostat, 2015), the individual interpretation of comfort may vary (De Looze, Kuijt-Evers, & Van Dieen, 2003).

4.1.1 Definition of Comfort

Many definitions of comfort can be found in literature. According to Oxford Dictionaries, comfort can be described as: '"state of physical ease and freedom from pain or constraint." But unlike this definition suggests, there is no balance between comfort and discomfort. According to Kremser, Guenzkofer, Sedlmeier, Sabbah, and Bengler (2012), comfort is not simply the absence of discomfort. In fact, comfort and discomfort can even occur at the same time. More specifically, discomfort is more related to objective physical measures, whereas comfort relates to psychological well-being (De Looze et al., 2003; Zhang, Helander, & Drury, 1996).

But what would then be the right definition of comfort? Lueder (1983) stated, based on a literature study, that the definitions have reflected the different disciplines of the researchers who formulated them. This means that for every discipline, another definition would be applicable. This makes giving an unambiguous definition of comfort even more difficult.

Although a lot of different definitions of comfort exist, one general remark on comfort could be made: comfort is a convenient experience that enhances product pleasure (Vink, Overbeeke, & Desmet, 2005).

4.1.2 Passenger Comfort Experience

Ahmadpour, Lindgaard, Robert, and Pownall (2014) indicated that the seat is an important aspect in relation to aircraft passengers' comfort perception. Rankin, Space, and Nagda (2000) suggested that seat comfort is the best predictor of overall flight comfort ($r=0.77$, $n=3630$, $p<0.01$). In addition, Vink and Brauer (2011) surveyed 10,032 aircraft passengers and found that 19 percent of the respondents expressed their opinions on the seat in their trip reports. Given the abovementioned studies, the design of the airplane seat seems to contribute considerably to a comfortable flight.

4.1.3 Ranking of Seat Features Contributing to Comfort

Although it is acknowledged that the seat can be an important contributor to passenger comfort, the seat can elicit different perceptions of the level of comfort due to its diverse features (Ahmadpour et al., 2014). In many studies, the large number of seat design features (e.g., armrest, bottom cushion) was considered when assessing comfort (e.g., Richards & Jacobson, 1977; Vink, Bazley, Kamp, & Blok, 2012; Vink & Brauer, 2011). However, the preferred seat characteristics depend on the in-seat activity that is being performed by the passenger (Hiemstra-van Mastrigt, 2015), and travel habits and expectations of airplane passengers are culturally dependent (McMullin et al., 2014).

Although information on expected importance of airplane seat features regarding comfort in relation to in-seat activity and geographical background could give direction to aircraft interior manufacturers on how to prioritize design efforts, we did not find scientific studies that investigated this relationship. Therefore, this study determines whether a ranking on seat features based on in-flight activities and geographical background can be made, by answering the following three research questions:

1. How are the seat features rated by passengers from different geographical groups (Asia, Europe, America)?
2. Which seat features are considered most important by different geographical groups (Asia, Europe, America) when performing in-flight activities (eating, working on a laptop, sleeping, reading, watching IFE)?
3. According to the passengers, which seat features require improvement?

4.2 Method

To answer the research questions, 246 respondents from different geographical regions—123 European (all Dutch citizens; 75 male, 48 female; age mode 20 to 30 years), 63 American (all US citizens; 35 male, 28 female; age mode 20 to 30 years), and 60 Asian (45 Indian, 9 Indonesian, 3 Chinese, and 3 Taiwanese citizens; 38 male, 22 female; age mode 20 to 30 years)—were recruited. All respondents had at least one long-haul flight experience within the past year. The respondents were recruited directly through our personal network and indirectly via online platforms (Facebook and forums). Participation was voluntary, and completing the survey took approximately ten minutes. The respondents were informed that the anonymized data would be used for research purposes at the faculty of Industrial Design Engineering at Delft University of Technology.

We composed a preliminary list of the different aircraft seat features based on the studies of Rankin, Space, and Nagda (2000) and Vink and Brauer (2011). These features were validated by interviewing experienced passengers, which resulted in a set of twenty-one relevant seat features, namely: armrest, color, bottom cushion, damage, foot rest, foot space, head support, head side support, hygiene, leg room, lumbar support, material, newness, recline, accessibility, overall space, storage lit pocket, storage under seat, tray table, usability, and seat width. All the seat features were presented to the respondents in a simplified drawing of an economy-class seat (see Figure 4.1).

The in-flight activities that were evaluated in this study are eating, working on a laptop or tablet, sleeping, reading, and watching the in-flight entertainment (IFE) screen. These activities were derived from McMullin et al. (2014), who queried 1,887 respondents from Brazil, Germany, Japan, and the United States about their in-flight activities.

To answer the first question—"How are the seat features rated by passengers from different geographical groups (Asia, Europe, America)?"—passengers were asked to rate each seat feature on a seven-point Likert scale (1: not important at all, 7: very important).

To answer the second question—"Which seat features are considered most important by different geographical groups (Asia, Europe, America) when performing in-flight activities (eating, working on a laptop, sleeping, reading, watching IFE)?"—passengers were asked to select three of the twenty-one seat features that they considered most important to perform the in-flight activities.

The questionnaire ended with the open-ended question "Which seat feature would you like to improve?" Besides the twenty-one features, respondents were able to mention any seat-related aspect that currently does not satisfy their needs.

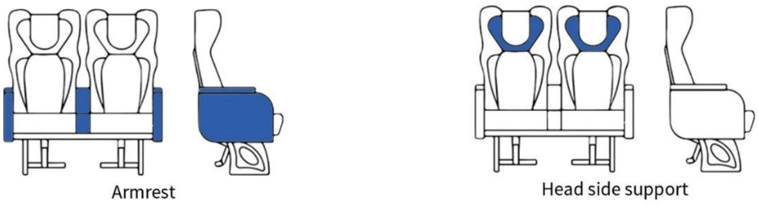

Figure 4.1 – Example of highlighted seat features

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Outliers (e.g., respondents who rated all the features with the same score) were filtered from the data. The nonparametrical data collected in questions 1 and 2 of the questionnaire were tested with a Kruskal Wallis test, followed by a pairwise comparison with Bonferroni correction in IBM SPSS 24. Significance was accepted at $p<0.05$. Features that were mentioned in question 3 were counted separately.

4.3 Results

4.3.1 How are the seat features rated by passengers from different geographical groups (Asia, Europe, America)?

The top five of most important seat features among the geographical groups consist of the same elements; however, the order based on the average rating per geographical group differs slightly (see table 4.1). An overview of the rating of all airplane seat features per geographical group is shown in Figure 4.2. This figure shows the rating of each seat feature for each geographical group. Significant differences among the geographical groups are indicated with an asterisk. For example, Asians rate the armrest significantly more important than European respondents do.

Table 4.1: Top five rating of important airplane seat features by different geographical groups

	European	American	Asian
#1	Leg room	Bottom Cushion	Hygiene
#2	Bottom Cushion	Hygiene	Leg room
#3	Foot Space	Leg room	Foot Space
#4	Hygiene	Foot Space	Bottom Cushion
#5	Overall Space	Overall Space	Overall Space

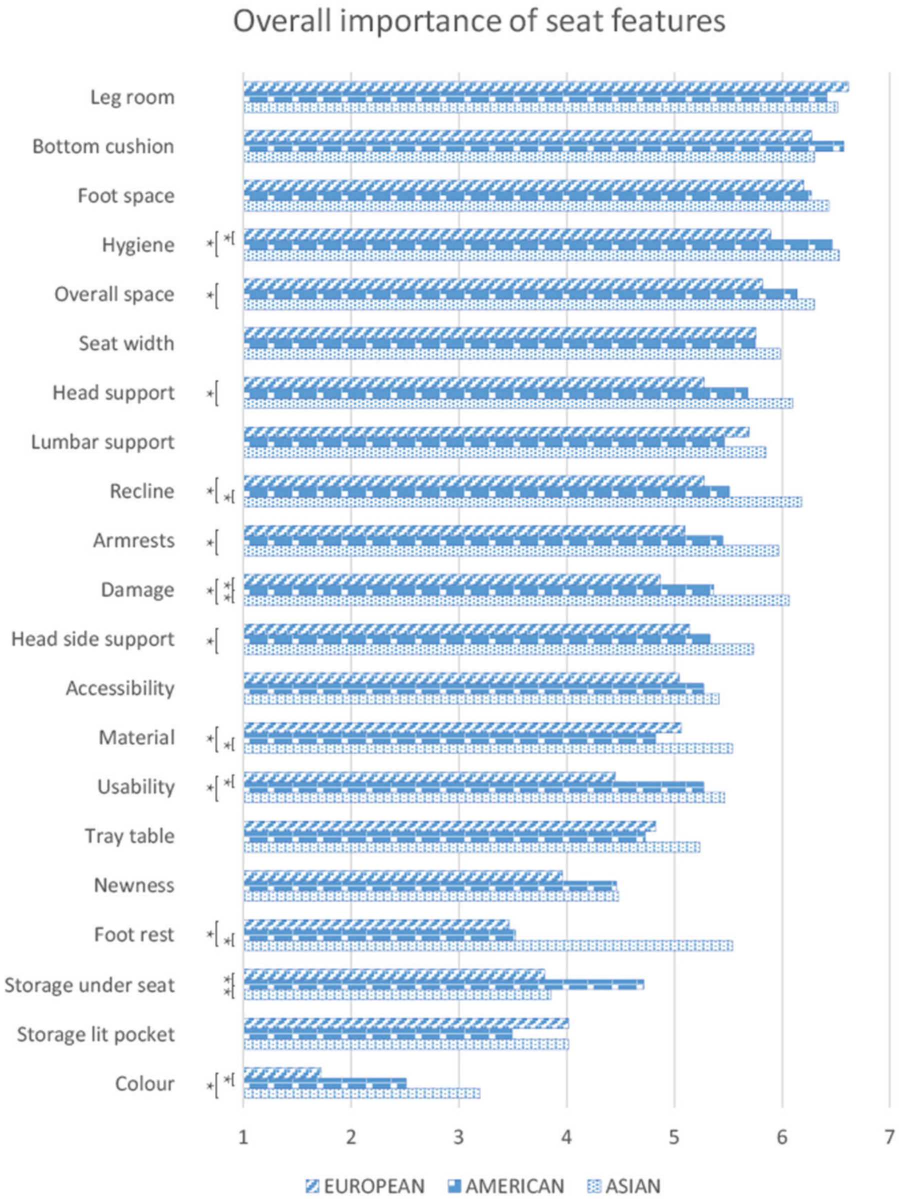

Figure 4.2. Importance of seat features according to all geographical groups (1: not important at all, 7: very important). An asterisk indicates a significant difference between the geographical groups.

4.3.2 Which seat features are considered most important by different geographical groups (Asia, Europe, America) when performing in-flight activities (eating, working on a laptop, sleeping, reading, watching IFE)?

Table 4.2 shows the top three rating of most important airplane seat features for different in-flight activities. Figures 4.3 to 4.7 show the complete results for all in-flight activities per geographical group.

Table 4.2. Top three rating of important airplane seat features for different in-flight activities

	Eating	Watching IFE	Reading	Sleeping	Working
#1	Tray table (79%)	Recline (41%)	Armrest (48%)	Head-side support (41%)	Tray table (83%)
#2	Hygiene (35%)	Bottom cushion (38%)	Overall space (36%)	Bottom cushion (41%)	Overall space (37%)
#3	Overall space (34%)	Head support (38%)	Bottom cushion (33%)	Recline (38%)	Armrests (34%)

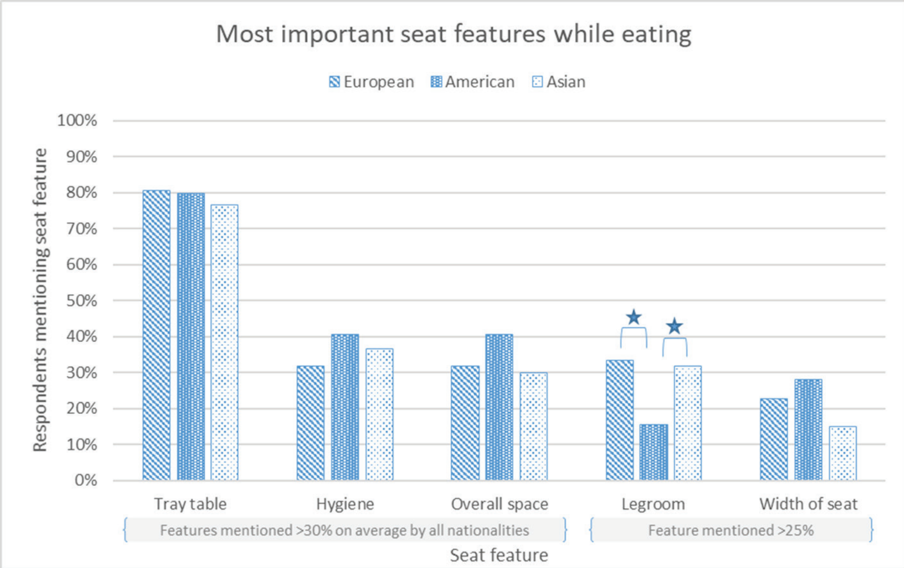

Figure 4.3. Important seat features for the activity of eating

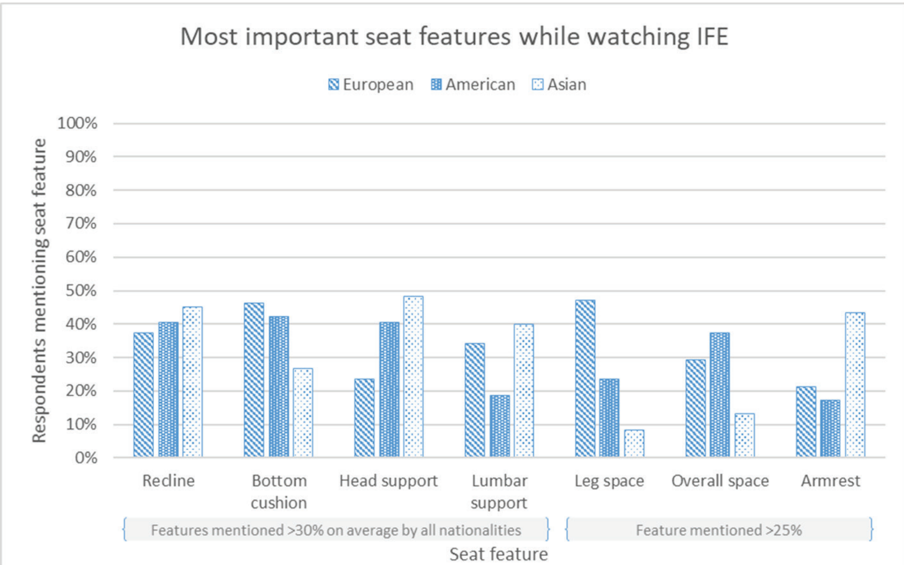

Figure 4.4. Important seat features for the activity of watching in-flight entertainment

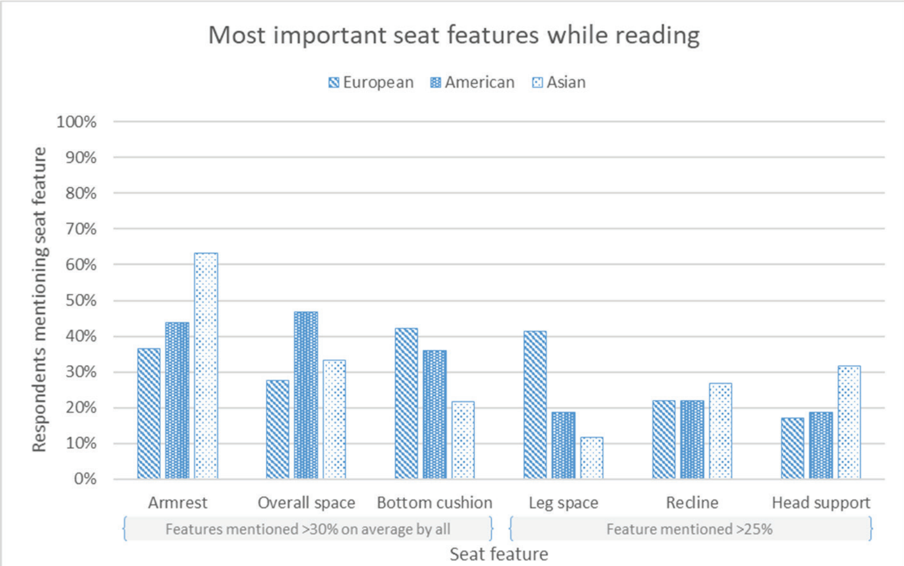

Figure 4.5. Important seat features for the activity of reading

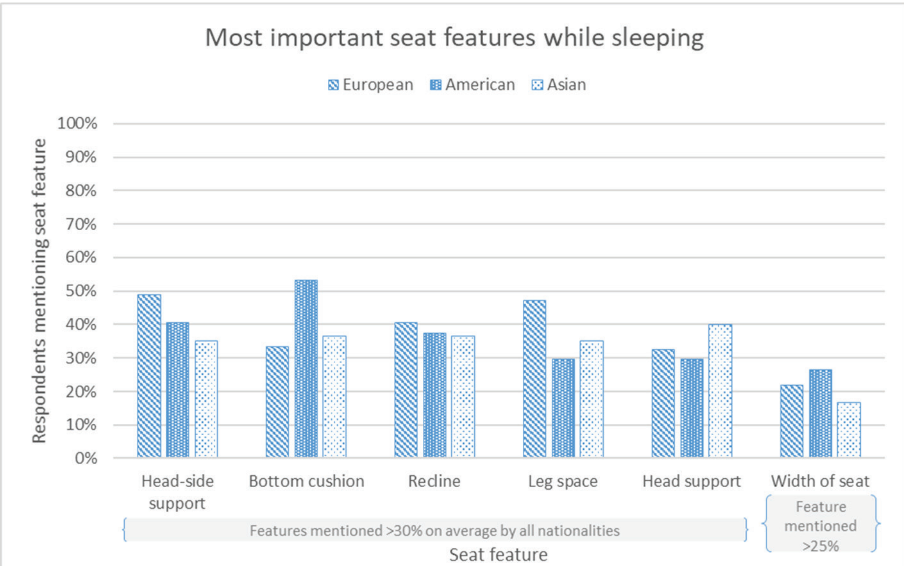

Figure 4.6. Important seat features for the activity of sleeping

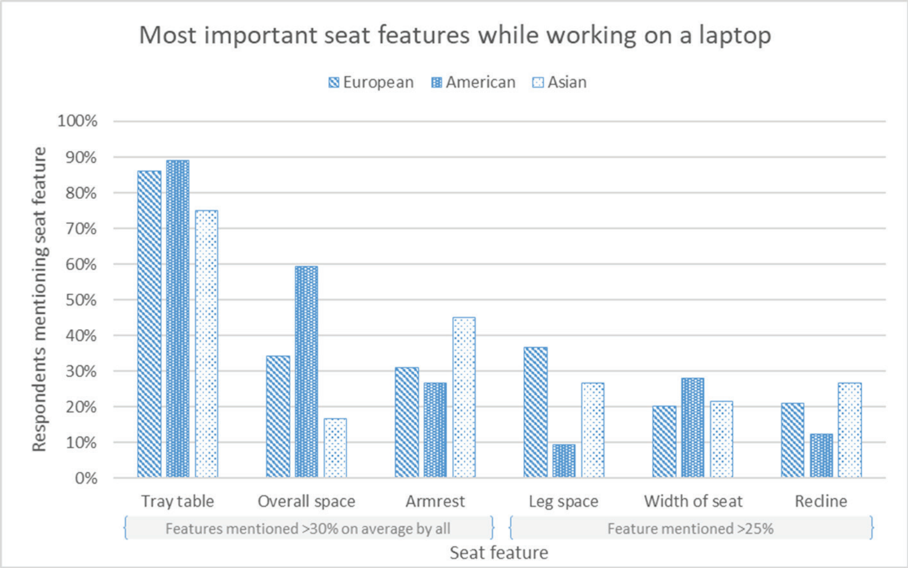

Figure 4.7. Important seat features for the activity of working on a laptop or tablet

4.3.3 According to the passengers, which seat features require improvement?

Features that require improvement according to the respondents are shown in Figure 4.8. The European respondents mentioned leg room most often (29 percent), followed by the width of the seat (12 percent), back support (11 percent), and overall space (11 percent). The Americans mentioned the seat cushion most often (19 percent), followed by the overall space (18 percent) and back support (12 percent). The Asian respondents most often mentioned leg room (22 percent), followed by head support (11 percent), and the width of the seat (10 percent).

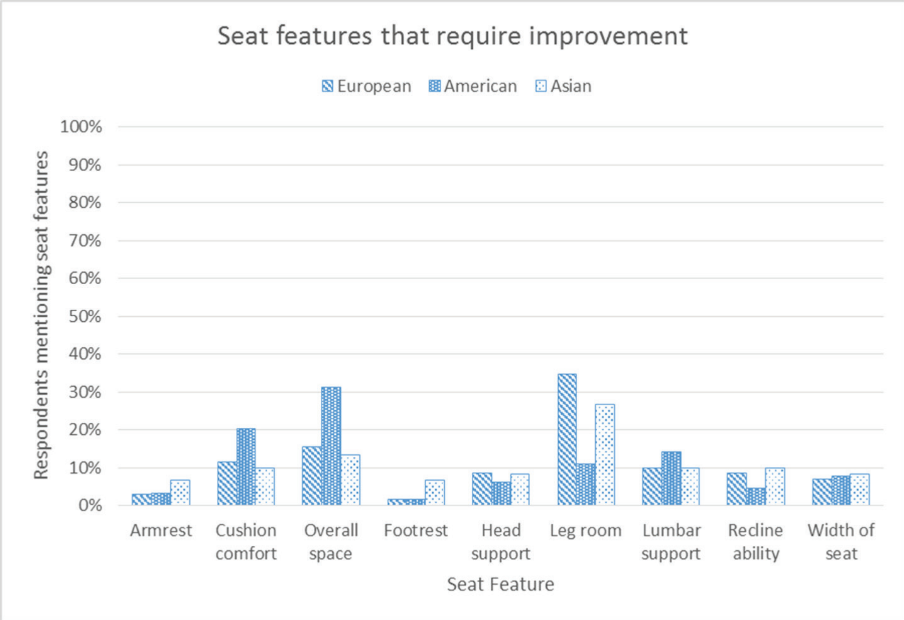

Figure 4.8. Features that require improvement according to the respondents

4.4 Discussion

4.4.1 Reflection on the results

The goal of this study was to investigate whether a ranking on seat features in relation to activity and geographical background could be made. The outcomes of this study indicate that some aspects were rated as more important than others.

When rating each factor of the seat, all respondents, independent of their geographical backgrounds, indicated that leg room, bottom cushion, foot space, hygiene, and overall space are the most important seat features. Nevertheless, hygiene is rated significantly more important by American and Asian respondents as compared to Europeans.

The space and size-related features of the airplane seat (leg room, foot space, overall space, and seat width) are rated as fairly important by respondents from all geographical groups. This might seem to be counterintuitive since the anthropometrics belonging to these groups differ (e.g., the average stature/

height of the Asian population is shorter than the height of the European and American populations, and the hip breadth while sitting is smaller for the Asian population as compared to the Europeans and North Americans [www.dined.nl]). However, this is in line with Beaulieu (2004), who found that Asians use a larger zone of personal space than Caucasians, followed by Mediterranean cultures and Latinos.

The important seat features of foot space and leg room relate to the seat pitch. Kremser et al. (2012) also found a relation between seat pitch and comfort experience and discovered that the optimal pitch depends on the passengers' anthropometry. In addition, Ahmadpour et al. (2014) stated that leg room was mentioned by at least 20 percent of their participants when asking about comfort. Also, Vink and Brauer (2011) found that leg room is strongly related to aircraft interior comfort (correlation coefficient of .72 between leg room and comfort, based on flight reports of 10,032 passengers). Nevertheless, in this study we did not investigate which airline, type of aircraft, and class (e.g., business class, economy class) our respondents experienced; therefore we cannot make design suggestions on the seat pitch based on our data.

The different in-flight activities also seem to influence the importance of the various seat features. This might be caused by different postures people take while performing distinct in-seat activities (e.g., slouching while watching a movie versus sitting upright while working) (Groenesteijn et al., 2014) and the attributes passengers use to do those activities (e.g., meals and laptops will be positioned on the tray table). However, for some activities a broader range of seat features was mentioned by the respondents as being important; for instance, sleeping requires more physical support offered by the airplane seat than working on a laptop since for the first activity, five aspects (head side support, bottom cushion, recline, leg space, and head support) were mentioned as important by more than 30 percent of the respondents from each geographical group.

4.4.2 Reflection on the method

First, it should be noted that since we made use of a survey, we were not able to control any external factors that can influence the experience, such as the type of airplane and the exact type of seat (e.g., brand and class) as well as the location of this seat (e.g., middle, aisle). However, these features could differ per airline, airplane, and flight and therefore also influence the experience of the passenger. As it was not possible to include all these factors in the scope of the present study, they have been excluded. The results of this study therefore give an initial indication of key seat features. Further research could be done to verify the outcomes.

Furthermore, the European and North American respondents were able to answer the questions in their native language (Dutch and English), whereas the Asian respondents had to read and respond in a language other than their native one (English). This could have had influence on the reading comprehension of this population. Besides, all European respondents were Dutch, and all American respondents were from the United States. Therefore, adding respondents from other European and American countries could result in even more representable and generalizable results.

In addition, the outcomes of this study are based on passengers' expectations based on experiences from the past and not on real-time experiences, which might have resulted in deviated ratings of the seat aspects. The color of the chair is rated as one of the least important seat features in this study, but practice shows that the comfort of an ugly-colored chair is rated significantly lower than the same chair in another color (Bronkhorst et al., 2001). Nevertheless, recalling comfort experiences or real-time reporting of comfort experiences will result in the same extreme high and low comfort peaks during a passenger's flight (Bouwens, Tsay, & Vink, 2017).

Finally, in this study the relationship between seat features and comfort was made. However, comfort experience is not solely defined by the design of a seat; environmental factors also play a role, of which passengers are often not aware. Mellert, Baumann, Freese, & Weber (2008) studied the impact of noise and vibration on the well-being of people during long-haul flights and in-flight simulators, and although noise was not mentioned as a problem, swollen feet and neck pain were reported more often by the flight crew in louder conditions. Also, the results of a study by Boeing illustrates that environmental factors play a significant role; a new sky interior resulted in higher appreciation of the airplane seats when compared to the exact same seats in a traditional aircraft (McMullin, 2013). Therefore, it could mean that respondents in this study rated features, such as color, as unimportant, because they were unaware of their importance, while in real life these features actually could have a significant impact on perceived comfort.

4.5 Conclusion

The outcomes of this study support the notion that different airplane seat features do not equally contribute to comfort. Also, based on the data gathered in this study, we suggest that different seat features are important to facilitate a variety of in-seat activities performed by passengers during a flight. For eating, this means a good tray table design, hygiene, and sufficient overall space. For watching IFE, the respondents indicated a recline function, bottom cushion, and head support as valuable features. For reading, the armrests, overall space, and bottom cushion were mentioned as important. Sleeping requires a good head-side support, bottom cushion, and recline function, and for working, the tray table, overall space, and armrests are indicated as important. Overall, space-related features are rated as fairly important by all geographical groups surveyed.

Aircraft seat manufacturers should take the rankings of these seat features into account when prioritizing design efforts for desired in-seat activities of passengers on different airlines.

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Chapter 5: Expected versus Experienced Neck Comfort

This chapter has been published as:

Bouwens, J.M.A., Schultheis, U.W., Hiemstra-van Mastrigt, S., Vink, P. (2018). Expected versus experienced neck comfort. *Human Factors and Ergonomics in Manufacturing & Service Industries, 28*(1), 29-37.

Abstract

There is certainly room for economy-class travelers to make their trips more pleasant. A travel pillow might improve comfort. In this study, the comfort expectations and experience of travel pillows were examined. Comparing these 2 aspects indicated that it is not always possible to predict the comfort experience associated with a product based on a picture, and that there is a discrepancy between expected and experienced comfort. Experienced comfort is highest for travel pillows that restrict head movements in all directions in order to maintain a neutral posture. The results of this study also support earlier studies that suggested that discomfort experience can be predicted by observing the number of participants' in-seat movements; more movements result in higher experienced discomfort.

Keywords: aircraft seat design, expectations, neck support, passenger comfort, travel pillow

5.1. Introduction

Over the past 5 decades, air travel has changed from a luxury into mass transportation (The World Bank, 2015). To ensure a high profit within a highly competitive market, most airlines fill their airplanes with the maximum number of passengers. This does not always contribute to optimized customer satisfaction (Nadadur & Parkinson, 2009). Thus, especially when traveling in economy class, passengers usually cannot expect a comfortable journey and have to find solutions to cope with the minimal living space available during their trip. With this in mind, it is hardly surprising that passengers often bring travel items, such as pillows and blankets, on their flight. This reaction is a result of expectations (Vink & Hallbeck, 2012) that might be based on the preconceived notions that airline passengers have preceding their flights (Dumur, Barnard, & Boy, 2004). Consequently, when studying the field of passenger comfort, the question of whether travel pillows improve travel experiences arises.

Although travel pillows are available in different shapes, sizes, and colors, it is unknown which type of pillow, if any, works best as additional head support for relieving the neck muscles and preventing neck pain. Findings in the field of psychophysiology indicate that an ideal headrest should support the body in a neutral position (O'Sullivan et al., 2010) such that the tragus and seventh cervical vertebra create an angle between 40.6 and 43.7 degrees (see Figure 5.1; Ankrum & Nemeth, 2000; Johnson, 1998; Raine & Twomey, 1997; van Veen, Hiemstra-van Mastrigt, Kamp, & Vink, 2014). Biomechanical studies indicate that the head is best balanced when rotated 20 degrees backward (see Figure 5.1) because the head's center of mass in this position is located right above the atlas, the pivot point of the head (Staarink, 2007). Regardless of the ideal position, current airplane seats do not always comply with the need to support the body in a neutral position (Bissell, 2009).

Comfort is a convenient experience that enhances product pleasure (Vink, 2004), whereas discomfort refers to physical inconveniences (De Looze, Kuijt-Evers, & Van Dieën, 2010). A product can only be comfortable or uncomfortable when it is in use (Vink & Brauer, 2011).

Researchers developed several methods to assess and measure comfort and discomfort. For example, discomfort caused by a seat has a relationship with pressure recorded by a pressure mat between a person and a seat; unevenly distributed body load or too much load on the thighs indicates discomfort (Zenk, Franz, Bubb, & Vink, 2012). Also, self-reported discomfort by the seat occupant is a method used to assess discomfort. Participants indicate on a body map to what extent the seat causes discomfort in a specific part of the human body (local postural discomfort) scale. Another frequently used way of measuring discomfort is the CP-50 category partitioning scale described by Shen and Parsons (1997) and used, for instance, by Franz, Durt, Zenk, and Desmet (2012). They studied the sensitivity of the head and neck area. They found that support of the neck required softer cushioning than the support of the back of the head in order to provide comfort, and they used these insights to develop a new headrest for a car seat. Tan (2010) found that aircraft passengers prefer to hold their head in a neutral position while resting and proposed a new headrest that actively corrects the position of the head when movements in the yaw-and-roll position occur. No literature has been found on the effectiveness of (cervical) travel pillows to support the head and neck of healthy passengers while sleeping upright.

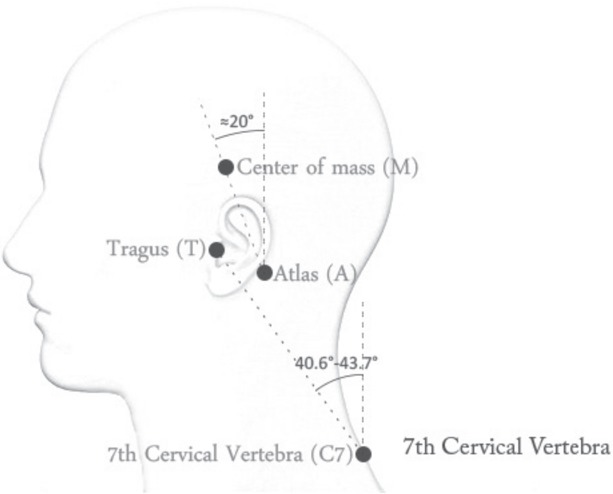


Figure 5.1. Psychophysiological and biomechanical neutral angle of the head

Comfort assessment is rather laborious because many factors play a role in comfort experience. Ahmadpour, Lindgaard, Robert, and Pownall (2014) researched airplane passenger comfort and found that not only physical well-being, but also, among other factors, aesthetics, such as color or tactile sensations, pleasure, and proxemics, contribute considerably to comfort experience. This means that when assessing product comfort researchers need to be aware of these “disruptive” factors.

Currently, evidence that suggests passengers have the ability to predict their perceived comfort is scarce. Only a few studies have described the relationship between expected and actual comfort. Also, the effect of using a travel pillow on the (dis)comfort experience of airplane passengers while resting is still unknown. Therefore, the aim of this study was to investigate the effect of having a travel pillow on comfort and to determine the relationship between the expected and actual comfort associated with the use of travel pillows. In other words, which travel pillow can actually provide the head and neck with ideal support, and does this correspond with the expected comfort when selecting a travel pillow?

5.2. Methods

To answer this question, five travel pillows were selected: i) Total Pillow, ii) J-pillow, iii) inflatable Travelrest, iv) Carex Memory Foam, and v) Embrace Sleep Collar (see Table 5.1). All these pillows were purchased online. Each of these pillows had different characteristics in terms of head and neck support and restriction of movement in some directions. To describe the effect of the pillow on the head position, three main axes were defined (see Figure 5.2). The Total Pillow is a doughnut-shaped pillow filled with microbeads that can be twisted to a preferable shape for optimal support of the head from the side or the back. The J-pillow is a pillow shaped in the letter J and filled with original pillow stuffing that supports the head on the side and under the chin. The inflatable Travelrest is a tall-shaped pillow that is inflatable; the pillow is positioned from the shoulder to the waist and provides support on the side of the head. The Carex Memory Foam pillow is a traditional horseshoeshaped travel pillow filled with memory foam, it is placed around the neck and supports the back and the sides of the head. The Embrace Sleep Collar is a hard plastic U shape, covered with foam that is tightly placed around the neck in order to support the head under the chin and on the side by restricting movement in these positions. All pillows originally had a dark blue or black fabric cover.

Table 5.1. Five head neck supports with different restrictions in neck movement

	Total Pillow	J-Pillow	Inflatable travelrest	Carex memory-foam travelpillow	Embrace sleep collar
					
Restricts ‘Yaw’	+	+	+	+	+
Restricts ‘Roll’	+	+	+	+	+
Restricts ‘Pitch’	-	+	-	-	+

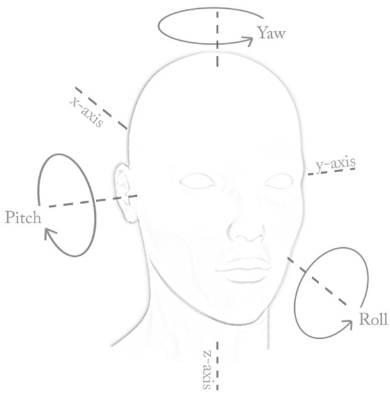


Figure 5.2. Movement of the head in yaw, pitch, and roll direction

5.2.1 Setup

5.2.1.1 Comfort expectations

To quantify the expectations of passengers, a questionnaire was sent to 50 participants who were recruited online by convenience sampling (23 men, 27 women), aged 18–59 years (average 29.8, SD [standard deviation] = 9.9) with previous flight experience. In this questionnaire, the participants were asked to rank six pictures. Five of these six pictures were of persons with the travel pillows used in this study, and one picture was a person without a travel pillow. The subjects had to rank the six pictures based on expected comfort.

5.2.1.2 Comfort experience

The comfort experience and user behavior were measured with 10 participants (4 men, 6 women), aged 30–58 years (average 41.9, SD = 12.2), with a mean weight of 84.3 kg (SD = 20.6) and mean height of 1.69 m (SD = 0.08), from different ethnicities (Caucasian, Hispanic, and Asian) without a history of back and neck pain, recruited by convenience sampling. All participants provided written informed consent preceding the study.

The participants were asked to evaluate six conditions (five conditions with the five different travel pillows and one condition without a pillow) while sitting in the center seat of the back row of two Zodiac 5751 triple-seat assemblies that were pitched at 32 in., fixed in the upright position, and equipped with an adjustable headrest (see Figure 5.3).

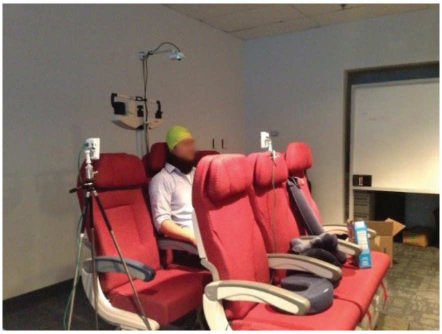


Figure 5.3. Setup of the seats and cameras

Four synchronized network cameras (cameras: Axis M1054m, software: Media Recorder, Noldus Information Technology B.V) were installed around the participant (see Figure 5.4). To better control the interpretation of head movement, participants wore a marked yellow swim cap (a Nike solid latex training cap).

Each of the aforementioned conditions was tested for 45 min in a different order for each participant. Two conditions were evaluated each day, and all conditions were presented to the participants within one week. The participants were instructed to rest or sleep during each condition because other activities might influence the positioning of the head and distract the participant from feeling discomfort (Hiemstra-van Mastrigt, 2015). Participants were able to adjust the pillows to their liking, for example, by adjusting the softness of the inflatable Travelrest or twisting the Total Pillow. After each condition, the participants were asked to rate their perceived discomfort on a visual analog discomfort scale (see Figure 5.5), followed by a 15-min refreshment break. After experiencing all conditions, the participants ranked the conditions from most comfortable to least comfortable.

Figure 5.4. Outputs of the four cameras

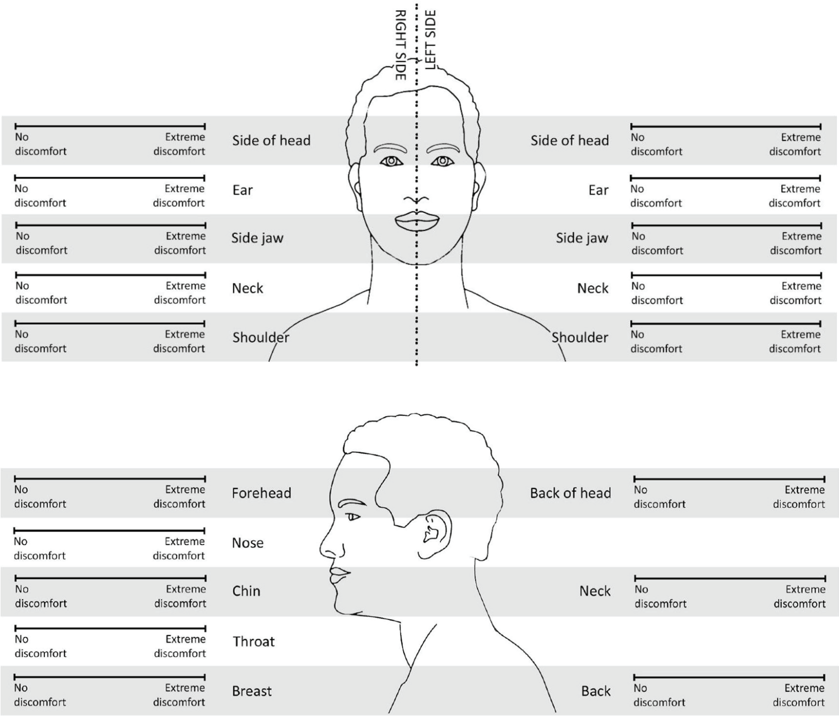


Figure 5.5. Visual analog discomfort scale maps of the head and neck area

5.2.2 Measurements and analysis/processing data

5.2.2.1 Comfort expectations

The comfort expectation rankings were statistically evaluated using a Wilcoxon test ($p < .05$).

5.2.2.2 Movement behavior

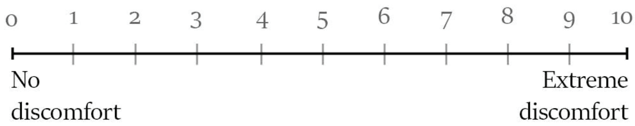
The data collection performed in the Human Factors and Ergonomics Laboratory of Zodiac Seats (Gainesville, Texas) resulted in 60 45-minlong video recordings (showing the participants' heads in different positions), 60 discomfort maps (as a result of the participants' ratings), and 10 comfort ranking interviews. All data were analyzed using behavioral science statistics software (IBM SPSS 22). Using the software package The Observer XT 12.5 (Noldus Information Technology B.V.), the video recordings were evaluated by coding the position of the head relative to three different axes: pitch (y-axis), roll (x-axis), and yaw (z-axis).

The positions of the head were subdivided for each axis (pitch, roll, and yaw) into positive, neutral, and negative regions. A neutral position was a position without a clear, visible deviation to one side. Twentyseven positions of the head were defined by combining rotations in all three directions (see Figure 5.2). The total time spent in each position was calculated, and the number of times the participants moved to a given position was recorded.

A one-way analysis of variance (ANOVA) was used ($p < .05$) both to determine whether there were any significant differences in the number of times participants adapted to another position and to determine the total time participants spent in a given position per travel pillow.

5.2.2.3 Discomfort experience

The indicated discomfort experience on the visual analog discomfort scale was measured with a ruler and converted to a discomfort score on a 10-point scale, as suggested by van Veen et al. (2014; see Figure 5.6). The differences in discomfort among the conditions were tested using the Friedman test ($p < .05$) because previous studies demonstrated that discomfort is not normally distributed (Grinten & Smitt, 1992; Hiemstra-van Mastrigt, 2015).



0	No discomfort at all	3	Average discomfort
0.5	Extreme little discomfort: almost not noticeable	4	Raised discomfort
		5-6	High discomfort
1	Very little discomfort	7-9	Very high discomfort
2	Little discomfort	10	Extreme high discomfort

Figure 5.6. Interpretation discomfort scale (Van Veen et al., 2014)

5.2.2.4 Comfort experience

The audio recordings of the individual comfort rankings and motivation given in the interview were transcribed. The differences in ranking were tested with a Friedman test, and individual differences were tested with a Wilcoxon test for two related samples ($p < .05$).

5.2.2.5 Expected comfort versus experienced comfort

The comfort-based ranking lists for expected and experienced comfort of all travel pillows are compared with each other using a Mann– Whitney test.

5.2.2.6 Movement behavior versus discomfort

To visualize the relationship between movement behavior (amount of movements) and discomfort experience of the participants, a trend line is plotted on a simple scatterplot. A single linear regression analysis is done to investigate whether the correlation is significant.

5.3 Results

5.3.1 Comfort expectations

Figure 5.7 shows the results of the ranking of all six conditions. Of the 50 participants, 26 expected that the Total Pillow would be the most comfortable pillow. None of the participants indicated any expected comfort based on seeing the pictures of the Carex Memory Foam, the Embrace Sleep Collar, or no pillow. Therefore, the expectations for these particular pillows/lack of a pillow were the lowest of all conditions. The Wilcoxon test indicated that the

Total Pillow was significantly more highly ranked than the Embrace Sleep Collar, no pillow, the Carex Memory Foam, and the inflatable Travelrest ($p < .01$). This test also revealed that the participants had significantly lower expectations for the Embrace Sleep Collar than for the other travel pillows when they viewed the pictures ($p < .01$).

No significant differences between the Total Pillow and the J-pillow were found ($p = .168$).

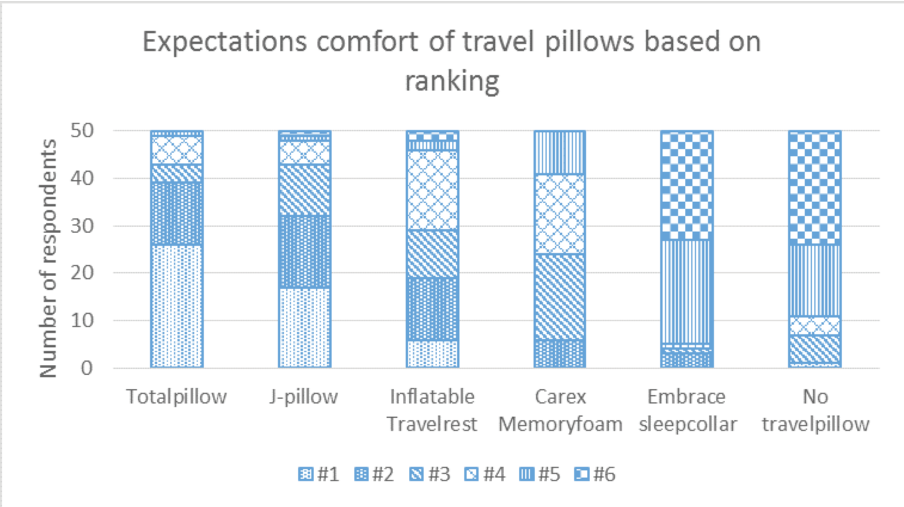


Figure 5.7. Expectations of the comfort of travel pillows based on ranking

5.3.2 Observations

5.3.2.1 Observations - movement counts

The average numbers of head movements over the three axes per travel pillow are presented in Figure 5.8. The inflatable Travelrest caused the highest number of head movements (average 78, SD = 58), and the Embrace Sleep Collar resulted in the lowest number (average 42, SD = 34). However, the one-way ANOVA did not reveal any statistically significant differences ($p = .468$) between the travel pillows.

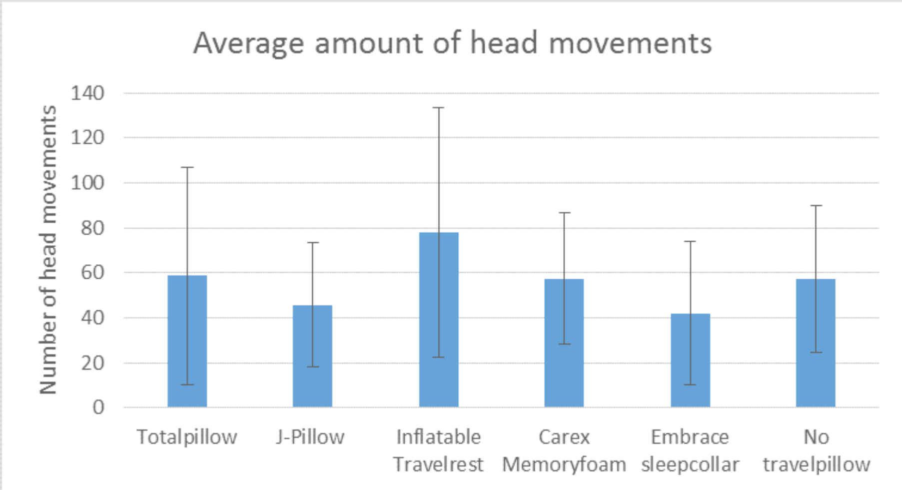


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Figure 5.8. Average amount of head movement per travel pillow in 45 min

5.3.2.2 Observations - duration

As described, the participant's head position was observed and analyzed with respect to three main axes (the pitch, yaw, and roll axes). The results are presented in Table 5.2 as percentages of the total testing time. The participants exhibited the least movement toward the pitched-down direction when using the Embrace Sleep Collar and the greatest movement when using the Total Pillow. The one-way ANOVA indicated that there is no significant difference between the pillows in the pitch down ($p = .160$), pitch neutral ($p = .229$), or pitch up ($p = .687$) direction.

The neutral roll position was most often assumed when using the Embrace Sleep Collar and least often when using the J-pillow. The oneway ANOVA indicates no significant difference between the pillows in the roll right ($p = .690$), roll neutral ($p = .604$), or roll left ($p = .979$) position.

In addition, the pillows caused variation in the time spent in all yaw positions; however, no significant difference was found between yaw position and travel pillow (one-way ANOVA: yaw right $p = .821$, yaw neutral $p = .865$, yaw left $p = .947$).

Table 5.2. Average duration head movement in pitch, roll, and yaw directions in percentage of time during 45 min

	Total Pillow (%)	J-Pillow (%)	Inflatable Travelrest (%)	Carex Memory Foam (%)	Embrace Sleep Collar (%)	No Travel Pillow (%)
Pitch down	54%	48%	40%	49%	23%	30%
Pitch neutral	33%	32%	58%	49%	62%	62%
Pitch up	12%	7%	2%	2%	16%	8%
Rolling right	35%	26%	27%	35%	19%	39%
Rolling neutral	38%	33%	53%	41%	60%	35%
Rolling left	27%	21%	20%	24%	21%	26%
Yaw right	29%	13%	32%	33%	26%	28%
Yaw neutral	40%	42%	45%	40%	60%	40%
Yaw left	29%	20%	21%	35%	20%	24%

5.3.3 Discomfort experience

The average discomfort perception per travel pillow is shown in Figure 5.9. This graph indicates that the inflatable Travelrest caused the most discomfort, whereas the Embrace Sleep Collar caused the least discomfort. However, this difference was not significant (Friedman test, $p = .314$).

Interestingly, literature indicates that over a specific time, a peak score greater than 2 (on a discomfort scale from 0 to 10) is associated with an increased risk of having neck pain with a factor of 2.56 and a score of 3 with an increased risk by 2.35 over a specific time (Hamberg van Reenen et al., 2008). Table 5.3 indicates that the inflatable Travelrest and having no travel pillow were associated with the highest peaks in perceived discomfort, which could increase the risk of neck pain in the long run, according to Hamberg-van Reenen et al. (2008).

Table 5.3. Average discomfort rating per travel pillow

		Total Pillow	J-Pillow	Inflatable Travelrest	Carex Memory Foam	Embrace Sleep Collar	No Travel Pillow
RIGHT	Side of head	1,5	1,2	3,1	1,3	0,5	2,6
	Ear	2,8	1,2	3,0	1,4	0,6	1,7
	Side jaw	2,8	0,8	3,1	1,0	0,9	1,6
	Neck	3,0	2,2	3,1	2,5	2,2	4,4
	Shoulder	2,1	0,8	2,1	1,3	1,2	3,6

LEFT	Side of head	1,2	1,2	3,1	1,3	0,5	2,6
	Ear	3,0	1,0	4,0	1,3	0,8	1,7
	Side jaw	2,8	0,6	3,6	0,8	1,1	1,8
	Neck	3,1	2,8	3,4	2,6	2,3	4,3
	Shoulder	2,0	1,4	3,0	1,3	1,4	3,6
	Forehead	0,5	0,4	0,4	0,5	0,3	0,3
	Nose	0,4	0,3	0,4	0,4	0,4	0,3
	Chin	1,4	0,7	2,5	1,1	0,9	0,7
	Throat	1,0	0,3	0,7	0,4	1,0	0,4
	Breast	0,6	0,3	0,6	0,5	0,4	0,3
	Back of head	1,4	1,4	2,2	1,7	1,3	3,7
	Neck	3,6	3,1	4,1	2,9	2,1	4,9
	Back	2,0	2,3	3,0	1,7	1,0	3,7
	TOTAL	34,9	22,1	45,3	23,9	18,8	42,3

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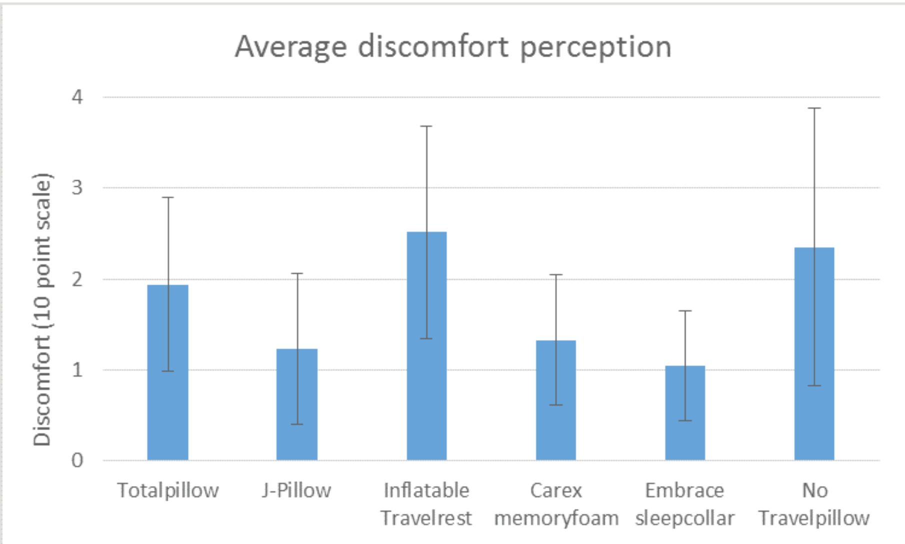

Figure 5.9. Average discomfort rating on a 10-point scale per travel pillow

5.3.4 Comfort experience

The results of the data collection after experiencing all six conditions (five with a travel pillow and one with no pillow) are summarized in Figure 5.10. Five of the 10 participants ranked the Embrace Sleep Collar in the number one position (#1) and the J-pillow was not ranked lower than 4 by any of the participants. These rankings were supported by the individual motivations of the participants, which are presented in Figure 5.10. However, a Friedman test indicated no significant differences in the rankings ($p = .089$). Remarkably, all participants preferred to be restricted in the pitch, roll, and yaw rotation directions.

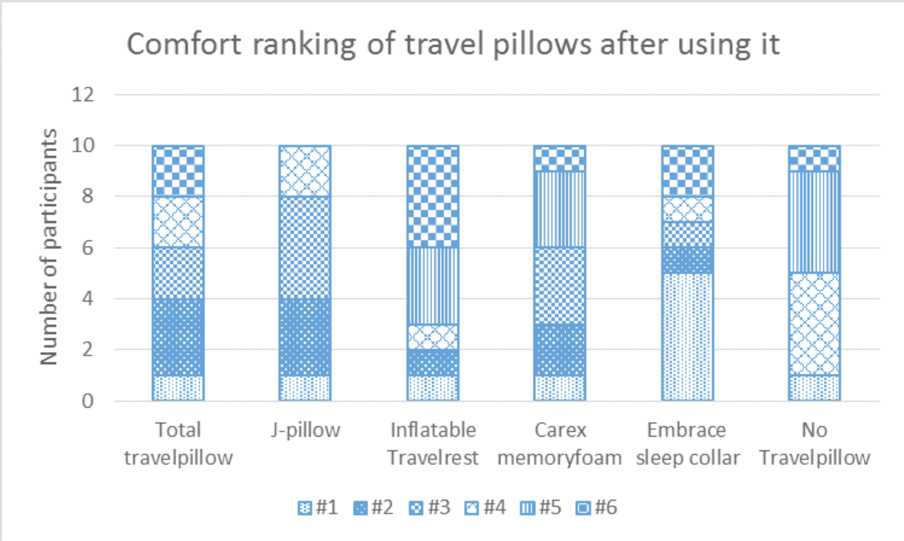

Figure 5.10. Comfort ranking of travel pillows after using it

5.3.5 Expected comfort versus experienced comfort

A comparison between expected versus experienced comfort rankings with a Mann–Whitney test shows that the Total Pillow ($p = .005$) and the inflatable Travelrest ($p = .004$) were expected to offer more comfort than they actually did, and the Embrace Sleep Collar ($p = .001$) and the headrest ($p = .033$) actually offered more comfort than expected. This indicates that there seems to be a discrepancy between expected comfort and experienced comfort.

5.3.6 Movement behavior versus experienced discomfort

A significant regression equationwasfound,$F(1, 58) = 18.559$, $p < .000$, with an R2 of .242. Participants' predicted discomfort is equal to 0.544 + 0.018 (head movements) discomfort points when the amount of head movements is measured. Participants' discomfort increased 0.018 for each head movement (Figure 5.11).

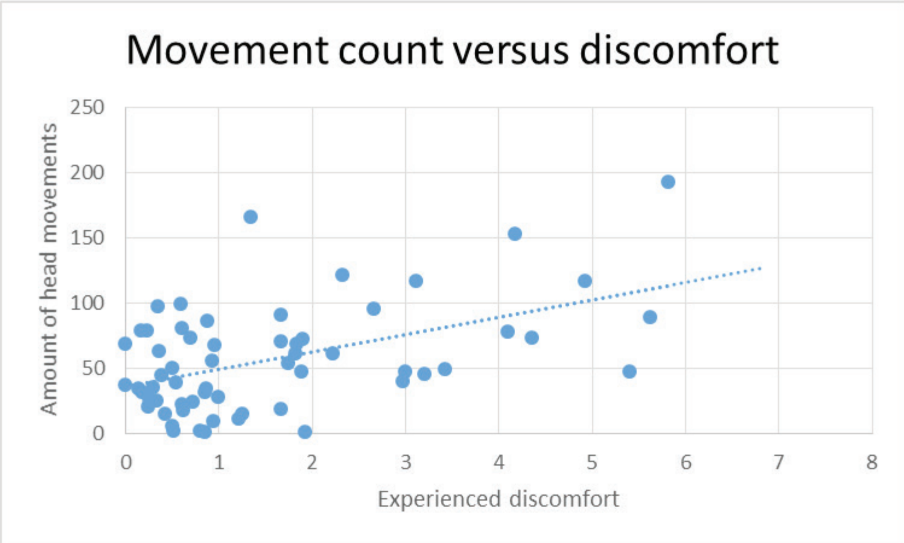

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Figure 5.11. Movement count versus discomfort

5.4 Discussion

The first aim of this study was to evaluate whether airplane passengers are able to improve and predict their perceived comfort level with a travel pillow. The majority of the 50 participants from the first study expected that the J-pillow and the Total Pillow would offer the most comfort. However, the results of the extended comfort study with 10 different participants indicated that these pillows caused medium discomfort in the head and neck area. Furthermore, the comfort ranking that the 10 participants made after experiencing all six conditions (five with travel pillows and one without a travel pillow) differed from the expected comfort by the 50 participants in study 1. These findings suggest that passengers are unable to predict the comfort associated with a travel pillow based on pictures, although solely assessing a product based on aesthetic qualities is nowadays commonly accepted by the growing popularity of online shopping. This is also suggested by earlier research by Bronkhorst et al. (2001). In their study, office workers evaluated four physically identical seats presented in different colors. Three of the four seats were light colored, and one was “ugly” brown. The brown seat was initially expected by the test participants to be the most uncomfortable one; however, after more than 40 min of use, all seats were evaluated equally. Also, the limited ability to assess travel pillows based on tactile characteristics could have led to lessconfident attitudes toward them (Peck & Childers, 2003).

What is the preferred position of the head?

The individual comfort ranking indicated that participants valued the support of a travel pillow to maintain a neutral posture. Although the physical characteristics in terms of body weight varied strongly among the participants, it seems from this study that there is no clear relation between posture preference, comfort, and body weight. This ranking was supported by the results because the travel pillows that supported neutral roll and yaw positions were generally ranked more highly.

Therefore, it suggests that a comfortable travel pillow must support the head by restricting head movement in all directions. Interestingly, this finding is not new. Several researchers (Ankrum & Nemeth, 2000; Johnson, 1998; Raine & Twomey, 1997; van Veen et al., 2014) described a preference for the neutral position of the neck, and Szeto, Straker, and Raine (2002) concluded that there was evidence that static neck postures other than the neutral position were accompanied by an increased risk of developing pain symptoms in the upper body. Huang, Hajizadeh, Gibson, and Lee (2016) found that a seat with a higher backrest reduces the compressive load in the lumbar joints by 29% compared with a seat with lumbar support only; however, the headrest provided in that study was barely used by the participants owing to the neutral position of the spine. Therefore, a usable neck support that maintains a neutral posture might not only contribute to better comfort but also contribute to reduced joint forces in the back.

Therefore, a recommendation for future travel pillow design (or even fixed headrest design) is to restrict the head movement in yaw, pitch, and roll directions with a socially accepted appearance. Hence, passengers should be careful in choosing their (existing) travel pillows because some pillows can harm their physical well-being. Bazley, Nugent, and Vink (2015) also described the value of interindividual differences in discomfort patterns. Passengers who do not think objectively will typically be unable to make the correct choice. Perhaps airlines could assist in this choice by offering preselected travel pillows to their passengers on long-haul flights.

Can movement behavior predict discomfort experience?

This research seems to support the statement that a participant's discomfort experience is objectively measurable by observing the movement behavior of the participant. The data suggested that the discomfort perception of participants in this study could be predicted by the frequency of head movements. The more the head moved to another position, the higher the participant rated the discomfort of the pillow. This is in line with the findings of Sammonds, Fray, and Mansfield (2017), who suggested that, as car drivers' subjective discomfort increases, the frequency of subjects' seat fidgets and movements increases congruently. Also Cascioli, Liu, Heusch, and McCarthy (2016); Jackson, Emck, Hunston, and Jarvis (2009); Le, Rose, Knapik, and Marras (2014); and Na, Lim, Choi, and Chung (2005) found that greater in-chair movement is related to increased discomfort.

5.4.1 Limitations

This experiment has taken place in a laboratory setting. Therefore, it was not feasible to simulate several cabin conditions, such as vehicle motion and vibrations. The travel pillows, however, will mainly be used during the cruise phase of the flight, wherein abrupt movements only occur incidentally and to a lesser extent than, for example, during a train ride. This might have had an effect on the comfort perception and the occurrence of discomfort and fatigue in the neck area, although cushiony body support can contribute to the absorption of such vibrations (Beard & Griffin, 2014).

This study took place within a time span of 7 days during different timeslots for each of the participants. Bazley et al. (2015) found that the basic discomfort pattern can fluctuate over such a time span, that is, a different time of day or a different day of the week could lead to a different comfort perception by study participants. However, the changes that Bazley et al. (2015) reported were small, and the results can still be generalized to indicate that a neutral position was perceived to be more comfortable. Furthermore, the objective and subjective data indicated the same outcomes. In this study, each condition was endured for 45 min. Thus, according to Sember (1994), this study can be considered a medium-term study in which perceived discomfort led to a behavioral response; however, this time span might be too short to sleep deeply (with total relaxation of the muscles). With respect to long-haul flights, long-term effects or the effect of position adjustment with and without a pillow should be studied further in future research.

Another limitation of this study is that the seats were fixed in the upright position (not in the reclined position) to limit the number of conditions. Although, ideally, passengers are able to sleep horizontally, while pillows support the head to maintain a neutral spine curvature when side-sleeping, this is often not feasible on a flight because the amount of inches a seat is able to recline is limited in economy class. Moreover, reclining is prohibited during TTL (taxi, takeoff, and landing) and unwanted during food services. Also on many low budget (short haul) flights the seat does not have a recline function and also on these flights passengers would like to use the time of the flight to relax and take a comfortable nap.

In addition, it is unknown whether the bathing caps influenced the participants' perceived comfort. The bathing caps were used in all conditions; therefore, it is assumed that the differences among the conditions were caused by the type of pillow. However, an interaction effect with the bathing cap was not excluded.

5.5 Conclusion

It is not always possible to predict the comfort experience associated with a product. This study showed that there is a discrepancy between expected and experienced comfort. The results of this study also support earlier studies that suggested that discomfort experience can be predicted by observing the amount of in-seat movements by participants.

DECLARATION OF INTEREST

None of the authors are related to the manufacturers of the travel pillows, nor did they receive any form of compensation from these manufacturers.

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Chapter 6: Being in Control of Noise Levels Improves the Aircraft Seat Comfort

6

This chapter is under review at Aviation Psychology and Applied Human Factors

Bouwens, J.M.A., Fasulo, L., Hiemstra-van Mastrigt, S., Schultheis, U.W., Naddeo, A., & Vink, P., (submitted). Being in control of noise levels improves the perception of airplane seat comfort.

Abstract

The aviation industry is constantly making compromises when designing comfortable airplane cabins. Providing passengers with a pleasant acoustic environment without adding weight to the cabin structure is a tension field that challenges cabin interior designers. The aim of this study is to investigate whether noise levels affect the comfort and physical discomfort experienced by airplane passengers, and whether control influences comfort perception. To this end, 30 participants experienced three conditions (silence, aircraft engine noise at 75 dB, and the same noise with the ability to use earplugs), and comfort and discomfort were measured using a questionnaire. It could be concluded that aircraft engine noise negatively affected the airplane passengers' comfort experiences. Having the ability to control this noisy environment with earplugs resulted in the lowest reported physical discomfort.

Key words: aircraft cabin noise, passenger comfort, discomfort, airplane seat, control

6.1. Introduction

The control of noise in aircrafts and automobile interiors has received considerable attention (e.g. Tichy, 1991), because the presence of noise might have negative effects on human health and comfort, both physiologically and psychologically (Mellert, Baumann, Freese, & Weber, 2008).

Physicists describe sound as observable vibrations that travel through a medium (air, water, etc.)(Rayleigh & Lindsay, 1998), while psychologists study sound as the perception of these vibrations by the brain (psychoacoustics). Sound is defined by volume (dB) and tone (frequency in Hz). The human hearing range lies between 20 and 20,000 Hz (Figure 6.1), and people are most sensitive to frequencies between 2,000 and 5,000 Hz. A volume of 0 dB is the hearing threshold for a child, and 150 dB corresponds to the volume of a rock concert when standing in front of the sound box.

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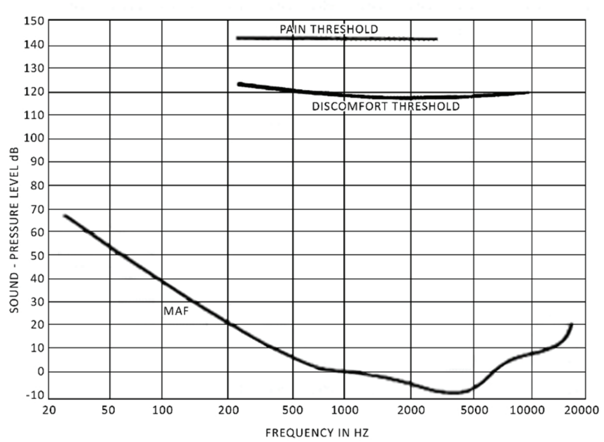

Figure 6.1 Human hearing range (Slater, 1985), showing the thresholds of discomfort and pain levels of hearing (MAF= minimal audible field) for every frequency with the corresponding sound pressure level (in dB)

The sound inside an airplane cabin predominantly originates from the aircraft power plant (propeller and engine) and the turbulent boundary layer (Wilby, 1996). It has an average level of 80 dB at cruise flight altitude (Figures 6.2 and 6.3) with a relatively low frequency (Hinninghofen & Enck, 2006; Ozcan & Nemlioglu, 2006; Smith, 1989). Although sound levels might vary between different seats inside the airplane depending on their location with regard to the engines (Wilby, 1989, 1992), the discomfort threshold (approx. 120 dB depending on the frequency) will not be reached (Figure 6.3) (Slater, 1985). Therefore, it is highly unlikely that aircraft cabin sound causes permanent hearing loss (Passchier-Vermeer, 1997), but sounds could still be perceived as annoying by airplane passengers.

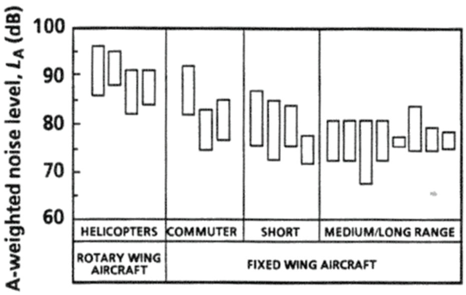

Figure 6.2 Typical ranges of interior sound pressure level in a fixed-wing aircraft and helicopter (in dB(A)) (Smith, 1989)

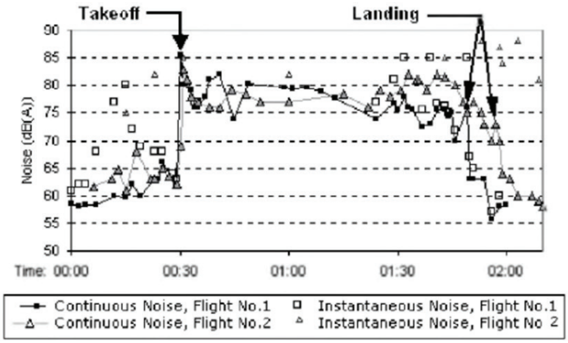

Figure 6.3 Recordings of noise levels during two flights (in dB(A)) (Ozcan & Nemlioglu, 2006)

On the one hand, Mixson and Powell (1985) indicate that sound with low frequencies (80-135 Hz) with a volume above 82 dB(A) result in annoyance among airplane passengers. On the other hand, Quehl (2001) states that annoyance caused by sound is based on individual preferences. Annoyance is significantly larger for sounds including tones than for noise alone (Mixson & Powell, 1985). Furthermore, the interpretation of sound is also influenced by cultural background (i.e. the sound of a car is perceived as sporty or luxurious) (Noumura & Yoshida, 2003). Nevertheless, DeHart (2003) argues that noise and vibration are a cause of physical stress from which passengers should be protected.

Airplane passengers are exposed to a wide range of sounds during the flight that originate not only from the aircraft engine noise, but also from announcements by the crew, conversations of fellow passengers, or even crying babies (Lewis et al., 2016). The effect of these sounds on individual comfort perception can differ; however, when recalling their last flight experiences, only 0.9% of surveyed airplane passengers mentioned noise, whereas 79% mentioned comfort and service (Vink, Bazley, Kamp, & Blok, 2012). This suggests either that passengers are not so aware of sound that they recall it, or that sound is a minor influencer of comfort.

However, real-time reported effects of noise indicate that sound can have a significant impact on airplane passengers' comfort experience, and that they might be unaware of this. The passenger's level of flight experience plays a role too: novice fliers may become more alarmed by and attentive to sudden changes in the aircraft acoustic environment than experienced fliers do (Västfjäll, Kleiner, & Görling, 2003). Weber et al. (2004) found that when noise increased (from 70 to 73 to 75 dB over 3 hours), cabin crew rated their annoyance level as significantly higher than when the noise decreased (from 75 to 73 to 70 dB). In line with this, Huang and Jiang (2016) suggest that subjectively measured discomfort increases with extended exposure duration. People in the airplane cabin are not always aware of the effect of noise. For example, Mellert et al. (2008) found that when the sound level increased during a flight, the crew was more aware of symptoms such as tiredness, difficulty concentrating, swollen feet, and headaches; in contrast, awareness of these symptoms was lowered when the noise level decreased. Besides Mellert et al. (2008), Pennig, Quehl, and Rolny (2012) also examined the effect of sound pressure levels (SPL) between 66 and 78 dB(A) on passengers' comfort experience and positive mood in the aircraft cabin. They suggest that aircraft interior noise could be optimized by reducing the SPL and high-frequency components (sounds described as "shrill" and "bright"), and reducing "irregular" sounds. However, total absence of noise might not be the solution, since the presence of a background noise masks other sounds, such as conversations between other passengers, and is therefore considered positive by train passengers (Khan, 2003). Similarly, in a study conducted with 237 office workers, conversations were a source of irritation in the working environment, while overall background noise levels of 65 dB were not related to annoyance (Pierrette, Parizet, Chevret, & Chatillon, 2015). Lewis (2015) found that the extant sound of a crying baby is so annoying that airplane passengers can hardly be distracted from it by virtual reality, whereas the latter seems to be an effective distraction from the discomfort caused by a lack of legroom.

As sound is partly a psychological phenomenon, its perception can be influenced by several factors, of which "being in control" is one. Bazley (2015) states that people prefer to be in control of their environment and that this contributes to less stress and more comfort, for example by adapting the temperature to their own situation (Ong, 2013) or having the ability to open the window (Leather, Pyrgas, Beale, & Lawrence, 1998). This theory (being in control benefits comfort) might also be applicable to noise.

6.1.1 Research questions

Based on the findings mentioned above, it can be suggested that sound and noise have a considerable influence on the perception of comfort. Although many inventions offer solutions to escape from (monotonous) sounds, sound might also be applied to mask other sounds or even to distract from discomfort originating from other sources.

The aviation industry constantly makes compromises when designing comfortable airplane cabins. For example, a large, cushiony lounge chair might be very comfortable for the passenger, but too heavy and too laborious to maintain in the aircraft. Sound design for the airplane cabin has a similar field of tension, since the interpretation of sound might depend on age and gender, while sound-reducing solutions are highly likely to add weight to the cabin structure. Therefore, it is interesting to more closely examine the effect of sound in relation to the perception of comfort (of an aircraft seat). This study investigates the following research questions:

- Does noise level affect airplane passengers' comfort and (physical) discomfort experiences?
    - How do these (dis)comfort experiences change over time?
    - Do noise levels influence the appreciation of the airplane seat?
    - What is the influence of having (limited) control over sound on (dis) comfort perception?

6.2. Method

6.2.1 Participants

To answer these research questions, a comfort experience study was performed with 30 participants [(17 male, 13 female), aged 19-56 years (average 25.9, SD 6.3) with a mean weight of 68.2 kg (SD 13.4) and mean height of 1.71 m (SD 0.097)] with flying experience. All participants reported that they did not suffer from any hearing disability, and provided written informed consent preceding the study.

6.2.2 Setup and procedure

The study took place in the audio laboratory at Delft University of Technology. The isolated audio cabin (Amplifon Silent Cabin Milano) was equipped with a decibel meter (Bruel&Kjaer 2270-S G4) and a sound box (Behringer Truth B2031A). A triple economy class passenger aircraft seat (Zodiac Aerospace) was placed inside the cabin, with the seat backs fixed in a reclined position (see Figure 6.4). The sound cabin had a window, but participants could only see a wall through it; this window was used by the researchers to check on the participants and to inform them when it was time to fill out the next discomfort questionnaire, without opening the isolated door.

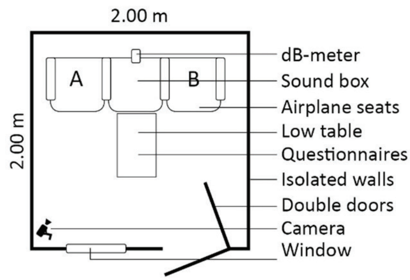

Figure 6.4 Setup of the study in the audio laboratory

Two participants were tested simultaneously per session, sitting in either the left or the right seat. The middle seat was intentionally not in use to provide participants with private armrests and to minimize the effect of having direct "neighbors." During the test, participants were not allowed to speak with each other, but were free to rest, sleep, or read a book.

The participants were exposed to three conditions:

- Silence: No sound was added to the audio cabin. The sound pressure level measured in the room was constantly 30 dB(A).
- Sound: In this condition, the constant aircraft cabin noise of a 777-300 (frequency between 20 - 16,000 Hz, with an emphasis between 20 - 500 Hz) was played in the cabin at an average level of 75 dB.
- Earplugs: The participants were provided with earplugs (Honeywell Howard Leight Quiet, noise reduction approximately 27.6 dB for frequency of 500 Hz according to AS/NZS 1270:2002) in the sound condition (aircraft cabin noise at 75 dB). Using the earplugs was optional and voluntary.

Each condition lasted for 45 minutes, followed by a 15 minute break. The order of the conditions was systematically randomized per pair of participants.

6.2.3 Measurements

The effect of sound on the airplane passengers' development of comfort and discomfort experiences throughout the conditions was measured by means of questionnaires. Mellert et al. (2008) found that higher noise levels caused increased muscle pain in the neck. Therefore, the development of physical discomfort was measured using the localized musculoskeletal discomfort (LMD) method (Grinten & Smitt, 1992) (see Figure 6.5). Participants ranked the level of their discomfort at the start of each condition and at every successive quarter of an hour (T0, T15, T30, T45), indicating the discomfort they experienced on an 11-point scale (ranging from 0 = no discomfort at all to 10 = extreme discomfort). In addition, a discomfort and comfort questionnaire was completed at the start and at the end of each condition (T0 and T45), where participants rated five factors related to comfort (I feel relaxed, The seat feels soft, I feel fit, I feel comfortable, I like the seat) and five factors related to discomfort (I feel stiff, I feel uneven pressure from the seat pan or seat back, I feel tired, Parts of my body feel numb, I feel uncomfortable) on a seven-point scale (ranging from 1=not at all to 7=extremely) (Helander & Zhang, 1997).

The participants were video recorded (GoPro Hero) while they were in the cabin during all conditions to determine whether they used the earplugs.

Figure 6.5 Localized Musculoskeletal Discomfort map

6.2.4 Data analysis

The LMD data were analyzed with a Wilcoxon and a Friedman test. The results of the comfort and discomfort questionnaires were analyzed using a reliability analysis followed by a Friedman test (IBM SPSS 22). Significance was accepted at $p<0.05$.

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6.3 Results

In this study, it was observed that in the earplug condition, 87% of the participants used the earplugs, while 13% did not use them at all. No significant differences were found between these groups in reported LMD, comfort, or discomfort. One participant did not understand how to fill out the LMD questionnaire (which resulted in LMD scores that were 3 standard deviations from the mean), and was therefore excluded from the LMD data analysis.

6.3.1 Localized musculoskeletal discomfort (LMD)

Figure 6.6 shows the averages of the LMD scores of all participants over time. Discomfort increased significantly over time (between T0 and T45) for all conditions (Wilcoxon signed rank test $p<0.001$). Furthermore, LMD between the silence, sound, and earplug conditions differed significantly for T15 (Friedman, $p=0.049$), T30 (Friedman, $p=0.004$), and T45 (Friedman, $p=0.008$). The standard deviations belonging to this data are presented in Table 6.1.

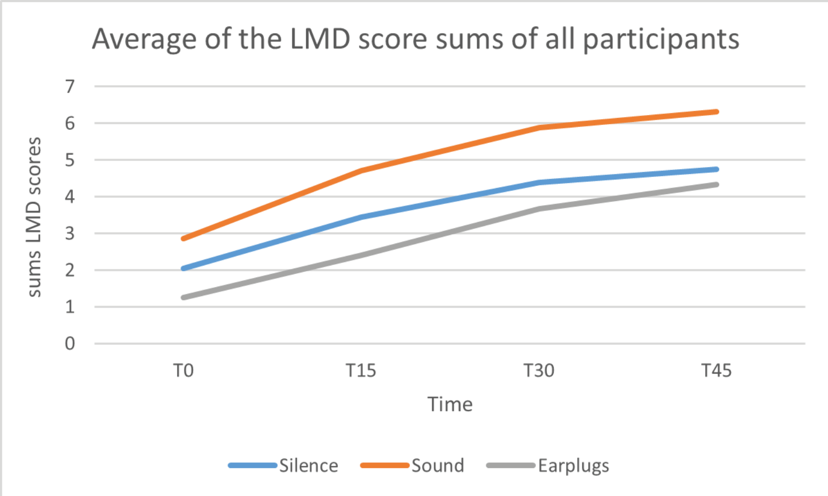

Figure 6.6 Average of the localized musculoskeletal discomfort (LMD) score sums of all participants for all body parts

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Table 6.1 Average of LMD score sums with standard deviations

	T0 LMD mean (sd)	T15 LMD mean (sd)	T30 LMD mean (sd)	T45 LMD mean (sd)
Silence	2.0 (2.5)	3.4 (3.0)	4.4 (3.7)	4.7 (3.6)
Sound	2.9 (3.2)	4.7 (3.6)	5.9 (3.9)	6.3 (4.5)
Earplugs	1.6 (1.2)	3.4 (2.4)	4.6 (3.7)	5.6 (4.3)

6.3.2 Discomfort and comfort ratings

6.3.2.1 Discomfort factors

Discomfort increased over time for all conditions (see Figure 6.7). Two reliability analyses with all discomfort-related factors at To and at T45 showed high internal consistency (Cronbach alpha >0.842). Significant differences between the silence, sound, and earplug conditions were found for To (Friedman p=0.006) and T45 (Friedman p=0.002).

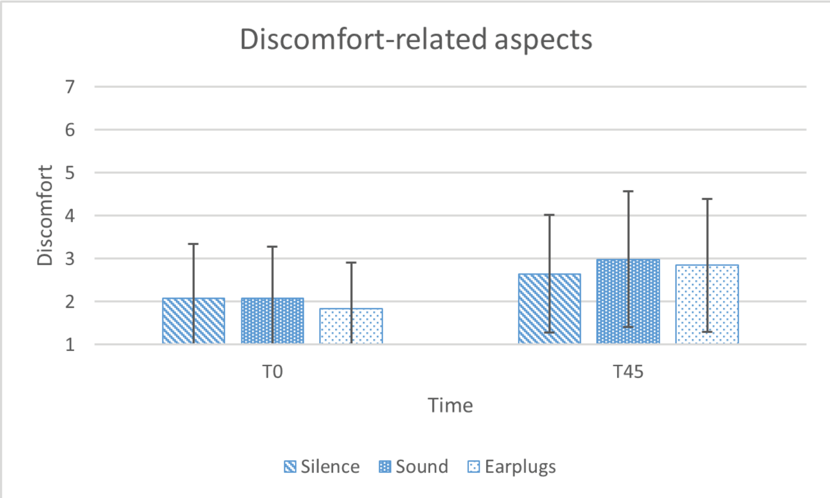


Figure 6.7 Average of discomfort-related aspects in all conditions

6.3.2.2 Comfort factors

Reliability analyses between the comfort-related aspects indicated that the different factors were highly internally consistent (Cronbach alpha > 0.901) at To and T45. A Friedman test was performed on the comfort-related aspects and indicated that there were significances between the silence, sound, and earplug conditions for To ($p=0.046$) and T45 ($p=0.002$) (see Figure 6.8).

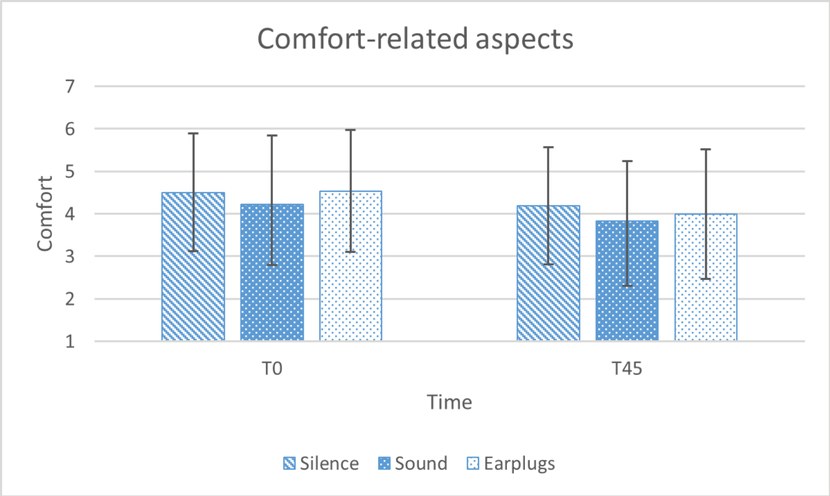


Figure 6.8 Average of comfort-related aspects in all conditions

6.3.2.3 Discomfort and comfort factors addressing seat appreciation

Three aspects in the comfort/discomfort questionnaire directly referred to the seat ("I feel uneven pressure from the seat pan or seat back," "The seat feels soft," "I like the seat"). A Friedman test was performed on these aspects and indicated that there were no significant differences between the silence, sound, and earplug conditions for To ($p=0.870$) and T45 ($p=0.682$).

6.4 Discussion

The aim of this study was to investigate whether noise levels affect airplane passengers' comfort and (physical) discomfort experiences differently. This section first answers the research questions, and then evaluates the general limitations of this study.

6.4.1 Research questions

How do discomfort and comfort experiences under different noise conditions change over time?

Self-reported LMD increased over time in all three conditions (silence, sound, and earplugs). The sound condition resulted in the highest physical discomfort, and the earplug condition in the lowest perceived physical discomfort after 45 minutes. Self-reported discomfort based on discomfort-related statements also showed an increase in discomfort over time for all conditions, whereas the comfort-related statements were given lower ratings over time for all conditions.

Given these points, no habituation effect (i.e. where the effect of the presence of noise on discomfort flattens out over time, and discomfort values will reach similar values for either noisy or silent conditions) was found in this study. This is in line with the findings of Banbury and Berry (2005) in their study of noise in office spaces.

Examining the individual conditions, the LMD scores were highest for the noise condition. This seems to be in line with Mellert et al.'s (2008) finding that more sound resulted in increased awareness of physical discomfort. However, the lowest LMD scores were not found in the silent condition, but in the earplug condition; hence, it can be suggested that the absence of noise in an airplane cabin does not automatically result in the most comfortable environment.

Do noise levels influence the appreciation of the airplane seat?

Three aspects in the comfort/discomfort questionnaire directly referred to the seat ("I feel uneven pressure from the seat pan or seat back," "The seat feels soft," "I like the seat"). The scores on these aspects did not show significant differences between the three conditions, which implies that noise levels did not influence direct appreciation of the airplane seat. However, the design of the seat might have indirectly caused physical discomfort, and since the obtained LMD scores indicate that the noise level did influence discomfort experience, sound might have made a poorly designed seat feel even worse.

What is the influence of having (limited) control over sound on comfort perception?

The findings of this study suggest that the relationship between sound level and comfort is not linear. Comfort levels reached in the silent condition were similar to those in the earplug condition. In the latter, the 87% of participants who did use earplugs experienced sound that was approximately 17 dB higher than the sound experienced during the silent condition. Thus, reducing noise did not necessarily lead to better comfort experience, which is in line with Khan's (2003) findings. On the other hand, a condition in which passengers were offered earplugs in a silent surrounding was not studied in this experiment. A combination of control and a quiet environment could possibly lead to even higher comfort levels. Given these points, aircraft cabin designers should focus on finding an optimal balance between implementing noise reducing solutions and offering control to passengers to optimize their comfort experience, which has also been suggested by Bazley (2015).

This study described the effect of aircraft cabin noise caused by the engines on passengers' comfort and discomfort perception. However, it is highly likely that passengers on a flight will be exposed to sounds from other sources as well, such as conversations between other passengers, spoken crew instructions, or the sound of a crying baby. Although not all these sounds will be perceived as bothersome, Lewis et al. (2016) suggest that it is difficult to distract airplane passengers from the sound of a crying baby.

6.4.2 Limitations

Since this study was performed in a laboratory setting, it was not feasible to simulate a complete airplane cabin environment while flying. Passengers in an airplane cabin are also subjected to vibrations caused by the airplane motor or turbulence caused by the weather. In this laboratory setting, it was unfeasible to simulate such physically perceptible vibrations; however, Dempsey, Leatherwood, and Clevenson (1979) suggest that noise and vibrations could be studied independently, which indicates that the absence of physical vibrations did not affect the results of the present study. Furthermore, the setup of this study did not allow an extra row of seats to be added in front of the participants to simulate restricted legroom and to provide them with a foldable tray table. However, this should not have affected the difference in comfort experiences between the conditions.

6.4.3 Future research

The outcomes of this study suggest that noise caused by airplane engines influences comfort and discomfort experiences. However, previous studies have shown that sound (or lack thereof) might also be used as an effective tool to steer passengers' mood. Västfjäll et al. (2003) reported that sound can affect the valence and activation level of the passenger. According to Thompson, Schellenberg, and Letnic (2012), loud and fast music results in a low reading comprehension, while an instrumental and vocal background has no influence on verbal learning (Jäncke, Brügger, Brummer, Scherrer, & Alahmadi, 2014). Furthermore, tasks that require creativity prosper with a moderate ambient noise of 50 – 70 dB (Mehta, Zhu, & Cheema, 2012), comparable with the environmental sound in a coffee bar. Classical music is a sound that calms down passengers, and Harmat, Takács, and Bodizs (2008) suggest that this intervention even helps to reduce sleeping problems. The effect of noise on consuming behavior is another well-researched field (Spence, 2014): loud music in a bar (88-91 dB), results in higher drink consumption compared to a quiet bar (72-75 dB) (Guéguen, Le Guellec, & Jacob, 2004); loud surroundings make food taste less salty or less sweet compared to the same food in a quiet environment; and crunchy food is perceived as crunchier in a noisy environment (Woods et al., 2011). Another condition that could be considered for future research is the use of noise-cancelling headphones instead of earplugs, since such headphones are readily available (and used by airplane passengers). It might also be possible that the perception of noise in relation to comfort is influenced by age or gender, or is even culturally dependent; however, the data gathered in this study can neither confirm nor deny this.

All in all, future research is needed to investigate how sound can be applied in aircraft cabins to establish an optimal comfort experience for each individual passenger by providing him or her with the right amount of control.

6.5. Conclusion

Aircraft engine noise negatively affected airplane passengers' comfort experiences in this study. When experiencing aircraft engine noise at 75 dB, significantly more physical discomfort (LMD) was experienced and less comfort was perceived than when experiencing silence after 15, 30, and 45 minutes. However, having the ability to control the noisy environment with earplugs (used by 87% of the participants in this study) resulted in the lowest reported physical discomfort. Different noise levels did not affect the appreciation of the aircraft seat differently.

Chapter 7: Effect of In-seat Exercising on Comfort Perception of Airplane Passengers

7

This chapter has been published as:

Bouwens, J. M. A., Fasulo, L., Hiemstra-van Mastrigt, S., Schultheis, U. W., Naddeo, A., & Vink, P. (2018). Effect of in-seat exercising on comfort perception of airplane passengers. *Applied Ergonomics, 73*, 7-12.

Abstract

Sitting still for extended periods of time can lead to physical discomfort and even serious health risks. Due to safety regulations, reducing passenger' sitting time in aircrafts is not feasible. This paper presents the results of a laboratory study, in where an interactive airplane seat was compared with a current economy class seat. Participants used both seats for 3.5 hours, and performed significantly more in-seat movements when using the interactive seating system. Furthermore, this interactive seat predominantly lead to significantly better comfort experiences and reduced discomfort experiences, however no significant differences have been found in self-reported localized musculoskeletal discomfort. Passengers indicated that they would prefer this interactive seat over a standard aircraft seat.

Keywords: in-seat exercise, passenger comfort, aircraft interior, airplane seat

7.1 Introduction

Physical well-being is one of the eight themes that conceptualize the comfort perception by airplane passengers (Ahmadpour, Lindgaard, Robert, & Pownall, 2014) and refers to the health condition of the passenger. This theme is subject to external influences such as cabin pressure, altitude, quality of the seat and the ability to move. Traditionally, passengers are transported seated, however being in this sitting position on a long haul flight (>4 hours) can lead to severe health risks such as lower back pain (Lis, Black, Korn, & Nordin, 2007), leg numbness, pain in buttocks, deep vein thrombosis and oedema (Brundrett, 2001). Physical inactivity due to long term sitting can on the longer term even lead to disorders, type II diabetes, depression, obesity and some forms of cancer (Commissaris et al., 2014).

Prevention of the health risks caused by long term sitting are, next to the aviation industry, also a concern of desk workers, car drivers and car passengers. Graf, Guggenbühl, and Krueger (1995) suggest that good seating depends on opportunities for significant changes in position and that seats design should not restrict movements at the workplace to the postures most frequently seen for a specific task. Obviously, diminishing sitting time can solve the problem, however changing people's behavior and habits can be complicated. An automatically rotating seat pan on office chairs does not require active participation and result in reduced oedema (Deursen, Deursen, Snijders, & Goossens, 2000). Also, dynamic workstations are introduced to unobtrusively activate people, and research suggest that the use of these workstations increase physical activity and heart rate compared to the 'normal' workstation (Botter et al., 2013).

Solutions in the field of transport require more creativity, due to the limited space that is available around the passengers. Hiemstra-van Mastrigt, Kamp, van Veen, Vink, and Bosch (2015) evaluated an active seating system, in where passengers can control a game by pushing their shoulders against the backseat of the car. They indicated that this way of activating physically passive passengers by stimulating in-seat movement could result in increased comfort and well-being. Also exercises that are performed on a regular basis in a pressurized airplane cabin can have a positive effect on the perceived muscular discomfort of airplane passengers (Muhm et al., 2007), however, interactive interventions might be more effective on increased muscle activity than written instructions (Van der Westelaken, Hu, Liu, & Rauterberg, 2011).

Since in-seat exercise seems to be beneficial for comfort, TU Delft and Zodiac Seats US developed an interactive seating system. This system uses variation in leg pressure on the bottom cushion to control a balance game. Passenger's leg movement is registered by fabric pressure sensors. The purpose of this study is to investigate the following questions:

- Does regular in-seat exercising by using the interactive seating system contribute to better comfort experience?
- Does regular in-seat exercising by using the interactive seating system contribute to a reduction of physical inconveniences (discomfort)?
- Does the interactive seating system contribute to more in-seat movement?
- What is the general acceptability of the interactive seating system by the passenger (questionnaire)?

7.2 Method

7.2.1 Participants

To answer the research question a study was performed with 12 participants (5 male, 7 female), aged 22-38 years (average 26.3, SD 4.1) with a mean weight of 70.2 kg (SD 11.9) and mean height of 1.74m (SD 8.6) with flying experience. All participants provided written informed consent preceding the study.

7.2.2 Setup

Interactive seating system

In order to register the participants' in-seat movements, the bottom cushion of the right seat in the back row was equipped with fabric pressure sensors. These sensors were placed between the upholstery and the foam of the cushion and connected to a laptop. By lifting the legs or extending the legs forward, while the arm rested on the armrests or on the thighs, participants could control a video game. This video game is a balance game; participants were able to roll a ball left, right, forwards and backwards in order to collect small blocks that are placed on a certain path. When all the blocks are collected without hitting the walls, the participant continues with the next level. The video game had 4 levels in total, with increasing levels of difficulty.

Laboratory setup

The study has taken in a laboratory at the faculty of Industrial Design

Engineering at Delft University of Technology. Two rows of triple economy class passenger aircraft seats (Zodiac Aerospace) were positioned with a 32 inch seat pitch to simulate restricted legroom; all seat backs were fixed in the upright position (see figure 7.1). Two 10.2 inch TFT LCD monitors with touch screens (CarTFT CTF1020-5) were installed on the back of the two outer seats of the front row to simulate inflight entertainment screens, which were used to show the video game (see figure 7.2) and series (Netflix).

Four synchronized network cameras (Axis M1054m) were placed around the seats to record the activities performed by the participants. A pressure sensitive mat (Medilogic ® Seat Pressure Measurement System) was used to record in-seat movement.

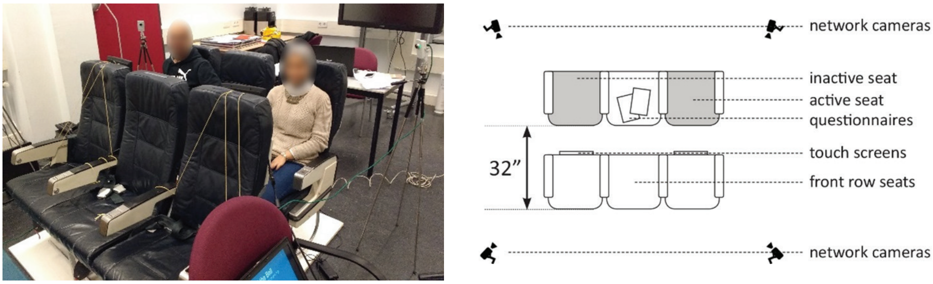


Figure 7.1 Research setup

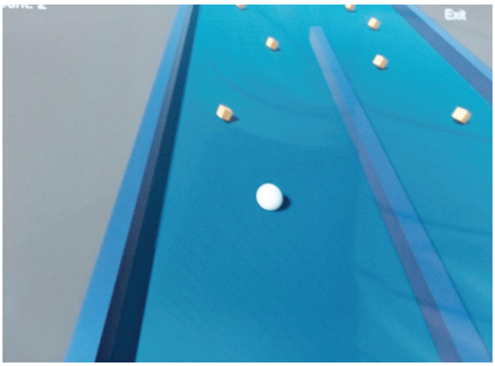


Figure 7.2 Interface videogame

Procedure

Two participants were tested per session, either sitting in the left or the right seat of the back seat. When they were sitting in the interactive seating system, they were explained and trained shortly on how to use the interactive seating system before the start of the test. The middle seat was intentionally left unused, in order to provide participants with private armrests. During the test, participants were not allowed to speak with each other and not allowed to use the restroom. They had to pick one activity (sleep/rest, watching movies/ series, read book or magazine, use mobile phone) that they were allowed to do for the entire testing time.

Since the setup of this experiment is a within subjects design all participants were exposed to two conditions, which last for 3.5 hours each:

- Interactive seating system

  The participant plays the movement game for 5 minutes every 30 minutes. In the meantime they do the activity they picked.

- Inactive seating

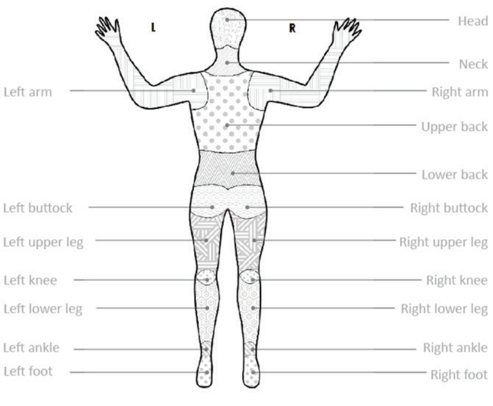
  The participant remains seated, doing their preferred activity, without doing exercises.

The order of the conditions were systematically randomized between participants. After 1.5 hours (after completing the questionnaire at T3), participants were offered a drink and a snack, and between the two conditions, participants had a 30 minute lunch break.

7.2.3 Measurements

7.2.3.1 Localized Musculoskeletal Discomfort

The development of discomfort was measured by means of the Localized Musculoskeletal Discomfort (LMD) method (Grinten & Smitt, 1992) (see figure 7.3). The level of experienced physical discomfort is reported at the start and after every half hour (T0, T1, T2, T3, T4, T5, T6, T7) on an 11 point scale (ranging from 0 = no discomfort at all to 10 = extreme discomfort).



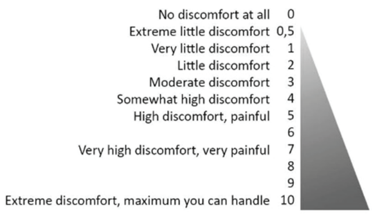


Figure 7.3 Localized Musculoskeletal Discomfort (LMD) map

To test whether there were differences in reported LMD in the left and the right side of the body, a Wilcoxon signed rank test (IBM SPSS Statistics 22) was done. If no significant differences were detected, the left and right body parts were analyzed as one body part (e.g. left and right arm were analyzed as arms) by calculating the average over the left and the right part of the body.

To measure the development of LMD over time, first the sum of all LMD scores of each body part that were reported per point in time (T_0, T_1, T_2, T_3, T_4, T_5, T_6, T_7) were calculated per participant for each condition. From this dataset differences between different points in time and different conditions have been tested with a Wilcoxon signed rank test (IBM SPSS Statistics 22). Significance was accepted at $p<0.05$.

To analyze the effect of each condition on the LMD in different body parts, the differences between the reported LMD score in each body part at T_7 were compared with a Wilcoxon signed rank test (IBM SPSS Statistics 22) for both conditions. Significance was accepted at $p<0.05$.

7.2.3.2 Comfort and Discomfort

In addition, the participants will report their experienced comfort and discomfort at T_0, T_2, T_4, T_6 and T_7. These 7 comfort related statements (I feel relaxed I feel refreshed, Chair feels soft, Chair is spacious, Chair looks nice, I like the chair, I feel comfortable) and 7 discomfort related statements (I have sore muscles, I have heavy legs, I feel uneven pressure, I feel stiff, I feel restless, I feel tired, I feel uncomfortable) were rated on a 7-point scale (Helander & Zhang, 1997). Internal consistency was determined for both the comfort related statements and the discomfort related statements with a Cronbach's alpha test (IBM SPSS Statistics 22). Then, when internal consistency was found, the comfort experience statements and the discomfort statements at different points in time were tested with a Wilcoxon signed rank test (IBM SPSS Statistics 22) and significance was accepted at $p<0.05$.

7.2.3.3 Movement count

A pressure sensitive mat was installed on top of the bottom cushion of the aircraft seat to measure the pressure distribution of the body. The pressure distribution was recorded for one hour consecutively for each condition. Based on the recorded pressure distribution, a center of pressure was calculated each 5 seconds. A change in the position of the center of pressure of 25 mm is defined as one detected movement. The difference between the amount of movements in the active and inactive condition were analyzed with a Wilcoxon signed rank test (IBM SPSS Statistics 22) and significance was accepted at $p<0.05$.

7.2.3.4 Acceptance of concept

To evaluate the acceptance of active seating as presented in this concept a semi structured interview is conducted after the participants experienced both the interactive and inactive seating conditions. This interview covered the following questions:

- What are your comments about the interactive seating system?
- If this system is offered by an airline, what would be the benefits and the disadvantages of the movement system?
- What are your recommendations for further development?
- Do you think that after flying and using the interactive seating system you will feel more fit/refreshed?
- Suppose you can choose between both seats, which one do you prefer, and why?

The interviews were transcribed and the outcomes were categorized (e.g. recommendations software/ hardware, physical benefits).

7.3 Results

7.3.1 Localized Musculoskeletal Discomfort

All participants indicated the Localized Musculoskeletal Discomfort in 18 body parts. No significant differences were found between the left and right parts of the body (e.g. left and right arm, right and left buttock, etc.), therefore these are analysed as one body part (e.g. arms, buttocks, etc.).

The total Localized Musculoskeletal Discomfort increased over time for both conditions (see figure 7.4). The average of the sum of LMD scores of the inactive seating condition increased from 2.2 at To to 10.6 at T7, and from 3.9 at To to 9.4 at T7 for the interactive seating system condition. For both conditions this increase in LMD score between To and T7 is significant (Wilcoxon signed rank test, $p\leq0.008$). The active seat seems to cause the least musculoskeletal discomfort, however no significant differences between the active and the inactive seat were found.

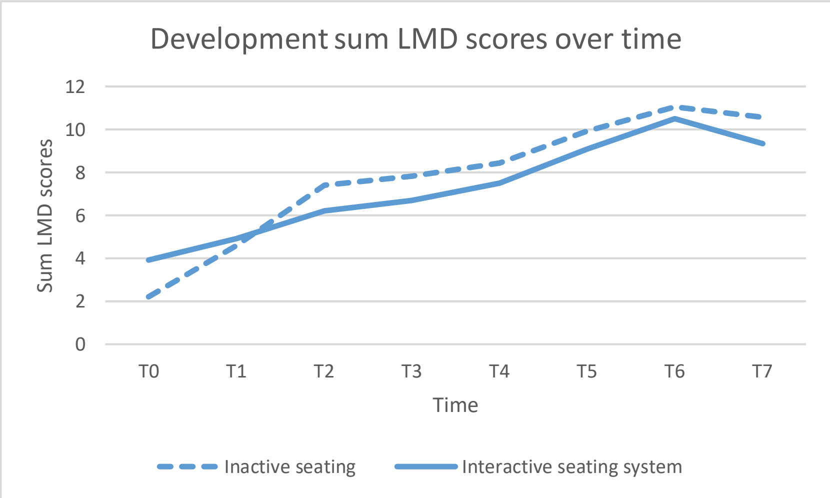


Figure 7.4 Development sum LMD scores over time

After sitting in the active and the inactive seat for 3.5 hours, participants reported the highest LMD in the neck, buttocks and lower back (see figure 7.5). However no significant differences have been found between the active and inactive seat.

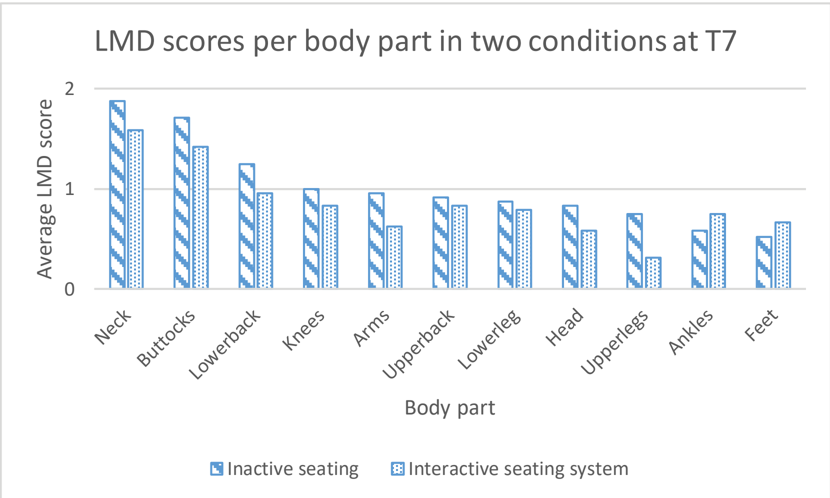


Figure 7.5 LMD scores per body part in two conditions at T7

7.3.2 Comfort and Discomfort questionnaire

Scores given on the comfort related statements (Cronbach α: 0.981) and discomfort related statements (Cronbach α: 0.986) showed high internal consistency. Therefore further analysis of the questionnaire data was done group wise (Group 1: The seat feels soft, I like the seat, the seat is spacious, I feel relaxed, I feel refreshed, the seat looks nice, I feel comfortable. Group 2: I have sour muscles, I feel uncomfortable, I have heavy legs, I feel uneven pressure from the seat pan or back, I feel stiff, I feel restless, I feel tired).

7.3.2.1 Comfort statements

Figure 7.6 shows the average scores of the comfort related statements in the active and inactive seating condition. The reported comfort is significantly higher in the active seating condition at T2, T4 and T6 (Wilcoxon signed rank, $p \leq .040$).

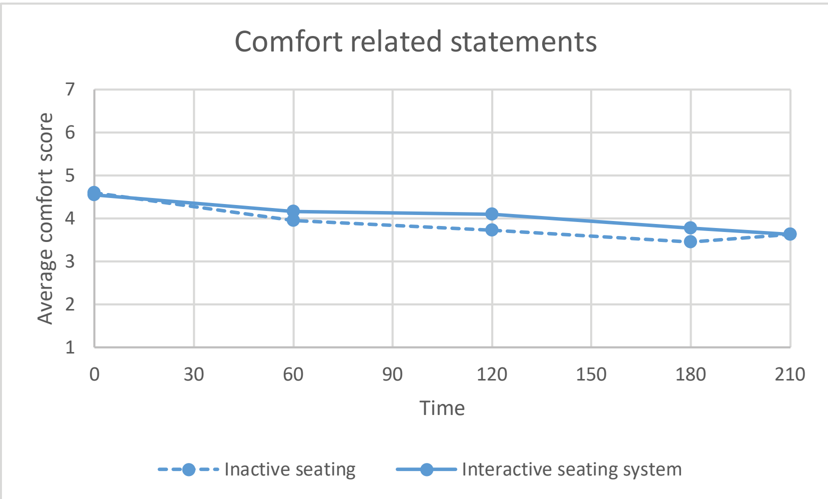


Figure 7.6 Comfort related statements at 0 (T0), 60 (T2), 120(T4), 180 (T6) and 210 (T7) minutes

7.3.2.2 Discomfort statements

The average scores of the discomfort related statements in the active and inactive seating conditions given by the participants (see figure 7.7), are significantly higher in the inactive seating conditions at T2 and T6 (Wilcoxon signed rank, $p \leq .023$).

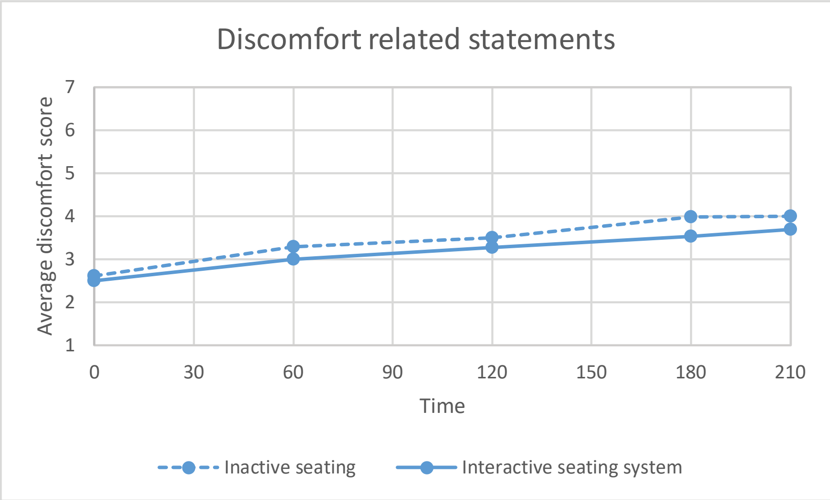


Figure 7.7 Discomfort related statements at 0 (T0), 60 (T2), 120(T4), 180 (T6) and 210 (T7) minutes

7.3.3 Movement count

When being in the active seat the participants performed significantly more in-seat movements (Wilcoxon signed rank, $p \leq 0.002$) (see figure 7.8).

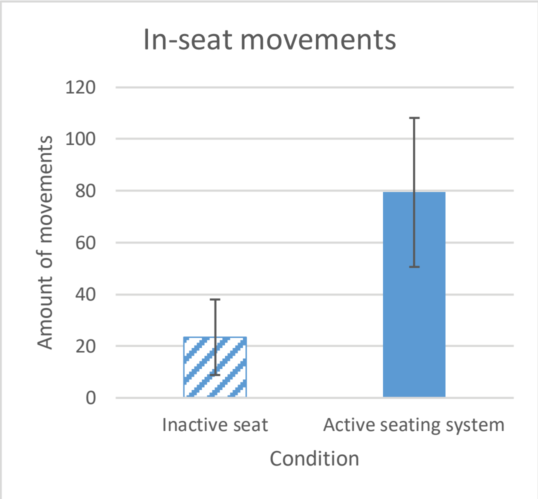


Figure 7.8 In-seat movements of active and inactive seat

7.3.4 Acceptance of concept

Based on the interviews with the participants, it could be suggested that the game seat is perceived positively overall. When asking the participants which of the two seats they would like to have on their next flight 8 out of

7

12 participants indicated that they would like to have the option of playing games in the seat.

Participant 6: '(...) and you can move more around in the plane for long duration flights it is better for your blood pressure, because it all sucks down and usually you cannot walk around in the plane. So you move a bit at least a bit it is better for your blood flowing through your legs at least.'

Participant 8: 'I think it would be nice to have this option of the game seat. And the best is that you can decide by yourself when you would like to use it.'

In this research setup participants had to play the game every 30 minutes. However some of the participants stated that they want to control the frequency themselves.

Participant 12: 'If it was a really nice game, I would play it more than once, but not if it was mandatory. It was fun, I would play it in-between movies, or when I notice it works then I would do it when I was having sleepy legs, then I would play it. But when it was mandatory it does not work for me.'

Next to the frequency of playing the movement game in the seat, some participants also suggested games other than the balance game with four levels that was currently implemented in the seat.

Participant 11: 'Instead of doing levels, you can do something with a high score. So then you can see that you go further.'

Participant 2: 'Then I would suggest to develop a game that is really motivating and nice to play. Because now there are already movies that they recommend that you can follow with exercises that you can do during the flight. I was curious and watched them, but I did not do them, they should really be engaging and attractive and be nice to play. Travelling together with some multiplayer people in the plane, maybe...'

Most of the participants of this study realize that in-seat movement contributes to reduce physical discomfort.

Participant 5: '(...) the movement helps to reduce the pain on my buttocks.'

And however they suggest to extend the in-seat movement to a 'full body workout', they realize that this behavior might bother fellow passengers.

Participant 11: 'Something with the arms as well, that you probably use your armrests that is maybe easier to do just one thing with your legs, so maybe right or left and up and down with your arms.'

Participant 5: 'Maybe you can annoy your back passenger if you keep doing like playing with moving your back you move the seat itself.'

Participant 1: 'There are hidden rules sitting next to a stranger; I don't want any physical touch.'

Most participants indicated that they felt more refreshed after the flight when using the game seat.

Participant 7: 'When I was in the game seat, I was a bit more focused, I was more alert, because I had to play the game, whereas in the other seat I was sleeping.'

Participant 4: 'Also some fun. It is more entertaining. It makes your flight a little bit less serious. I don't know how to explain, a bit more relaxed, a bit more comfy.'

7.4 Discussion

7.4.1 Research Questions

Does regular in-seat movement by using the interactive seating system contribute to better comfort experience?

The results of this study suggest that in-seat activities lead to significantly more movement and predominantly higher comfort perception than a normal seat. This is in line with the findings of Hiemstra-van Mastrigt et al. (2015), who suggested that active seating by controlling a game with pushing the shoulders backwards on the backseat of a car might stimulate movements and thereby increasing comfort and well-being.

Does regular in-seat movement by using the interactive seating system contribute to a reduction of physical inconveniences (discomfort)?

Physical discomfort (LMD) increased over time for both conditions in this study, which is in line with the study of Hiemstra-van Mastrigt, Meyenborg, and Hoogenhout (2016), although in our study the in-seat movements and refreshments did not result in a 'dip' in discomfort development as was detected by Hiemstra-van Mastrigt et al. (2016) after passengers stretched their legs or enjoyed a refreshment.

The reported LMD is not significantly higher for either one of the conditions, however the self-reported discomfort by means of the discomfort related statements was significantly higher at T2 and T6 in the inactive seat. Admittedly, the difference in discomfort between T6 and T7 is not significant, however it is worthy of note. A possible explanation might be that people were aware of approaching the end of the condition, and therefore already felt relieved (and thereby experienced less discomfort) with the end of the condition in prospect, which is in line with the findings of Bazley, Nugent, and Vink (2015).

Does the interactive seating system contribute to more in-seat movement?

The interactive seating system of this study leads to significantly more in-seat movement, when used twice per hour for five minutes. Moreover it contributes to higher comfort experience. The seat, however, requires active participation to positively contributing to comfort.

Varela, Gyi, Mansfield, Picton, and Hirao (2017) developed an active car seat that moved automatically while driving (fore-aft movement, cushion and backrest angle movement) and suggested that discomfort in the buttock area after 60 minutes of driving in a simulator was significantly higher in a static seat than in the active seats. A similar dynamic seating system was developed and studied by van Veen, Orlinskiy, Franz, and Vink (2015). They found that after using their dynamic car seat, participants felt significantly more active, energetic, stimulated, pleasantly surprised, pleased and comfortable, accepting and calm and on the other hand less tired and less bored. Activating muscles of the human body while sitting therefore seems to be beneficial for optimal comfort perception. Besides it also seems to reduce experienced discomfort.

Some researchers correlated the number of in-seat movements with discomfort (Cascioli, Liu, Heusch, & McCarthy, 2016; Sammonds, Fray, & Mansfield, 2017; Telfer, Spence, & Solomonidis, 2009), and suggest that the number of postural changes or fidgeting is a predictor of discomfort. This theory is not applicable to this study. In-seat movement in this study is considered as 'intended exercising', and not as fidgeting.

What is the general acceptability of the active seating system by the passenger?

The participants evaluated in the interview that they prefer to use the active seat over the inactive seat. This outcome is similar to the findings of Groenesteijn, Commissaris, Van den Berg-Zwetsloot, and Hiemstra-van Mastrigt (2016), who suggested that the acceptance of office workers regarding in-seat exercising during work hours was high.

The participants also suggested improvements to the active seat. Although some improvements were related to the maturity level of the prototype, most participants mentioned they would like to be in control while using the active seat, in terms of timing (when to use the active seat and for how long) and picking their own preferred (multiplayer) game. This corresponds with the findings of Bazley (2015), who indicated that people want to control their environment, and that this control is beneficial for comfort. Multiplayer player games might also contribute to more in-seat movement; O'Donovan et al. (2012) found that playing games on a Xbox Kinect or on a Wii in multiplayer modus result in a higher metabolic equivalent (MET) and an increased heart rate for the player. Future research should investigate whether (different) games can activate intrinsic motivation to move regularly during a flight.

7.4.2 Setup of the study

The economy class aircraft seats in this study were installed with a 32 inch pitch, which is considered as a regular distance between seats. Kremser, Guenzkofer, Sedlmeier, Sabbah, and Bengler (2012) suggested that a seat pitch of 34 to 40 inches lead to maximum overall well-being of the passenger. Quigley, Southall, Freer, Moody, and Porter (2001) advised to increase the seat pitch and seat sizes to accommodate increasing body dimensions of the European population and ensure a safe and fast evacuation of passengers in case of emergency. When airlines take note of these recommendations when installing seats in the airplane, no problems are foreseen to use the active seat.

7.4.3 Limitations

This study is done in a lab environment in where the 'living environment' of the airplane passenger is simulated by installing two rows of airplane seats. However there are more aspects to an airplane environment, such as vibrations, that might influence the comfort experience of the passenger while performing in-seat exercises, but were not possible to simulate in this study.

In order to objectively measure the in-seat movements a pressure mat was used. However adding this rather thin layer of flexible material to the bottom cushion of the seat might have influenced the comfort perception of the seat by the participants.

The participants who volunteered in this study were recruited on the university campus. Therefore the age of the participants was relatively young. It stands to reason that this group has a quick understanding of the balance game without physical limitations, whereas it might be possible that older people will need more time to master controlling the game. Nevertheless O'Donovan and Hussey (2012) suggest that unexperienced gamers will have a higher energy expenditure compared to experienced gamers while playing active video games on the Nintendo Wii.

7.5. Conclusions

Passengers perform significantly more in-seat movements when using the interactive seating system. Furthermore these movements predominantly lead to significantly better comfort experiences and reduced discomfort experiences, however no significant differences have been found in self-reported localized musculoskeletal discomfort. Passengers indicated that they would prefer this interactive seat over a standard aircraft seat.

7.6 Acknowledgements

We thank prof. Nicola Cappetti (University of Salerno) for his assistance with programming the pressure mat.

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Chapter 8: General discussion and conclusions

The aim of this thesis was to investigate how to provide airplane passengers with a comfortable flight experience by designing airplane cabin elements that meet their individual needs. This thesis presented insights as to what factors must be taken into account when designing for airplane passenger comfort. This chapter contains an overview of the results from the studies, a reflection on the focus and methodology, applications for the industry and recommendations for future research.

8.1 Overview of the results

In this thesis, the passenger journey is defined as the journey between two airports (Chapter 1). Passengers report experiencing the lowest level of comfort between the two meal services, when the airplane is at cruise flight altitude (Chapter 2). Therefore, this is the stage that requires attention by the airlines when aiming to provide a comfortable experience to their passengers. While at cruise flight altitude, passengers engage in different in-flight activities, such as sleeping, reading and listening to music. The lowest level of comfort is experienced when sleeping, which suggests that this activity requires attention in the aircraft. For this reason. the study on head support while sleeping (Chapter 5) was conducted.

Environmental factors are important extrinsic factors for airplane passengers that influence comfort. These factors can be classified into six main themes: smell, light, vibrations, noise, climate and physical ergonomics. In Chapter 3 an attempt was made to define the relative importance of each of the factors, which could be helpful in setting priorities in aircraft interior design. Passengers indicated that different in-flight activities require different environmental properties in order to facilitate passenger comfort during a flight. However, related to anthropometry, the seat appears to be the most important aspect for all investigated activities. This is an important argument for studying the elements of the seat in contributing to comfort (Chapter 4).

In Chapter 3 it was found that the seat contributes so much to comfort because the airplane seat is the main point of interaction with the airplane cabin for passengers. The design of the seat consists of many features, (e.g. armrests, tray table and recline function) that are not considered equally important for different in-flight activities (Chapter 4). For the activity of sleeping, side head support is considered most important, for reading the armrests are most important, and for watching the in-flight entertainment (IFE) screen the recline function is most important. the tray table is considered most important for the activities eating and working on a laptop. Also, small differences in appreciation of seat features were found based on nationality. Asian respondents consider a foot rest to be very valuable, contrary to North American and European respondents. Nevertheless the top five rating of important airplane seat features by the different geographical groups consist of the same five features, namely: legroom, bottom cushion, foot space, hygiene and overall space.

After environmental factors, expectations, control and the passenger's own behavior are important factors that influence comfort perception of aircraft passengers. Although expectations directly affect comfort (Vink & Hallbeck, 2012), it appeared that passengers are not always able to predict the comfort experience associated with a product based on an image of that product (Chapter 5). Since the findings of Chapter 2 suggested that passengers should be aided in sleeping more comfortably, Chapter 5 investigated whether travel pillows can assist with this. This chapter found that the pillow that people expected to be comfortable in fact did not offer sufficient support to be truly comfortable during use. Thus, it seems that there is a discrepancy between expected and experienced comfort.

In addition to expectations, giving passengers a sense of control is also beneficial for comfort (Chapter 6). Providing passengers with earplugs increased comfort, even though some participants did not even use them. It is likely that simply having the possibility of using the earplugs resulted in increased feelings of control and thereby comfort. This finding is in line with the findings of Ahmadpour et al. (2014), who suggested that proxemics (the passenger's concern for having a level of autonomy or control over personal affairs and immediate space) is a prominent factor in comfort experience in the airplane cabin.

Chapter 2 described that passengers experience the lowest comfort at cruise flight altitude and Chapter 3 specified the seat as the element of the airplane cabin that needs most attention in order to improve comfort. To improve comfort at cruise flight altitude through improving the seat and stimulating human movement, an experiment was conducted (Chapter 7) in which passengers were enticed to move their legs in order to control a game while seated. This study showed that passengers can influence comfort perception with their behavior. Performing physical in-seat exercises on a regular basis can lead to significantly improved comfort experiences and reduced discomfort experiences (Chapter 7).

8.1.2 Relationships across the results

Although the chapters describe individual studies, they should not be treated as separate entities, since there is consensus among the outcomes. The importance of providing passengers with relevant means to support their heads was identified in Chapter 4 and 5. Chapter 4 found that side head support is considered important for sleeping by people of all investigated nationalities (41% of 248 respondents). Chapter 5 showed that for sleeping and resting, restriction of the head in roll, pitch and yaw direction (with a travel pillow) is desired in order to keep it in a comfortable position.

Another hypothesis that was supported by multiple case studies was that control benefits comfort. Chapter 6 found that providing participants with earplugs (and therefore facilitating their ability to control environmental noise) resulted in the best perceived comfort (even over a silent condition). Furthermore, Chapter 7 discussed that participants indicated that they preferred the interactive seat over the normal seat, however they would like to use it whenever they wanted (control their own journey).

Chapter 2 identified that passengers experience the lowest comfort while sleeping. Chapters 3, 4 and 5 researched aspects of the cabin interior by examining in-flight activities. The activity of sleeping was investigated in each chapter and resulted in complementing insights. These include: (1) control over the airplane seat is the most important factor in the airplane cabin in order to sleep comfortably, according to passengers (Chapter 3); and (2) support of the head in order to keep the body in a neutral position (i.e. support under the chin and support on the side of the head) is key when designing a head support that facilitates sleeping (Chapter 4 and 5). These insights on seat requirements are useful for aircraft seat manufacturers.

8.2 Reflection on focus and methodology

It is clear that many aspects affect the comfort experience during the passenger journey. This thesis focuses on some specific aspects, and the resulting limitations are discussed in this section.

8.2.1 Focus on in-flight experience

The focus of this thesis was on the in-flight comfort experience of airplane passengers, since this phase of the travel journey was reported as the least comfortable (Chapter 2). Vink et al. (2017), however, discuss that each phase of the travel journey is interdependent and that comfort and discomfort are influenced by previous experiences and effects over time. The conclusions of the experiments (Chapters 5, 6, and 7) should be generalized after considering the preceding and subsequent phases of the travel journey. In the experiments, these phases were not considered in order to standardize conditions. For studying the effects of the aircraft interior on passenger comfort, it was decided that complicating factors, such as traveling to the airport, check-in procedures, flight delays, connecting flights and luggage collection were to be excluded. Future research on these and other interdependencies is advised in order to study interrelationships and define the best interventions to increase comfort.

8.2.2 Focus on adult airplane passengers

Participants of the studies all belong to the working age population (18-65 years old). However, the preferences and abilities of children (<18) or the elderly (>65) might differ from this group. Naturally, children have different anthropometric measurements (DINED, 1993), and people's agility tends to decrease over the years (McMullin et al., 2014). Furthermore, McMullin et al. (2014) found that reading and resting are the most common in-flight activities for older passengers, whereas playing (video) games was the least common. The results of the experiment with the interactive seating system (Chapter 7) showed that in-seat exercising led to better comfort experiences. However, before implementing such a system, additional research on the acceptance, understanding and operability of the system among children and the elderly is necessary.

8.2.3 Focus on the (extrinsic) environmental comfort factors

The focus of this thesis was on (extrinsic) environmental comfort factors. However, the comfort experience of airplane passengers is also influenced by (intrinsic) personal factors (Dumyahn et al., 2000). Since the aim of this thesis is not to define ideal circumstances for people with, for instance, a specific anxiety or health status, these intrinsic factors were not evaluated. However, by recruiting healthy adult participants from different cultural backgrounds, different genders and a wide variety of anthropometric measurements, an attempt was made to collect representable and generalizable data that can lead to design requirements for comfortable aircraft interiors. Nevertheless, when aiming to design comfortable interiors for a target group with specific characteristics (e.g. children, passengers with anxieties), more research is needed to define design requirements that meet their individual needs.

8.2.4 Focus on quantitative and qualitative research

The focus of this thesis was on identifying and quantifying comfort factors. Therefore, a combination of quantitative and qualitative research methods were applied. The quantitative measuring methods used were questionnaires. The advantage of quantitative research is that it can either confirm or reject a hypothesis based on numerical data that is reported through statistical analyses. The qualitative measuring methods used were observation and semi-structured interviews. The advantage of qualitative research is that rich data gives insights into human experiences and behavior. The interviews enabled participants to express their experiences, and the observations enabled the researchers to analyze human behavior. Nevertheless, these research methods may also have disadvantages, since data analysis of qualitative research reflects the interpretation of the researcher, and results from a questionnaire depend on the memory of the respondent.

In this thesis, several qualitative and quantitative measuring techniques were combined to avoid biased results (Johnson & Christensen, 2008). In Chapter 2, for example, in-flight comfort experiences were measured both during a flight and after a flight, to control for the outcomes affected by memory gaps of the respondents. Furthermore, in Chapters 5 and 7, participants had to report their comfort experience on paper during the test and were able to elaborate on this experience during an interview. In Chapter 5 movement behavior was observed using cameras, and comfort was investigated by means of questionnaires. Therefore, using mixed research methods in the context of this thesis strengthened the reliability of the results, and is it advised to apply mixed research methods in further research as well.

8.3 Application of the results

This thesis provides information for designers of aircraft interiors. Most attention should be given to optimizing the environment for activities passengers perform between two meal services at cruise flight altitude (Chapter 2). More specifically, sleeping is where the lowest comfort level is experienced. Thus, providing passengers with the appropriate means to sleep is beneficial for comfort. In relation to this, it is important to provide passengers with adaptable seats (Chapter 3) that offer side head support (Chapter 4), as well as support under the chin when the seat is in the upright position (Chapter 5). Also, controllable temperature and noise are important aspects to consider when designing for comfortable in-flight sleeping. These last two components could be addressed by offering heated and cooled seats or by facilitating noise cancellation with headphones or earplugs (Chapter 6). Another possibility to improve the environment between two meal services is to stimulate passenger movement. Since getting up from the seat is often an undesired activity given the safety regulations the cabin crew must comply with, in-seat exercising is preferred. Lifting and extending legs regularly while seated is a verified way to improve comfort (Chapter 7).

The findings of this thesis might also be applied in other fields, such as in car and train interiors or in waiting rooms and offices, since these situations are also comprised of a predefined environment where people are mainly sitting for prolonged periods of time. Moreover, results of research in other fields show overlap with the findings of this thesis. Hiemstra-van Mastrigt (2015) found that the activities of train passengers require different seat configurations. This is also suggested for office seats; seat configurations here should adapt to the task of the worker (Groenesteijn, 2015) for optimal comfort. The design of a waiting room may also influence comfort (Bazley, 2015). Furthermore, similar to an airplane passenger, the environment of a car cabin (scent and local cooling) may benefit the comfort experience of a driver (van Veen, 2016).

8.4 Recommendations for future research

The experiments that are part of this thesis were carried out in laboratory settings. The advantage of this is that the test is replicable due to the controllability of the investigated variables, and that the results can be directly attributed to the tested intervention. This artificial setting, however, may produce unnatural behavior that does not reflect reality. For example, participants do not experience the hassle of checking their luggage at the airport or experience any delays that may cause frustration. Therefore, further research is necessary to investigate whether the effects found can also be applied on real flights.

Another limitation is that all the experiments were conducted with economy class seats. Although the results are relevant for a large share of aircraft travelers who fly economy class, the results might not be applicable to premium economy, business and first-class seats. Typically, these higher-class seats have different seat features (e.g. option to go full flat) and surroundings (e.g. better service and privacy). Therefore, further research should investigate whether expectations, control and human behavior also affect comfort of business class and first-class passengers.

According to this thesis, considering environmental factors is relevant when designing comfortable aircraft interiors, and although the effects of cabin noise and physical ergonomics on passenger comfort were investigated, other environmental factors (i.e. light, vibrations, smell, and climate) were not studied. Nevertheless, aircraft interior designers should consider these factors when aiming for a comfortable cabin. Therefore, more research about the effect of each individual environmental factor is necessary in order to formulate design requirements that are beneficial for passenger comfort.

The focus of this thesis was on extrinsic environmental comfort factors. However, more knowledge of intrinsic personal comfort factors would benefit passengers on an individual level (based on age, gender, culture, health status and lifestyle). Future research could evaluate the influence of personal factors on passenger comfort experience. Insights on passengers' individual preferences could enable aircraft interior manufacturers to realize an inclusive design for airplane cabins.

8.5 Final statement

The results from this thesis can be used by designers and researchers to understand the importance of the passenger (expectations, behavior and control) and the context (cabin environment, passenger activity) for creating the optimal comfort experience.

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Summary / Samenvatting

Summary

The aim of this thesis is to investigate how to provide airplane passengers with a comfortable flight experience by designing airplane cabin elements that meet their individual needs. The number of passengers travelling by airplane is increasing, and it can be assumed that all of these passengers are seeking a comfortable experience when travelling by airplane. Nevertheless, there are many factors that influence the preferred environment for comfort. These factors could be divided into intrinsic (personal) and extrinsic (environmental) components. Environmental components consist of the themes smell, light, vibrations, noise, climate, and physical ergonomics. Personal factors, on the other hand, consist of, among others, activity, behavior, and cognitive functioning. It seems that a comfortable airplane cabin depends on the design of the physical environment, but also on individual preference, on the performed activity, and on the expectations of the passenger. However, more knowledge is needed to quantify these factors, therefore, this thesis studies (1) the relation between comfort and the context (journey, nationality, and environment) of the passengers, and (2) the effect of passenger control, expectations and behavior on comfort perception.

Passengers report experiencing the lowest level of comfort between the two meal services, when the airplane is at cruise flight altitude (Chapter 2). Therefore, this is the stage that requires attention by the airlines when aiming to provide a comfortable experience to their passengers. While at cruise flight altitude, passengers engage in different in-flight activities, such as sleeping, reading and listening to music. The lowest level of comfort is experienced when sleeping, which suggests that this activity requires attention in the aircraft. For this reason the study on head support while sleeping (Chapter 5) was conducted.

Environmental factors are important extrinsic factors for airplane passengers that influence comfort. These factors can be classified into six main themes: smell, light, vibrations, noise, climate and physical ergonomics. In Chapter 3 an attempt was made to define the relative importance of each of the factors, which could be helpful in setting priorities in aircraft interior design. Passengers indicated that different in-flight activities require different environmental properties in order to facilitate passenger comfort during a flight. However, related to anthropometry, the seat appears to be the most important aspect for all investigated activities. This is an important argument

for studying the elements of the seat in contributing to comfort (Chapter 4).

In Chapter 3 it was found that the seat contributes so much to comfort because the airplane seat is the main point of interaction with the airplane cabin for passengers. The design of the seat consists of many features, (e.g. armrests, tray table and recline function) that are not considered equally important for different in-flight activities (Chapter 4). For the activity of sleeping, side head support is considered most important, for reading and watching the in-flight entertainment (IFE) screen the bottom cushion is most important, and for working on a laptop the tray table was indicated as most important. Also, small differences in appreciation of seat features were found based on nationality. Asian respondents consider a foot rest to be very valuable, contrary to North American and European respondents.

After environmental factors, expectations, control and the passenger's own behavior are important factors that influence comfort perception of aircraft passengers. Although literature suggests that expectations directly affect comfort, it appeared that passengers are not always able to predict the comfort experience associated with a product based on an image of that product (Chapter 5). Since the findings of Chapter 2 suggested that passengers should be aided in sleeping more comfortably, Chapter 5 investigated whether travel pillows can assist with this. This chapter found that the pillow that people expected to be comfortable in fact did not offer sufficient support to be truly comfortable during use. Thus, it seems that there is a discrepancy between expected and experienced comfort.

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Chapter 2 described that passengers experience the lowest comfort at cruise flight altitude and Chapter 3 specified the seat as the element of the airplane cabin that needs most attention in order to improve comfort. To improve comfort at cruise flight altitude through improving the seat and stimulating human movement, an experiment was conducted (Chapter 7) in which passengers were enticed to move their legs in order to control a game while seated. This study showed that passengers can influence comfort perception with their behavior. Performing physical in-seat exercises on a regular basis can lead to significantly improved comfort experiences and reduced discomfort experiences (Chapter 7).

Although the chapters describe individual studies, they should not be treated as separate entities, since there is consensus among the outcomes. The importance of providing passengers with relevant means to support their heads was identified in Chapter 4 and 5. Chapter 4 found that side head support is considered important for sleeping by people of all investigated nationalities (41% of 248 respondents). Chapter 5 showed that for sleeping and resting, restriction of the head in roll, pitch and yaw direction (with a travel pillow) is desired in order to keep it in a comfortable position.

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Chapter 2 identified that passengers experience the lowest comfort while sleeping. Chapters 3, 4 and 5 researched aspects of the cabin interior by examining in-flight activities. The activity of sleeping was investigated in each chapter and resulted in complementing insights. These include: (1) control over the airplane seat is the most important factor in the airplane cabin in order to sleep comfortably, according to passengers (Chapter 3); and (2) support of the head in order to keep the body in a neutral position (i.e. support under the chin and support on the side of the head) is key when designing a head support that facilitates sleeping (Chapter 4 and 5). These insights on seat requirements are useful for aircraft seat manufacturers.

The results from this thesis can be used by designers and researchers to understand the importance of the passenger (expectations, behavior and control) and the context (cabin environment, passenger activity) for creating the optimal comfort experience.

Samenvatting

Het doel van dit proefschrift was om te onderzoeken hoe het ontwerp van de vliegtuigcabine, die aansluit bij individuele behoeftes van de vliegtuigpassagiers, bijdraagt aan een comfortabele vliegervaring. Het aantal vliegtuigpassagiers neemt toe, en het kan worden aangenomen dat al deze passagiers streven naar een comfortabele vliegervaring. Desalniettemin, zijn er veel factoren die het comfort van passagiers beïnvloedt. Deze factoren kunnen worden ingedeeld in intrinsieke (persoonlijke) en extrinsieke (omgevings-) factoren. Omgevingsfactoren bestaan uit de thema's geur, licht, trillingen, geluid, klimaat en fysieke ergonomie. Persoonlijke factoren bestaan onder andere uit activiteit, gedrag en cognitief functioneren. Het lijkt erop dat een comfortabele vliegtuigcabine afhangt van het ontwerp van de fysieke omgeving, maar ook individuele voorkeuren, uitgevoerde activiteit en de verwachtingen van de passagier spelen hierbij een rol. Echter, meer kennis is nodig om deze factoren te kwantificeren, daarom richt dit proefschrift zich op (1) de relatie tussen comfort en de context (reis, nationaliteit en omgeving) van de passagier, en op (2) het effect van controle, verwachtingen en gedrag van de passagier op de ervaring van comfort.

Passagiers geven aan het laagste comfort niveau te ervaren tussen twee maaltijden in het vliegtuig, wanneer het vliegtuig zich op cruise vlieghoogte bevindt (Hoofdstuk 2). Daarom behoeft dit gedeelte van de reis aandacht van de luchtvaartmaatschappijen, wanneer ze ernaar streven hun passagiers een comfortabele ervaring te bieden. Wanneer passagiers zich op cruise vlieghoogte bevinden oefenen ze verschillende activiteiten uit zoals slapen, lezen en luisteren naar muziek. Het laagste comfort level wordt ervaren tijdens het slapen, wat suggereert dat deze activiteit aandacht vereist. Om deze reden is er een studie uitgevoerd naar de ondersteuning van het hoofd tijdens slapen (Hoofstuk 5).

Omgevingsfactoren zijn belangrijke extrinsieke factoren die het comfort van vliegtuigpassagiers beïnvloeden. Deze factoren kunnen worden ingedeeld in zes hoofdthema's: geur, licht, trillingen, geluid, klimaat en fysieke ergonomie. In hoofdstuk 3 is er een poging gedaan om de relatieve belang van elke factor te definiëren, wat van belang kan zijn bij het maken van prioriteiten in het ontwerp van een vliegtuig interieur. Passagiers geven aan dat verschillende activiteiten tijdens de vlucht verschillende omgevingskenmerken nodig heeft, echter de stoel, die gerelateerd is aan antropometrie, blijkt de belangrijkste factor voor alle onderzochte activiteiten. Dit is een belangrijk argument om de elementen van de stoel die bijdragen aan comfort te onderzoeken (Hoofdstuk 4).

In Hoofdstuk 3 is gevonden dat de stoel aan comfort bijdraagt, omdat de vliegtuigstoel het belangrijkste interactiepunt tussen passagier en de vliegtuigcabine is. Het ontwerp van de stoel bestaat uit verschillende facetten (bijvoorbeeld: armleuningen, tafeltje en rugleuning) die niet allemaal even belangrijk worden bevonden voor verschillende activiteiten tijdens de vlucht (Hoofdstuk 4). Voor de activiteit slapen is de ondersteuning aan de zijkant van het hoofd het meest belangrijk, voor lezen en kijken naar het IFE (in-flight entertainment) scherm is het kussen van de zitting het meest belangrijk, en tijdens werken op een laptop wordt de tafel aangegeven als meest belangrijkste facet van de vliegtuigstoel. Er zijn ook kleine verschillen in de waardering voor verschillende stoel facetten gevonden tussen nationaliteiten. In tegenstelling tot Noord Amerikaanse en Europese respondenten, vinden Aziatische respondenten een voetensteun erg waardevol.

Naast omgevingsfactoren zijn ook verwachtingen, controle en het gedrag van de vliegtuigpassagiers belangrijke factoren die comfort van passagiers beïnvloeden. Hoewel literatuur suggereert dat verwachtingen het comfort beïnvloeden, lijkt het erop dat passagiers niet altijd in staat zijn om comfort geassocieerd met een product te voorspellen gebaseerd op een afbeelding (Hoofdstuk 5). Hoofdstuk 2 suggereert dat passagiers beter moeten worden gefaciliteerd in comfortabel slapen, daarom onderzoekt Hoofdstuk 5 of reiskussens hierin kunnen bijdragen. Uit het onderzoek van dit hoofdstuk blijkt dat de reiskussens waarvan participanten dachten dat ze het meeste comfortabel waren, eigenlijk niet genoeg ondersteuning boden om daadwerkelijk comfortabel te zijn tijdens gebruik. Daarom lijkt het erop dat er een discrepantie is tussen verwacht- en ervaren comfort.

Aanvullend op verwachtingen, draagt ook controle bij aan het comfort van de passagier (Hoofstuk 6). Passagiers die de beschikking hebben over oordopjes ervaarden meer comfort, zelfs wanneer de oordopjes niet gebruikt werden. Daarom is het aannemelijk dat eenvoudigweg de mogelijkheid tot het gebruiken van oordopjes bijdraagt aan een verhoogd gevoel van controle, en hiermee een verhoogd comfort niveau.

Hoofstuk 2 omschrijft dat passagiers het minst comfort ervaren tijdens cruise vlieghoogte en Hoofdstuk 3 specificeert dat de stoel het meest aandacht nodig heeft om het comfort in de vliegtuigcabine te verbeteren. Om het comfort tijdens cruise vlieghoogte te verhogen door het verbeteren van de stoel en stimuleren van lichaamsbeweging, is een experiment uitgevoerd (Hoofdstuk 7) waarin participanten werden aangemoedigd hun benen te bewegen om een spel aan te sturen terwijl ze zitten. Deze studie laat zien dat passagiers hun comfort beleving kunnen beïnvloeden met hun gedrag. Regelmatige lichaamsbeweging tijdens zitten kan leiden tot significant verhoogd comfort en een afname van discomfort (Hoofdstuk 7).

Ondanks dat de hoofdstukken van dit proefschrift individuele studies omschrijven, moeten ze niet als verschillende entiteiten worden behandeld, daar er consensus is gevonden tussen de uitkomsten. Het belang van het aanbieden van relevante hoofdondersteuning is gevonden in Hoofdstukken 4 en 5. Hoofdstuk 4 heeft gevonden dat de ondersteuning van de zijkant van het hoofd belangrijk wordt bevonden door respondenten van alle onderzochte nationaliteiten (41% van 248 respondenten). Hoofdstuk 5 laat zien dat voor slapen en rusten, restricties van het hoofd in roll, pitch and yaw positie (knikken, schudden en kantelen met het hoofd) (door middel van een reiskussen) is gewenst om een neutrale positie van het hoofd te behouden.

Een andere hypothese die wordt onderbouwd door meerdere studies is dat controle bijdraagt aan comfort. Hoofdstuk 6 laat zien dat mensen die voorzien zijn van oordopjes (en ze hierdoor faciliteren in hun vermogen om het omgevingsgeluid te controleren) het meeste comfort ervaren (zelfs meer dan in een stille omgeving). Verder geven participanten in Hoofdstuk 7 aan dat ze een interactieve stoel boven een normale stoel verkiezen, echter willen ze deze interactieve stoel gebruiken wanneer ze dat zelf willen (controle over hun reis).

Hoofdstuk 2 geeft aan dat passagiers het minst comfort ervaren tijdens het slapen. In Hoofdstukken 3, 4 en 5 werden aspecten van het vliegtuiginterieur onderzocht in relatie tot verschillende activiteiten. De activiteit slapen was onderzocht in elk hoofdstuk en resulteerde in aanvullende inzichten, waaronder: (1) controle van de vliegtuigstoel is de belangrijkste factor in de vliegtuigcabine om comfortabel te slapen (Hoofstuk 3), en (2) ondersteunen van het hoofd om een neutrale positie te behouden (bijvoorbeeld ondersteuning onder de kin en aan de zijkant van het hoofd) zijn de belangrijkste factoren voor het ontwerpen van een hoofdsteun die slapen faciliteert (Hoofdstuk 4 en 5). Deze inzichten met betrekking tot ontwerpeisen aan de stoel zijn bruikbaar voor fabrikanten van vliegtuigstoelen.

De resultaten van dit proefschrift kunnen worden gebruikt door ontwerpers en onderzoekers om de passagier (verwachting, gedrag en controle) en de context (omgeving van de vliegtuigcabine, activiteit van de passagier) te begrijpen, om zo een optimale comfort ervaring te kunnen creëren.

Curriculum Vitae

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About the author

Joyce Bouwens was born on February 23, 1987 in Bergen op Zoom, the Netherlands. After completing her secondary school education at Mollerlyceum in Bergen op Zoom in 2005, she started studying industrial design engineering at Delft University of Technology. She finished her bachelor's degree in 2009, and continued with the Master in Design for Interaction. She obtained her master's degree in 2011, after which she started working as a sports innovation project manager at the Hogeschool West Vlaanderen (Howest), in Kortrijk, Belgium. In 2012, she worked as a communication manager at the Yes!Delft startup Xpozer, and in 2013 she became a sports innovation project manager again, this time at the Municipality of Delft (Gemeente Delft), while simultaneously working as a sports innovation researcher at Delft University of Technology. In 2014, she moved to Texas to start the research presented in this PhD thesis in the Human Factors and Ergonomics department of Zodiac Seats US.

List of publications

Publications part of this thesis

Bouwens, J.M.A., Tsay, W.J., Vink, P. (2017). The high and low comfort peaks in passengers' flight. *Work, 58*(4), 579-584.

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Nijholt, N., Tuinhof, T., Bouwens, J.M.A., Schultheis, U., & Vink, P. (2016). An estimation of the human head, neck and back contour in an aircraft seat. *Work*, 54(4), 913-923.

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Bouwens, J.M.A., 2017. Ranking of the human senses that contribute to passenger comfort. 7th International Conference Innovative Aircraft Seating, Hamburg (Germany), December 5, 2017. (Invited speaker)

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Posters

Bouwens, J.M.A., Schultheis, U.W., Vink, P., 2016. We can see comfort now. How measuring behavior might help to assess comfort perception objectively. Poster presented at Measuring Behavior, Dublin, 25-27 May 2016. (Poster)

Acknowledgements

Now that this thesis is finished, I can look back on a challenging and educational research period. In the past four years I combined carrying out scientific experiments in an academic setting with working at the company Zodiac Aerospace. This required good communication and cooperation with many different people. The thesis that is in front of you is not only a product of my personal endeavors, in fact, it would not be possible to finish it without the help and support of many others, which I would like to thank here.

First of all, I would like to thank my promotor prof. dr. P Vink. Peter, je aanstekelijke enthousiasme en energie hebben ervoor gezorgd dat ik de moed niet in mijn schoenen liet zakken halverwege mijn promotietraject. Je bent een enorm bevlogen wetenschappelijk onderzoeker met een indrukwekkende hoeveelheid aan parate kennis, waar ik erg veel van heb geleerd de afgelopen jaren.

Then, I would like to thank my co-promotor dr. U.W. Schultheis. Udo, thank you for giving me the opportunity to start my PhD at Zodiac Aerospace in Gainesville. I had such a great time living in Texas, doing relevant research at the facility and at remote destinations such at Japan and France. Your knowledge on psychology together with your inspiring stories 'back in the days', when you were a fighter pilot made you a vital link in my PhD project.

At the same time, I would like to thank my second co-promotor dr. ir. S. Hiemstra- van Mastrigt. Suzanne, je bent niet alleen een ervaringsdeskundige in het doen van een PhD in passagierscomfort, je bleek ook nog eens erg bevlogen in je rol als daily supervisor en later natuurlijk als copromotor. Ik heb erg genoten van onze meetings, waarbij ik veel van je heb geleerd over het opzetten van experimenten en waarbij er altijd ruimte was voor een gezellig praatje!

Dear members of the doctoral committee, thank you for taking the time to thoroughly read my thesis, and for travelling to Delft to being part of my committee. I am honored to have such knowledgeable people around me.

The experiments that are part of this dissertation have been carried out at Zodiac Seats US and at the faculty Industrial Design Engineering at TU Delft. First, I would like to thank my colleagues in Gainesville for all the support and advice during the studies. Rusty, thank you for being such a good research assistant. Foek, thank you for being such an enthusiastic colleague, critical pilot participant, and best (cover) designer I know. Reza, Michael and Jeff, thanks for sharing all your engineering skills to let me understand how to

design (and not to design) and airplane seat. Raul and Marc, thanks for all the amazing lunches and beers we shared! Secondly I would like to thank Bertus, without you this adventure did not even start, thank you for introducing me to Peter! But more importantly, I would like to thank you for the very practical advice and support you gave me while setting up the studies at TU Delft. Luisa, my Italian friend, your graduation assignment was to support me with carrying out experiments, I could not have had a better assistant. You are very knowledgeable, passionate and funny, and can make the best tiramisu in the world, thank you!

Next to that I would like to thank my co-authors, for their support in preparing and documenting the experiments. Nienke, bedankt dat ik jouw artikel als hoofdstuk in mijn proefschrift mocht opnemen, en voor de vele gezellige uurtjes die we samen hebben gewerkt aan het finetunen van het artikel.

Next to help during the experiments I would like to thank colleagues at Zodiac Alkmaar for their support and interest in my PhD project. Ad, thank you for the interest you showed during my project, and for adopting me on several projects within Zodiac Alkmaar towards the end of my PhD course. Ron and Tom, thank you for inviting me as a speaker at the TedXAlkmaar, and for consulting me with human factors related questions. Jenny, we published together, shared an office in Delft and in Alkmaar; thank you for being such a lovely colleague! Jacqueline and Sabine, thank you for arranging everything for me in Alkmaar!

My fellow PhD candidates and AED section colleagues at TU Delft, thank you for the inspiration and support during my PhD. In het bijzonder Maxim, eerst als student, toen als Zodiac collega en nu als TU Delft collega en mede PhD kandidaat, bedankt voor alle heerlijke baksels en gezellige meetings. Marian, bedankt voor alle gezellige lunches op IO, waarin we ook gewoon over kippen konden babbelen.

Lieve vrienden en familie, bedankt voor de afleiding en support! Ik vind het fantastisch dat een aantal van jullie me zelfs in Texas zijn komen bezoeken, en heb geweldig genoten van de vele cadeautjes en lieve berichtjes die ik van jullie kreeg toen ik aan de andere kant van de oceaan woonde, en de interesse die jullie tot op de dag van vandaag in mijn onderzoek tonen.

Ik wil ook mijn paranimfen, Fenne en Manon, bedanken dat ze naast me willen staan tijdens de verdediging. Fenne, als TU Delft collega's zijn we

Europa door gevlogen, en daar heb ik genoten van onze 'culturele' uitjes. Je hebt me laten zien dat het doen van een PhD ontzettend leuk kan zijn, bedankt voor alles! Manon, als Zodiac collega in Texas hebben we menig vliegtuigstoel-gerelateerd-probleem uitgebreid geanalyseerd, niet zelden tijdens het bakken van een quiche of in de OSDH&CP onder het genot van een biertje. Laten we dat vooral blijven doen!

Lieve pa, 'ik wil later slim worden, net als mijn vader… die wil later ook slim worden'; denk je dat dat is gelukt inmiddels? Lieve ma, 'zolang je maar je stinkend harde best doet'; dat heeft me tot hier gebracht. Bedankt voor jullie eindeloze vertrouwen en steun!

Lieve Chris, jij weet altijd het beste in me naar boven te halen. Soms door een spreekwoordelijke schop onder mijn kont, maar meestal door de juiste vragen te stellen. Zonder jouw onvoorwaardelijke steun en liefde was dit proefschrift er nooit gekomen. Lieve Lars, elke dag is jouw brede glimlach de grootste beloning die er is. Bedankt mannen!