

Smart system for aircraft passenger neck support

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Smart System for Aircraft Passenger Neck Support

CHEEFAI TAN

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Smart System for Aircraft Passenger Neck Support

PROEFONTWERP

ter verkrijging van de graad van doctor aan de Technische Universiteit Eindhoven, op gezag van de rector magnificus, prof.dr.ir. C.J. van Duijn, voor een commissie aangewezen door het College voor Promoties in het openbaar te verdedigen op dinsdag 14 december 2010 om 16.00 uur

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Acronyms

AC	Alternating Current
Ag	Silver Metal
AgCl	Silver Chloride
ANOVA	Analysis of Variance
BMI	Body Mass Index
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CCTV	Closed Circuit Television
CE	Concurrent Engineering
DC	Direct Current
ECG	Electrocardiography
EEG	Electroencephalography
EMG	Electromyography
ICSP	In-Circuit Serial Programming
LA	Left Airbag
M	Mean
MR	Mean Rank
MVC	Maximal Voluntary Contraction
N	Number of Data Points
PCA	Principal Component Analysis
PDS	Product Design Specification
RA	Right Airbag
SCM	Sternocleidomastoid
SD	Standard Deviation
SEAT	Smart tEchnologies for Stress free Air Travel
SnS ²	Smart Neck Support System
SVGA	Super Video Graphics Array
TD	Total Design
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Travel by air is becoming a common activity to people due to the low cost flight and accessibility for individuals of all ages. With the growing number of aircraft passenger, it is important to provide a comfortable flight. The passenger may experience different levels of psychological stress during the air travel process, such as unfamiliarity with the airport departure process, food served during flight, different environment conditions in the aircraft cabin, seat position, flight duration, and seat design. Besides, the changes of time zone during air travel may cause jet lag and affect the passenger's health. Airline companies are already trying to improve the comfort of the aircraft passenger (Brundrett, 2001). But the latest aircraft such as Airbus A380 is now flying non-stop for 15 hours and long haul air travel is not a natural human activity. Many people experience different levels of physiological and psychological discomfort during air travel. Discomfort during air travel may endanger the aircraft passenger's health (Kalogeropoulos, 1998; Brundrett, 2001; World Health Organization, 2007).

1.1.1 Seating Comfort and Discomfort during Air Travel

Comfort is an important requirement of today's aircraft passenger. Hertzberg (1972) describes comfort as 'the absence of discomfort or the state of no awareness of a feeling'. The term 'seat comfort' is defined as the short-term effect of a seat to the human body (Kolich, 2008). Comfort is a subjective feeling that relates to physiological and psychological aspects of humans (Shen and Parsons, 1997). The subjective comfort feeling of aircraft passengers is affected by the aircraft features and the cabin environment. During air travel, the aircraft passenger's seat is an important feature to provide comfortable seating conditions to the passenger. The aircraft seat also is a place where the passenger spends most of his/her time during air travel. The airline industry is a highly competitive industry in which the airline companies always try to maximize their profit by maximizing the number of seats (Quigley et al., 2001). The increase of seat numbers causes a reduction of seating space for passengers, especially in economy class seats (Hinninghofen and Enck, 2006). Brundrett (2001) describes the aircraft passenger seating discomfort as related to the restriction on the tilt

degree of the seat, close seat pitch and insufficient leg room. In some cases, the close seat pitch causes the aircraft passenger to experience discomfort in different body parts, for example leg numbness, deep vein thrombosis, neck pain, shoulder pain and back pain (Brundrett, 2001; Dumur et al., 2004). Quigley et al. (2001) found that aircraft passengers complained about discomfort at lower back, buttocks and neck during air travel. They also found that the comfort of the aircraft passenger is affected by flight duration. During long haul flight, the aircraft passenger feels discomfort and is unable to have a good sleep. Alexander (2005) found that some economy class aircraft passengers only sleep for about three hours during overnight air travel. The seating discomfort can affect the aircraft passenger during air travel. Therefore, we are interested in the primary question related to aircraft passenger seating discomfort as follows:

- How can we contribute to reduce economy class aircraft passenger seating discomfort during air travel?

1.1.2 Study on Seating Comfort and Discomfort

From the literature review about seating comfort and discomfort, we found that the research was mainly related to ground vehicle seats and office seats. The research on ground vehicles such as cars and trucks can be found in various research areas e.g. seat pressure study (Boileau and Rakheja, 1990; Gyi et al., 1998), seat comfort modeling (Kolic, 2008; Runkle, 1994), posture study (Kolic, 2008), seat vibration study (van Niekerk et al., 2003), ergonomic study (Alem and Strawn, 2003; Chang et al., 1996), and seat thermal study (Fung, 1997; Cengiz and Barbalik, 1996). The research on office seats can be found in the work by De Looze (2003), Zhang (2000) and Helander and Zhang (1997). There are a few publications related to aircraft seat research, for example, seat design (Nadadur and Parkinsin, 2009; Teo, 1999), thermal comfort (Bartels, 2003), cushion design (Petit et al., 1999), and pilot seat design (Lusted et al., 1994; Goossens et al., 2000). There is also information related to aircraft passenger seats in published patents, for example, aircraft passenger seat (Schonenberg and Konig, 2002; Papaopannou et al., 1997), cushion (Boren et al., 2008), and seat headrest (Clough, 2004; O'Connor and Steuer, 2001).

The small amount of public accessible research on aircraft passenger seating comfort and discomfort may be due to the competitiveness and confidentiality of the airline industry.

In the current development of aircraft seat, InNova (Sutter and Acuna, 2003) has created a seat design called 'the bubble'. 'The bubble' design increases the passenger's perception of space by moving the hand luggage compartment to underneath the seat. On the other hand, B/E Aerospace developed a moving seat called 'ICON seating' (Elliott, 2006). The movable seat surface enables the passenger to change into back sleep and side sleep. Besides, side support wings on the seat bottom can be adjusted to provide leg support in a side sleep posture. The advantage of ICON seating is that it enables the passengers to control their comfort condition and to provide personal space. Lantal Textiles (2006) has developed a pneumatic cushions comfort system for an aircraft seat in which the conventional foams are replaced by an air chamber. The aircraft passengers can adjust the air chamber pressure manually based on their preferences. The following questions related to the study of aircraft passenger seating comfort and discomfort need to be answered:

- Will a smart neck support system be able to reduce the economy class aircraft passenger's neck discomfort during air travel?
- How can we contribute to the development of a smart system reducing the economy class aircraft passenger's seating discomfort during air travel?

In this thesis, we answer these questions and investigate how to contribute to reduce neck discomfort for economy class aircraft passenger during air travel.

1.2 RESEARCH OBJECTIVE

The research presented in this thesis has the following three objectives:

- **To discover the body back discomfort of economy class aircraft passenger.**
Subjective methods such as questionnaires will be used to survey body back discomfort. The results from the study should be able to provide input and requirements for the development of a smart system.
- **To develop a smart neck support system (SnS²) to reduce neck discomfort for economy class aircraft passengers during air travel.**
The designed smart neck support system (SnS²) is expected to reduce neck discomfort of economy class aircraft passengers in an adaptive manner. The system should be validated through subjective and objective measurements.
- **To evaluate the design in an aircraft cabin simulator.**
An aircraft cabin simulator should be used for the validation of the developed smart neck support system (SnS²). The simulator should be capable to simulate the economy class section environment.

1.3 ORGANIZATION OF THE THESIS

This thesis consists of six chapters.

Chapter 1: Introduction provides an overview of the thesis, scope and motivation of the research question. It is followed by research objectives and the outline of the thesis.

Chapter 2: State of the Art describes the literature research study on recent development of the vehicle seat design which is available in current literature and products. Subsequently, questionnaires on seating comfort and discomfort are described. Four surveys aim to investigate the comfort factor for economy class

aircraft seat, body back discomfort among truck drivers and economy class aircraft passengers during travel, as well as the relationship between seat location and sitting posture.

Chapter 3: Development of a Smart Neck Support System is to reduce the sternocleidomastoid neck muscle stress for aircraft passenger during air travel. The development process of a smart neck support system (SnS²) is described.

Chapter 4: Design of an Aircraft Cabin Simulator is to validate the developed smart neck support system for economy class aircraft passenger seat in the aircraft economy class cabin-like environment. An aircraft cabin simulator is a testbed that is designed and built to conduct the validation experiment for a smart neck support system. The development of an aircraft cabin simulator is discussed in this chapter.

Chapter 5: Evaluation of a Smart Neck Support System is conducted with two experiments, namely a calibration experiment and a validation experiment. The calibration experiment is designed to measure the sternocleidomastoid muscle stress of participants in relation to head rotation angle, time and neck support conditions. The validation experiment is designed to validate a smart neck support system (SnS²) in an aircraft cabin simulator. The details of both experiments are described in this chapter.

Chapter 6: Conclusion summarizes the main results of this thesis.

1.4 CONTRIBUTION OF THE THESIS

We consider the problem of how to develop a smart system to reduce the seating discomfort of the aircraft passenger during air travel. The following contributions are made in this thesis.

Chapter 2

- We study the state of the art on seating comfort and discomfort (e.g. office chair, car, truck and aircraft).
- We describe the objective and subjective methods to measure the seating comfort and discomfort.
- We determine the comfort factors related to the economy class aircraft passenger seat.
- We define the body back discomfort level for Dutch truck driver after one hour and after five hours of travel.
- We define the body back discomfort level for economy class aircraft passenger after one hour and after five hours of travel.
- We identify the relationship between seat location and sitting posture for economy class aircraft passengers.

The key results of Chapter 2 have been published in:

Tan, C.F., Delbressine, F. and Rauterberg, M. 2007. Vehicle Seat Design: State of the Art and Recent Development. Proceedings of 3rd World Engineering Congress 2007 (WEC2007), Penang, Malaysia, pp. 51-61.

Tan, C.F., Delbressine, F., Chen, W. and Rauterberg, M. 2008. Subjective and objective measurement for comfortable truck driver seat. 9th International Symposium on Advanced Vehicle Control (AVEC2008), Kobe, Japan, pp. 851-856.

Tan, C.F., Chen, W. and Rauterberg, M. 2009. Self-reported seat discomfort amongst economy class aircraft passenger in the Netherlands. World Congress on Bioengineering 2009 (WACBE2009), Hong Kong Polytechnic University, Hong Kong, China, pp. 211.

Tan, C.F. Chen, W. and Rauterberg, M. 2010. Seat discomfort of Dutch truck driver: a survey study and analysis. SAE World Congress, Detroit, Michigan, paper no. 2010-01-0774.

Chapter 3

- We propose a framework for a smart neck support system (SnS²) to reduce the sternocleidomastoid muscle stress adaptively in an automatic manner.
- We develop a smart neck support system (SnS²).

The key results of Chapter 3 have been published in:

Tan, C.F., Chen, W., Kimman, F. and Rauterberg, M. 2009. Sleeping posture analysis of economy class aircraft seat. World Congress on Engineering 2009, London, UK, pp. 532-535.

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Development of adaptive aircraft passenger seat system for comfort improvement. Proceedings of International Conference for Technical Postgraduates, Kuala Lumpur, Malaysia, paper no. CC02-05.

Tan, C.F. Chen, W., Hao Liu and Rauterberg, M. 2009. Adaptive framework and user preference modeling for economy class aircraft passenger seat. 2009 Third UKSim European Symposium on Computer Modeling and Simulation, Greece, Athens, pp. 66-69.

Chapter 4

- We develop an aircraft cabin simulator to validate the developed smart neck support system (SnS²).

The key results of Chapter 4 have been published in:

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Interactive aircraft cabin testbed for stress-free air travel system experiment: an innovative concurrent design approach. International Conference on Advances in Mechanical Engineering ICAME 2009, Shah Alam, Malaysia, p. 137.

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Design of aircraft cabin testbed for stress free air travel experiment. 5th International Conference on Planning and Design, Tainan City, Taiwan, p. 157.

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Creative thinking of design and redesign on SEAT aircraft cabin testbed: a case study. 14th International Conference on Thinking, Kuala Lumpur, Malaysia, pp. 122-131.

Tan, C.F. Chen, W. and Rauterberg, M. 2010. Total design of low cost aircraft cabin simulator. Design 2010, Cavtat, Croatia, pp. 1721-1728.

Chapter 5

- We design a head angle measurement apparatus to define the head rotation angle.
- We define the relationship between sternocleidomastoid electromyography value with head rotation angle, time, sternocleidomastoid muscle and neck support conditions.
- We validate a smart neck support system (SnS²) in our aircraft cabin simulator.

The key results of Chapter 5 have been published in:

Tan, C.F., Chen, W. and Rauterberg, M. 2010. The Relationship of head rotation angle and SCM EMG value for the development of AnS². World Congress on Engineering (WCE2010), London, U.K., pp. 2082-2085.

Tan, C.F. Chen, W. and Rauterberg, M. 2010. An approach to study the sitting position and neck discomfort of economy class aircraft passenger during air travel. International Conference on Applied Human Factors and Ergonomics (AHFE2010), Miami, Florida, USA, Chapter 40, pp. 376-382.

Tan, C.F., Chen, W. and Rauterberg, M. 2010. Experimental design for sternocleidomastoid muscle stress measurement. 7th International Conference

CHAPTER 1 INTRODUCTION

on Methods and Techniques in Behavioral research (Measuring Behavior 2010),
Eindhoven, the Netherlands, pp. 44-47.

CHAPTER 2

STATE OF THE ART

2.1 INTRODUCTION

This chapter¹ describes the state of the art related to the issues of seating comfort and discomfort, current aircraft seat, measurement methods and survey on seating comfort and discomfort. The state of the art was acquired through literature review of research in the field of seating comfort. The involvement of the author in the development of the aircraft cabin simulator for European Project SEAT (Smart tEchnologies for Stress free Air Travel) motivated the author to focus on the aircraft related product research. The section begins with the seating comfort and discomfort and its relationship with air travel. Next, the current aircraft seats are described. Subsequently, objective and subjective measurements are discussed to assess comfort and discomfort. It is followed by four surveys studying the seating comfort and discomfort.

¹ This chapter is partially based on the following articles:

Tan, C.F., Delbressine, F. and Rauterberg, M. 2007. Vehicle Seat Design: State of the Art and Recent Development. Proceedings of 3rd World Engineering Congress 2007 (WEC2007), Penang, Malaysia, pp. 51-61.

Tan, C.F., Delbressine, F., Chen, W. and Rauterberg, M. 2008. Subjective and objective measurement for comfortable truck driver seat. 9th International Symposium on Advanced Vehicle Control (AVEC2008), Kobe, Japan, pp. 851-856.

Tan, C.F., Chen, W. and Rauterberg, M. 2009. Self-reported seat discomfort amongst economy class aircraft passenger in the Netherlands. World Congress on Bioengineering 2009 (WACBE2009), Hong Kong Polytechnic University, Hong Kong, China, pp. 211.

Tan, C.F. Chen, W. and Rauterberg, M. 2010. Seat discomfort of Dutch truck driver: a survey study and analysis. SAE World Congress, Detroit, Michigan, paper no. 2010-01-0774.

2.2 BACKGROUND

This section describes the study in relation to issues of seating comfort and discomfort, vehicle seat, and different measurement methods to quantify seating comfort and discomfort. The background study was acquired through literature review of research in the field of seating comfort. The section begins with the seating comfort and discomfort and its relationship with vehicle seat e.g. car, truck and office. Next, the current aircraft seat is described. Subsequently, objective and subjective measurements are discussed to assess comfort and discomfort.

2.2.1 Seating Comfort and Discomfort

The Cambridge Advanced Learner's dictionary (2008) defined comfort as 'a pleasant feeling of being relaxed and free from pain'. Seat comfort is determined subjectively because the user justifies the seat comfort based on his/her subjective experience in using the seat (Runkle, 1994). Helander (2003) stressed that a good ergonomic design of the seat is a precondition for seat comfort. De Looze et al. (2003) described comfort as affected by different factors such as physical, physiological and psychological factors. Helander and Zhang (1997) noted that there is a difference between seating comfort and discomfort in office chairs. They described how comfort is related to emotional aspects like feeling safe and luxury. Discomfort is more related to physical aspects like feeling pressure and muscle pain.

The Theoretical Model of Comfort and Discomfort

There is no widely agreeable definition of comfort and discomfort in sitting (De Looze et al., 2003). Comfort, as described by Shen and Vertiz (1997), is defined as 'lack of discomfort'. One of the definitions of comfort by Dumur et al. (2004) is 'the pleasant and satisfying feeling of being physically or mentally free from pain and suffering, or something that provides this feeling'.

According to the 'European Union Legislation for Drivers and Promote' (Euroactiv, 2007), the weekly driving time for truck drivers shall not exceed 56 hours. Commercial trucks are designed to transport heavy loads over long distances. The long hours of sitting during driving can cause risks of buttocks and body back discomfort (Floyd and Roberts, 1958). The study by Adler et al. (2006) showed that the driver's posture is not static and changes over time. The study also showed that drivers change their postures to avoid mechanical load and ischemia of tissue. Discomfort feeling, as described by Helander and Zhang (1997), is mainly affected by biomechanical factors and fatigue.

Zhang and Helander (1996) presented a model that illustrates the interaction of comfort and discomfort as shown in Figure 2.1. The model shows the transition of comfort and discomfort. When the person performs a task for a longer period while sitting, the discomfort factor will increase. In contrast, when the person feels well being during sitting, the comfort factor will increase.

Kolich (2008) described that seat designers are required to satisfy different cultural background and perception of seat comfort for different people. Kolich (2008) described that in general Western Europeans prefer firmer seats than North Americans. Posture as described by Kolich (2008) is the most important factor for individual seating comfort. Demographics and anthropometry also contribute to the individual factors. The seat factors include stiffness, geometry, contour, breathability and styling. For the social factors, the seat comfort may be affected by vehicle nameplate as well as the car selling price. Lastly, the car factors are influenced by seat height/eye position, pedal position, head/knee room and transmission type. Runkle (1994) described the Lear's seat comfort benchmarking methodology which incorporates and integrates four tools into a single comprehensive seat comfort analysis, such as market research studies, benchmarking studies, body pressure distribution analyses and human factors studies of anthropometric data. The results concluded that good aesthetics, well-design and comfort are more important than physical parameters in seat design.

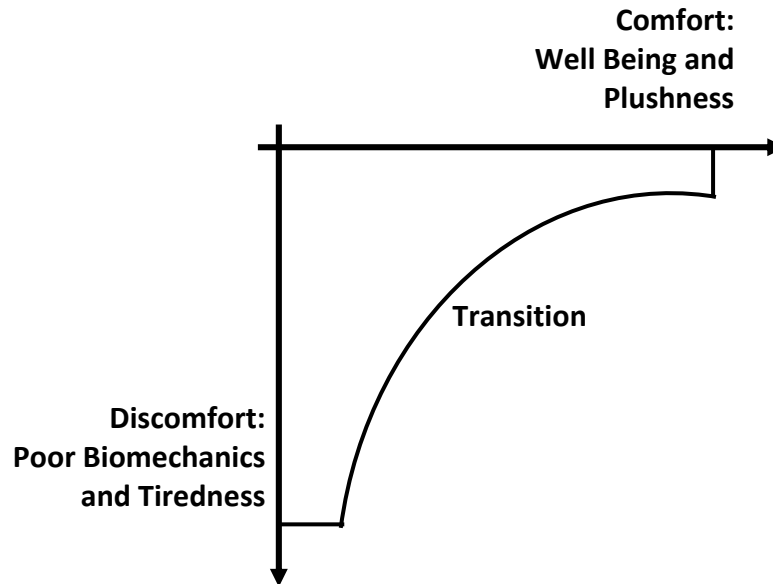


Figure 2.1 Hypothetical models of discomfort and comfort.
(Diagram reprinted from Zhang and Helander, 2006)

2.2.2 Aircraft Passenger Seat

The aviation industry is a highly competitive industry. In the past, the aviation industry focused on the business class and premiere class sections that enable the higher profit margin than the economy class section. Nowadays, the profit margins of the aviation industry have been undercut by the low cost airlines. The booming business relationship between Asia and Europe strongly encourages business long haul air travel between regions. To secure the market share, the airline companies offer attractive service and hardware to ensure a comfortable air travel for aircraft passengers. The aircraft seat manufacturers also play an important role to design and manufacture aircraft seat for comfortable air travel.

Current Aircraft Passenger Seat

A Swiss company designed an air chamber to replace the conventional foam of aircraft seat. The company claimed that the air chamber cushion is able to adapt to the seating positions of aircraft passenger (Lantal Textiles, 2010a). Since year 2009, all business class and first class seats of the SWISS airline for long-haul fleet

were installed with the air cushion system (Figure 2.2). Four seat companies, namely B/E Aerospace, Contour, ZIM Flugsitz and Recaro, implemented Lantal's air cushion system in their aircraft seats (Lantal Textiles, 2010b). The Lantal's pneumatic comfort system is a passive control system, where passenger needs to adjust the hardness of the air chamber manually.



Figure 2.2 Air cushion system of Swiss Air first class and business class seat.
(Photograph reprinted from Swiss Air, 2010)

Thompson Solutions developed a new economy seat, the Cozy Suite (Figure 2.3). The purpose of this seat is to help aircraft passengers to sleep. The seat has a contoured shoulder area and wider knee space between seats (James and Kington, 2008). The new seat design claims to increase 14% of economy class passenger seats in Boeing B767-400. The Cozy Suite focuses on legroom, armrests, airline revenues, seat quantity, ease of egress, personal space and dedicated sleeping area (Thompson Aero Seating, 2009).



Figure 2.3 The Cozy Suite.

(Photograph reprinted from Thompson Solutions, 2010)

B/E Aerospace exhibited its economy class 'Spectrum' passenger seat. The seat platform is 10% lighter in weight and provides over 14% additional space. The developed seat includes a sculpted Crytalflex back support system and meets the 2009 Head Injury Criteria requirements. RECARO Aircraft Seating presented a new version of its single-beam Comfort Line 3610 economy class seat (Figure 2.4). The seat increases the legroom even at a relatively short seat pitch. The seat has comfort features including kinematics that improve the seating angle, a flexible headrest, a foot net and ultra-thin lightweight aluminum backrest with comfort netting (James and Kington, 2008).



Figure 2.4 The Comfort Line 3610 economy class seat (Photograph reprinted from RECARO, 2009).

Air New Zealand introduced the 'Skycouch' (Figure 2.5), a lie-flat economy class and premium economy class seat in year 2010. The 'Skycouch' is a lie-flat seat which consist a row of three seats. The seat can be changed to a kid playground or a flat surface for passengers to relax and sleep (Air New Zealand, 2010).



Figure 2.5 The Skycouch (Photograph reprinted from Dailymail, 2010).

2.2.3 Objectifying and Subjectifying of Seat (Dis)Comfort

Relationship of Objective Measurements to Seating Comfort and Discomfort

The improvement on driving comfort is the main consideration in the vehicle's seat design for vehicle manufacturers. Comfort measurement is difficult to quantify and influence by factors such as user subjectivity, occupant anthropometry, seat geometry and amount of time spent sitting (Thakurta et al., 1995). Various researches have been conducted to predict seat comfort objectively. The objective methods such as pressure study, vibration study and muscle stress study can be used for seat comfort measurement. The objective measurement results are compared with subjective measurement data for better seat comfort prediction (Nawayseh and Griffin, 2005). Research by Boggs (2004) has shown that some of the main factors that affect seating comfort are seat-interface pressure distribution, whole-body vibration and pressure change rate.

A vast majority of objective measures are used for evaluating comfort and discomfort. From the literature search, the objective measurement methods (Table 2.1) used for seat are for example pressure distribution, posture, computer-aided engineering (CAE), temperature and humidity, vibration, and physiological e.g. electromyography (EMG), adrenaline etc.

Table 2.1 Overview of different objective measurement methods for seat comfort and discomfort.

No.	Objective Measurement Method	References
1.	Computer-aided engineering (CAE)	Verver et al., 2004; Hix et al., 2000; Marler et al., 2007
2.	Physiological	Inagaki et al., 2000; Uehishi et al., 2002; Zhang et al., 2006; Lim et al., 2006
3.	Posture	Bustrom et al., 2006; Scarlett et al., 2007; Kolich et al., 2006; Schust et al., 2006
4.	Pressure distribution	Nawayseh and Griffin, 2005; Andreoni et al., 2002; Gyi et al., 1997; Lee et al., 1998; Yun et al., 1992
5.	Temperature and humidity	Mehta and Tewari, 2000
6.	Vibration	Choi and Han, 2003; Wereley and Choi, 2005; Ofori-Boetang, 2003

Pressure Measurements: From the literature search e.g. ScienceDirect, pressure measurement is the most common objective method used by researchers to measure seat comfort. Several researchers have measured the pressure at the human-seat interface using electronic sensors (capacitive, resistive, strain gauge), pneumatic and electro-pneumatic. However, the visco-elastic behavior at the interface is completely altered by the sensors used (Nawayseh and Griffin, 2005). Andreoni et al. (2002) used a pressure mat to gather cushion and backrest pressure data during static conditions and real driving activity. Gyi et al. (1997) evaluated the seat pressure measurement technologies to predict driver

discomfort in various car seat designs and provided early design information for designers and manufacturers. Lee et al. (1998) recruited 100 subjects and 16 seats to find the correlation between pressure data and comfort. They described that the correlation is not high enough to be the basis for any design decision. Yun et al. (1992) studied the correlation between pressure distribution and local discomfort of car seats. The study found that the pressure distribution at the low back and buttocks area was statistically correlated to local discomfort in car seats.

There are various objective measures (Table 2.2) used for evaluating comfort. They were created based on the comparison of different seat designs with similar types of seat cushions that are widely used in vehicles. Further studies should be performed using alternative methods of evaluation to effectively evaluate the interaction between the seat cushion and the human body.

Table 2.2 Various pressure measurement techniques.

No.	Pressure Measurement Technique	References
1.	Force transducer	Bush and Hubbard, 2000
2.	Optic fibers device	Brazier et al., 2002
3.	Pliance system (Pressure distribution)	Dhingra et al., 2003
4.	Pressure mat	Zenk, 2006; Uenishi et al., 2002; Inagaki et al., 2000; Park and Kim, 1997; Thakurta et al., 1995
5.	Pressure sensors	Zenk et al., 2007
6.	SAE AM50 Buttocks Form	Montmayeur et al., 2007
7.	Seat deformation measuring device	Inagaki et al., 2000
8.	Talley pressure monitor system	Shen and Parsons, 1997
9.	Xsensor pressure imaging system	Parakkat et al., 2006

Posture Analysis: Driver posture is one of the important issues to be considered in the vehicle design process (Wu and Chen, 2004; Kolich et al., 2006; Schust et al., 2006). Posture analysis evaluates individual's sitting posture mechanically and digitally. Various objective measurement methods as shown in Table 2.3 are used for posture measurement.

Table 2.3 Objective measurement techniques for posture analysis.

No.	Posture Measurement Method	References
1.	3D coordinate measuring machine	Kyung et al., 2008
2.	3D laser scanning	Choi et al., 2007
3.	Body movement	Adler et al., 2006
4.	Cameras	Hanson et al., 2006
5.	Driving posture monitoring system	Park et al., 2000
6.	Motion measurement system	Bush and Hubbard, 2000
7.	Optoelectronic system	Andreoni et al., 2002
8.	Posture analysis	Brazier et al., 2002; Gunston et al., 2004
9.	Transient and steady-state method	Seigler and Ahmadian, 2003

Vibration Measurements: The main vibration experienced by the human body in the car is through the seat (Choi and Han, 2003). The human body is affected by whole-body vibrations e.g. vertical vibrations through the buttocks and body back via vehicle seat (Wereley and Choi, 2005). The instruments (Table 2.4) used are vertical vibration simulator, angular rate sensor, accelerometer and whole body vehicular vibration measurement.

Table 2.4 The objective measurement methods for vibration analysis.

No.	Vibration Measurement Method	References
1.	Accelerometer	Fard et al., 2003
2.	Angular rate sensor	Fard et al., 2003
3.	Vertical vibration simulator	Rakheja et al., 2006
4.	Whole body vehicular vibration simulator	Choi and Han, 2003; Wang et al., 2006

Temperature and Humidity Measurements: Thermal comfort is one of the important factors of seat design and ergonomics evaluation. Mehta and Tewari (2000) described that thermal comfort is influenced by different variables in vehicle environment and the evaluation process is complex. There are four temperature and humidity measurements (Table 2.5) found in the literature research, such as air speed, air temperature, humidity and mean radiant temperature.

Table 2.5 The objective measurement methods for temperature and humidity.

No.	Temperature and Humidity Measurement Method	References
1.	Air speed sensor	Brooks and Parsons, 1999; Olesen and Brager, 2004
2.	Air temperature sensor	Brooks and Parsons, 1999
3.	Humidity sensor	Brooks and Parsons, 1999
4.	Mean radiant temperature	Brooks and Parsons, 1999
5.	Skin temperature sensor	Cengiz and Babalik, 2007

Computer-aided Engineering: Due to the advancement of the computer system, computer-aided engineering (CAE) is used to support scientists and engineers in tasks such as simulation, analysis, design, manufacture, planning, diagnosis and repair. The seat with human can be simulated for design evaluation in the early stages of the seat design process. Verver et al. (2004) used the finite element method to evaluate the static pressure distribution of human buttocks. Hix et al. (2000) developed engineering methods and expertise in the area of truck seat modeling to capture the effects of seat dynamics on ride quality. Various objective measurement methods of CAE as shown in Table 2.6 are used to measure the seated person’s comfort such as finite element method (Choi et al., 2007), virtual reality (Marler et al., 2007), simulation method (Kolic and White, 2004; Seitz et al., 2005; Verver et al., 2005) and artificial intelligence technique e.g. artificial neural network (Kolic et al., 2004).

Table 2.6 CAE measurement methods for seat development

No.	CAE Measurement Method	References
1.	AnyBody modeling system	Rasmussen et al., 2007
2.	Artificial intelligence	Gundogdu, 2007; Lee, 2008; Kolic et al., 2004
3.	MADYMO	Verver et al., 2004
4.	MATHEMATICA	Seitz et al., 2005
5.	PAM comfort simulation tool	Montmayeur et al., 2007; Choi et al., 2007
6.	RAMSIS	Seitz et al., 2005
7.	Virtual human	Marler et al., 2005; Marler et al., 2007

Physiological Measurements: The physiology of human such as brain, muscle, heart, skin and spine can be used to measure the seated person’s comfort or discomfort level objectively. Various physiological measurement methods (Table 2.7) can be used for example electromyography (EMG) signals is used to measure the myoelectrical activity of muscles (Inagaki et al., 2000; Parakkat et al., 2006); adrenaline content in urine is used to measure the human

stress level (Uenishi et al., 2002); electroencephalography (EEG) is used to measure the human brain activity (Zhang et al., 2006), and oxygen saturation (Parakkat et al., 2006) is used to check the human discomfort. Lim et al. (2006) used a method of electrocardiography (ECG) measurement without direct contact with the skin while subjects sat on a chair wearing normal clothes.

Table 2.7 Various objective measurement methods for physiological analysis.

No.	Physiological Measurement Method	References
1.	Adrenaline	Uenishi et al., 2002
2.	Body temperature	Nilsson, 2006
3.	Computed axial tomography scan	Choi et al., 2007
4.	Electroencephalography (EEG)	Zhang et al., 2006
5.	Electromyography (EMG)	Inagaki et al., 2000; Lee et al., 1995; Mehta and Tewari, 2000; Parakkat et al., 2006
6.	Ergometer	Mehta and Tewari, 2000
7.	Metabolic rate	Fountain et al., 1994
8.	Oxygen saturation	Mehta and Tewari, 2000; Parakkat et al., 2006
9.	Physiological climate simulator	Solaz et al., 2005
10.	Skin moisture	Tsutsumi et al., 2007
11.	Spinal loading	Lee et al., 1995; Wilker et al., 2001

Relationship of Subjective Measurements to Seating Comfort and Discomfort

The car manufacturers used subjective measurement methods to identify the seat comfort due to the lack of concrete analytical metrics. The car manufacturers used questionnaire methods to quantify the subjective evaluation of seat comfort (Ahmadian et al., 2002). The questionnaires developed by Yagiz (2004) evaluated the defined seat section for discomfort feelings. The questionnaires used a 10 point Likert scale to quantify the discomfort feelings of participants subjectively and the result was transformed into design requirements. The result from a well designed questionnaire is able to formulate the seating comfort and discomfort theories (Brooks and Parsons, 1999).

Local Discomfort Rating: Local discomfort rating is used to measure the discomfort of subjects while sitting. According to Kolich (2008), many researchers have adopted Hertzberg (1972) definition because in the current environment, it is more straightforward to quantify discomfort than to measure comfort. The local discomfort rating scale can be rated on a different Likert scale, such as 1 to 10 or -10 to 10. Shen and Parsons (1997) used the category partitioning scale (CP50) for rating seated pressure intensity and perceived discomfort. In the study of Mehta and Tewari (2000), a 10 point scale local discomfort is used to measure the tractor seat comfort. The work is to project the most appropriate method of assessment and selection of tractor seats from engineering and biomechanical view point. Eklund and Corlett (1987) used local discomfort with a visual analogue scale to study the correlation between trunk and back discomfort.

Local Comfort Rating: Kyung et al. (2008) used subjective rating schemes to study the most effective way in designing and evaluating car seat. A total of 27 participants completed short-term driving sessions in six different seats, two vehicle classes and two driving venues. Overall ratings were obtained from the experiment, as well as the subjective data about comfort and discomfort of the whole body and local body parts. For the aircraft seat, Parakkat et al. (2006) investigated the long duration effects of sitting in the ejection seat cushion. Subjective comfort survey data and cognitive performance data were used in the investigation. Zhang et al. (2007) studied the thermal sensations, overall thermal acceptability and thermal comfort on visual analogue scales. A 7-point scale thermal comfort for each of the body sections is used in the study of Zhang et al. (2007).

Body Mapping: In the body mapping method, the discomfort rating is focused to a body part. The discomfort feeling scale is used to rate the body part. Kyung et al. (2008) used a visual body mapping analogue scale as shown in Figure 2.6 to obtain overall ratings of comfort and discomfort for different body parts. For the work by Zenk et al. (2007), the body parts of seated participants were rated on the discomfort scale as well.

Seat Mapping: In the seat mapping method, the seat is divided into different sections to evaluate the seating comfort and discomfort. Inagaki et al. (2000) divided the seat into 16 segments to evaluate seat comfort based on a 5 point scale. The 'fit' feeling and 'soft' feeling of the sitting position were converted to points of stimulation that the human body received. Figure 2.7 shows the seat mapping method by Inagaki et al. (2000).

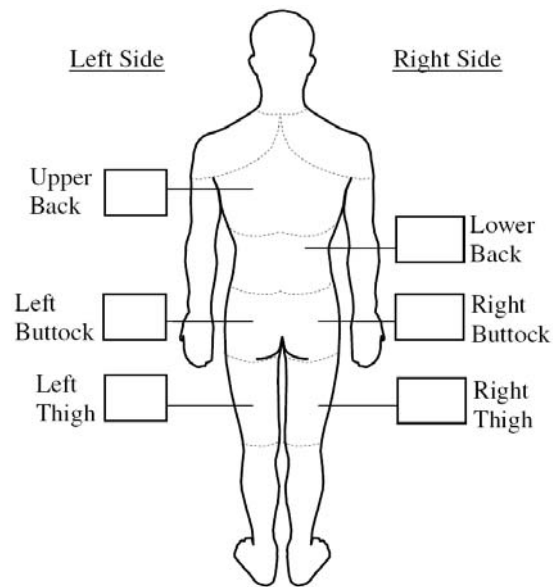


Figure 2.6 The body mapping for comfort and discomfort rating (Photograph reprinted from Kyung et al., 2008).

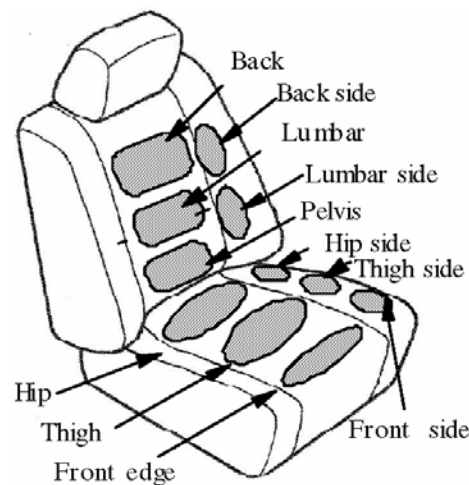


Figure 2.7 Evaluation of seat comfort based on seat mapping (Photograph reprinted from Inagaki et al., 2000).

2.2.4 Summary and Conclusions

Literature has provided theoretical model of seating comfort and discomfort. There are different factors that affect the human comfort during travel, such as pressure, vibration, temperature and posture. The passenger has different levels of comfort and discomfort during air travel. Based on the study on current aircraft passenger seat development, the aircraft seat manufacturers and airlines were focused on lighter and thinner seat as well as more seats to install in the cabin. The main purpose is to gain profit in the economy class section. There are different approaches used to understand the comfort and discomfort of sitting objectively as well as subjectively. Objective and subjective measurement methods can be combined for assessing both comfort and discomfort properties of seats. Therefore, it is important to use objective and subjective measurement methods to investigate the seating comfort and discomfort properties as well as to validate a smart neck support system (SnS²).

2.3 QUESTIONNAIRE ON SEATING COMFORT AND DISCOMFORT

2.3.1 Introduction

This section describes four surveys which were carried out to study the seating comfort and discomfort. The aims of the study were to find (1) the seating comfort factors for aircraft seat, (2) the body discomfort ratings of professional truck drivers in relation to travel time, (3) the body discomfort ratings of economy class aircraft passengers in relation to travel time, (4) the relationship of sitting posture and sitting location in an aircraft cabin.

The first survey identifies and investigates the relationship of comfort and discomfort factors for economy class aircraft passenger seat. The objective of the first survey is to identify the factors that influence the comfort and discomfort of economy class aircraft passenger seat. In order to achieve this goal, seating comfort and discomfort factors were collected and their relative importance was analyzed. Furthermore, the factors were classified into factor groups. The second

survey is on the body discomfort for truck drivers. The objective of this investigation is to identify the body seating discomfort while driving and to identify the discomfort level for each defined body part after one hour and after five hours of travel. The third survey investigates the body seating discomfort for economy class aircraft passengers. The survey identifies the body seating discomfort and indicates the discomfort level for each defined body part after one hour and after five hours of travel. It also sets out to examine the relationship between seating discomfort and travel time. The fourth survey investigates the relationship of the seat location and sitting posture of passengers in the economy class aircraft cabin. During a real long haul flight, the postures of selected passengers were observed and recorded based on seven predefined seating postures.

2.3.2 Identifying Factors of Seating Comfort

In this subsection, the questionnaire is developed to determine the relationship between the selected factors and comfort in economy class aircraft passenger seat. Zhang et al. (1996) identified the comfort and discomfort factors of office chair. The research defined 23 comfort factors and 20 discomfort factors in using office chair. Kuijt-Evers et al. (2004) investigated comfort and discomfort factors in using hand tools where 40 comfort factors were defined.

Selection of Comfort Factors

First, all possible comfort factors related to sitting were collected from various journal articles and online journal database. The journal articles were studied to select the possible comfort and discomfort factors. For example, the factors selected from Kolich (2008) paper were 'breathability' and 'styling'.

From the literature review, potential factors were selected based on their relationship with seating comfort and discomfort. Next, 28 studies were used (De Looze et al., 2003; Demontis and Giacoletto, 2002; Ebe and Griffin, 2001; Gryp, 1999; Gurram and Vertiz, 1997; Han and Huang, 2005; Harrison et al., 1999; Hassan and McManus, 2001; Haynes and Williams, 2008; Helander, 2003;

Helander and Zhang, 1997; Hertzberg, 1972; Hinz et al., 2006; Hsio and Keyserling, 1991; Hubbard et al., 1993; Inagaki et al., 2000; Kolich, 1999; Kolich, 2003; Kolich, 2008; Kolich and Taboun, 2004; Kyung et al., 2008; Mehta and Tewari, 2000; Na et al., 2005; Park et al., 1998; Pywell, 1993; Seigler and Ahmadian, 2003; Smith et al., 2006; Thakurta et al., 1995). From the selected studies, 41 factors were selected.

Methods

There were 55 students (N = 55) recruited from Department of Industrial Design, Eindhoven University of Technology, the Netherlands to volunteer in the main study. The online questionnaire (Appendix A.1) with 41 factors was developed by using QuestionPro systems and send to respondents via electronic mail. The respondents rated the factors in terms of comfort on a four point scale (1 = not related to comfort, 2 = slightly related to comfort, 3 = closely related to comfort, 4 = very closely related to comfort). 55 respondents filled in the questionnaire online.

Data Analysis

In the study, 41 comfort factors were ranked on mean ranks (MR) of their rating score with the Friedman test. The factor which was not rated by the subject was coded as '99' and regarded as a missing value. Next, 41 factors were classified into factors with Principal Components Analysis (PCA) with Varimax Rotation method.

Results

The 41 comfort factors were ranked from 1 to 41. The Friedman test, which evaluated differences in medians among the 41 comfort factors, is significant $\chi^2 (40, N = 41) = 274, p < 0.001$. From the result as shown in Table 2.8, 'spacious' (MR = 29.68) exhibited the highest comfort factor level. It was followed by 'adjustable' (MR = 28.83), 'ergonomic' (MR = 28.62), 'head rest' (MR = 28.04), 'seat contour' (MR = 26.90) and 'neck support' (MR = 26.37). The comfort factors

were ranked based on mean ranks. The information about means and standard deviation of the 41 comfort factors can be referred to Appendix A.2.

A factor analysis was conducted to identify the underlying dimensions of the comfort factors. Scores on the 41 factors were submitted to PCA with Varimax Rotation. The comfort factors were classified into 12 factors with eigenvalues greater than 1. Thus, the six factors solution yielded the best solution (Table 2.9). Factor number one to number six explained 58.69% of the variance in the data. The other six factors explain 19.37%, which showed less variance than the first six factors and will not further discussed.

The first factor included eight factors that described the 'no irritation in sitting' i.e. 'no shock', 'no strained', 'no fatigue', 'no pressure', 'not tired', 'no sore muscles', 'not bouncy' and 'no heavy leg'. The first factor explained 22.92% of the variance in the data. The second factor included eight factors i.e. 'leg support', 'side support', 'arm rest', 'spacious', 'neck support', 'adjustable', 'head rest' and 'ergonomic'. This factor appeared to reflect the support of economy class aircraft passenger seat and it was labeled as 'body support'. The third factor included four factors i.e. 'safety', 'reliable', 'intelligent' and 'functionality', and was labeled as 'seat function'. The fourth factor was labeled as 'feeling in sitting' and included five factors i.e. 'no hardness', 'no vibration', 'firmness of back rest', 'warm' and 'no stiffness'. The fifth factor was labeled as 'long hour sitting' and included three factors i.e. 'long duration', 'seat cushion firmness' and 'fit'. The sixth factor included three factors i.e. 'relax', 'adaptable' and 'restful'. Therefore, it was labeled as 'relaxing'.

Table 2.8 The mean ranks for comfort factors.

No.	Factor	Mean Rank
1	Spacious	29.68
2	Adjustable	28.83
3	Ergonomic	28.62
4	Head rest	28.04
5	Seat contour	26.90
6	Neck support	26.37
7	Relax	25.59
8	Firmness of backer st	25.38
9	Seat cushion firmness	25.27
10	Restful	24.67
11	Safety	24.00
12	Adaptable	23.38
13	Arm rest	22.91
14	Lumbar support	22.90
15	No stiffness	22.60
16	Breathability	22.41
17	No sore muscles	22.40
18	No fatigue	22.37
19	Fit	21.77
20	Side support	21.37
21	Leg support	20.49
22	No hardness	19.78
23	No pressure	19.56
24	Not tired	19.26
25	No shock	19.15
26	No vibration	18.93
27	Reliable	18.79
28	Well being	18.70
29	Warm	18.41
30	No uneven pressure	18.29
31	Functionality	18.24
32	No uneasy	18.01
33	Massage	18.00
34	No heavy leg	17.66
35	No strained	17.41
36	Automatic adjustment	16.28
37	Long duration	16.17
38	Pleasurable	16.07
39	Intelligent	12.72
40	Not bouncy	12.07
41	Short duration	11.55

Table 2.9 Factor loading of the comfort factors.

No.	Factors	Factor					
		1	2	3	4	5	6
		No irritation in sitting	Body support	Seat function	Feeling in sitting	Long hour sitting	Relaxing
1	No shock	0.828					
2	No strained	0.798					
3	No fatigue	0.736				0.470	
4	No pressure	0.689					
5	No tired	0.673					
6	No sore muscles	0.658					
7	No bouncy	0.649					
8	No heavy leg	0.462					
9	Leg support		0.844				
10	Side support		0.786				
11	Arm rest		0.774				
12	Spacious		0.682				
13	Neck support		0.647				
14	Adjustable		0.541				
15	Head rest		0.470				
16	Ergonomic		0.463				
17	Safety			0.798			
18	Reliable			0.771			
19	Intelligent			0.638		0.452	
20	Functionality			0.509			
21	No hardness				0.755		
22	No vibration				0.676		
23	Firmness of backrest			0.459	0.596		
24	Warm	0.477			0.575		
25	No stiffness				0.554		
26	Long duration					0.743	
27	Seat cushion firmness					0.635	
28	Fit					0.561	
29	Relax						0.853
30	Adaptable						0.630
31	Restful						0.523
32	Lumbar support						
33	Well being						
34	No uneven pressure						
35	Automatic adjustment						
36	No uneasy	0.551					
37	Seat contour						
38	Short duration						
39	Pleasurable						
40	Massage						
41	Breathability						
Explained variance		22.92%	12.06%	7.27%	6.38%	5.63%	4.43%
Cronbach's alpha		0.860	0.840	0.730	0.790	0.660	0.730

Note: only factor loadings > 0.450 are displayed

Discussion and Conclusions

The comfort factor, namely 'spacious', was most related to comfort in experiencing economy class aircraft passenger seat, followed by 'adjustable', 'ergonomic', 'head rest', 'seat contour', and 'neck support'. Next, the Factor Analysis with Varimax Rotation is used to classify the selected comfort factors into factors. The first six factors, which explained 58.69%, were selected. The first six factors were 'no irritation in sitting', 'body support', 'seat function', 'feeling in sitting', 'long hour sitting' and 'adaptability'. The main study showed that the factors of the factor 'no irritation in sitting' are most related to comfort and the factors of the factor 'relaxing' are least related to comfort. From the factor analysis result, it can be assumed that the main perception of respondents about the economy class aircraft passenger seat comfort is 'no irritation in sitting'. It is followed by 'body support', where the respondents felt that the body support of the aircraft passenger seat will improve the seating comfort.

2.3.3 Survey on Body Discomfort for Truck Driver during Travel

The truck driver is driving while sitting and the economy class aircraft passenger are resting while sitting. Commercial trucks are designed to transport heavy loads over long distances. The trucks have high priority to be durable and functional. In contrast, cars are made to commute passengers over shorter distances than trucks (Ahmadian et al., 2002). Truck drivers are at risk of body discomfort caused by long hours sitting and experience significant discomfort at different body parts. The truck driver's seat plays an important role to position the driver to perform the driving task, meet the safety requirements and provide comfort feelings to the driver.

The truck drivers are required to sit for long periods of time, approximately eight hours. The extended period of sitting includes higher risk of back problems, numbness and discomfort in the buttocks due to surface pressure under the thighs (Floyd and Roberts, 1958). Adler et al. (2006) described that the driver posture is not static and changes over time. The drivers change their posture to avoid seating discomfort caused by mechanical load and ischemia of tissue.

Hulshof and van Zanten (1997) reported that truck drivers are exposed to whole body vibration when driving for some periods of time and this has caused pain in the lower back. Poor posture of some truck drivers has been linked with neck and trunk discomfort (Massaccesi et al., 2003). In the study of Porter et al. (2003), it was observed that buttocks discomfort increased over time. The prolonged sitting and uneven pressure distribution at the buttocks may cause discomfort for truck drivers. The study by Chow and Odell (1978) reported that a sitting person automatically and unconsciously adjusts his body position when he feels discomfort. There is an inverse relationship between the tolerable pressure levels and the time duration of the pressure. This time pressure relationship depends on many factors such as general health of the person, the diet, seat pan and backrest cushion type etc.

This subsection describes a survey that was designed to examine the relation between seating discomfort and travel time for professional Dutch truck drivers. The truck drivers were selected for comparison with economy class aircraft passenger because truck drivers are in the professional domain whereas economy class aircraft passengers are considered to be in the non-professional domain.

Method

Questionnaire development

The questionnaire (Appendix A.3) consists of two sections: (1) questions regarding discomfort levels of each part of their body after one hour and after five hours travel; (2) questions about demographic background. The questionnaire begins with a short, self-explanatory introduction in which the purpose and background of the survey was explained; it also emphasized that data would be treated with confidentiality and analyzed in an anonymous manner.

The primary means of investigation is to identify the body discomfort level over travel time during truck driving. This was devised to identify the body part discomfort and indicate the discomfort level for each defined body part after one hour and after five hours. In order to identify the body part discomfort level, a

body mapping method is used. In this method, the perception of discomfort is referred to a defined part of the body back. The participant is asked for discomfort experiences during sitting while driving for each defined body part as shown in Figure 2.8, and to assess the discomfort level using five smiley symbols. Five smiley symbols represent a five point Likert type scale as shown in Table 2.10.

Table 2.10 The five point Likert scale.

Smiley	Scale	Description
☹️	1	Normal
😞	2	Little uncomfortable
😓	3	Uncomfortable
😡	4	Very uncomfortable
😤	5	Extremely uncomfortable

Questionnaire administration

For the truck driver body discomfort questionnaire, the content of the questionnaire was discussed and agreed with BGZ Wegvervoer (Road transport). The BGZ Wegvervoer is an organization which aims to improve working conditions and create better health policies in Dutch road transport companies. Due to the confidentiality of the BGZ Wegvervoer Dutch truck driver member database, 1000 questionnaires were distributed by mail in hardcopy through BGZ Wegvervoer with returned post attached. A total of 215 questionnaires were returned by post with a return response rate of 21%. The questionnaire took between five to six minutes for completion. The data collection took place from June to July 2008.

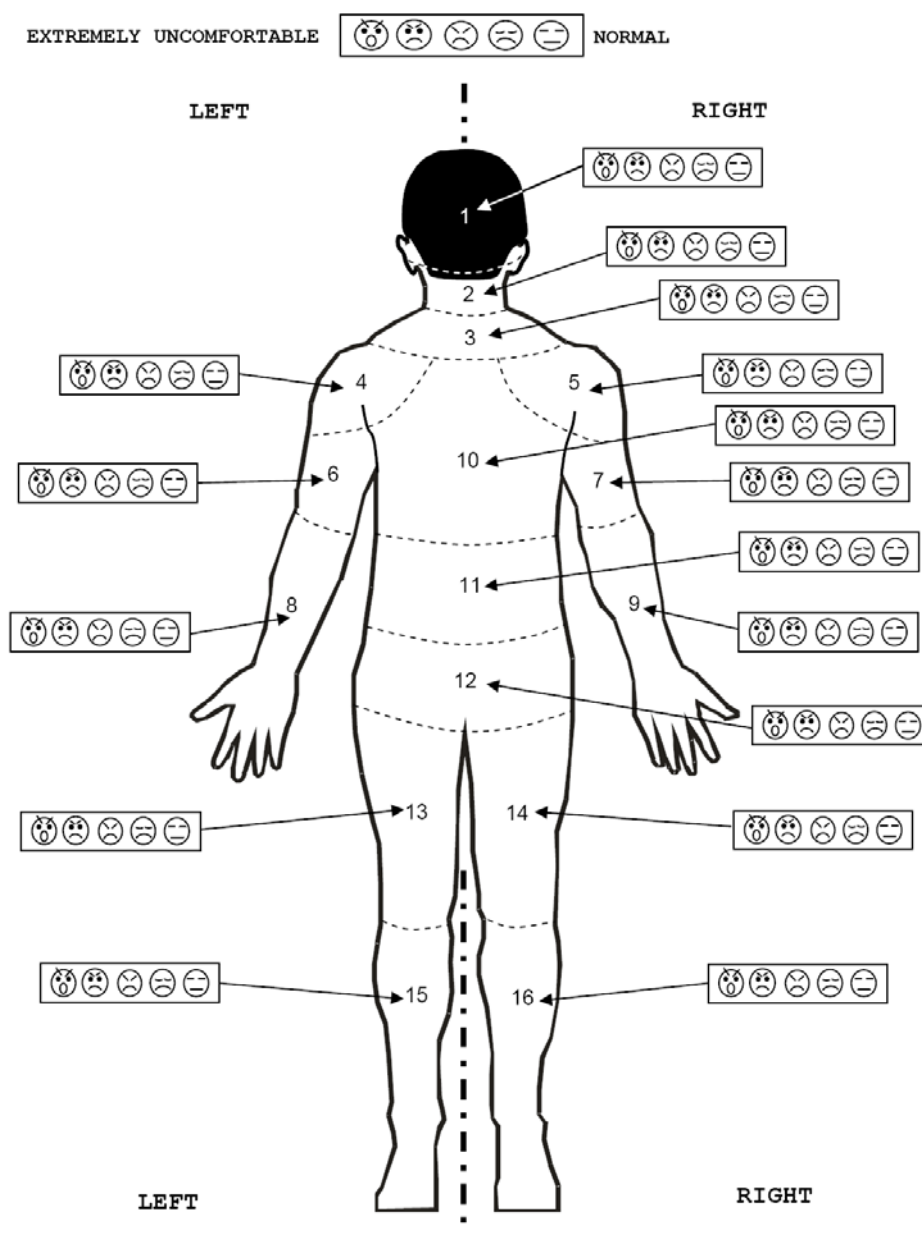


Figure 2.8 Body map and scales for body discomfort evaluation.

Results

Demographics

The respondents consisted of 215 individuals (211 male and 4 female). The demographic details for Dutch professional truck drivers is shown in Table 2.11. The average age of the respondent was 45.6 years old, the average weight

was 92.6 kilograms and the average height was 1.81 m. The average body mass index (BMI) of the respondent was 28.32 kg/m².

Table 2.11 Demographic details for truck driver.

Variable	Range	M	SD	N
Age (years)	19-69	45.60	10.60	215
Weight (kg)	60-165	92.60	17.40	215
Height (m)	1.58 – 2.11	1.81	8.20	215
BMI (kg/m ²)	19-43	28.32	4.70	215

Body part discomfort level

From the statistical analysis, no significant difference between gender and body discomfort could be determined due to the small female sample size in the survey. There was a significant difference between age and right shoulder discomfort after one hour travel (Pearson's $r = 0.139$, $p < 0.05$, two tailed). In general, older truck driver felt more discomfort in their right shoulder after one hour travel than younger truck drivers. Height was negatively correlated with head discomfort (Pearson's $r = -0.161$, $p < 0.05$, two tailed) and neck discomfort (Pearson's $r = -0.139$, $p < 0.05$, two tailed) after one hour travel, taller drivers tend to feel less comfortable than shorter drivers. The taller truck drivers felt less discomfort at head and neck after one hour travel than shorter truck driver.

For the relation between weight and body discomfort, the correlation showed that there was a significant difference between weight and neck discomfort (Pearson's $r = -0.171$, $p < 0.05$, two tailed) and shoulder discomfort (Pearson's $r = -0.145$, $p < 0.05$, two tailed) after one hour travel. Subsequently, it was discovered that body mass index (BMI) was correlated with right lower leg discomfort after one hour travel (Pearson's $r = -0.138$, $p < 0.05$, two tailed). It was indicated that truck drivers with higher BMI tended to feel more discomfort at

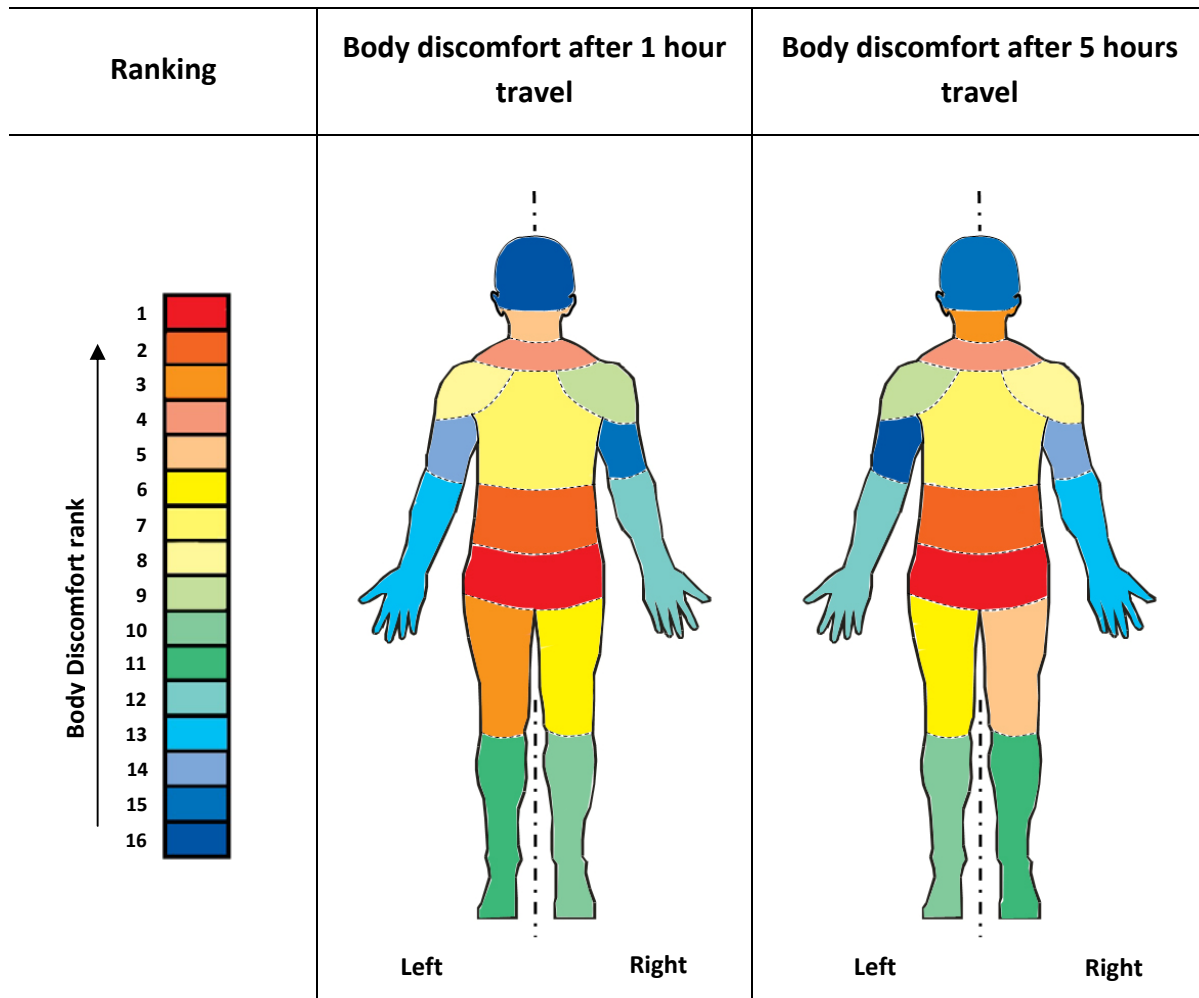
right lower leg after one hour travel. For after five hours of travel, there was no significant correlation between body discomfort and age, height, weight or BMI.

The body discomfort level for different body parts after one hour and after five hours travel was compared. Most of the respondents felt that the buttocks were the most discomfort body part after one hour travel (MR = 10.75) as well as after five hours travel (MR = 11.42). It was followed by lower back, neck, shoulder and right upper leg. Four body parts e.g. buttocks, lower back, left upper leg and shoulder show same ranking after one hour and after five hours of travel. Univariate analysis of variance was conducted to find out the differences of body discomfort level for truck drivers between after one hour and after five hours travel. The results also showed that the body discomfort level after five hours travel was higher than after one hour travel.

The nonparametric Friedman test was used to find the mean rank of sixteen variables. For each body part, 16 body discomfort rating scores are ranked from one to sixteen. The test statistic is based on these ranks. The average ranks for the body part discomfort groups after one hour and after five hours travel are shown in Table 2.12. The highest body discomfort is represented with '1' and the lowest body discomfort is ranked with '16'.

For the result of body discomfort after one hour travel, we can see that buttocks (MR = 10.75) exhibited the highest discomfort ranking among the others. It was followed by lower back (MR = 10.49) and shoulder (MR = 9.23). The Friedman test, which evaluated differences in medians among the 16 body discomfort scores after one hour travel, is significant $\chi^2 (15, N = 215) = 327.27, p < 0.001$. For the body discomfort level after five hours travel, the result showed that buttocks (MR = 11.42) are ranked as the highest discomfort ranking. It was followed by lower back (MR = 10.89) and neck (MR = 9.37). For the mean rank, means and standard deviation value for each body part after one hour and after five hours of travel can be referred to Appendix A.4. The differences in medians among 16 body discomfort scores after five hours travel, is significant $\chi^2 (15, N = 215) = 452.43, p < 0.001$.

Table 2.12 Body discomfort ranking of truck drivers after one hour and after five hours of travel.



Discussion and Conclusions

There were different levels of body discomfort for truck drivers after one hour travel. The most discomfort body part for truck drivers is the buttocks, followed by lower back, neck, shoulder, left upper leg and right upper leg. With respect to body discomfort after 5 hours travel, the most discomfort body part for truck driver is also at the buttocks; it is followed by lower back, neck, shoulder and right upper leg.

In this study, the aim is to gain more insights into truck driver seat body discomfort level after one hour and five hours of travel. The demographic background of the respondents such as gender, age, weight and height is taken into consideration for analysis. There were 215 professional Dutch truck drivers completed a questionnaire regarding body discomfort after one hour and after five hours travel. The body discomfort of truck drivers is associated with travel duration. The analysis showed that the subjective body discomfort for truck drivers after five hours of travel was higher than after one hour travel. The findings also showed that buttocks, lower back and shoulder were the top three most discomfort body parts after five hours travel for truck drivers. These results can contribute to the design of economy class aircraft seat and for better understanding of body discomfort during long haul travel.

2.3.4 Survey of Body Discomfort For Economy Class Aircraft Passenger

Long haul economy class aircraft passengers are at risk of discomfort for long sitting and experience significant discomfort at different body parts. This study was set out to examine the relationship between body discomfort and travel time for economy class aircraft passengers. There were 104 anonymous questionnaires completed at Schiphol International Airport, the Netherlands, from October through November 2008.

Methods

Questionnaire development

The objective of the questionnaire (Appendix A.5 and Appendix A.6) is to investigate the seating discomfort for economy class aircraft passengers over travel time. The questionnaire consists of three sections: (1) questions about the respondents' air travel frequency per year, common flight duration and the travel class; (2) questions about their discomfort level for each body part after one hour and five hours flight; (3) questions about demographic background of respondents.

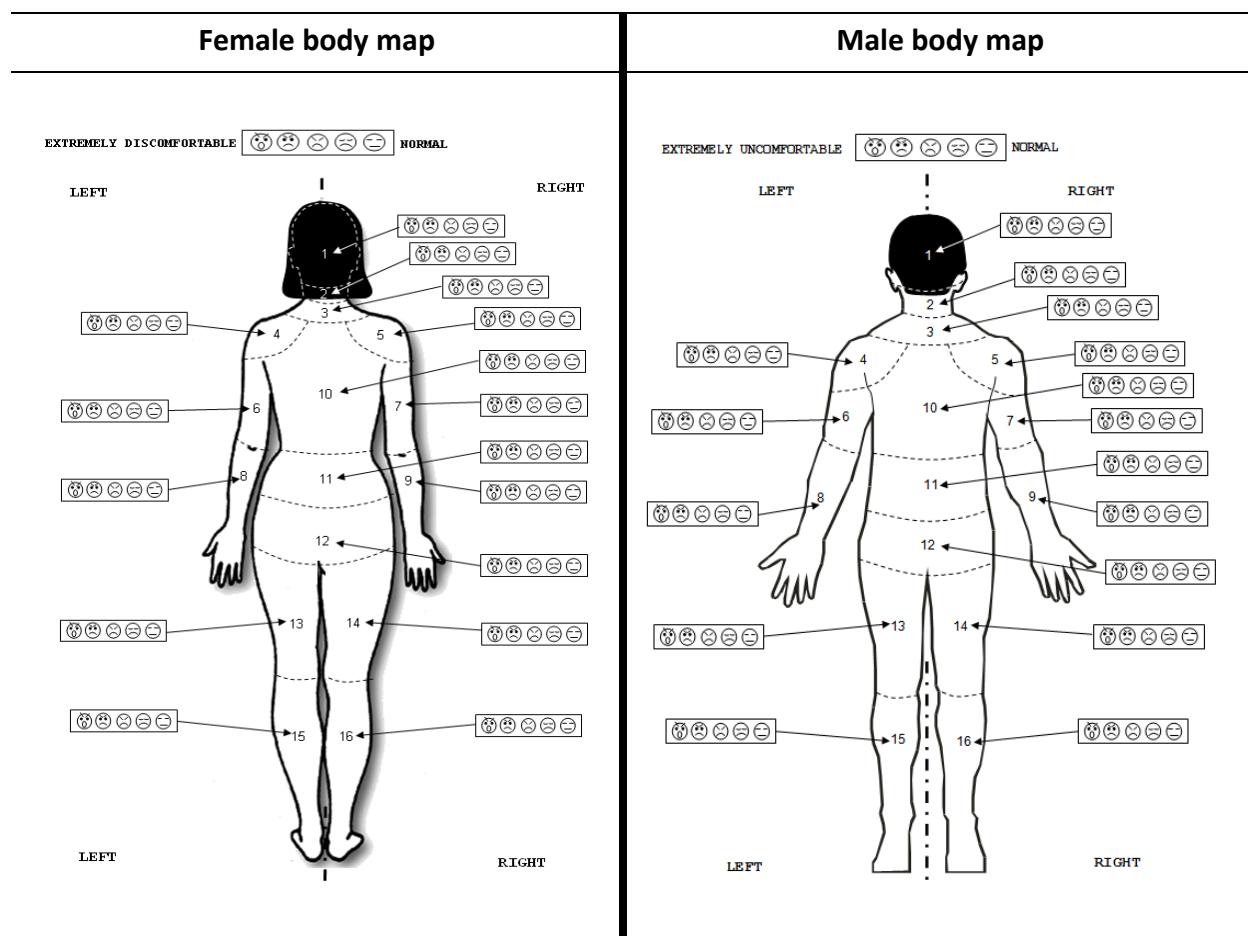
The questionnaire begins with a short, self-explanatory introduction in which the purpose and background of the survey are explained; it is also emphasized that data will be treated with confidentiality and analyzed in an anonymous manner. An example how to answer the question correctly is shown in the introduction part.

The respondents were asked to report on travel frequency in a four point scale (1 = 1 time, 2 = 2-5 times, 3 = 6-10 time, 4 = 11 times or more), common flight duration in a four point scale (1 = less than one hour, 2 = 2-5 hours, 3 = 6-10 hours, 4 = 11 hours or more) and the travel class in a three point scale (1 = economy class, 2 = business class, 3 = first class). The questionnaire was devised to identify the body part discomfort, to indicate the discomfort level for each defined body part after one hour and after five hours travel. In order to identify the body part discomfort level, a body mapping method is used. The body map and scales as shown in Figure 2.9 were used for discomfort assessment. In this method, the perception of discomfort is referred to a defined part of the body. The subject is asked for the discomfort experiences during flight for each defined body part. The subject is asked to assess the discomfort level using a five point Likert type scale as shown in Table 2.10. The scales are graded from 'extremely discomfort' to 'normal'. The body map and scales of body discomfort evaluation for economy class aircraft seat is shown in Table 2.13.

Questionnaire administration and sampling

The questionnaire was completed by 104 aircraft passengers who were randomly sampled at Schiphol International Airport in the Netherlands. The investigator was present on each occasion, during which aircraft passengers were approached and the aims of the investigation were briefly outlined. The questionnaire with female body map (Appendix A.5) was distributed to female respondents and the questionnaire with male body map (Appendix A.6) was distributed to male respondents. Approximately 90% of those approached accepted to participate. The questionnaire took between three to five minutes for self-completion.

Table 2.13 Body map and scales for body discomfort evaluation.



Results

Demographics

There were 104 respondents (50 females and 54 males) who completed the questionnaire. A wide range of ages was represented (17 to 75 years). The mean BMI (M = 24.09, SD = 4.93) of the respondents was 24.09 kg/m². The demographic details are summarized in Table 2.14.

Table 2.14 Demographic details for 104 aircraft passengers who participated in the study.

Variable	Range	M	SD	N
Age (years)	17-75	34.5 0	15.50	104
Weight (kg)	44-165	74.90	17.20	104
Height (m)	1.48-1.94	1.76	9.60	104
BMI (kg/m ²)	18.4-58.5	24.10	4.90	104

Travel information

The travel frequency (M = 1.67, SD = 0.78) was categorized into '1 time', '2-5 times', '6-10 times' and '11 times or more in a year'. Most respondents (46%) travelled at least '1 time' in a year; 40% had travelled for '2-5 times' per year, 10% had travelled for '6-10 times' in a year and 3% indicated that they had travelled for '11 times or more' in a year.

The travel duration (M = 2.63, SD = 0.85) of the respondents is measured between the origin airport and the final destination of the flight. For example, the average travel time of direct flight from Amsterdam Schiphol International Airport, the Netherlands to Kuala Lumpur International Airport, Malaysia is about 12 hours. Most of the respondents (46%) travelled '2 to 5 hours' with aircraft, 32% between '6-10 hours', 18% travelled '11 hours or more' and only 3% travelled 'less than one hour'. In the aircraft cabin, the seats were categorized into 'first class', 'business class' and 'economy class'. From the result, 98 percent of respondents choose economy class as their first choice and two percent respondents travelled with 'business class'. Due to none of the respondent travel in 'first class' and the small sample size of 'business class', they were not included for further analysis.

Factor analysis on body part discomfort level

We conducted a factor analysis on body part discomfort level for 104 respondents in relation to after one hour and after five hours of flight, to identify the underlying dimensions of the body part discomfort of economy class aircraft

passengers. Scores on the 16 statements were submitted to principal components Factor Analysis with Varimax Rotation. A Scree-plot indicated that the eigenvalues started to level off after three factors. Thus, a three factor solution yielded the best solution.

After one hour travel

For 'after one hour flight', the three factors explained 73% of the variance in the data. An overview of the composition of the three factors for body part discomfort after one hour flight is shown in Table 2.15. The first factor included five items that described the body discomfort at buttocks, upper leg (left and right) and lower leg (left and right). This factor appeared to reflect the lower body of the respondent. Therefore, it was labeled as 'Lower body'. The second factor included four items. All four items described the body part, which are upper arm (left and right) and lower arm (left and right). The second factor was labeled as 'Arm'. The third factor included seven items, namely head, neck, shoulder, left shoulder, right shoulder, upper back and lower back. The third factor was labeled as 'Upper body'.

For the relationship between travel duration and body discomfort factors after one hour travel, a one way ANOVA method was used. There was a significant difference between travel duration and arm discomfort section after one hour travel (one-way ANOVA; $F(4, 99) = 7.54, p < 0.001$). The results showed that passengers who travel between 6 to 10 hours ($M = 0.19, SD = 1.11$) experienced highest body discomfort level at arm section.

To test the differences between the gender and body discomfort level after one hour travel, we conducted one-way ANOVA on the scores on the three body discomfort factors. There is a significant difference between gender and lower body discomfort section after one hour travel (one-way ANOVA; $F(2, 101) = 11.12, p < 0.001$). The results showed that males ($M = 0.41, SD = 1.08$) scored higher on body discomfort level at lower body section than females ($M = -0.42, SD = 0.69$).

Table 2.15 Results of factor analysis of body part discomfort after one hour travel.

No.	Body part	Factor			N
		Lower body	Arm	Upper body	
1	Right lower leg	0.910			104
2	Right upper leg	0.902			104
3	Left upper leg	0.896			104
4	Left lower leg	0.890			104
5	Buttocks	0.716		0.405	104
6	Right upper arm		0.902		104
7	Left upper arm		0.880		104
8	Right lower arm		0.763		104
9	Left lower arm		0.739		104
10	Neck			0.831	104
11	Shoulder			0.772	104
12	Lower back			0.683	104
13	Upper back		0.428	0.659	104
14	Right shoulder		0.568	0.612	104
15	Left shoulder		0.568	0.612	104
16	Head			0.588	104
	Explained variance	46.76%	14.41%	11.58%	
	Cronbach's Alpha	0.950	0.890	0.860	

Note: Only factor loadings > 0.580 are selected

To test the differences between ages with the body discomfort level after one hour travel, a correlation analysis was conducted. The results show that there is a significant correlation between age and arm discomfort section after one hour travel (Pearson's $r = 0.229$, $p < 0.05$, two tailed). Older people feel more discomfort in their arm after one hour travel.

For the differences between BMI and body discomfort level after one hour travel, the correlation analysis show that there is a significant correlation between BMI and lower body discomfort section after one hour travel (Pearson's $r = 0.221$,

$p < 0.05$, two tailed). The results show that passenger with higher BMI feel more discomfort at the lower body after one hour travel.

After five hours travel

For 'after 5 hours flight', the three factors explained 74.04% of the variance in the data. An overview of the composition of the three factors for body part discomfort after five hours travel is shown in Table 2.16. There were four items labeled as 'Arm' in first factor. The first factor included left lower arm, left upper arm, right lower arm and right upper arm. The second factor included six items that described the body discomfort at neck, shoulder, left shoulder, right shoulder, upper back and lower back. This factor appeared to reflect the upper body of the respondent. The second factor was labeled as 'Upper body'. The third factor included five items, namely buttocks, right lower leg, right upper leg, left lower leg and left upper leg. The third factor was labeled as 'Lower body'.

To test the differences in travel frequency with body discomfort factors after five hours of travel, a one way ANOVA was conducted on the scores in the three body discomfort factors. Passengers who travel more than 11 times or more ($M = 0.44$, $SD = 0.93$) in a year experienced the highest body discomfort level at the upper body section. There is a marginally significance between travel frequency by aircraft and upper body section discomfort after 5 hours of flight (one-way ANOVA; $F(4, 99) = 2.43$, $p = 0.05$).

A one way ANOVA analysis is used to test the differences between gender and body discomfort factor after five hours travel. The result showed that there is a significant difference between gender with upper body discomfort factor (one-way ANOVA; $F(2, 101) = 4.27$, $p < 0.01$) and the lower body back discomfort factor (one-way ANOVA; $F(2, 101) = 5.58$, $p < 0.01$) after five hours flight. For the upper body discomfort factor, female respondents ($M = -0.28$, $SD = 1.03$) scored higher discomfort levels than male respondents ($M = -0.25$, $SD = 0.91$). For the lower body discomfort factor, male respondents ($M = 0.31$, $SD = 0.95$) scored higher discomfort levels than female respondents ($M = -0.32$, $SD = 0.96$).

Table 2.16 Results of factor analysis of body part discomfort after five hours travel.

No.	Body part	Factor			N
		Lower body	Arm	Upper body	
1	Left lower arm	0.904			104
2	Left upper arm	0.881			104
3	Right lower arm	0.869			104
4	Right upper arm	0.829			104
5	Head		0.489		104
6	Shoulder		0.866		104
7	Neck		0.843		104
8	Lower back		0.800		104
9	Upper back		0.671		104
10	Left shoulder	0.550	0.648		104
11	Right shoulder	0.585	0.603		104
12	Right lower leg			0.904	104
13	Left lower leg			0.879	104
14	Right upper leg			0.838	104
15	Left upper leg			0.805	104
16	Buttocks		0.428	0.593	104
	Explained variance	47.10%	15.48%	11.46%	
	Cronbach's Alpha	0.940	0.890	0.900	

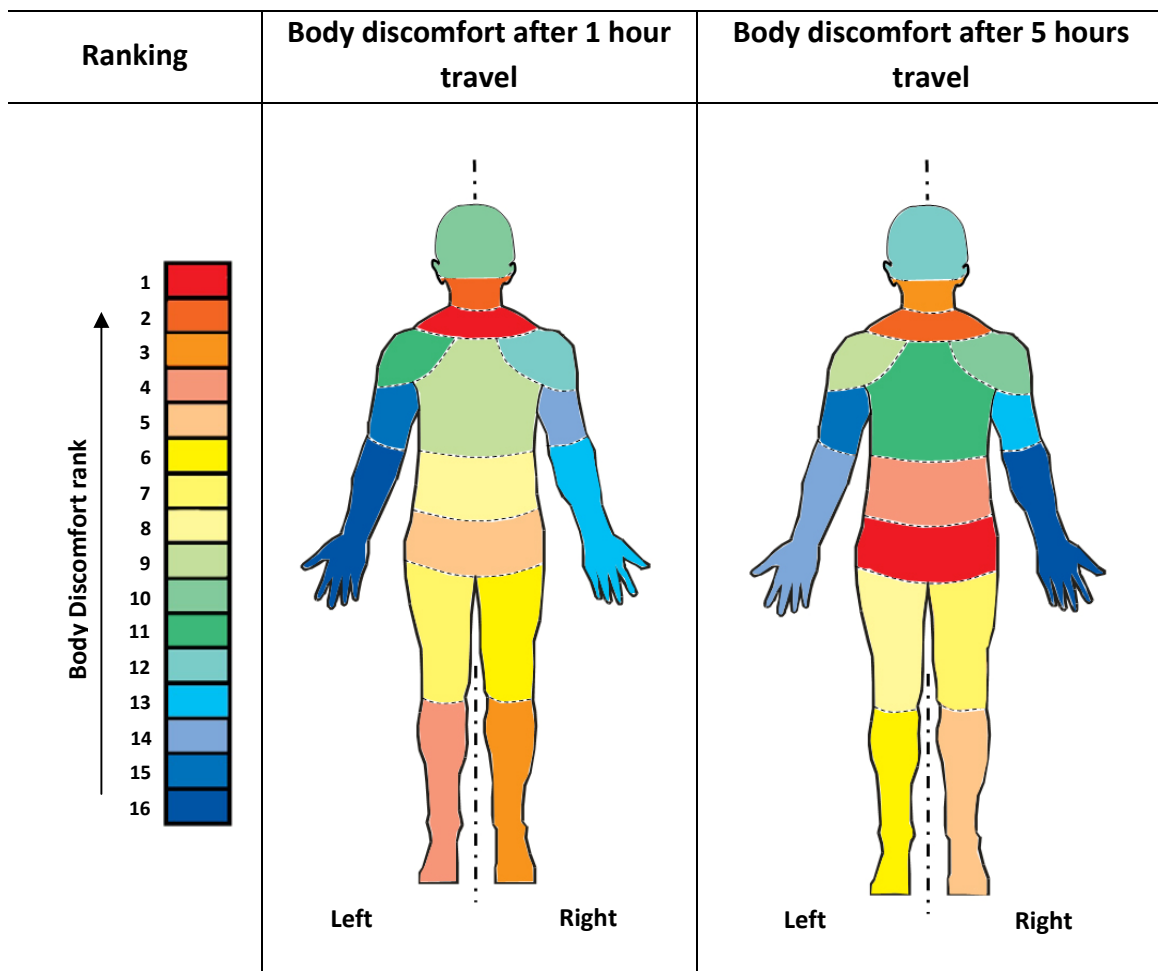
Note: Only factor loadings > 0.590 are selected

The body discomfort ranking after 1 hour and after 5 hours travel

The nonparametric Friedman test was used to test the mean rank of the sixteen body parts. For each body part, the sixteen body parts were ranked from 1 to 16 based on body discomfort rating score. The test statistic is based on these ranks. From the result of body discomfort after one hour travel, it showed that shoulder (MR = 10.57) exhibited the highest discomfort ranking. It was followed by neck (MR = 10.37) and right lower leg (MR = 10.29). The difference in medians among 16 body discomfort after one hour travel, is significant $\chi^2 (15, N = 104) = 286.27$,

$p < 0.001$. For the body discomfort level after five hours travel, the result showed that buttocks (MR = 10.74) was ranked as the highest discomfort level after five hours travel. It was followed by shoulder (MR = 10.24) and neck (MR = 10.15). The difference in medians among 16 body discomfort after one hour travel, is significant $\chi^2 (15, N = 104) = 312.93, p < 0.001$. Univariate analysis of variance was conducted to find the differences of body discomfort level between after one hour travel and after five hours travel. The results showed the body discomfort level after five hours travel was higher than after one hour travel. The detailed comparison between body discomfort ranking after one hour travel and after five hours travel is shown in Table 2.17. The information about mean rank, means and standard deviation between body discomfort ranking after one hour travel and after five hours travel can be referred to Appendix A.7.

Table 2.17 Body discomfort ranking of aircraft passengers after one hour and after five hours of travel.



Discussion and Conclusion

The subsection describes a study to investigate the relationship between body discomfort and travel time of economy class aircraft passengers. The majority of respondents travelled with economy class during air travel. Most respondents travelled at least once per year and travel time between two to five hours. With respect to travel duration, passengers who travelled more than five hours reported highest body discomfort level. Male respondents felt higher body discomfort level at lower body section than female respondents.

The body discomfort parts after one hour and after five hours travel were grouped into same meaningful factors e.g. 'lower body', 'arm' and 'upper body'. For 'after one hour travel', respondents who normally travel between six to ten hours feel most discomfort at their arm section. For lower body section, male respondents feel more discomfort than female respondents. On the other hand, older aircraft passengers felt that their arm was more discomfort after one hour flight. The passengers with higher BMI reported that their lower body section is more discomfort after one hour flight. There were different levels of body discomfort for economy class aircraft passenger after one hour travel. The most discomfort body part for economy class aircraft passenger after one hour travel is the shoulder; it is followed by the neck and right lower leg. For body discomfort after five hours travel, passengers who travel more than 11 times or more per year experienced highest body discomfort level at upper body section. Female respondents feel more discomfort than male respondents at upper body section. In contrast, male respondents feel more discomfort than female respondents at lower body section. The study found that buttock is the most discomfort body part after five hours travel; it is followed by the shoulder and neck.

In the present study, we sought to gain more insights into economy class aircraft passenger body discomfort level for after one hour travel and after five hours travel, especially with regard to flight frequency, flight duration and gender. There were 104 respondents who filled up the questionnaire about body discomfort after one hour and after five hours travel. In line with the survey hypothesis, findings confirmed that the body discomfort of aircraft passenger after five hours

travel is higher than after one hour travel. The body discomfort of economy class aircraft passengers was associated with flight duration. The male aircraft passenger is more discomfort than the female aircraft passenger at lower body section after one hour and after five hours of travel. The finding also showed that the neck is one of the top three most discomfort body part after one hour and after five hours of travel. The result of the study on body discomfort of economy class aircraft passenger demonstrates the need for the development of a smart neck support system.

2.3.5 Survey of Relationship between Seat Location and Sitting Posture

During air travel, passengers can book the preferred seat location or receive an assigned specific seat location during check-in. The seat location in the economy class cabin can be classified to aisle, centre and window seat (Quigley et al., 2001). The observation method was used in economy class aircraft cabin to investigate a) the relationship between different economy class aircraft passenger seat location and sitting posture, and b) the relationship between gender and sitting posture. The observation was conducted in the economy class cabin of Malaysia Airlines (Boeing 747-400). The flight was from Kuala Lumpur International Airport, Malaysia to Schiphol International Airport, the Netherlands. The departure time was at 11:55 p.m. on 27 May 2009 and the arrival time was at 6:35 a.m. on 28 May 2009. The flight duration was 12 hours 40 minutes. The sitting postures of 12 passengers within observer eye view were observed and recorded.

Methods

Observation administration and recording

The observer and observed subjects sat at the location as shown in Figure 2.9. The sitting location of the observer was seat number '35C'. The seat numbers of observed subjects were '34B', '34C', '34D', '35A', '35B', '35D', '35E', '35F', '35G', '36D' and '36E'. The observed subjects were within the observation range of the observer. The other seats were occupied by passengers as well but they were out

of the observation range of the observer. The observer recorded the sitting postures of the subjects in every 15 minutes.

	A	B	C		D	E	F	G
33				Aisle	SUBJECT 5 (Female)			
34		SUBJECT 1 (Male)	SUBJECT 2 (Male)		SUBJECT 6 (Male)			
35	SUBJECT 3 (Female)	SUBJECT 4 (Male)	OBSERVER		SUBJECT 7 (Male)	SUBJECT 8 (Female)	SUBJECT 9 (Female)	SUBJECT 10 (Male)
36					SUBJECT 11 (Male)	SUBJECT 12 (Female)		

Figure 2.9 The sitting location of observer and observed subjects.

The sitting posture was pre-defined and coded in seven postures as referred to Table 2.18. The explanation of seven postures as follows:

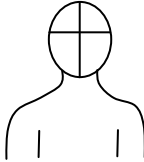
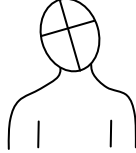
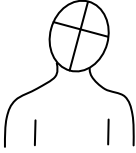
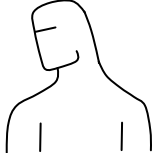
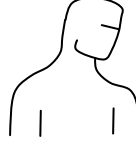


- 1) Sitting posture 'A': the passenger's head faces forward.
- 2) Sitting posture 'B': the passenger's head tilts to right.
- 3) Sitting posture 'C': the passenger's head tilts to left.
- 4) Sitting posture 'D': the passenger's head rotates to right.
- 5) Sitting posture 'E': the passenger's head rotates to left.
- 6) Sitting posture 'F': the passenger's head and body rotate to right.
- 7) Sitting posture 'G': the passenger's head and body rotate to left.

If subject leaves the seat, we code this condition as 'others'.

Results

A Crosstab and Chi-square method was used to analyze the recorded data. The first analysis investigates the relationship between seat location and sitting posture. Next, the relationship between the gender and sitting posture was examined.

Table 2.18 The coding of sitting posture for observation purpose.

No.	Sitting posture
A	
B	
C	
D	
E	
F	
G	
Others	Subject leaves the seat

For crosstab analysis on the relationship between seat location and sitting posture, out of 330 postures that are recorded in the aisle seat, 185 postures are position 'A' (56%) and 64 postures are position 'D' (19%). The results showed that the preferred sitting positions in aisle seat are position 'A' and position 'D'. For the centre seat, position C (10%), position D (19%) and position E (14%) were preferred by the subjects. For the window seat, out of 110 recorded postures, position 'B' (22%) and position 'E' (13%) were preferred by the subjects. On average, the seat location of passengers will affect their sitting posture during air travel. A Chi-square test showed that this difference was significant ($\chi^2(10) = 43.332, p < 0.001$). Position A was preferred by 51% of observed passenger because it is the most comfort position (See also Tilley and Dreyfuss, 2002).

For the relationship between gender and seat location, a Crosstab and Chi-square methods was used. The observed subjects were seven males and five females. Out of 262 postures that were recorded from female passengers, females preferred position 'B' (12%), position 'C' (10%), position 'D' (20%) and position 'E' (13%). In contrast, males preferred position 'A' (58%) as referred to the 374 recorded positions. On average, there was a significant difference between the gender of passengers and their sitting posture during air travel. A Chi-square test showed that this difference was significant ($\chi^2(5) = 21.687, p < 0.05$).

Discussion and Conclusion

In the present observation, 12 subjects were observed during the real flight from Malaysia to the Netherlands. The purposes of the observation are to investigate the relationship of sitting posture and seat location as well as gender. Different seat location might affect the sitting posture of aircraft passengers. Most of the passengers were observed in the position where the passenger's head is facing front, because it is the most comfort head position (Tilley and Dreyfuss, 2002). For the gender, female and male showed different preferences in sitting posture during air travel. The results show that different seat locations affect the sitting posture of aircraft passenger. Moreover, the sitting posture of different gender was also affected by the sitting location in the aircraft. The observed and

recorded sitting postures can be considered as important information for the development of the smart system for aircraft passenger neck support in the early design stage.

2.3.6 Summary and Conclusions

Four surveys were designed and developed to study the seating comfort and discomfort. The first survey showed that the comfort factor 'spacious' is the highest among other factors of economy class aircraft passenger seat. It is followed by 'adjustable', 'ergonomic', 'head rest', 'seat contour' and 'neck support'. For the truck seat survey, the results showed that the body discomfort rating after five hours travel was higher than the body discomfort rating after one hour travel. The top three most discomfort body parts for truck drivers after five hours are buttocks, lower back and neck. There were similar results found in the economy class aircraft passenger body discomfort survey. The findings show that the economy class aircraft passengers who travel after five hours is more discomfort than the passengers who travel after one hour. The top three main body discomfort ratings after five hours travel are buttocks, shoulder and neck. Both truck drivers and economy class aircraft passengers showed the discomfort body parts after five hours travel in buttocks and neck. The difference between truck drivers and economy class aircraft passengers is that the professional truck drivers are driving while sitting whereas the economy class aircraft passengers are resting while sitting. Both body discomfort levels for truck driver seat and economy class aircraft passenger seat discomfort were associated with travel duration. From the study of economy class aircraft passenger body discomfort, 'neck' is one of the top three most discomfort body parts after one hour and after five hours of travel. Lastly, the fourth survey showed that the sitting posture of aircraft passenger was affected by different sitting locations in the aircraft. The survey showed that there was a relationship between sitting posture and seat location as well as gender among economy class aircraft passengers. Most people prefer the sitting position where their face is facing forward because it the most comfort sitting position.

2.4 OVERALL CONCLUSIONS

The literature review showed that seating comfort and discomfort is a subjective issue. The dimension of seating comfort and discomfort is interchangeable where comfort feeling of seating can be changed to discomfort feeling and vice versa. The seat designer and researcher used different types of objective and subjective measurement methods to quantify the seating comfort and discomfort. Both objective and subjective measurement results are compared and analyzed to gain better understanding of seating comfort and discomfort. The current study of the aircraft seat found that most of the economy class aircraft seat design focuses on space optimization as well as light weight. For the current economy class aircraft seat with adjustable head rest support, the passenger needs to adjust it manually to suit their preference. The seat support is unable to adjust the head rest automatically. From the study on seating comfort and discomfort of economy class aircraft seat, we found that neck support is one of the important comfort factors. For the study of body discomfort after one hour and after five hours travel for truck drivers and economy class aircraft passengers, both domains also showed that the necks as one of the main body discomfort parts. For the economy class aircraft passengers, the study showed that the neck is one of the top three most discomfort body parts after one hour and after five hours travel. The observation study also showed that the economy class aircraft passengers preferred sitting position with head facing front. It is because the sitting position with head facing front is the most comfort position (Tilley and Dreyfuss, 2002). Therefore, the main argument here is the need for a neck support system which is adaptive and autonomous to support economy class aircraft passenger's neck during air travel.

CHAPTER 3

DEVELOPMENT OF A SMART NECK SUPPORT SYSTEM

3.1 INTRODUCTION

In the previous chapter, a literature review and four surveys were conducted to establish the knowledge of seating comfort and discomfort, the measurement methods on seating (dis)comfort, aircraft seats and which body part of economy class aircraft passengers is most suitable for the development of a smart system. The literature review showed that seating comfort and discomfort is subjective and interchangeable. Objective measurements and subjective measurements can be used to measure and understand seating comfort and discomfort. The current economy class aircraft seat is a passive system where the passenger needs to do the adjustment manually. The survey on seating comfort and discomfort was designed to understand the seating comfort descriptor, truck driver's body discomfort over travel time, economy class aircraft passenger's body discomfort over travel time and the relationship between sitting posture and sitting location. The survey results indicate that the neck is one of the most discomfort body parts after one hour and after five hours travel for truck drivers as well as economy class aircraft passengers. In the survey, we also found that neck support is one of the top ranking comfort descriptors for economy class aircraft seat. The observation in the economy class aircraft cabin also indicates that most observed passengers preferred sitting posture with head facing forward. The head facing forward is the most comfortable head position (Tilley and Dreyfuss, 2002). Therefore, the author develops a smart system prototype that focuses on neck support. The objective of a smart system is to reduce the neck muscle stress of the economy class passengers during air travel. This chapter¹ describes the

¹ This chapter is partly based on the following articles:

Tan, C.F., Chen, W., Kimman, F. and Rauterberg, M. 2009. Sleeping posture analysis of economy class aircraft seat. World Congress on Engineering 2009, London, UK, pp. 532-535.

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Development of adaptive aircraft passenger seat system for comfort improvement. Proceedings of International Conference for Technical Postgraduates, Kuala Lumpur, Malaysia, paper no. CC02-05.

Tan, C.F. Chen, W., Hao Liu and Rauterberg, M. 2009. Adaptive framework and user preference modeling for economy class aircraft passenger seat. 2009 Third UKSim European Symposium on Computer Modeling and Simulation, Greece, Athens, pp. 66-69.

development of a smart neck support system (SnS²) for passenger seat. The SnS² is a working and functional prototype that is able to support the passenger's neck in an adaptive and autonomous way. Commercial product design method e.g. total design is used for the development of SnS².

3.2 EXISTING NECK SUPPORT DURING TRAVEL

In this subsection, the study on the neck support for long haul travel and vehicle seat e.g. aircraft, bus and train are described.

3.2.1 Travel Type Neck Support

From the product search using web services, several neck supports related products were found. There are different types of neck supports that are used during air travel such as inflatable neck pillow (Pilot Paul, 2010), polyester filled pillow (Pilot Paul, 2010), memory foam pillow (Pilot Paul, 2010), feather filled pillow (Nick Robinson, 2010) and the aircraft seat with mechanical neck support (KLM, 2010; Air France, 2010; Malaysia Airlines, 2010; Cathay Pacific, 2010; Qantas, 2010).

Inflatable Neck Pillow

The inflatable neck pillow is low in price and can be found in the travel shop. The air pressure in the inflatable air pillow is proportional to the aircraft flying altitude. When the aircraft flies in the higher altitude, the air pillow will expand and it will contract in the lower altitude. The aircraft passenger will be disturbed by the air pillow when the flying altitude changes. The air pillow holds the passenger's head in one position and the passenger is unable to change the head posture freely. Most of the inflatable air pillows are made from vinyl material that will cause the user to feel hot and sticky. The advantages of the inflatable pillow are that it is easy to store and light-weight (Pilot Paul, 2010).

Memory Foam Travel Pillow

The memory foam travel pillow provides good and comfortable support during travel. The memory foam is able to respond to the passenger's body shape and to hold the passenger's head firmly. The memory foam pillow can be compressed into smaller size for storage purpose. The memory foam pillow is light-weight and durable. On the other hand, the memory foam pillow is the most expensive in comparison with commercially available neck support pillows (Pilot Paul, 2010)

Polyester Travel Pillow

The polyester travel pillow does not provide good support for aircraft passenger. The polyester pillow will become flat after it is used for some time. Some people also have polyester allergy because the polyester pillow is made from synthetic material. Some airlines such as Air France-KLM Airlines, Malaysia Airlines and China Southern Airlines do supply polyester pillows in the cabin. The advantage of polyester travel pillow is its very low cost (Pilot Paul, 2010).

Feather Filled Pillow

The feather filled pillow is soft and easy to mold around the passenger's head for better support. The feather filled pillow is light in weight and can be scrunched. On the other hand, the feather filled pillow will sink into some degree when it is used for some time. The passenger needs to adjust the feather filled pillow to its preferred loft from time to time. The feather filled pillow creates noise when passenger moves their head during resting condition (Nick Robinson, 2010).

3.2.2 Long Distance Commercial Vehicle Passenger Seat with Neck Support

The Coach Passenger Seat with Neck Support

Long-distance coach services, e.g. express buses, are transporting passengers from city to city and serve as main commuter for towns without any railway service (van de Velde, 2009). The coach passenger seat is one of the important

features to ensure the comfort of the passenger for long distance travel. For example, an express coach that travels from Singapore to Thailand as shown in Figure 3.1 was equipped with neck, side and leg support for their passenger's comfort during long distance bus travel.



Figure 3.1 The luxury coach passenger seat with neck support (Photograph reprinted from Five Star Tours, 2010).

The Train Passenger Seat with Neck Support

Long distance high speed railway companies, such as ICE, Thalys and Eurostar offer luxury passenger seat to ensure the seating comfort of passengers during train travel. German ICE offers a passenger seat with the neck support as shown in Figure 3.2. The neck support is a soft cushion attached to the seat with two strings. Thalys (Figure 3.3) and Eurostar (Figure 3.4) offer similar passenger seat with the same side support for head and neck.



Figure 3.2 The German train ICE passenger seat with neck support.



Figure 3.3 The French train Thalys passenger seat with neck support (Photograph reprinted from Raileurope, 2010).



Figure 3.4 The Eurostar passenger seat with neck support (Photograph reprinted from Bembridge, 2007).

The Aircraft Passenger Seat with Neck Support

The economy class seat of major airlines such as KLM, Malaysia Airlines, Qantas Airlines and Cathay Pacific Airlines are equipped with adjustable head rest to improve the head and neck comfort during air travel. The headrest of an economy class seat is a mechanical device that supports head and neck. The device needs to be adjusted manually by the passenger for comfort improvement. The headrest (Figure 3.5) available in the economy class aircraft seat of Cathay Pacific Airlines can be adjusted in four ways - up, down and sideways (with the adjustable ears).

The headrest aims to maximize comfort and support for the passenger's head and neck (Cathay Pacific, 2010). Subsequently, the Qantas A380 economy class seat (Figure 3.6) is also equipped with the head rest 'wing' for head and neck support (Qantas, 2010). Most of the headrests available in current aircrafts are a mechanical system where the passenger needs to adjust the head rest manually to the required position.



Figure 3.5 The Cathay Pacific Airlines economy class aircraft seat with built-in neck support
(Photograph reprinted from Cathay Pacific, 2010).



Figure 3.6 The Qantas Airline economy class aircraft seat with neck support
(Photograph reprinted from Travelhouseuk's Travel Blog, 2010).

3.3 A SMART NECK SUPPORT SYSTEM

A smart neck support system is developed to reduce neck muscle stress during air travel for economy class aircraft passenger seat. Feedback loop for smart neck support system is illustrated in Figure 3.7. The system commences by detecting the passenger's head posture. Two air pressure sensors are embedded in the seat body to detect the head posture of the passenger. Subsequently, the information of the head posture is sent to a smart control module which performs the following functions:

- 1) Providing support to the passenger's head based on his or her current head posture;
- 2) Changing the head rotation angle of the passenger to reduce neck muscle stress in an adaptive and autonomous way. When the smart control module detects that the passenger is in low activity and the passenger has been in contact with the airbag for some time, the smart control module will be activated to provide neck support to the passenger. The passenger's head will be moved towards front facing position, as this would reduce the neck muscle stress and it is known that the head facing front position is the most comfortable position (Tilley and Dreyfuss, 2002).

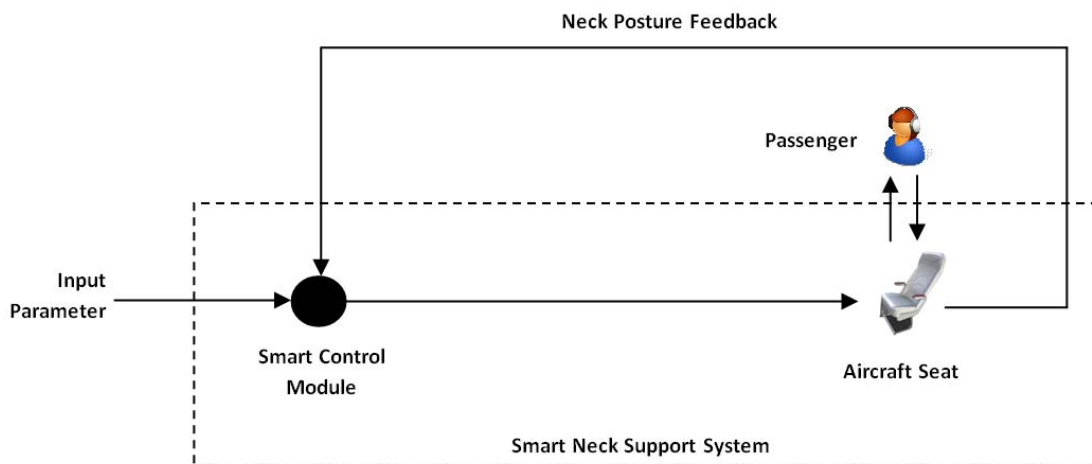


Figure 3.7 Feedback loop for smart neck support system.

3.3.1 The Architecture of a Smart Neck Support System

The architecture of a smart neck support system is shown in Figure 3.8. Both sides of the upper part of the aircraft passenger seat are embedded with air pressure sensors. The sensors are used to detect the passenger's head posture. The input parameter to the smart control module is the analog value from the air pressure sensor and the potentiometer. The air pressure sensor is used to measure the air pressure in the airbag and the potentiometer detects the presence of passenger. The output parameter is the analog value from the smart control module used to control the proportional solenoid valve. The proportional solenoid valve is used to control the air flow to and from the airbag. The smart control module is the core component of the system where it is used to mediate between sensors and actuators. The air pressure detection model is the main component in the smart control module. The algorithm for the system is to support the aircraft passenger's neck adaptively. The database is used to record the airbag pressure as well as to provide input to the smart control module. The output from the system is the actuators. The actuators will change the airbag condition such as inflate and deflate.

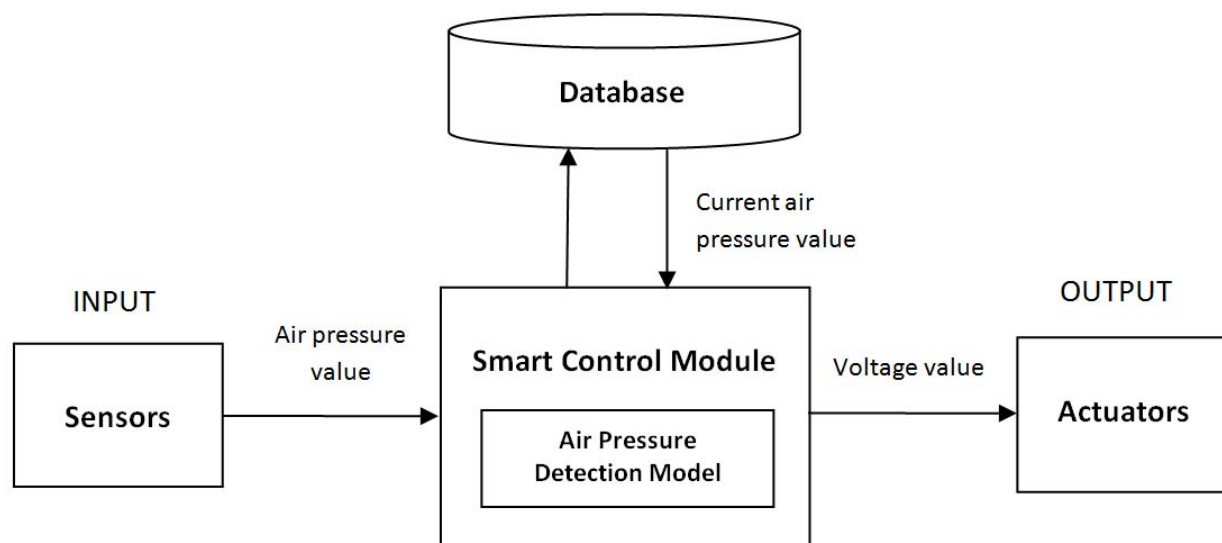
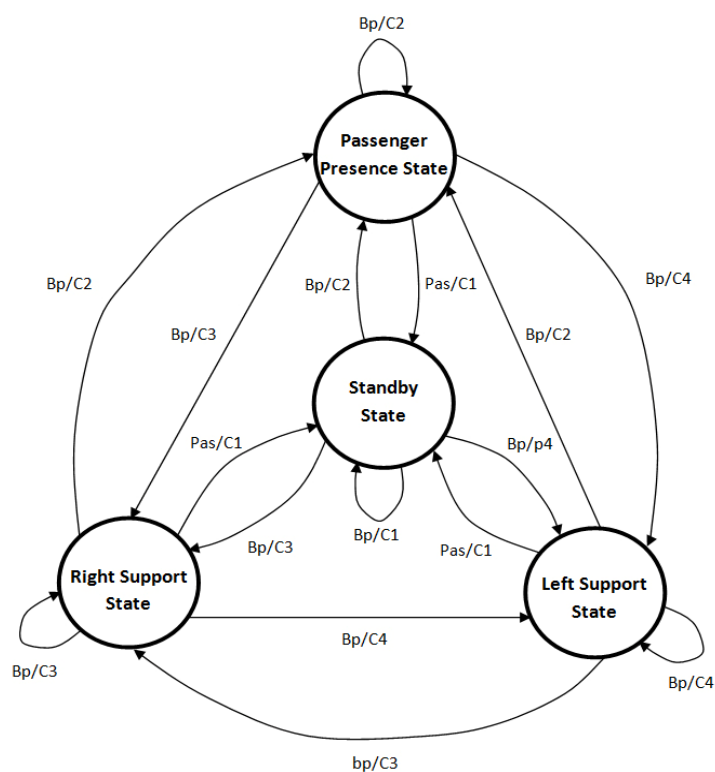


Figure 3.8 The simplified architecture of a smart neck support system.

3.3.2 System Design

State Transition Diagram

The state transition diagram (Figure 3.9) is used to describe the behavior of SnS². The state transition diagram describes the possible states of the airbags as events occur. Each circle represents a state. All states are inter-related to each other. When the passenger is not in touch with SnS², the SnS² is in the initial airbag pressure condition (C1). For example, when the passenger head is in contact with the head cushion (Figure 3.12) and the system senses the presence of the passenger (C2), the system will move from ‘Stand-by State’ to ‘Passenger Presence State’. If the passenger’s head turns to the right and is in contact with the right airbag for *t* time (p3), the system will move from ‘Passenger Presence State’ to ‘Right Support State’. Similarly, if the passenger’s head turns to the left and is in contact with the left airbag for *t* time (C4), the system will move from ‘Passenger Presence State’ to ‘Left Support State’. When the passenger leaves the system, all states will transit to ‘Standby State’ and become condition one (C1).



Legend:

Input Stimuli:

Bp: airbag pressure increase/decrease
 Pas: passenger is move away from SnS²

Conditions:

C1: initial airbag pressure
 C2: the passenger is presence
 C3: the passenger is in touch with the right airbag for *t* time
 C4: the passenger is in touch with the left airbag for *t* time

States:

Standby state
 Passenger presence state
 Right support state
 Left support state

Figure 3.9 State transition of SnS².

State Transition Description for Smart Neck Support System

State transition is used to describe the behavior of a smart neck support system. There are four transition states of a smart neck support system. The description of the state transition of SnS² is as follows:

Standby State

In 'Standby State', the right airbag (RA) and the left airbag (LA) are filled with air based on a pre-set air pressure. The arrangement of the head cushion, right airbag and left airbag is shown in Figure 3.10. Each airbag is equipped with an air pressure sensor and a potentiometer. The SnS² is in stand-by mode.

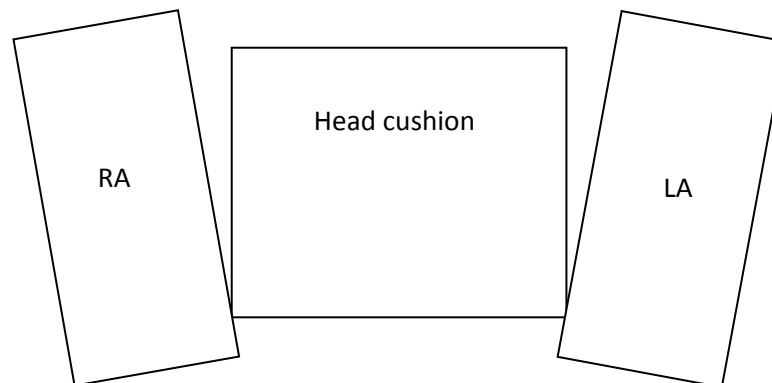


Figure 3.10 Schematic of 'Standby State'.

Passenger Presence State

The head cushion detects the presence of the passenger. As shown in Figure 3.11, the passenger's head is perpendicular to the head support and it is not in touch with the right and left airbag.

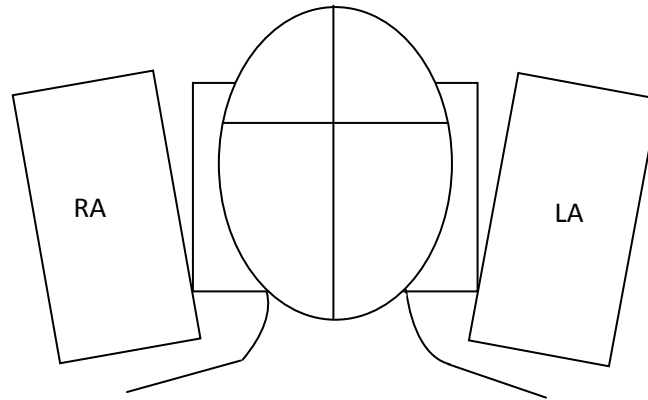


Figure 3.11 Schematic of 'Passenger Presence State'.

Right Support State

In the 'Right Support State' (Figure 3.12), the passenger's head moves to the right and is in touch with the right airbag. After one minute, when the system detects low activity of the passenger, the system is activated. Low activity is defined as the change of the air bag pressure during a time window to be within a predefined upper threshold and lower threshold. If the passenger stays in position for some time, the neck support system is activated to give support to the passenger's head. The rotation angle of the right airbag for the initial position and the supported position is shown in Figure 3.13. When the system is activated, the airbag will be inflated from the initial position (45°) to the supported position (15°).

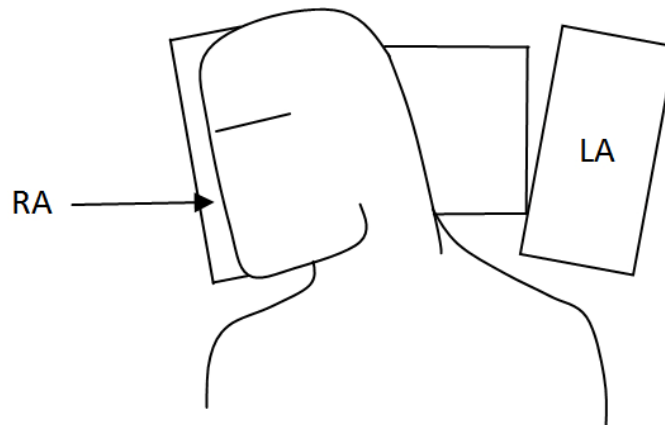


Figure 3.12 Schematic of 'Right Support State'.

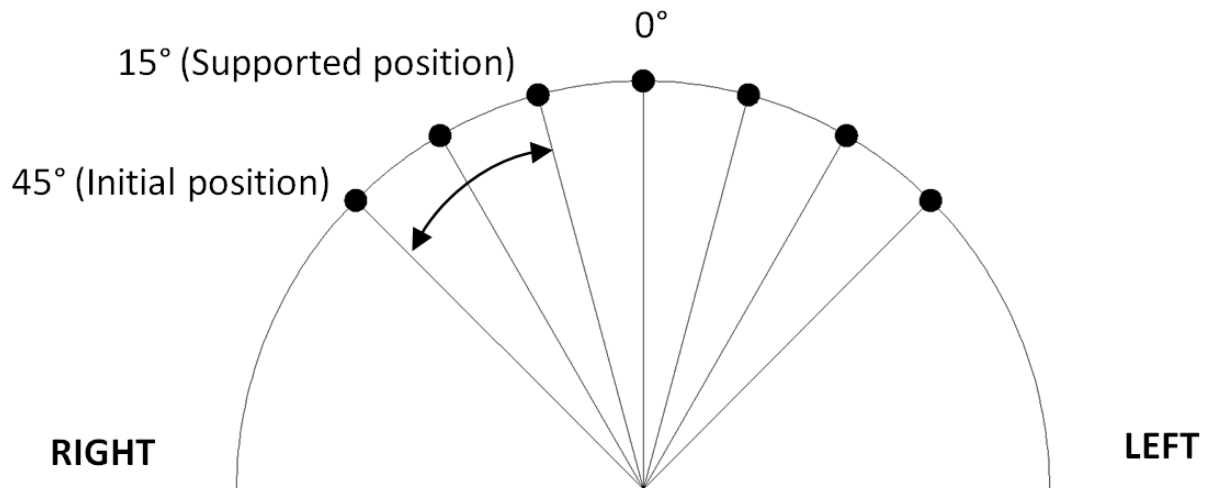


Figure 3.13 The schematic of example initial position and supported position for right airbag.

Left Support State

In 'Left Support State', the passenger's head is in touch with the left airbag (Figure 3.14). The right airbag will be reset to initial state mode. If the passenger's head is in touch with left airbag and in low activity mode for one minute, the neck support system is activated to give support on the left side of the passenger's head. The rotation angle of the left airbag for the initial position and the supported position is shown in Figure 3.15. During the activation of the system, the airbag will be inflated from initial position (45°) to supported position (15°).

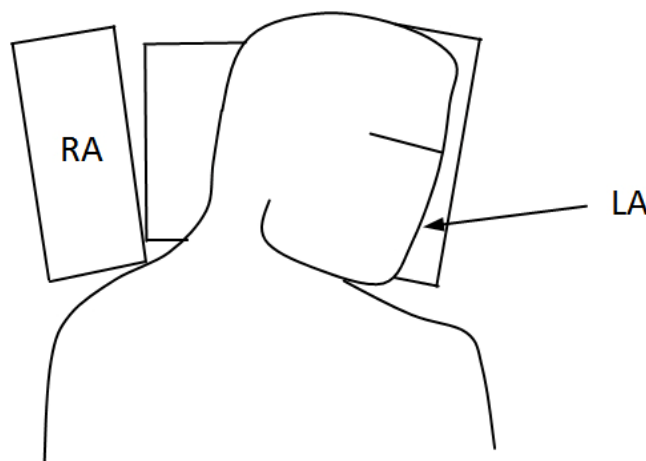


Figure 3.14 Schematic of 'Left Support State'.

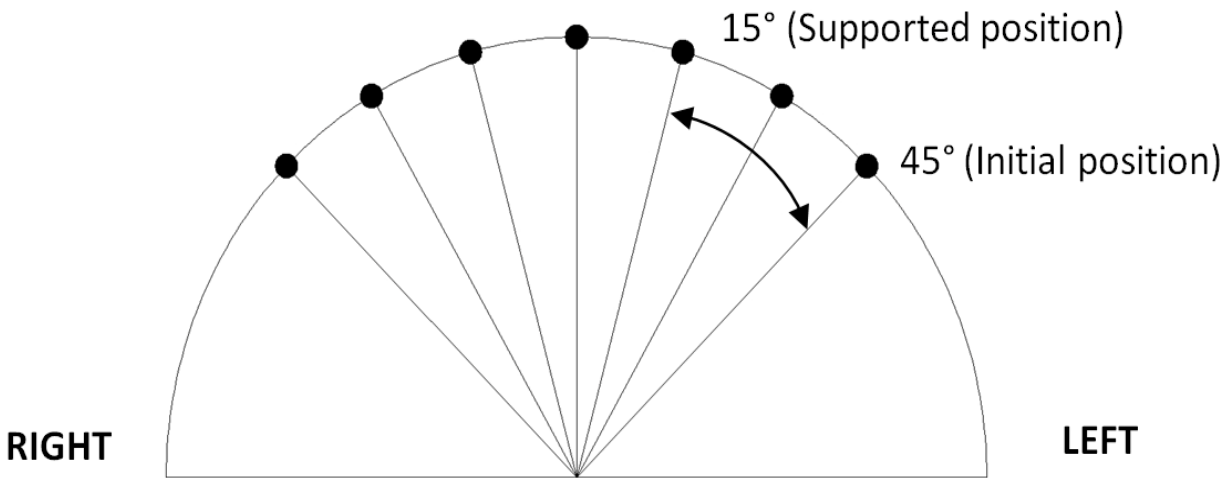


Figure 3.15 The schematic of example initial position and supported position for left airbag.

Air Pressure Detection Model

An air pressure detection model was developed. The objective of the developed air pressure detection model is to detect the passenger's head position by using an airbag system. The developed model takes into account the passenger's head posture while computing the air pressure differences in the airbag. The air pressure detection model is used for the right airbag and the left airbag. The proposed model records the increase and decrease of air pressure in the airbags. The actuator is not activated when the recording of air pressure takes place. This is because the air that flows into the airbag or exhaust from the airbag will be interfering with the current air pressure value. The model can be easily modified to take into account any variation in the air pressure during implementation. For example, if the passenger's head is away from the supported airbag, the current air pressure in the airbag will change.

Let,

$P_{current}$ = current air pressure in the airbag

$P_{recorded}$ = recorded air pressure when passenger is in touch with the airbag

n_1 = value for upper threshold

n_2 = value for lower threshold

P_{airbag} is the difference between the recorded air pressure and the current air pressure. P_{airbag} is defined as

$$P_{airbag} = P_{recorded} - P_{current} \quad (4.1)$$

P_{airbag} is used for data logging purpose.

Mathematically,

When passenger is in touch with the airbag,

$$P_{current} < P_{recorded} + n_1 \ \&\& \ P_{current} > P_{recorded} - n_2 : \text{comparing the airbag pressure}$$

If the current air pressure in the airbag is within the defined upper threshold and the lower threshold, the SnS² is activated.

When passenger is away from the airbag that supports the neck,

$$P_{current} < P_{recorded} \quad : \quad \text{comparing the airbag pressure}$$

The current air pressure in the airbag will decrease to a value that is less than the recorded air pressure when the head is not in touch with airbag. Hence the system can infer that passenger's head has left the airbag and deactivate the SnS². The algorithm of air pressure detection model for the right airbag and the left airbag is shown in Figure 3.16.

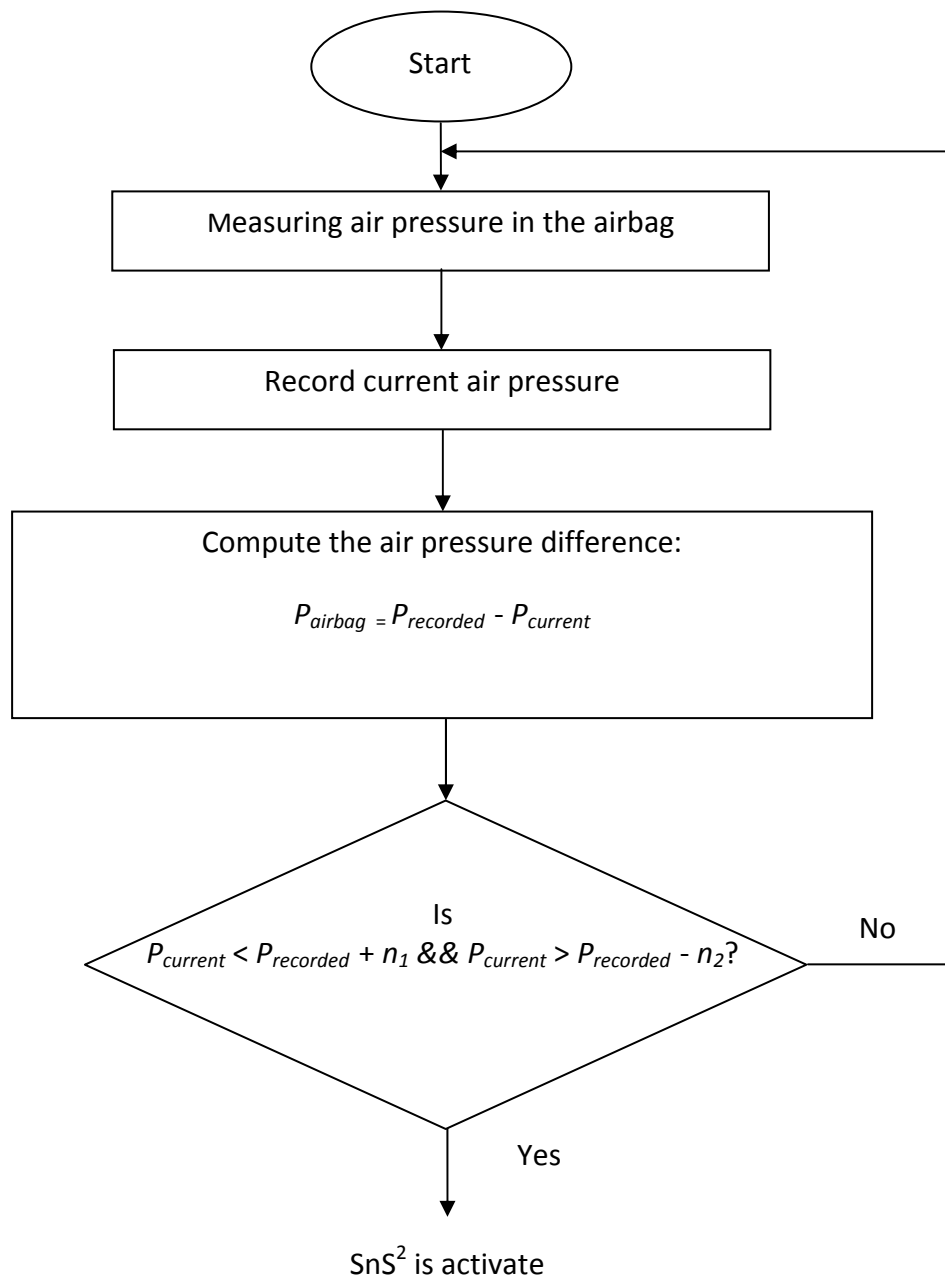


Figure 3.16 Flowchart for the neck support state transitions when the passenger is touching the airbag.

3.3.3 Mechanical Modeling of Airbag

This section describes the mechanical characteristics of the airbag used for SnS². This section discusses the mechanical model and the physical principles of the right and left airbag. Each airbag comprise of four air cells that are interconnected with each other. The air cell size is affected by the head pressure from the passenger's head. A mechanical model is created to predict the mechanical behavior of the airbag. The developed mechanical model is referring to the mathematical model that was developed by Ofori-Boateng (2003). The study defines the physical characteristics of air inflated cushions for heavy truck seat. The air inflated cushion has many air cells that are interconnected with each other. Besides, the mathematical model considered driver's weight as one of factors that affect the air cell size. There were some similarities in mechanical characteristics for the air inflated cushion and the airbag of SnS² such as air cell and loading factor.

The Mechanical Characteristics of Airbag

The airbag in this study is a prototype that is used to support the neck as well as to reduce SCM stress. The neck support includes interconnected airbags to allow for the airflow between the bags. The interconnections also allow for the neck support to support and rotate the passenger's head near to the seat centre when the passenger is in a contact position for some time. The mechanical model of the airbag can be used to design an airbag that is reliable and able to withstand the passenger head pressure.

The Mechanical Modeling of Airbag

The behavior of the airbag can be modeled in a simplified schematic as shown in Figure 3.17. The force that is caused by the weight of the supported head is equal to the increased pressure in the airbag.

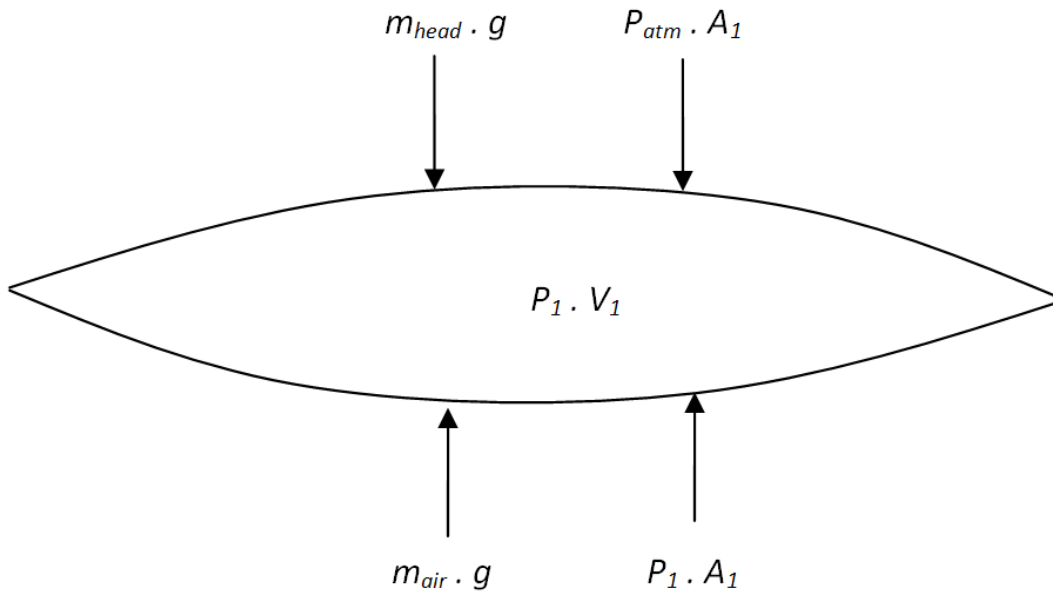


Figure 3.17 The schematic of the forces that act on the single airbag.

As illustrated in Figure 3.17, the total force that acts on the airbag is derived as:

$$F_{airbag} = \sum F = (m_{air} \times g) + (P_1 \times A_1) - (m_{head} \times g) - (P_{atm} \times A_1) \quad (4.2)$$

Where,

- F_{airbag} = force on airbag (N)
- m_{air} = mass of air in airbag (kg)
- g = gravitational force (Nm^2Kg^{-2})
- P_1 = pressure of air in airbag (Nm^{-2})
- A_1 = area in airbag (m^2)
- m_{head} = mass of passenger's head (kg)
- P_{atm} = atmospheric air pressure (Nm^{-2})

The airbag prototype is rectangular in shape; the volume of the airbag is described as

$$V_{supported} = (l \times w) (h - x) \quad (4.3)$$

Where,

- $V_{supported}$ = Volume of airbag when supporting head (m^3)
- l = Length of airbag (m)
- w = Width of airbag (m)
- h = Height of airbag (m)
- x = Height difference of airbag (m)

3.4 THE TOTAL DESIGN OF A SMART NECK SUPPORT SYSTEM

The total design technique (Pugh, 1990; Ion, 1995) was used to design and develop a smart neck support system. Pugh (1990) defined total design as the systematic approach in product development. Total design includes the activity of market investigation, conceptual design, product evaluation and marketing of the final product. Total design is an integrating framework that includes all product development aspects (Ion, 1995). Total design is a design method used in the development of commercial products. For this subsection, total design is used for the development of working and functional SnS² prototypes.

Several idea generation methods like brainstorming and morphological chart have been used. Extensive application of the morphological charts enabled the designer to identify the sub-solutions to each sub-function of the simulator. The evaluation matrix was used to decide on the final concept of SnS². SnS² is used to support and reduce the seating discomfort of the economy class aircraft passenger. The aim of this section is threefold. First, it describes the design methodology of SnS². Next, it describes the application of different methods to design and determine the design. Lastly, the section concludes the development of SnS² with the total design method.

3.4.1 Design Methodology

The total design model of SnS² is shown in Figure 3.18. Market survey is the first process in the design techniques. Various patents, journals, technical report and websites were investigated for related information such as basic technology, industry analysis, legal and policy issues, engineering definition, benchmarking and industry analysis. The output from the market survey is the product requirement. The product requirement (Table 3.1) is a guideline for the development of SnS². Next, creative method and morphological chart were used as a tool to develop the conceptual design. Subsequently, the design was visualized in three dimensional views for evaluation purposes. Different conceptual designs were evaluated based on weighted objective method.

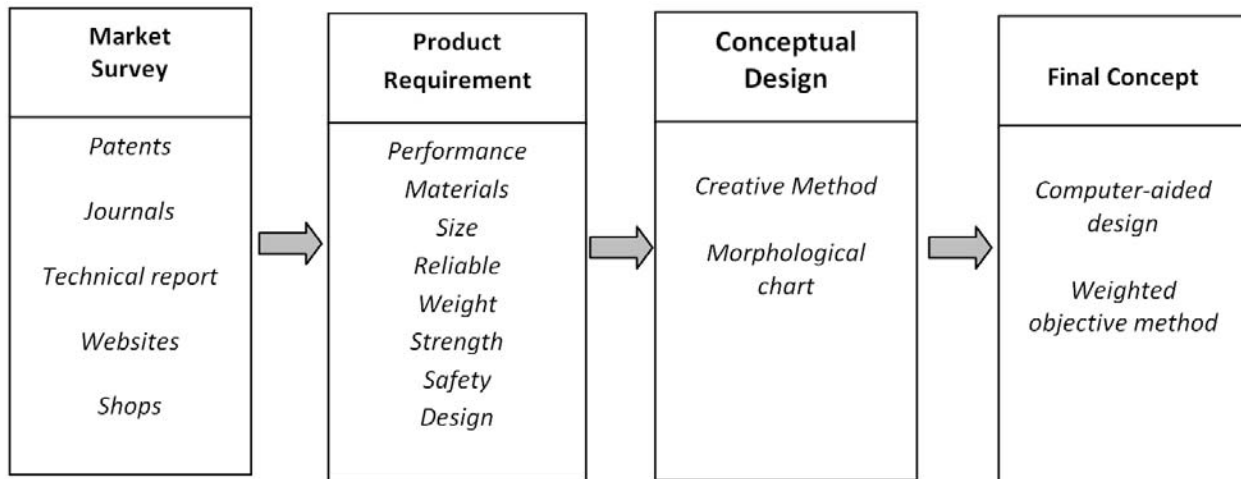


Figure 3.18 The design process of SnS².

3.4.2 Conceptual Design

Based on the product requirement as shown in Table 3.1, the design concepts were generated. The development of the SnS² employed two methodologies for concept generation. Brainstorming (Cross, 2008) and morphological chart (Pugh, 1990; Cross, 2008; Cross, 1994) were used in the conceptual stage of design.

Table 3.1 The description of the product requirement for SnS².

No.	Elements	Description
1.	Performance	SnS ² must be functional and responsive to the passenger's head position change for providing support.
2.	Materials	SnS ² is made from material that is easy to find, low cost and good for prototyping purposes.
3.	Size	SnS ² must be able to fit on the standard economy class aircraft seat.
4.	Reliable	SnS ² must be reliable during experimental stage.
5.	Weight	SnS ² must be light weight.
6.	Strength	The functional prototype should be designed to withstand the force from the subject's head and air pressure.
7.	Safety	Safety is an integral part of all aspects of design. Thus consideration should be given to the safety of all personnel whether operating the equipment, maintaining the equipment or installing the equipment.
8.	Design	In the interests of prototyping, functionality, maintainability and simplicity of design are key factors.

Brainstorming was the creative method used in the design of SnS². Brainstorming was used to generate as many ideas as possible and as many solutions to each idea as possible. The brainstorming was conducted in a small group session of about five individuals. The author also participated in the brainstorming session. Four individuals were invited as volunteer in the brainstorming session. They were working people. Each individual was encouraged to express their ideas freely without critical judgment. Next, the recorded ideas were identified through the final discussion. Lastly, the agreed ideas were changed into five design concepts.

The morphological chart (Pugh, 1990; Cross, 2008) is a method used to combine design ideas in a systematic way. The combined ideas generate a solution as well as search for possible new solutions. The morphological chart of the airbag system for SnS² is shown in Figure 3.14. The sub-functions identified are material, control medium, shape, feedback system and actuator. For each sub-function, there are between two to four solutions being generated. The combinations of the final solutions were highlighted. The final concept of the airbag system is an airbag that is made from polyester and rectangular in shape. The polyester has been chosen because it is easy to purchase from a shop and low cost. The airbag is rectangular in shape because it is easy to seal with the heat sealer machine. The air had been chosen as control medium because of the simplicity of design and control, good in reliability and safety (Wikipedia, 2010b). An air pressure sensor was selected to detect the air pressure change inside the airbag. A proportional valve was used to control the deflation and inflation of the airbag proportionally. An Arduino (Arduino, 2010) with an embedded ATmega microcontroller was chosen to be the main controller for SnS².

Table 3.2 The morphology chart for SnS² airbag prototype.

Solution	1	2	3	4
Sub-function				
Material	Polyurethane	Natural rubber	Neoprene	Polyester
Control medium	Liquid	Air		
Shape	Round	Rectangular	Triangular	Cylindrical
Feedback system	Air pressure sensor	Load cell	Membrane potentiometer	
Actuator	Directional valve	Proportional valve		
Microcontroller	ATmega	PIC	ARM	Motorola
Programming language	C++	Arduino	Java	Processing

3.4.3 Final Concept and Design

In the final concept, five design concepts were generated. The explanations of concepts are as follows:

Concept 1: there are two cushions that support the neck on the left side and the right side. Both cushions are static.

Concept 2: there is only one neck support cushion. It is cylindrical in shape and placed between head and shoulder. The cushion is static.

Concept 3: there are two cylindrical shaped side supports. Each side support is rectangular in shape. Both side supports are placed on the left and the right side of the head. Both airbags are parallel with each other. Both side supports can be activated mechanically.

Concept 4: there are two rectangular shape side supports. The side supports are placed on the left and the right side. Both side supports are activated at the same time. Both side supports are powered by compressed air. The air flow to the airbags is controlled by a directional valve. The microcontroller is ATmega and the programming language is *Processing*.

Concept 5: there are two rectangular shape side supports. The side supports are placed on the left and the right side of head. Each side support can be tilted and activated differently in order to support the head effectively. Both side supports are powered by compressed air. The air flow to the airbags is controlled by a proportional valve. The air pressure is measured by the air pressure sensor. A membrane potentiometer is used to detect the presence of passenger. The microcontroller is ATmega. The programming languages are *Processing* and *Arduino*.

Concepts Evaluation

The evaluation of the five concepts was carried out by using the weighted objective method (Pugh, 1990). The five concepts were evaluated based on the requirements as shown in Table 3.1. The evaluation of the five concepts is shown in Table 3.3. Eight requirements have been set to evaluate the five concepts. Each element was provided with relative weight e.g. performance (0.20), materials (0.10), size (0.10), reliable (0.20), weight (0.05), strength (0.15), safety (0.05) and design (0.15). Two requirements, namely performance and reliable, were rated with highest weight because the SnS² prototype should be functional and support the passenger’s head as well as reliable during the validation experiment. During the brainstorming session, each concept is rated with scores (S) using ten point scales. Each point is multiplied by the objective weight to give relative values (V). Each value is summed up to get the total value for each concept. Subsequently, the total values for each concept are compared and the highest values are selected. Concept 5 as shown in Table 3.3 represented the highest values and was selected as best concept. Concept 5 was selected because the concept is able to perform with good functionality, cost effective material, adjustable size, reliable, light weight prototyping material, good strength, safe and easy to maintain. The solid modeling software, namely SolidWork, was used to visualize concept 5 in three dimensions (3D) as shown in Figure 3.19. The exploded view of the SnS² prototype is shown in Figure 3.20.

Table 3.3 Weighted objective evaluation of SnS² prototype concepts.

No.	Element	Weight	Concept 1		Concept 2		Concept 3		Concept 4		Concept 5	
			S	V	S	V	S	V	S	V	S	V
1.	Performance	0.20	2	0.40	2	0.40	5	1.00	5	1.00	6	1.20
2.	Materials	0.10	3	0.30	2	0.20	4	0.40	4	0.40	4	0.40
3.	Size	0.10	5	0.50	2	0.20	5	0.50	6	0.60	6	0.60
4.	Reliable	0.20	5	1.00	3	0.60	3	0.60	5	1.00	5	1.00
5.	Weight	0.05	4	0.20	5	0.25	3	0.15	3	0.15	4	0.20
6.	Strength	0.15	3	0.45	2	0.30	4	0.60	4	0.60	5	0.75
7.	Safety	0.05	3	0.15	2	0.10	3	0.15	4	0.20	4	0.20
8.	Design	0.15	3	0.15	3	0.45	4	0.60	4	0.60	5	0.75
Total value			3.15		2.50		4.00		4.55		5.1	

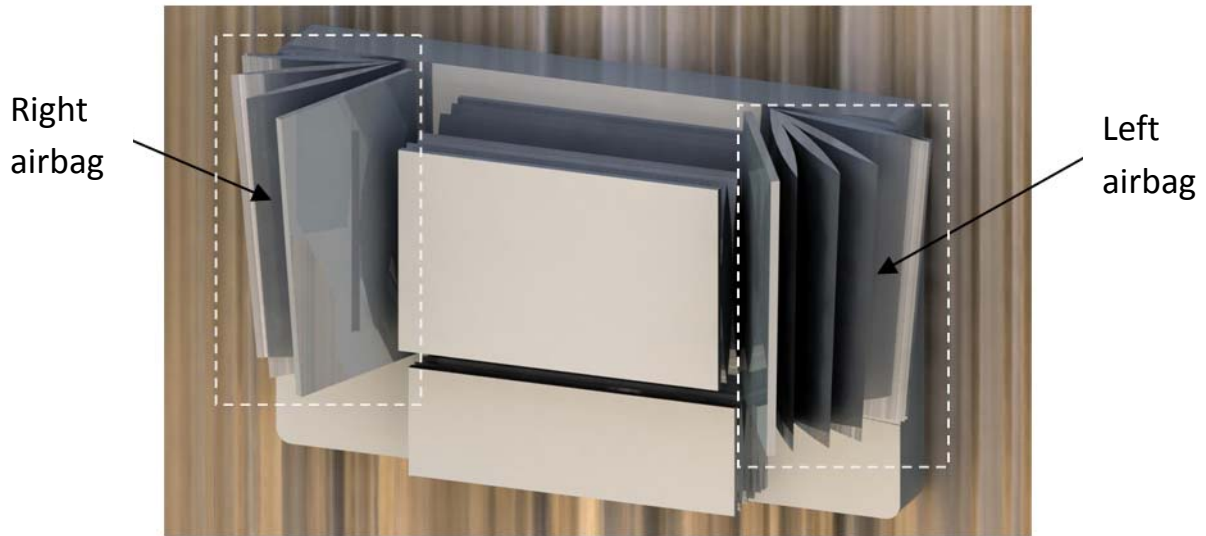


Figure 3.19 The 3D isometric view of SnS² prototype.

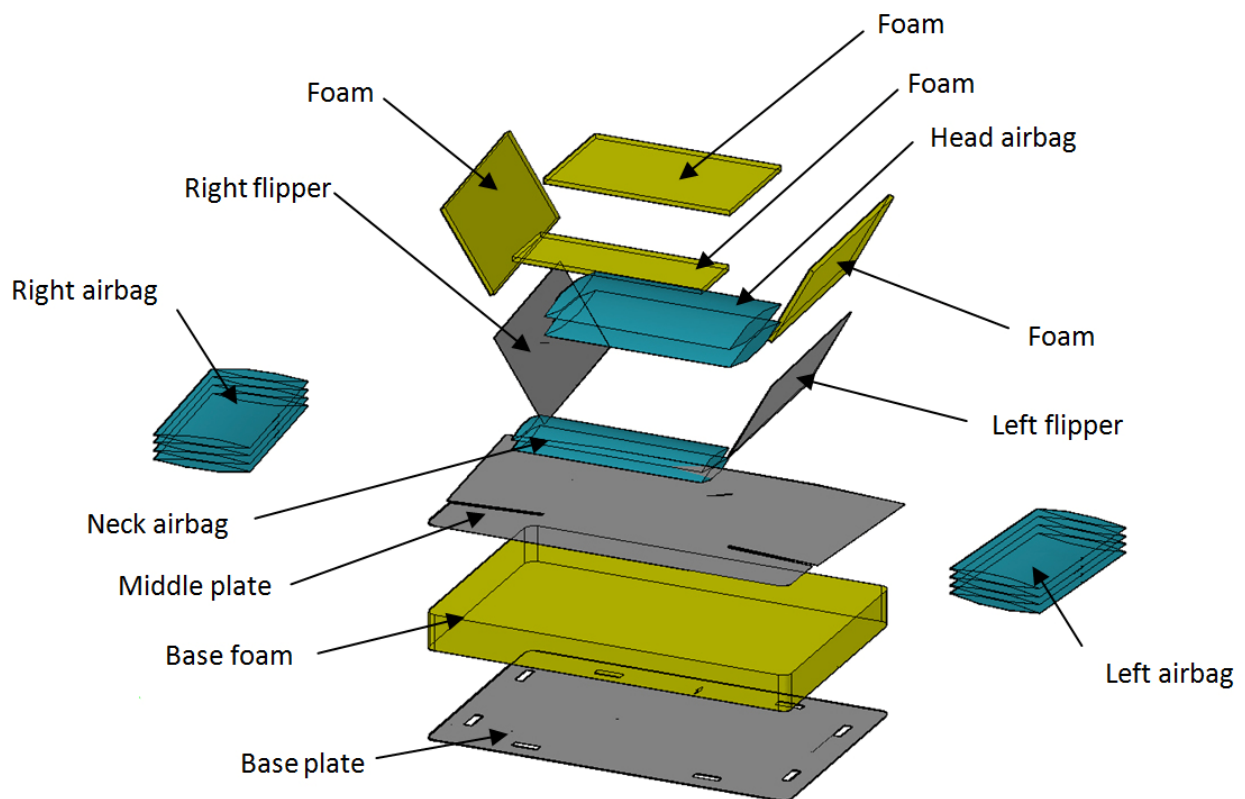


Figure 3.20 The exploded view of SnS² prototype.

Based on the evaluation results, the smart neck support system prototype was built. Figure 3.21 shows the first SnS² prototype. Figure 3.22 shows the installation of the final SnS² prototype to the economy class seat in the aircraft cabin simulator. Figure 3.23 shows an overview of the final SnS² prototypes in the aircraft cabin simulator for experimental purpose.

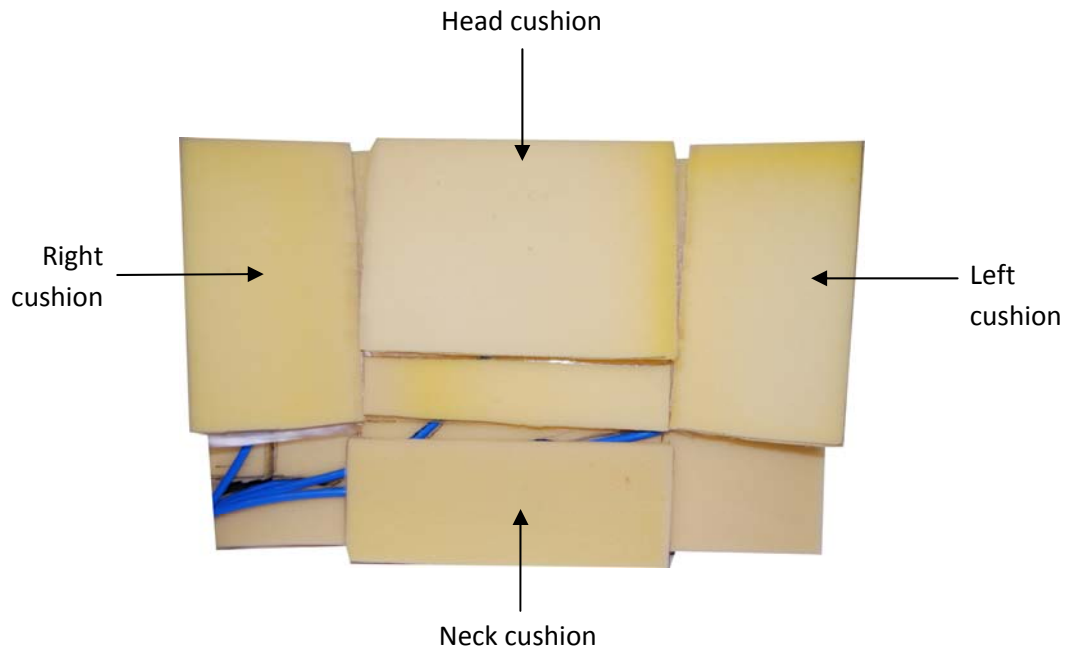


Figure 3.21 The first SnS² functional prototype.



Figure 3.22 The installation of the final SnS² functional prototype to the economy class seat in the aircraft cabin simulator.



Figure 3.23 Three SNS² prototypes embedded in an economy class aircraft seat.

3.5 PROTOTYPE

The final prototype setup is a smart neck support system that contains a head cushion, a neck cushion, two side airbags, a microcontroller with sensors and actuators connected. Figure 3.24 illustrates a block diagram to visualize the information flow of SnS².

As illustrated in Figure 3.24, the information flows from microcontroller to transformer and proportional solenoid valves or from sensors to microcontroller as well as from microcontroller to and from computer. The air pressure sensors measure the air pressure change in the airbag and send the analog data to the microcontroller. The analog data from the sensor are converted to digital form and then processed by the microcontroller. The digital data are mediated between microcontroller and computer. The computer acts as a database to

record the sensor data and provide input to the microcontroller as well. After the microcontroller processes the sensor data, analog data are sent to the proportional solenoid valve through a transformer. The transformer is a custom made device that acts as a medium between 12 volts microcontroller and 24 volts proportional solenoid valve.

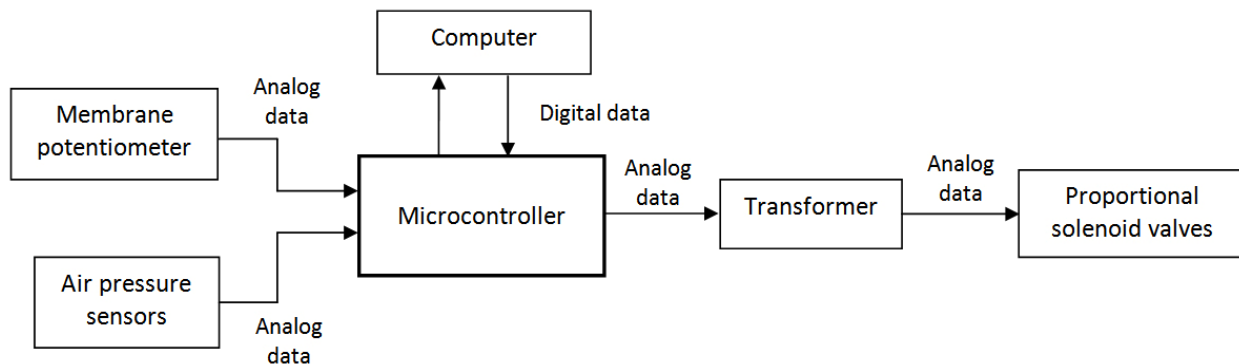


Figure 3.24 Block diagram of information flow.

3.5.1 Hardware

Arduino Mega (Arduino, 2010), transformer, air pressure sensor and proportional solenoid valve were used to build the control system for SnS². The Arduino MEGA is a microcontroller board based on the ATmega1280. It has 54 digital input/output pins (of which 14 can be used as pulse with modular outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header and a reset button. Arduino is an open-source electronic device that used for prototyping purpose. The Arduino receives input from sensors and controls the output such as actuator and valve. The communication between the Arduino Mega and the computer is using 9600 baud via USB cable.

The pneumatic control unit² (Figure 3.25) is a device used to mediate between the Arduino Mega and the proportional solenoid valve. The pneumatic control unit consists of the transformer and the Arduino Mega. The transformer receives

² The pneumatic control unit was designed by Geert van den Boomen and the author.

12 volts analog data from Arduino Mega and output 24 volts analog data to the proportional solenoid valve. Both Arduino Mega and transformer is the pneumatic control unit for SnS².

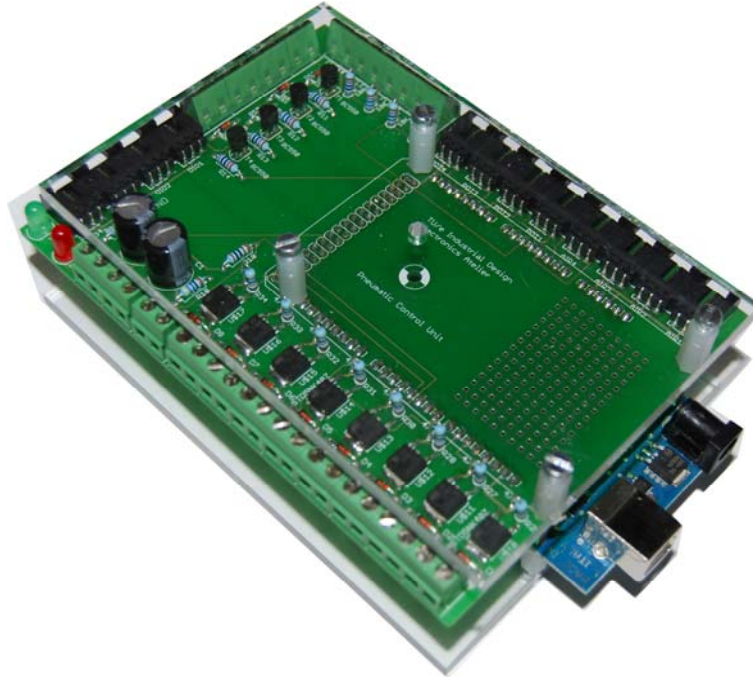


Figure 3.25 The pneumatic control unit.

The air pressure sensor is a Phidget 1115 (Phidget, 2010) type sensor that is used to measure the air pressure inside the airbag. It measures absolute gas pressure from 20 to 250 kPa with a maximum error of $\pm 1.5\%$. The air pressure sensor is a ratiometric sensor. The membrane potentiometer is a sensor embedded in the head cushion and used to detect the presence of the passenger. The resistance of the membrane potentiometer can be changed linearly from 100 Ohms to 10,000 Ohms (Eztronics, 2010).

Since the airbag is powered by compressed air, the pneumatic system as shown in Figure 3.26 is setup. A compressed air cylinder provides the necessary compressed air to the airbag. The air service unit is filtered and it cleans the compressed air from compressed air cylinder. Two proportional solenoid valves (SMC PVQ33-5G-16-01F) are used to control the air flow into and from the airbag. The vacuum pump is used to deflate the airbag.

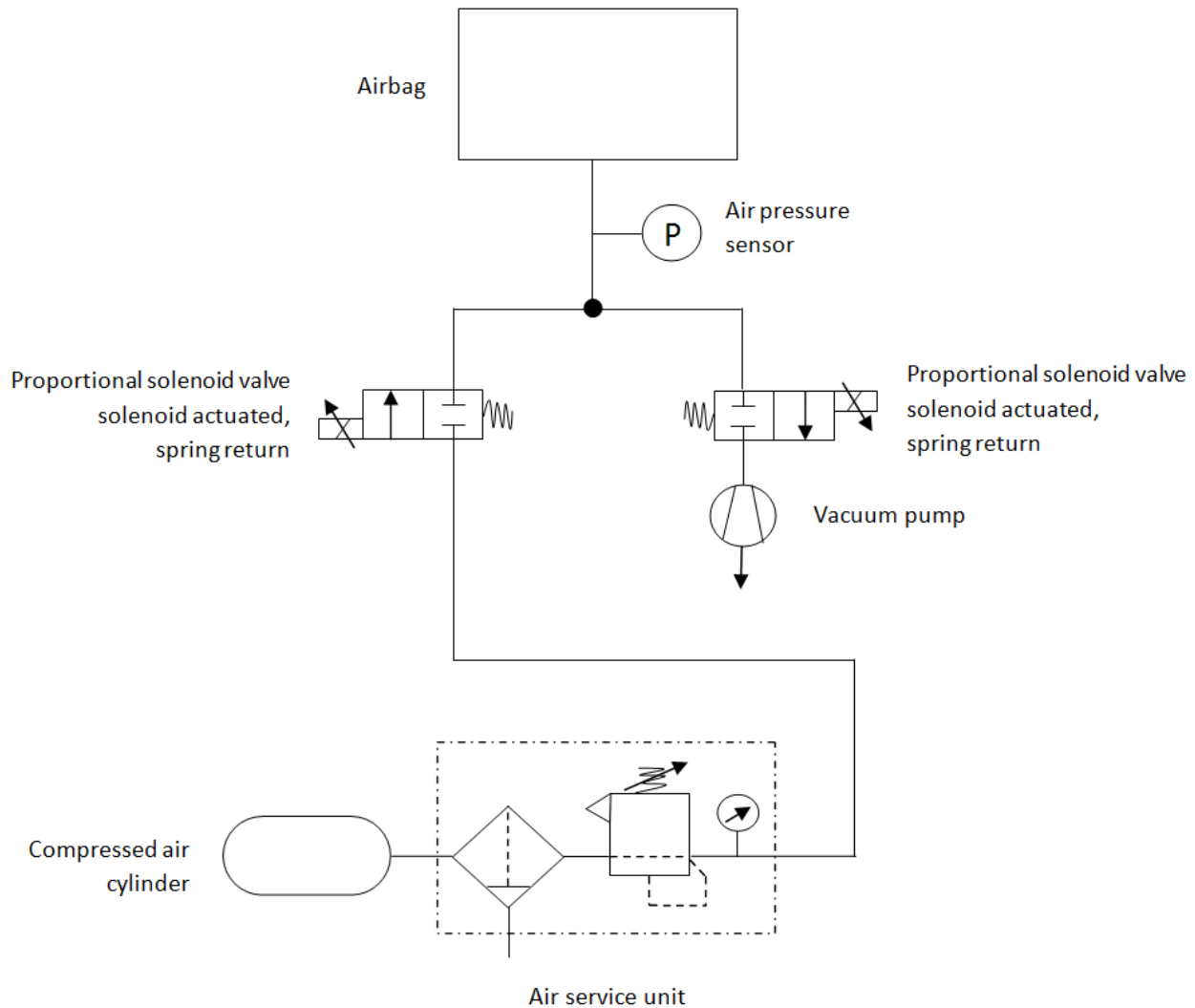


Figure 3.26 The pneumatic system for the airbag.

3.5.2 Software

The software is an integral part of SnS². It enables different components to be controlled and integrated in the way best suited to the functions of the smart neck support system, ensuring data flow and information flow throughout the system. The aims of the developed program are to control the right and the left airbag of SnS².

In term of programming implementation, two programming languages were used in the SnS² prototype. Arduino programming language (Arduino, 2010) was used to program the Arduino microcontroller. The Arduino programming language is based on Wiring (Wiring, 2010) and the Arduino development environment was based on Processing (Processing, 2010). The Arduino programming language is an open-source program and the environment is written in Java. For the database development, we used *Processing* to write the code. Processing (Processing, 2010) is an open source programming language and environment for prototyping purposes. Processing was used to log the sensors and actuators data.

3.6 RECOMMENDATION FOR FUTURE WORK

The recommendations of future work for SnS² are as follows:

- a) We recommend that the EMG sensor should be embedded in the airbag surface in order to detect the neck muscle stress directly. With the EMG sensor contact with passenger's neck, the system is able to provide necessary support to the passenger based on the current neck condition.
- b) Further development of SnS² is required to provide the user customization of the neck support angle and the softness of the airbag. The aircraft passenger can adjust the system based on his/her preference as well as let the system determine the neck support condition for the passenger.
- c) The smart system can be expanded to support other body parts such as head, body back and lumbar region. The aircraft seat cushion can be replaced with individual airbags that can support different body parts in an adaptive and autonomous way.
- d) The activation of SnS² may create noise and vibration disturbance to the passenger. The SnS² can be more user-friendly and more comfortable through sound proof and vibration absorption mechanism such as using soft material.
- e) The air pressure sensor of SnS² is used for prototyping purpose only. The design of SnS² has not considered any atmospheric pressure change due to altitude factor. We recommend the application of special air pressure sensor for aviation purpose in the future.

3.7 SUMMARY

This chapter presents the development of a smart neck support system to improve the neck comfort during air travel. The architecture of SnS² described the structure of the system which consists of sensor, actuator, database and central processor. The framework showed the behavior of the developed system that can improve the aircraft passenger neck comfort. The state transition diagram was used to describe the behavior of SnS². Four transition states were designed and implemented. The air pressure detection model was related to the airbag system. The air pressure detection model is used for the implementation of SnS², the airbag is capable to detect the passenger's posture and support the passenger's neck adaptively. Next, mechanical model was developed to predict the behavior of the airbag system. We also presented the development of SnS² using the total design method. The total design approach is able to guide the designer to develop the functional SnS² prototype. The total design approach is a useful tool for the development of a product from concept to functional prototype. The market survey, design knowledge and design experience were important in the first stage of the project. The product requirements provided the designer with a way to keep track of the design process. The morphological chart helped the designer to identify the various design solutions and product functions in a systematic way. The weighted objective method was used in the brainstorming and mind mapping session to generate and determine the final concept. The final setup of smart neck support system contains a head cushion, a neck cushion, two side airbags, an Arduino microcontroller with air pressure sensors and a proportional solenoid valve connected. The open-source programming language, namely Arduino and Processing, were used for programming implementation in SnS².

CHAPTER 4

DESIGN OF AN AIRCRAFT CABIN SIMULATOR

4.1 INTRODUCTION

This chapter¹ describes the design, development and implementation of an aircraft cabin simulator to validate the developed smart neck support system of Chapter 5. A testbed is a platform used for experimental purposes as well as product evaluation purposes. The aircraft cabin simulator is developed for the European Project SEAT (Smart tEchnologies for Stress free Air Travel). The SEAT project aims to develop a new radical approach through integration of cabin systems with multimedia features. Eindhoven University of Technology (TU/e) contributes as the Work Package 4 (WP4 leader). The aim of TU/e is to develop a new intelligent in-flight entertainment system where both entertainment contents and entertaining interactive patterns are sensitive to the passenger's personal information and different fly phases to address the passenger's personalized entertainment requirements (SEAT, 2010). The aircraft cabin simulator is funded by the SEAT project to test and validate the new intelligent in-flight entertainment system. The author was involved in the design and development of the aircraft cabin simulator. Due to this reason, the author developed SnS² for economy class aircraft passenger and utilized the aircraft cabin simulator to validate the SnS² prototype.

¹ This chapter is partially based on the following papers:

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Interactive aircraft cabin testbed for stress-free air travel system experiment: an innovative concurrent design approach. International Conference on Advances in Mechanical Engineering ICAME 2009, Shah Alam, Malaysia, p. 137.

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Design of aircraft cabin testbed for stress free air travel experiment. 5th International Conference on Planning and Design, Tainan City, Taiwan, p. 157.

Tan, C.F. Chen, W. and Rauterberg, M. 2009. Creative thinking of design and redesign on SEAT aircraft cabin testbed: a case study. 14th International Conference on Thinking, Kuala Lumpur, Malaysia, pp. 122-131.

Tan, C.F. Chen, W. and Rauterberg, M. 2010. Total design of low cost aircraft cabin simulator. Design 2010, Cavtat, Croatia, pp. 1721-1728.

The development of the aircraft cabin simulator is aided by computer tools such as computer-aided design (CAD) and engineering design methods under the perspective of concurrent engineering. The aim of this chapter is to describe the development and evaluation of the aircraft cabin simulator. The commercial product design method, namely total design (TD), was implemented for the development of the aircraft cabin simulator. The aircraft cabin simulator is fully designed and built at Simulation Lab, Department of Industrial Design, Eindhoven University of Technology. The simulator consists of a small scale cabin-like testing platform, an inventory section, a simulation section and a control section. The interior of the aircraft cabin consists of an economy class section, a business class section, a galley and a lavatory. Each passenger seat and the lavatory are provided with a personal entertainment touch screen monitor. The inventory section is used to store the testing related equipments. A sky-like panorama projection environment is created. In addition, the simulator is built with an innovative low-cost motion platform. The motion platform is used to simulate the flight environment such as taxiing, taking off, turbulence, descending and landing. The control section is fully equipped with a state of the art computer system that is used to control and monitor the simulator remotely. The aircraft cabin simulator was evaluated with ten hours of experiments. A presence questionnaire was used to examine the simulator and the result was statistically analysed.

4.2 RELATED WORK

4.2.1 The Current Application of Aircraft Cabin Simulator

Flight simulation is an important activity of aeronautical research. Flight simulation uses a highly complex system to simulate the real aircraft environment. Simulation enables the aviation researcher to evaluate a new system in a safe environment without endangering the test subject. Simulation also provides experimental data in a short time and saves cost (Rehmann, 1995).

Aircraft cabin simulators have different applications and purposes such as training and research. Czech Airlines is equipped with a cabin simulator for the Airbus

A320 series aircraft. The cabin is used to train the cabin crews and the pilots. Besides, the cabin is also used by public and standard on-board passenger services. The simulator (Figure 4.1) used by Czech Airlines is mounted on a movable base, which enables it to simulate realistic flight conditions. The motion of the cabin simulator is using hydraulics as control medium. Some aircraft windows are also replaced with monitors for flight simulation views (Czech Airlines, 2009).



Figure 4.1 The aircraft simulator of Czech Airlines (Photograph reprinted from Czech Airlines, 2009).

United Airlines Training Centre is equipped with an aircraft simulator for training purpose. The simulator is a mockup of a Boeing 747 passenger cabin. United Airlines uses the cabin to train their cabin crews. The interior of aircraft simulator is the same as the real aircraft cabin. It allows United Airlines to train their cabin crew in a small group and large groups of passenger environment (United Airlines, 2009).

Cranfield University houses two aircraft cabin simulators, the Large Cabin Evacuation Simulator (Figure 4.2) and the Boeing 737 cabin simulator. Both of these simulators are used to conduct research on cabin safety. The aircraft cabin simulators are equipped with video cameras to observe and record the

experiment. Both aircraft cabin simulators were not installed with motion platform (Cranfield University, 2009).



Figure 4.2 Aircraft cabin simulator in Cranfield University (Photograph reprinted from Cranfield University, 2009).

Experiments in an aircraft cabin simulator (Figure 4.3) by Weber et al. (2004) are carried out to study the effects of controlled variation of environmental factors (air temperature & humidity; noise and vibration) on the comfort of passengers, flight and cabin crew. The simulator is part of an Airbus A300 B4.

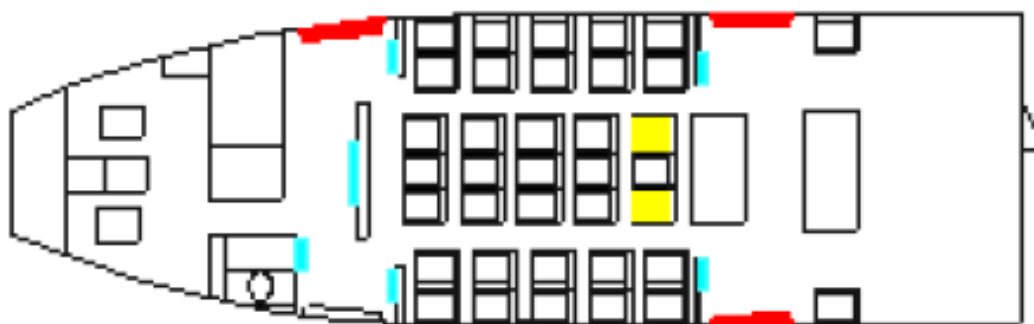


Figure 4.3 Schematic of aircraft cabin environment (Figure reprinted from Weber et al., 2004).

European project HEACE investigating the relation between environmental parameters in cabin and cockpits. The researches were conducted in simulators.

The pre-tests were carried out in the emergency trainer of Austrian Airlines (Figure 4.4 (a)) and main simulator test at Watford (Figure 4.4 (b)) (Millers et al., 2008).



(a)



(b)

Figure 4.4 Emergency trainer of Austrian Airlines (left) and test rig at BRE (right) (Photographs reprinted from Mellert et al., 2008).

Zhang et al. (2009) studied the airflow and contaminant transport in airliner cabins in a full-sized twin-aisle aircraft cabin mockup. The aircraft cabin mockup (Figure 4.5) was constructed inside the chamber. The cabin mockup had four rows with 28 passenger seats.



Figure 4.5 The cabin mock-up (Photograph reprinted from Zhang et al., 2009).

In the study by Wang et al. (2008), the aircraft cabin (Figure 4.6) containing 35 mannequins were used to investigate the ventilation effectiveness and characterize the air distribution. The aircraft cabin simulated a Boeing 767-300. The wooden structure of the aircraft cabin was built according to the actual dimensions of a Boeing 767-300 aircraft cabin.



Figure 4.6 The mockup of the Boeing 767-300 aircraft cabin (Photograph reprinted from Wang et al., 2008).

4.3 DESIGN METHODOLOGY OF AIRCRAFT CABIN SIMULATOR

4.3.1 Design Process

A systematic design process (Figure 4.7) is used in the development of the aircraft cabin simulator. The systematic design process is similar to the interactive design process as described by Rauterberg (2006). At the product planning stage, a market survey about the current aircraft cabin simulator was conducted. The market survey was done mainly through company information, website, patents and technical reports of the related design. The output from the design planning was the product requirements. The product requirements are useful in the early stages of conceptual design. After that, conceptual design of the simulator was generated based on the project requirements and constraints. For the detailed

design, computer-aided design (CAD) was used to generate a three dimensional (3D) view. For the final design stage, designers, builders and customers were gathered to discuss the final design in detail. In this stage, the outcome from the preliminary stage decided whether the design was going to proceed or not. During the construction stage, the aircraft cabin simulator was built. After the completion of simulator, the simulator was tested for durability and safety.

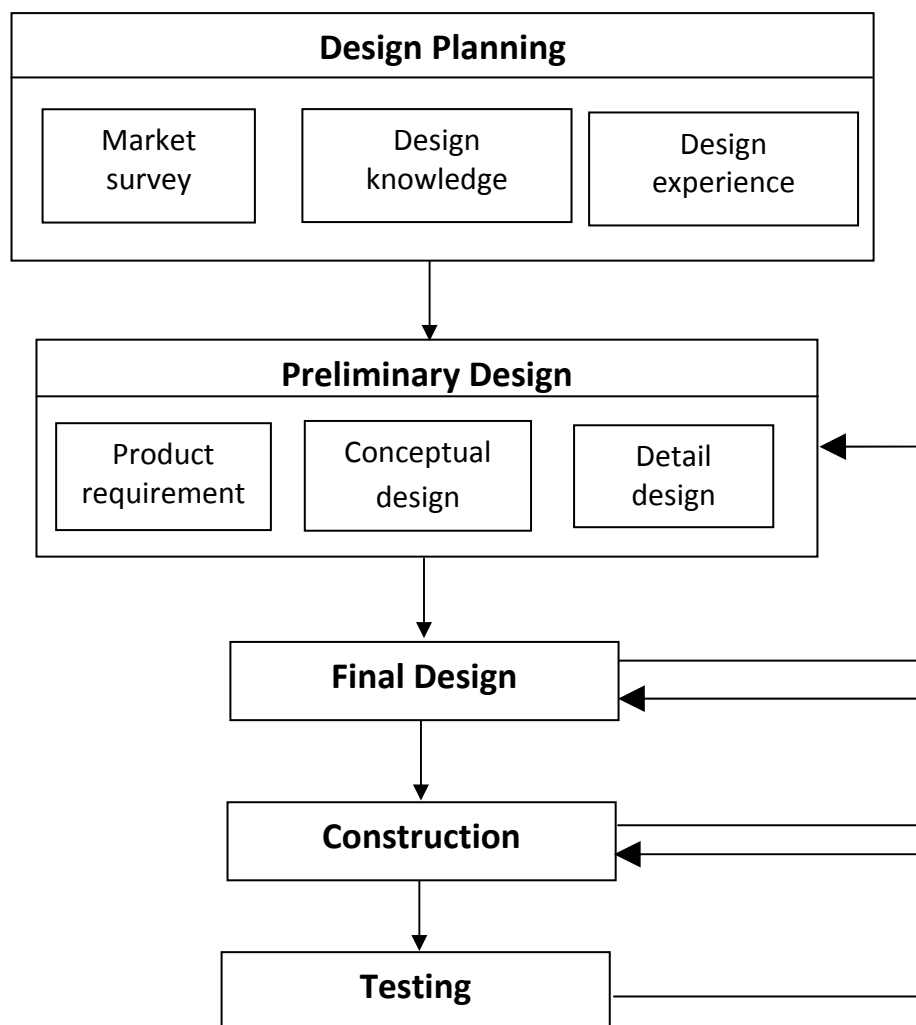


Figure 4.7 The architecture of the aircraft cabin simulator design process.

4.3.2 Preliminary Design

In the preliminary design stage, the product requirements (Table 4.1) were derived as a design guideline for the aircraft cabin simulator.

Table 4.1 The requirements for the aircraft cabin simulator.

No.	Elements	Description
1.	<i>Performance</i>	The simulator is able to work during the experiments without failure. The simulator also provides a real flight experience such as motion, sound and temperature.
2.	<i>Materials</i>	The simulator is constructed from a mixture of low cost and durable materials. These materials are selected from European Standards.
3.	<i>Size</i>	The simulator must be able to fit into the provided space in the Simulation Lab.
4.	<i>Weight</i>	The floor at the Simulation lab is able to withstand the simulator weight without failure. The structure of the simulator foundation is able to withstand the loads e.g. equipments and participants.
5.	<i>Strength</i>	The construction should be designed to withstand the loads, shocks and vibrations that occur during experiments.
6.	<i>Safety</i>	Safety is an integral part of all aspects of design. Due consideration should be given to the safety of all personnel whether operating the equipment, maintaining the equipment or during the experiment.
7.	<i>Design</i>	In the interests of production, reliability and maintainability, simplicity of design is a key factor. Features such as modular packaging and a wiring interface which simplifies future expansion or modifications, are standard practices applied within the design review
8.	<i>Cost</i>	The total cost to build the simulator must be within the limited budget of the SEAT project.

4.3.3 Conceptual Design

The design and development of the aircraft cabin simulator encountered different kinds of problems which needed to be tackled in a stepwise manner. Before the design of a simulator, the designer needed to have the following:

- Confidence that the simulator can be built
- Knowledge of how it will be built
- Knowledge of cost
- Knowledge of the usage of the simulator
- Knowledge of material source and supplier
- Knowledge of the materials that might be used and their properties
- Knowledge of the part dimensions and specifications
- Definition of component design requirements
- Knowledge of experts for information
- Knowledge of location specifications
- Knowledge of problems and constraints
- Knowledge of duration
- Need for verification of performance by computer-aided engineering

Methodology

The development of a product employs different methodologies for the concept generation. Three methods, namely brainstorming, objective tree method and morphological chart, were used in the conceptual design stage of the aircraft cabin simulator. The brainstorming sessions involved three members of SEAT project. The brainstorming was conducted during each group meeting. During the brainstorming sessions, each member expressed their ideas freely. Each idea was recorded and agreed ideas were developed into five design concepts.

The objective tree method was used to classify the objectives of an aircraft cabin simulator in a diagram as shown in Figure 4.8. It shows the relationships between each objective and the sequence of objectives. The objective tree is used to present clearly the project objectives in a systematical way.

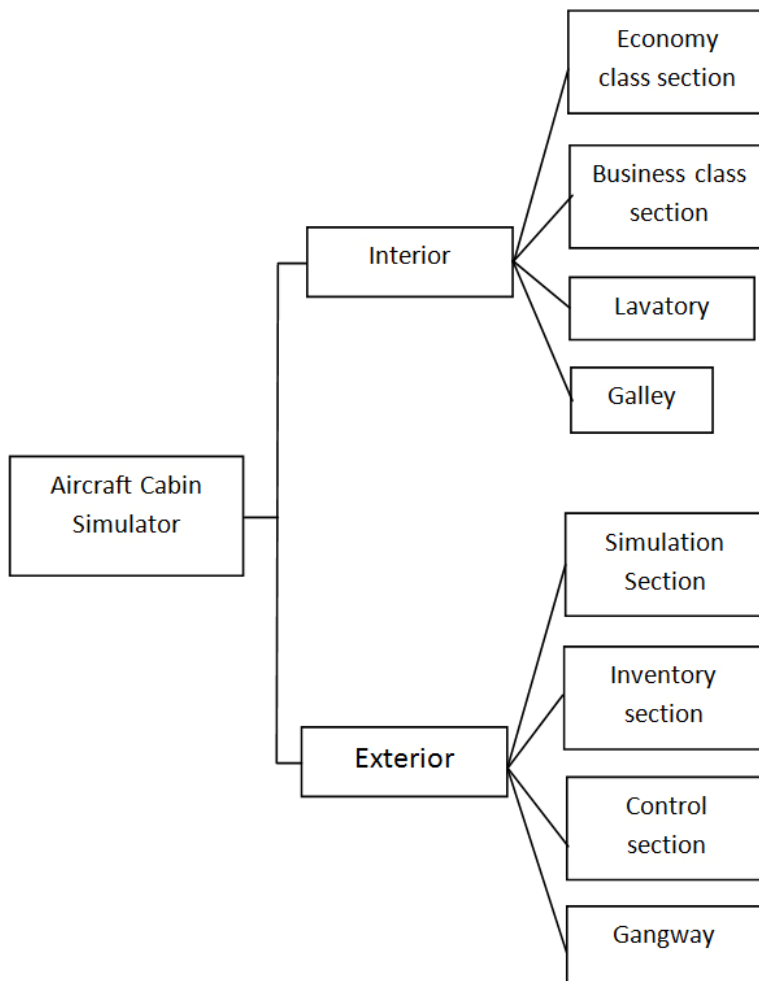


Figure 4.8 The objective tree of the aircraft cabin simulator.

Concept Development

Economy class section concept

Morphological chart method is used to generate alternative designs for each function of the economy class section. The morphological chart of the economy class section is shown in Table 4.2. The sub-functions identified are interior lighting, dim light, floor type, observation system, interior color and wall. For each sub-function, between two to four solutions are generated. The combinations of final solutions are highlighted. The descriptions of final concepts for economy class section are as follows:

- a) Interior lighting: the fluorescent lamp was selected because it is similar to the lighting in a real aircraft cabin.
- b) Dim light: the incandescent light was selected because it is similar to the dim light color in a real aircraft cabin and the illumination can be controlled.
- c) Floor type: the carpet was selected similar to a real aircraft cabin floor type.
- d) Observation system: the closed circuit television (CCTV) is selected because CCTV is more reliable than web cam and it can record the video.
- e) Interior color: The beige color was selected to match the interior color of a real aircraft cabin.
- f) Wall: The curtain and printed paper were selected. The curtain is used to cover the secondary exit of the aircraft cabin simulator. The wall behind the economy class aircraft seat was attached with a color printed paper to extend aircraft cabin view (Figure 4.9) enhancing the view in psychological sense.

The economy class aircraft seats (two row of three seats), luggage compartment and window panels were second hand aircraft cabin items. The design of economy class section is to simulate the standard economy class cabin.

Table 4.2 Morphological chart of the economy class section.

Solution Sub-function	1	2	3	4
Interior lighting	Electroluminescent lamp	Fluorescent lamp	High-intensity discharge lamp	Incandescent lamp
Dim light	Electroluminescent lamp	Fluorescent lamp	High-intensity discharge lamp	Incandescent lamp
Floor type	Carpet	Wood	Resilient	
Observation system	Web cam	CCTV	Digital video	
Interior color	White	Beige		
Wall	Curtain	Printed paper		



Figure 4.9 The wall with extended aircraft cabin view.

Business class section concept

The functions selected for the business class section are almost the same as the economy class section. Factors like interior lighting, dim light, floor type, observation system, seat type and television type were considered. Similarly, two to five solutions are generated and finally combinations of solutions from each function are chosen for the final concept. The selected concepts are indicated by highlighting as shown in Table 4.3. The selection for interior lighting, dim light, floor type, observation system and interior color were the same as the description in economy class section concept. The descriptions of the final concepts for business class section are as follows:

- a) Seat type: the home massage seat was selected because it is similar to the first and business class seat available in a real aircraft cabins. Besides, the home massage seat provides body massage function as well as adjustable functions. A real aircraft first and business class seat was not possible to

select due to the shortage of second hand supplied and expensive for a new seat.

- b) Television type: the ambient liquid crystal display television was selected because it can create a special environment with ambient light effect for future research.
- c) Door type: sliding door was selected because this door type saves cabin space and is easy to open.

Table 4.3 Morphological chart of the business class section.

Solution Sub-function	1	2	3	4
Interior lighting	Electroluminescent lamp	Fluorescent lamp	High-intensity discharge lamp	Incandescent lamp
Dim light	Electroluminescent lamp	Fluorescent lamp	High-intensity discharge lamp	Incandescent lamp
Floor type	Carpet	Wood	Resilient	
Observation system	Web cam	CCTV	Digital video	
Interior color	White	Beige		
Seat type	Aircraft business class seat	Aircraft first class seat	Home massage seat	Sofa seat
Television type	Liquid crystal display	Plasma	Ambient liquid crystal display	
Door type	Sliding	Folding	Hinged	

Galley concept

For the galley, some similar functions as in the economy class section are used. The morphological chart of the galley is shown in Table 4.4. The descriptions of the final concepts for the business class section are as follows:

- a) Interior lighting: the high-intensity discharge lamp was selected because it is a match with the real galley lighting color.
- b) Floor type: the carpet was selected to match the floor in a real aircraft cabin.
- c) Interior color: the silver color was selected because it matches with the color in a standard aircraft galley.
- d) Refrigerator: the small size home refrigerator was selected because the power supply to the aircraft cabin simulator is 220 volts.
- e) Food warming apparatus: the combination microwave oven was selected because it can provide food heating in two ways.
- f) Basin type: the basin without water supply was selected because the basin is just used to dispose waste water.

Table 4.4 Morphological chart of the galley section.

Solution Sub-function	1	2	3	4
Interior lighting	Electroluminescent lamp	Fluorescent lamp	High-intensity discharge lamp	Incandescent lamp
Floor type	Carpet	Wood	Resilient	
Interior color	White	Beige	Silver	
Refrigerator	Table	Bar	Camping	Home
Food warming apparatus	Combination microwave oven	Electric oven	Microwave oven	
Basin type	With water supply	Without water supply		

Lavatory concept

The morphological chart of the lavatory concept is shown in Table 4.5. The descriptions of the final concepts for lavatory section are as follows:

- a) Interior lighting: the fluorescent lamp was selected to match with the standard aircraft.
- b) Floor type: the resilient floor was selected because it is water resistant.
- c) Interior color: the flax color was selected to match with standard lavatory color.
- d) Toilet type: the camping chemical toilet was selected because the aircraft cabin simulator is located in a room without a waste water disposal system.
- e) Basin type: the camping type plastic basin was selected because it is light weight and easy to install.
- f) Water type: the cold and warm water was used to match with the water supply in standard aircraft lavatory.

Table 4.5 Morphological chart of the lavatory section.

Solution Sub-function	1	2	3	4
Interior lighting	Electroluminescent lamp	Fluorescent lamp	High-intensity discharge lamp	Incandescent lamp
Floor type	Carpet	Wood	Resilient	
Interior color	White	Beige	Silver	Flax
Toilet type	Dry (home)	Flush (home)	Compositing (home)	Chemical (camping)
Basin type	Stainless steel (home)	Ceramic (home)	Plastic (camping)	
Water type	Cold	Warm	Cold and warm	

Inventory section concept

The inventory section is used to place the main controller of the motion platform system for aircraft cabin simulator. This section also stores the compressed air cylinder and simulator related items such as extra window panels and maintenance equipment.

Projection section concept

The projection section is to project the airport and sky-like panorama view outside the cabin. The morphological chart of projection section is shown in Table 4.6. The selected concepts are highlighted. The descriptions of the final concepts for the projection section are as follows:

- a) Wall color: white color was selected because it can provide better brightness and reflection than other colors.
- b) Projection distance: short distance was selected because the aircraft cabin simulator is located in a small room.
- c) Projection angle: wide angle was selected because the projector needs to project the video for 6100 mm width which is the width of the whole simulation lab.
- d) Projector type: short focus projector was selected because it can project the video over a short distance and in a wide angle.
- e) Projection fitting location: the simulation room ceiling was selected because the projection from this location will not interfere with the aircraft cabin simulator structure and movements.
- f) Speaker type: the computer multimedia speaker was selected because it can provide the required sound volume as well as is cost effective.

Table 4.6 Morphological chart of the projection section.

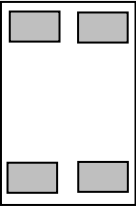
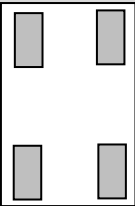
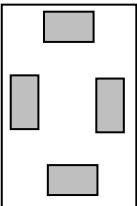
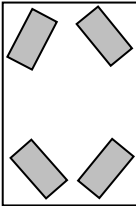
Solution Sub-function	1	2	3	4
Wall color	White	Grey	Light blue	Tan
Projection distance	Short	Normal	Long	
Projection angle	Narrow	Normal	Wide	
Projector type	Portable	Cinema	Short focus	
Projector fitting location	Floor of simulation lab	Simulator roof	Ceiling of simulation lab	Wall of simulation lab
Speaker type	Home theater system	Computer multimedia speaker	Hi-fi radio	

Motion platform concept

The motion platform is to simulate the activity of the general aircraft motion. The motion platform needs to be designed to simulate motions such as taxiing, take off, flying, turbulence, descending and landing. In addition, the motion platform needs to be cost effective. Various sub-functions were considered and evaluated. The morphological chart of the projection section is shown in Table 4.7. The selected concept is highlighted. The descriptions of the final concepts for the motion platform are as follows:

- a) Motion device: air jack was selected because it is easy to install, without any fixing on the floor, flexible and easy to maintain.
- b) Control device: programmable logic controller was selected because it is used for industrial control and it is more reliable than other devices.
- c) Control medium: air was selected because it is required to control the air jack.
- d) Arrangement of motion device: the second arrangement was selected for motion device because the arrangement is easy to install and maintain.

Table 4.7 Morphological chart of the motion platform.

Solution Sub-function	1	2	3	4
Motion device	Hydraulic cylinder	Pneumatic cylinder	Mechanical jack	Air jack
Control device	Computer	Microelectronic	Programmable logic controller	
Control medium	Oil	Air		
Arrangement of motion device				

Gangway concept

The gangway is used to simulate the standard gangway in the airport before the passengers enter the aircraft. The gangway is built with two doors, a high intensity discharge lamp, movable bridge with slope and folding curtain. The movable bridge with slope is used to bridge between gangway and the motion platform. The folding curtain is used to close the gap between gangway and aircraft cabin simulator.

Climate control concept

The climate control is to simulate the environment (temperature and humidity) in the cabin. A portable air conditioner is used to simulate the required temperature and humidity in the cabin.

4.4 CONCEPT SELECTION

4.4.1 Concept Generation

During the concept development, five design concepts were generated. All concepts are drawn in 3D view so that they can be visualized and compared. The computer-aided drawing of concept two is shown in Figure 4.10.

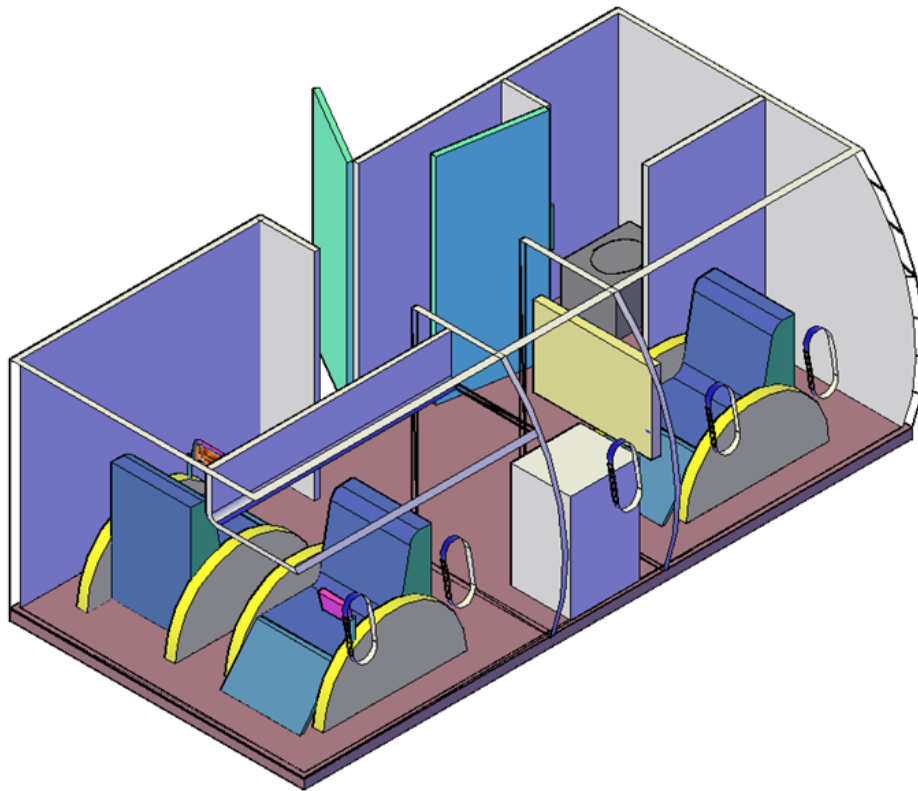


Figure 4.10 The concept two.

The detailed explanations of the concepts are as follows:

- 1) *Concept 1*: the simulator has an economy class area. There are two rows of economy class seats. New economy class seats will be used. The simulator is built with a static platform. The simulator structure is built with steel beam. Recyclable materials are used.

- 2) *Concept 2*: the simulator has a galley, a lavatory and two business class areas. There are two individual business class seats. The simulator is built with a static platform. Recyclable materials are used.
- 3) *Concept 3*: the simulator has a galley, a lavatory, an economy class area and a business class area. There are two rows of economy class seats and one business class seat. The simulator is built with a motion platform. Recyclable materials are used.
- 4) *Concept 4*: the simulator has a galley, a lavatory, an economy class area and a business class area. There is one row of economy class seats and one row of two person business class seats. The simulator is built with a motion platform. Recyclable materials are used.
- 5) *Concept 5*: the simulator has a galley, a lavatory and two economy class areas. There are two rows of economy class seats. The simulator is built with a static platform.

4.4.2 Concept Evaluation and Selection

The evaluation of the five concepts was carried out by using the weighted objective method. Seven requirements (Table 4.1) have been set to evaluate the concepts with weighted objective method. The evaluation of the five concepts is shown in Table 4.8. Each requirement was provided with relative weight, such as performance (0.20), materials (0.10), size (0.10), weight (0.05), strength (0.15), safety (0.05), design (0.10) and cost (0.25). The requirement with highest weight is 'cost' because the aircraft cabin simulator needs to be built within the limited SEAT budget. It is followed by performance and strength. The proposed aircraft cabin simulator should provide standard flight and function without any failure during the experiment. Each concept is rated with 10-point scores (S). Each score is multiplied by the relative weight to give relative values (V). Each value is summed up to get the total values for each concept. Subsequently, the total values of each concept are compared and the highest values are selected. Concept 3 as shown in Table 4.8 represents the highest values and is selected as best concept.

Table 4.8 Evaluation of the overall simulator concept using the weighted objective method.

No.	Element	Weight	Concept 1		Concept 2		Concept 3		Concept 4		Concept 5	
			S	V	S	V	S	V	S	V	S	V
1.	Performance	0.20	4	0.80	5	1.00	9	1.80	7	1.40	7	1.40
2.	Materials	0.10	4	0.40	6	0.60	7	0.70	5	0.50	6	0.60
3.	Size	0.10	6	0.60	7	0.70	8	0.80	5	0.50	7	0.70
4.	Weight	0.05	8	0.40	7	0.35	5	0.25	6	0.35	7	0.35
5.	Strength	0.15	8	1.20	8	1.20	8	1.20	7	1.05	8	1.20
6.	Safety	0.05	5	0.25	5	0.25	5	0.25	5	0.25	5	0.25
7.	Design	0.10	5	0.50	5	0.50	8	0.80	6	0.60	5	0.50
8.	Cost	0.25	9	2.25	6	1.50	6	1.50	7	1.75	8	2.00
Total value		1.00	6.40		6.10		7.30		6.40		7.00	

4.5 FINAL DESIGN AND IMPLEMENTATION

The final design of aircraft cabin simulator was tested with a CAD/CAM system and built at Simulation Lab, Department of Industrial Design, Eindhoven University of Technology. The aircraft simulator includes an economy class section (with two rows of three person economy class seats), a business class section (with a business class seat), a galley and a lavatory. The simulator is built with wood and medium density fiberboard (MDF) material. There are eight touch screens in-flight entertainment systems one for each passenger as well as one inside the lavatory. The foundation was enhanced to withstand the dynamic impact that is caused by the motion action. The overall setup of the aircraft cabin simulator laboratory is shown in Figure 4.11. The final design of aircraft cabin simulator from top view is shown in Figure 4.12.

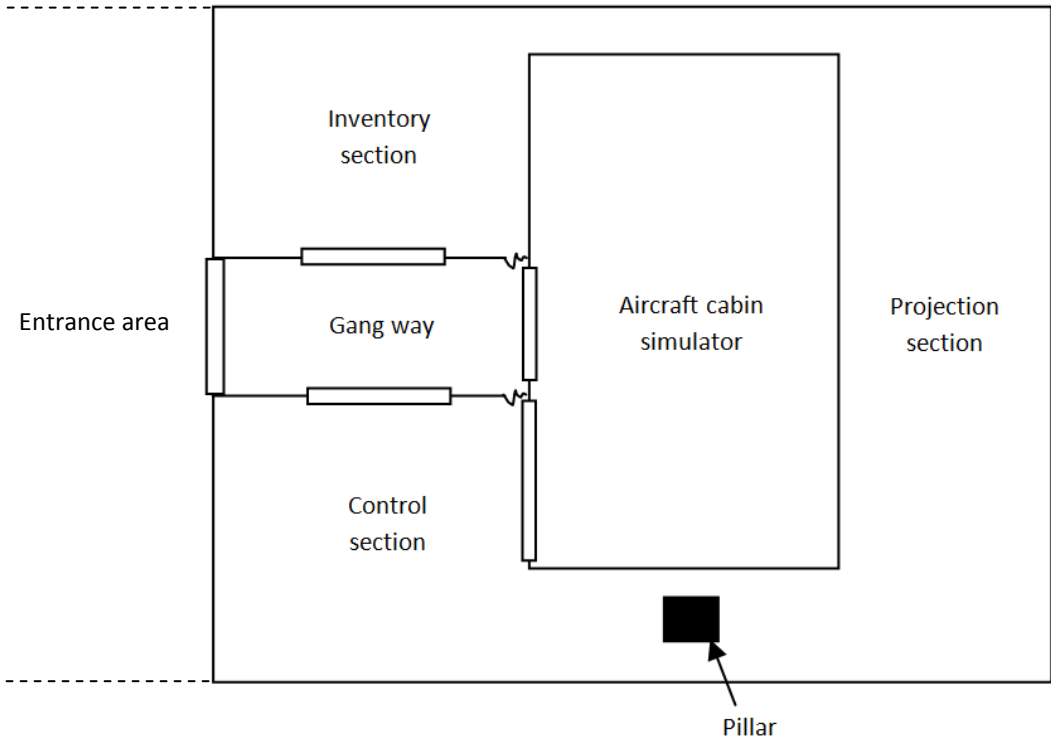


Figure 4.11 The overall setup of aircraft cabin simulator in the simulation lab.

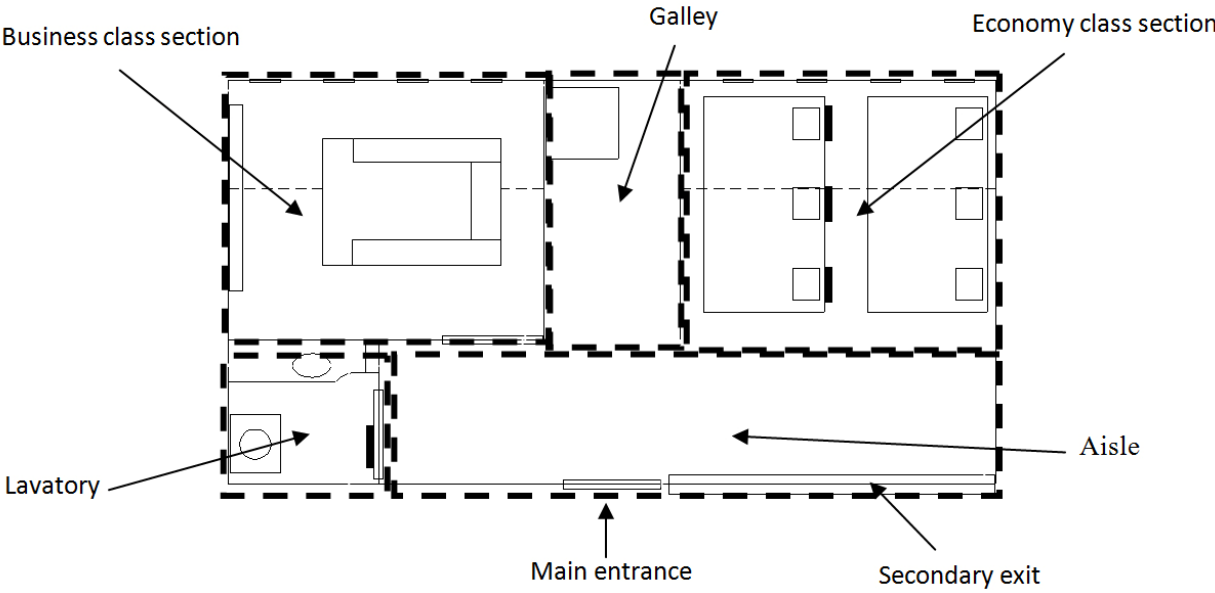


Figure 4.12 The final design of cabin layout from top view (not to scale).

The business class section (Figure 4.13) is equipped with a massage chair, a touch screen monitor, a high quality surround sound system and a 47 inches ambient LCD television. The setup will be used for future research purposes. In the economy class section (Figure 4.14), two rows of economy class seats were set up; each of the seats was equipped with a touch screen monitor and a noise reduction ear phone. The seat was embedded with a series of sensors to detect the physiological and posture change of the passenger.



Figure 4.13 Business class section.



Figure 4.14 Economy class section.

The simulator was designed with a galley function (Figure 4.15) with the setup of a compartment to store items. The compartment is a second hand aircraft storage compartment. The galley is also equipped with a refrigerator and a combination microwave. The galley was used to provide the food and beverage to the participants during the experiments. The lavatory (Figure 4.16) was equipped with a chemical toilet, a wash basin and a touch screen monitor. Both galley and lavatory were purposely built for the passengers of long haul flight experiments. The external view of aircraft cabin simulator is shown in Figure 4.17 and the internal view of aircraft cabin simulator is shown in Figure 4.18.



Figure 4.15 Galley.



Figure 4.16 Lavatory.



Figure 4.17 External view of the aircraft cabin simulator at projection side.



Figure 4.18 Overall internal view of the aircraft cabin simulator.

4.5.1 Motion Platform

The motion platform is designed to move in 5 axis (X, Y, Z, A and B) as shown in Figure 4.19. The movement of the testbed can be manually controlled or automatically controlled. An industrial automation device, namely programmable logic controller, is used to control the motion. The airbags for the motion platform are commercial available air jacks for off-road vehicles. The specification of the airbags is shown in Table 4.9.

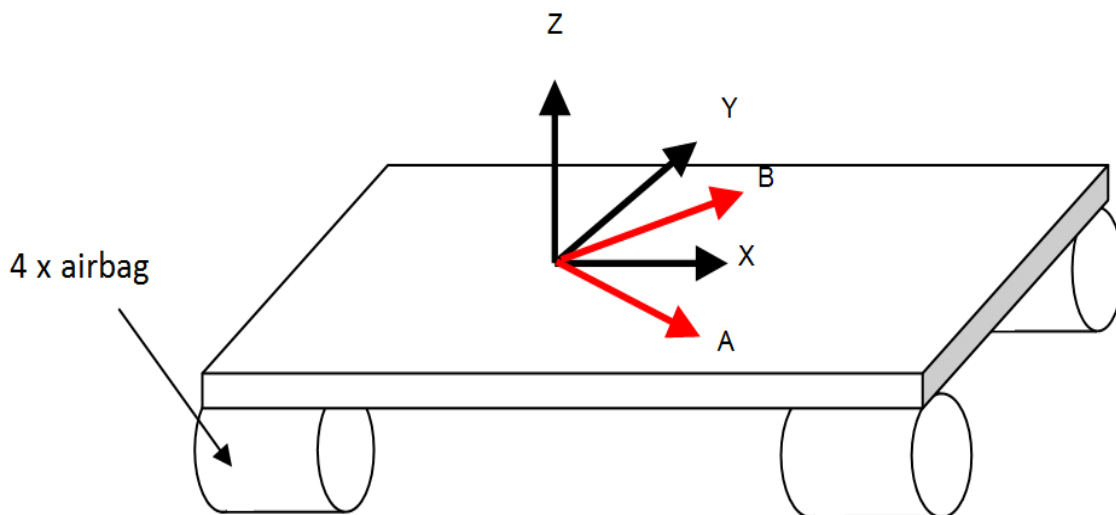


Figure 4.19 The schematic of the motion platform.

Table 4.9 The specification of the airbag.

Materials	Reinforced PVC
Height, H	750 mm
Diameter, D	600 mm
Volume, V	212 liter
Capacity	4000 kg
Working pressure	69 KN/m ²

The industrial automation device, namely programmable logic controller (Panasonic FP-X C30R) is used to control the motion of the simulator. The movement of the aircraft cabin simulator can be manually controlled or automatically controlled. A compressed air cylinder with 200 bars was used to supply the air into the four airbags. Four proportional solenoid air valves with air return (Festo CPE24-M3H-3GLS-QS-10) were used to inflate and deflate the airbags. A personal computer was used to update the program and monitor the motion platform. The architecture of the motion platform system is shown in Figure 4.20.

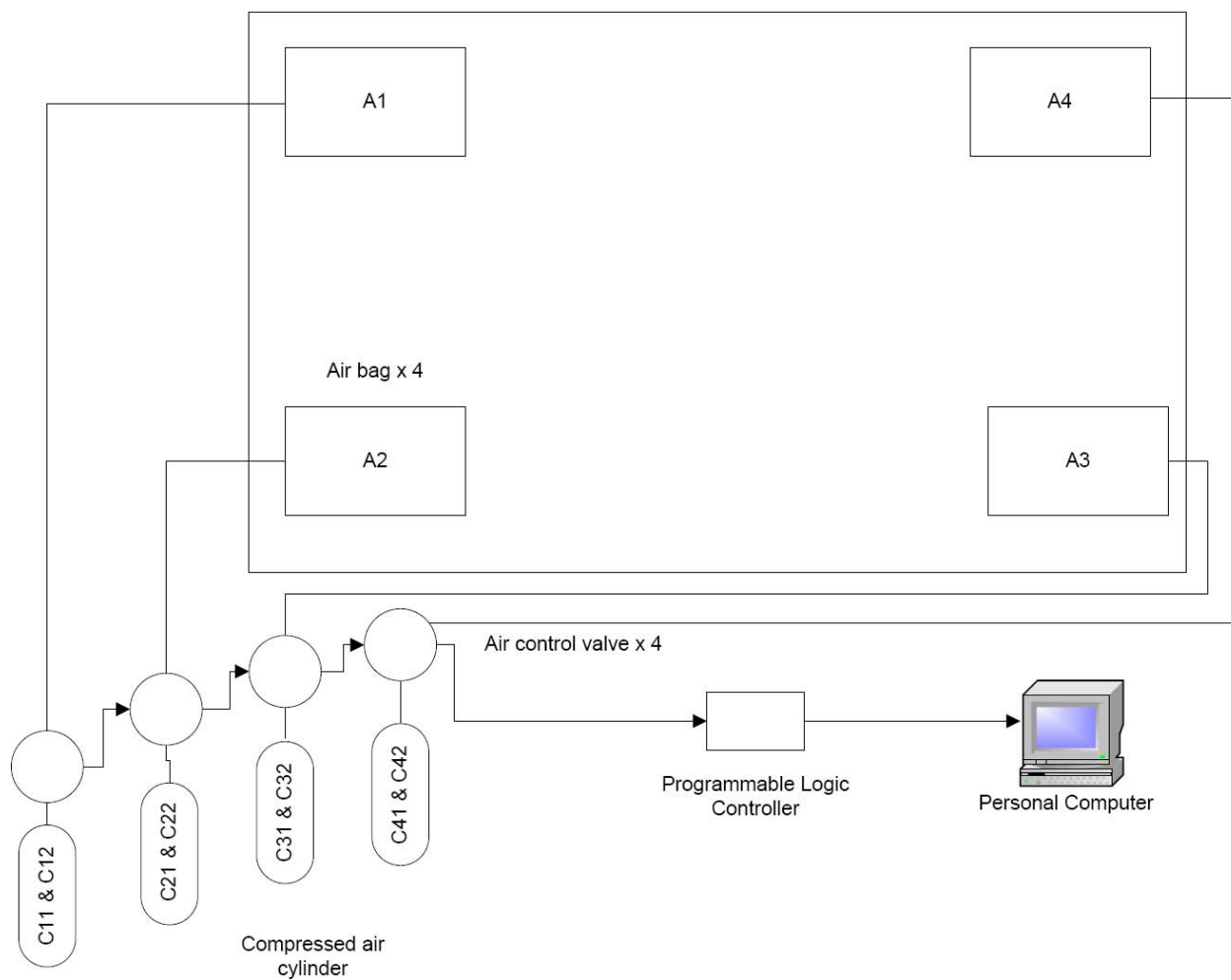


Figure 4.20 The schematic of the motion platform system.

4.6 COST EVALUATION

The developed aircraft cabin simulator was compared with commercially available aircraft simulators. Quotations were requested via email from three companies with the same requirements. Two companies replied and the information is shown in Table 4.10. These two companies manufacture aircraft simulators for aviation industry. Due to confidentiality, two companies that send the quotation are anonymous. The price quoted by the company does not include the overhead cost, labor cost and administrative cost.

Referring to Table 4.10, the aircraft cabin simulator was compared with the simulators from two commercial companies. The main difference between all specifications is that company A and company B do not offer motion effect, visual effect and sound effect. Both company A and company B showed that the cost is higher than TU/e aircraft cabin simulator. It can be concluded that our developed aircraft simulator can be considered as a real low cost simulator.

Table 4.10 The comparison between different options regarding hardware, functionality and cost.

	Company A	Company B	TU/e
Hardware, functionality and cost description	Aircraft service mock up <ul style="list-style-type: none"> • 2 passenger seat rows economy class • 1 passenger seat row business class • 1 lavatory • 1 galley • Without motion • Without visual effect • Without sound effect 	Wide body cabin equipped with <ul style="list-style-type: none"> • 2 passenger seat rows economy class • 1 passenger seat row business class • 1 lavatory • 1 galley • Without real aircraft door • Without motion • Without visual effect • Without sound effect 	Aircraft cabin simulator <ul style="list-style-type: none"> • 2 passenger seat rows economy class • 1 passenger seat row business class with complete massage function • 1 lavatory • 1 galley • Luggage compartments • With in-flight entertainment system • With motion • With visual effect • With sound effect • With temperature control
Cost (Euro)	54,000	100,000	52,000

4.7 VALIDATION OF AIRCRAFT CABIN SIMULATOR

The validation experiment of the aircraft cabin simulator was carried out with using the presence questionnaire (Usoh et al., 2000). The presence questionnaire is used to measure the presence between real and simulated flight experiences in aircraft cabin simulator. The validation experiment was designed by Hao Liu and the author. The validation experiment was conducted as a part of the experiment to validate the developed in-flight entertainment system by Hao Liu (Liu et al., 2010) for SEAT project. The participants were required to sit inside the cabin simulator to simulate a flight from Schiphol International Airport, the Netherlands to Shanghai Pudong International Airport, China.

4.7.1 Methods

Participants

Twelve participants (six females and six males) were invited to participate in our validation experiments. The age of the participants ranges from 21 to 33 years. The professions in the first experimental group include one reporter, two workers and three engineers. The professions in the second experimental group include one student, two workers and three engineers. The participants were recruited through advertisement in regional news (newspaper, radio and television) and were given Euro 50 upon completion.

Supporting Personnel

A former professional flight attendant from Swiss Air was invited to provide cabin service during user experiments. Hao Liu acted as the simulated flight captain. The author provided technical supports. Matthias Rauterberg coordinated and directed the experiments.

Experimental Setup

We conducted the validation experiment for the aircraft cabin simulator inside the simulation lab in the Main Building of Eindhoven University of Technology. 12 participants were allocated to two experiments. Each experiment consisted of six participants. The participants were tested at the economy class section in the aircraft cabin simulator. The in-flight entertainment system was installed and used by the participants as well. Both experiments simulate the KLM KL0895 flight from Schiphol International Airport to Shanghai Pudong International Airport. Both experiments were conducted with the same environment and procedure following the real flight schedule.

Questionnaire

Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another (Witmer and Singer, 1998). In this paper's context, presence means the "passenger's" subjective experience of being in a long haul flight; even when the "passenger" is physically sitting in the aircraft cabin simulator. The presence questionnaire by Usoh et al. (2000) is used to measure the perceived presence of participants. It is customized resulting in the following five questions:

1. Please rate your sense of being in the long haul flight on the following scale from 1 to 7.

I had a sense of "being there" in the long haul flight:

Not at all Very much
 1 2 3 4 5 6 7

2. To what extent were there times during the experience when the laboratory became the "real long haul flight" for you, and you almost forgot about the "real world" of the laboratory in which the whole experience was really taking place?

There were times during the experience when the virtual "long haul flight" became more real for me compared to the "real flight"...

At no time Almost all
 1 2 3 4 5 6 7 the time

3. When you think back about your experience, do you think of the laboratory more as the lab that you saw, or more as somewhere that you visited? Please answer on the following 1 to 7 scale:

The laboratory seems to me to be more like...

Laboratory that I saw	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	somewhere that I visited
	1	2	3	4	5	6	7	

4. During the time of the experience, which was the strongest on the whole, your sense of being in the long haul flight, or of being in the real world of the laboratory?

I had a stronger sense of being in...

the real world of the laboratory	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	the virtual reality of the Longhaul flight
	1	2	3	4	5	6	7	

5. During the time of the experience, did you often think to yourself that you were actually just sitting in a laboratory or did the “long haul flight” overwhelm you?

During the experience I often thought that I was really sitting in the laboratory....

most of the time I realised I was in the lab	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	never because the Longhaul flight overwhelmed me
	1	2	3	4	5	6	7	

The questionnaire was distributed to participants at the end of the simulated flight.

Apparatus and Data Recording

The following hardware was used for both experiments:

- Observation camera
- Computer
- Aircraft cabin simulator

A CCTV observation camera was used to record the situations inside the simulator throughout the experiment. Two CCTVs were installed in the economy class section of the simulator. The activity of the participants was observed and monitored. The recorded data were saved in the computer. Two snapshots of the video recordings in the aircraft cabin simulator are shown in Figure 4.21.



(a) Time: 22:16:49



(b) Time: 03:15:31 (+1 day)

Figure 4.21 The video recording inside the aircraft cabin simulator.

Experimental Procedure

In order to simulate a real flight experience, the participants were requested to bring along their hand luggage and the mockup air tickets which were issued beforehand. Before the experiment started, 15 minutes of briefing was conducted. Next, the participants were positioned to the seat according to the mockup air ticket. The participants were given a drink and snack before the departure. The general simulated procedure in the KLM economy class as well as flight procedure was used. The flight simulation procedure is shown in Figure 4.22. The departure time of the flight is Amsterdam local time 6:18 p.m. The arrival time of the flight is Amsterdam local time 4:55 a.m. + 1 day (Shanghai local time 10:55 a.m.). The flight duration is 10 hours and 35 minutes. The first experiment was conducted on

31st July, 2009 (Friday); the second experiment was conducted on 7th August, 2009 (Friday).

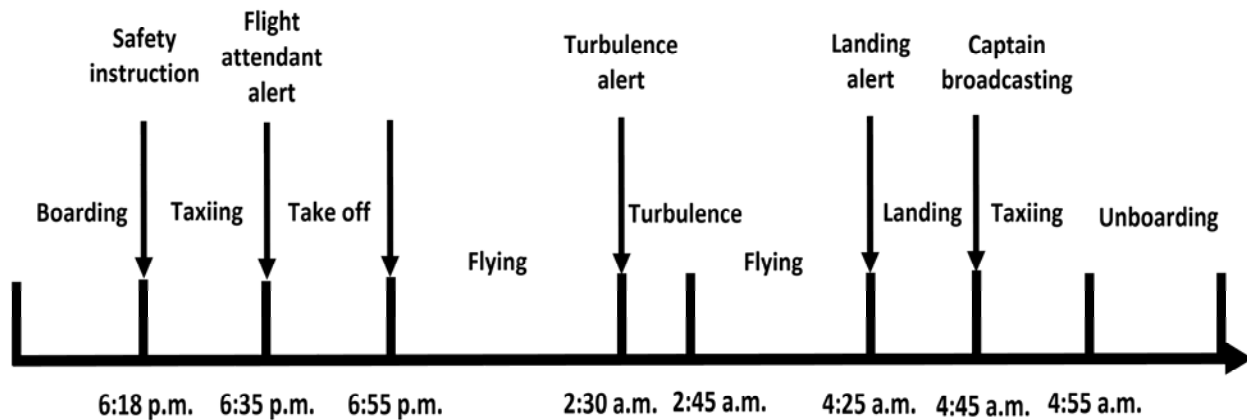


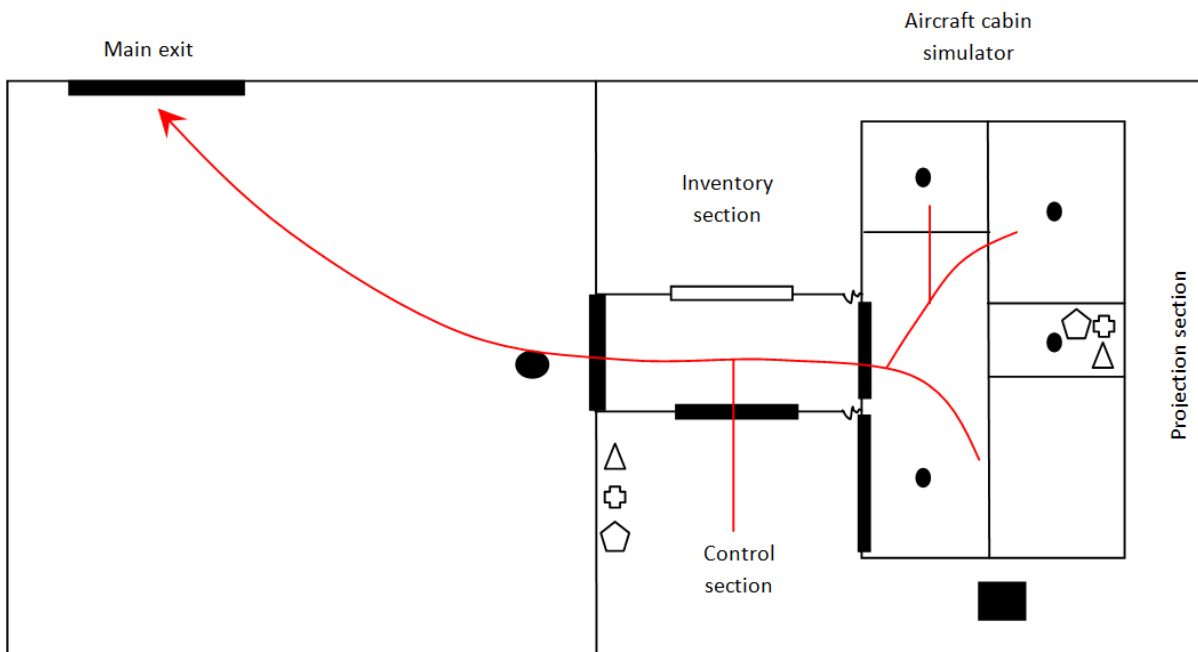
Figure 4.22 Procedure of the flight simulation.

Safety Precaution

The safety precaution provides information intended to prevent personal injury to the participants, the experiment operators and property damage. During the experiment, the participants seated inside the aircraft cabin simulator for more than ten hours. The aircraft cabin simulator setup is equipped with electrical and electronic equipments such as a computer and a beamer. Subsequently, smoke detectors were installed inside the simulator as well as the ceiling of the Simulation Lab. Fire extinguishers and fire blankets were equipped at the control section and inside the simulator. An evacuation plan was also designed for an emergency evacuation. Figure 4.23 shows the evacuation route during emergency as well as the location of the smoke detectors. The university security was informed about the experiment and permission to stay overnight was granted before the experiment started.

Statistical Analysis

Applied statistics was used to analyze the questionnaire data. The statistical analysis was carried out with SPSS® version 17.0 for Windows®.



Legend:

- ⊕ First aid kit
- Smoke detector
- △ Fire extinguisher
- ⬠ telephone

Figure 4.23 The floor plan for emergency evacuation and the location of safety equipment.

4.7.2 Results

The results of the presence questionnaire for 12 participants are described in this section. The raw data analysis of the questionnaire is described in Liu et al. (2010). The means and standard deviations of the questionnaire scores are shown in Table 4.11.

As referring to Table 4.11, the first question about “*I had a sense of “being there” in the long haul flight*” showed the neutral result ($M = 4.000$, $SD = .739$). The Question 2 is about “*There were times during the experience when the virtual “long haul flight” became more real for me compared to the “real flight”*”. The statistical result ($M = 3.750$, $SD = 1.215$) showed that the participants tend to experience the real world of the laboratory. Next, the result at Question 3 ($M = 3.583$, $SD = .793$) showed that the participants think that they felt the simulator is

more like the lab that they saw than somewhere that they visited. The result of Question 4 (M = 3.917, SD = .793) showed that the participants have a stronger sense of being in the real world of the laboratory than in the virtual reality of the long haul flight. Lastly, the result of Question 5 (M = 3.500, SD = 1.087) showed that the participants realized that they were in the lab most of the time rather than “never because the long haul flight overwhelmed me”.

Table 4.11 Means (M) and standard deviations (SD) of presence questionnaire.

No.	Question	M	SD	N
1.	<i>I had a sense of “being there” in the long haul flight</i>	4.00	0.74	12
2.	<i>There were times during the experience when the virtual “long haul flight” became more real for me compared to the “real flight”...</i>	3.75	1.22	12
3.	<i>The laboratory seems to me to be more like...</i>	3.58	0.79	12
4.	<i>I had a stronger sense of being in...</i>	3.92	0.79	12
5.	<i>During the experience I often thought that I was really sitting in the laboratory....</i>	3.50	1.09	12

4.7.3 Discussion and Conclusions

Based on the results of our presence questionnaire by twelve participants inside the aircraft cabin simulator, they felt that they were experiencing the laboratory environment more than real long haul flight situation. Subsequently, the overall mean ratings (M = 3.750, SD = 0.925) are 0.25 lower than mean rating of neutral (4). The overall result showed that the developed aircraft cabin simulator is able to simulate the average aircraft cabin for research purpose.

4.8 RECOMMENDATION FOR FUTURE WORK

The recommendation for future work of aircraft cabin simulator as follows:

- *Turbulence effect*: The turbulence effect of the current aircraft cabin simulator is caused by human force. When the simulator is above the floor, the simulator operator will shake the simulator to create the turbulence effect. We recommend a rotary type electric motor to be installed in aircraft cabin simulator to create the turbulence effect automatically. The turbulence effect can be correlated with the visual effect from the beamer.
- *Floor space*: The current aircraft cabin simulator occupies half of the floor space in Simulation Lab at Main Building of Eindhoven University of Technology. The floor space constraints in Simulation Lab caused some limitations during the early design stage of aircraft cabin simulator, such as the limited movement of the simulator, limited space in the aircraft cabin simulator, small control area and narrow projection area. Wider floor space is needed for future aircraft simulator design.
- *Sound proof and pressurized environment*: The developed aircraft cabin simulator was built with wood and medium density fiberboard material. We recommend the simulator should be built with aluminum material, installed with sound absorption material and using soundproof rubber seals at the gaps between walls. We also recommend the simulator should be pressurized to create real flight environment.
- *Coordination between simulator motion and video*: We recommend the simulator motion such as taxiing, take off and descending to be coordinated with video automatically. With the coordination between motion and video, the simulation effect can be improved.

4.9 SUMMARY

The aircraft cabin simulator was designed with the systematic total design approach. The total design method was useful for the development of the aircraft cabin simulator from concept to complete buildup. The market survey, design

knowledge and design experience were important inputs for the development of the aircraft cabin simulator. Product requirement provided the designer a way to keep track in ongoing project. The morphological chart helped the designer to identify the various design solutions and product functions in a systematic way. The weighted objective method was used in the brainstorming and mind mapping sessions to generate and determine the final concept. The final aircraft cabin consists of a control section, an inventory section, a projection section and an aircraft cabin simulator with motion platform. Two experiments were conducted to validate the aircraft cabin simulator. The aircraft cabin simulator was validated with twelve participants for a 10 hours simulated flight. The presence questionnaire was used to examine the perceived realism of the developed aircraft cabin simulator. The statistical result showed that the developed aircraft cabin simulator can sufficiently simulate an economy class aircraft cabin.

CHAPTER 5

EVALUATION OF A SMART NECK SUPPORT SYSTEM

5.1 INTRODUCTION

The previous chapter presented the development of the smart neck support system (SnS²) and the aircraft cabin simulator. In Chapter 3, the design of the developed SnS² was described. In Chapter 5¹, two experiments, namely a calibration experiment and a validation experiment, were designed to evaluate the developed system. Electromyography (EMG) method was used to measure sternocleidomastoid (SCM) muscle stress. In order to objectify the EMG value of SCM muscle at a pre-defined head rotation angle, the calibration experiment was carried out. The calibration experiment was conducted to find the relationship between defined head rotation angle, gender, duration and the SCM EMG value.

5.2 NECK MUSCLE AND ELECTROMYOGRAPHY MEASUREMENT

The SCM muscle is 'a paired muscle in the superficial layers of the anterior portion of the neck'. The SCM muscle is responsible for flexion and rotation of the human head (Wikipedia, 2010a). Costa et al. (1990) described that the SCM muscle is responsible for head movements that were defined as heterolateral inclination, protraction, extension and flexion. Sommerich et al. (2000) also described that the SCM muscle is responsible for flexion, rotation and lateral bending. Figure 5.1 shows the sternocleidomastoid muscle.

¹ This chapter is partly based on the following articles:

Tan, C.F., Chen, W. and Rauterberg, M. 2010. The Relationship of head rotation angle and SCM EMG value for the development of AnS². World Congress on Engineering (WCE2010), London, U.K., pp. 2082-2085.

Tan, C.F. Chen, W. and Rauterberg, M. 2010. An approach to study the sitting position and neck discomfort of economy class aircraft passenger during air travel. International Conference on Applied Human Factors and Ergonomics (AHFE2010), Miami, Florida, USA, Chapter 40, pp. 376-382.

Tan, C.F., Chen, W. and Rauterberg, M. 2010. Experimental design for sternocleidomastoid muscle stress measurement. 7th International Conference on Methods and Techniques in Behavioral research (Measuring Behavior 2010), Eindhoven, the Netherlands, pp. 44-47.

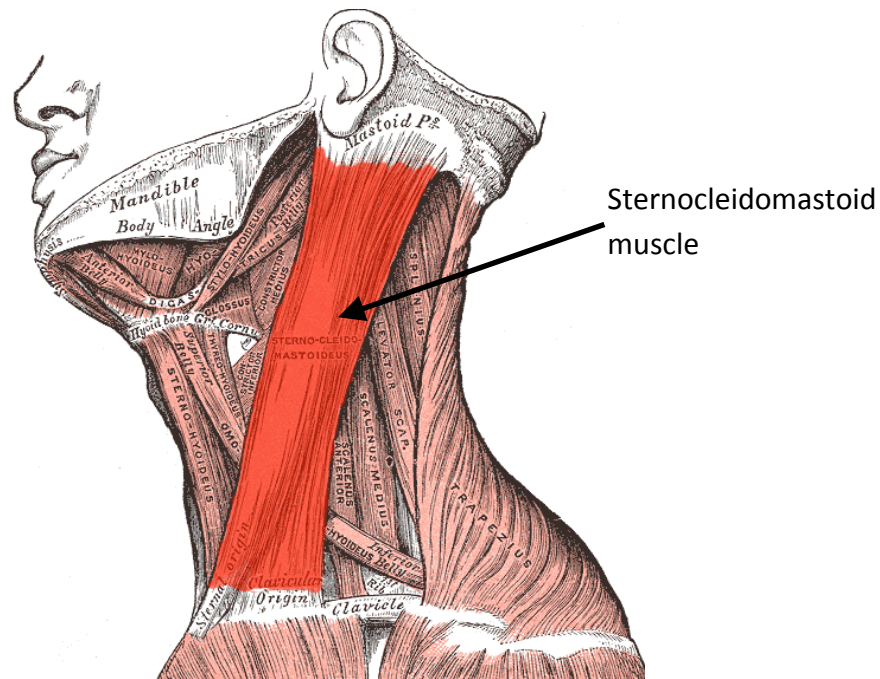


Figure 5.1 The SCM muscle (Photograph reprinted from Wikipedia, 2010a).

Johnston et al. (2008) studied the electromyography signals from the SCM muscle to determine differences between computer workers with varying levels of neck pain in terms of work stressors, employee strain, EMG amplitude and heart rate response to various tasks. Various studies (Ylinen et al., 2003; Bexander et al. 2005; Gabriel et al., 2004; Moon et al., 2003; Lin and Huang, 2008) showed that there is a relationship between EMG activity of the SCM muscle and head rotation. Tilley and Dreyfuss (2001) conducted human factors research about impact of everything in daily life. In their measurement on head rotation angles for man and woman, they defined that the head facing front or in 0° is the most comfortable head position. From 0° to 45° is the easy head rotation angle range and 60° is the maximum head rotation angle. EMG signal is used to measure the myoelectrical activity of muscles. Muscle contractions provide an electrical signal and are recorded by EMG (Lee et al., 1995; Stegeman et al., 2000). Surface electromyography (sEMG) has been used in research and clinical applications to measure neck muscles (Falla et al., 2002). Based on the literature review, the SCM muscle is a muscle that is related to head rotation and can be measured with EMG. Therefore, the SCM muscle was selected to validate the developed SnS².

5.3 CALIBRATION EXPERIMENT

The calibration experiment was conducted to find the difference between the SCM muscle stress with relation to the neck support conditions: with support and without support, time and the neck rotation angle. The calibration experiment used a questionnaire to investigate the neck condition and support during air travel of the participants. A headset with laser beam and head rotation angle apparatus was used to determine the head rotation angle. The EMG method was used to measure the SCM muscle stress. A statistical method was used to analyse the questionnaire results and experimental results. The purpose of the calibration experiment was to provide input such as the neck support condition, time factor and the neck rotation angle to validate the developed SnS².

5.3.1 Hypotheses

There are several research questions that are related to the calibration experiment. First, it is about the effect of the neck support condition on the SCM muscle stress for a sitting person. Second, it is about the influence of time and head rotation angle on the SCM muscle stresses of sitting person. Third, the significant different of SCM muscle was tested. Fourth, these four hypotheses are derived as follows:

Hypothesis 1

H₀: The mean ratings of SCM EMG value for a sitting person with support condition are equal to without support condition.

H₁: The mean ratings of SCM EMG value for a sitting person with support condition are unequal to without support condition.

The first hypothesis is to test whether the SCM EMG value for a sitting person will be lower than the neck is supported or higher when the neck is without support.

Hypothesis 2

H₀: The mean ratings of SCM EMG value for a sitting person are equal over the increase of time.

H₁: The mean ratings of SCM EMG value for a sitting person are unequal over the increase of time.

The hypothesis 2 is to test whether SCM EMG value for a sitting person will be higher or lower with relation to the increase of time.

Hypothesis 3

H₀: The mean ratings of SCM EMG value for a sitting person are equal over the increase of head rotation angles.

H₁: The mean ratings of SCM EMG value for a sitting person are unequal over the increase of head rotation angles.

The third hypothesis is to check whether SCM EMG value for a sitting person will be higher or lower with relation to the increase of head rotation angle.

Hypothesis 4

H₀: The mean ratings of SCM EMG value of SCM muscle for a sitting person are not significantly different between both SCM muscles (left and right).

H₁: The mean ratings of SCM EMG value of SCM muscle for a sitting person are significantly different between both SCM muscles (left and right).

The last hypothesis is to test whether there is a significant difference between right and left SCM muscle for a sitting person.

The results from the hypotheses are important information for calibrating and validating the developed smart neck support system.

5.3.2 Methods

Participants

Four participants (n = 4) with no neck pain over the last three months were recruited for this experiment. The group consisted of two females and two males aged between 26 and 30 years old (means 28.25 years old). They were postgraduate students and working people. The participants were recruited through invitation and were given Euro 25 upon completion. They were informed regarding the experiment which involved a short questionnaire, sitting inside the head rotation angle measurement apparatus, wearing a head set with laser beam, video recording and electromyography measurement. Table 6.1 shows the demographic profile of participants.

Table 5.1 Demographic profile of participants.

Variable	M	SD	N
Age (years)	28.25	1.50	4
Weight (kg)	65.75	10.87	4
Height (m)	1.75	0.13	4
BMI (kg/m ²)	21.34	0.63	4

Experimental Setup

We conducted the experiment by using a head set with laser beam and a head rotation angle measurement apparatus. The head set with laser beam was used to direct the participant's head to the defined angle at the head rotation angle measurement apparatus. The headset as shown in Figure 5.2 was initially developed for EEG measurement (Aart et al., 2007; Aart et al., 2008). In order to adapt the headset in the experiment for pointing the predefined angle on the head rotation angle measurement apparatus, a laser device with battery was added. A participant with the special headset sitting inside the head rotation angle measurement apparatus is shown in Figure 5.3. The location of the experiment is in the simulation laboratory in the Main Building of Eindhoven

University of Technology. An observation camera was installed in front of the participants to record the activities of the participants throughout the experiment.

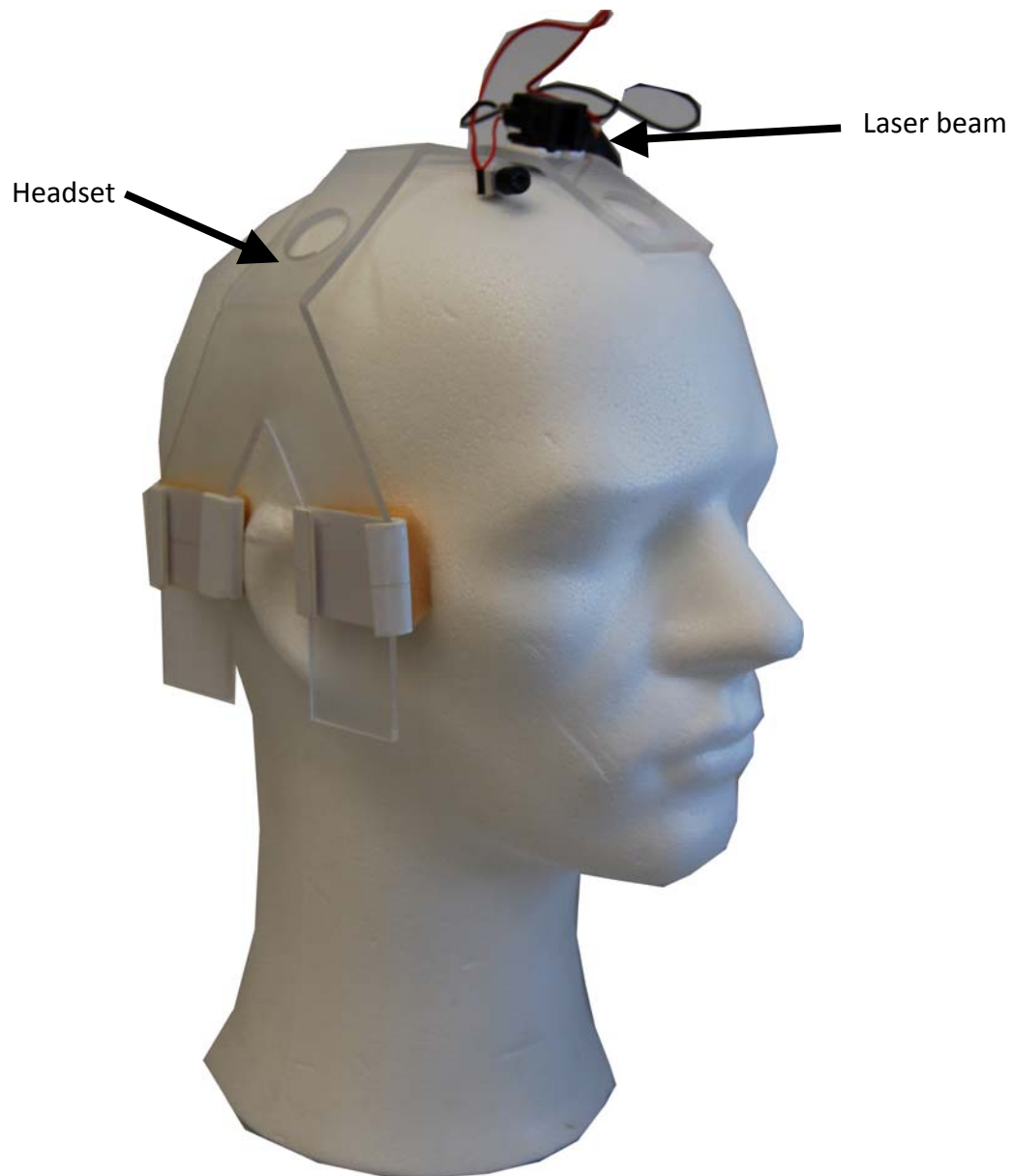


Figure 5.2 The headset (Aart et al., 2007; Aart et al.,2008).

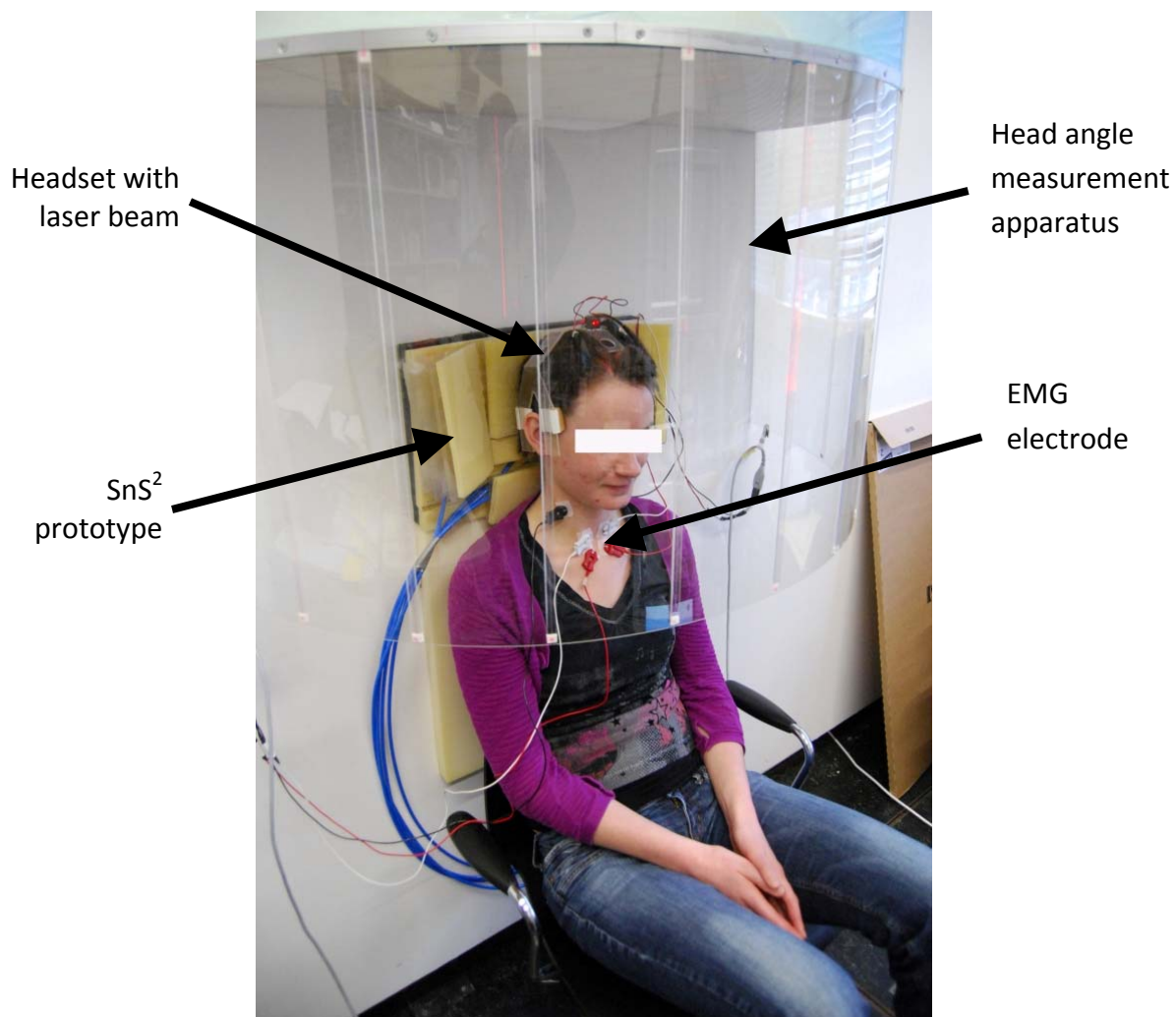


Figure 5.3 A participant attached with EMG electrodes, wearing the headset with laser beam, sitting inside the head angle measurement apparatus and leaning against SnS² prototype.

Questionnaire

An inquiry via questionnaire was conducted before the experiment. The questionnaire (Appendix A.8) consisted of two sections: (1) questions regarding neck pain, flight information and neck support during air travel; (2) questions about demographic background. The primary goal of our investigation is to understand the neck condition and support during air travel.

The first question was asked about the presence of neck pain in the last three months. The following questions were about the common flight duration and flying class. Subsequently, four questions were asked about the neck support during air travel. The answering categories were 'strongly disagree', 'disagree', 'neutral', 'agree' and 'strongly agree'. Respondents could indicate their degree of discomfort based on a five point Likert scale (-2 = strongly disagree; 0 = Neutral; 2 = strongly agree). The questionnaire also included questions assessing demographic variables of the participant.

Apparatus and Data Recording

In order to gather EMG values of the SCM muscle in different pre-defined head rotation angles, dedicated hardware was used. The hardware used during the experiment is as follows:

- MP150 Biopac Systems with surface EMG module (Figure 5.4)
- Head rotation angle measurement apparatus
- Head set with laser beam
- Laptop
- Observation camera



Figure 5.4 MP150 Biopac systems with electrodes and cables.

The MP150 Biopac System (Biopac Systems, Inc., USA) with EMG module was used to measure the SCM muscle. The head rotation angle measurement apparatus was used to define the head rotation angle during the calibration experiment. The apparatus was made from wood and transparent acrylic material. As shown in Figure 5.5, there are seven angles being L45°, L30°, L15°, RL0°, R15°, R30° and R45° (L = left, R = right) used in the calibration experiment. The headset with laser beam was used to make sure the participant was facing the defined angle during experiment. The laptop was used to collect the EMG data from MP150 Biopac System. An observation camera was used to record the activities of the participants throughout the experiment.

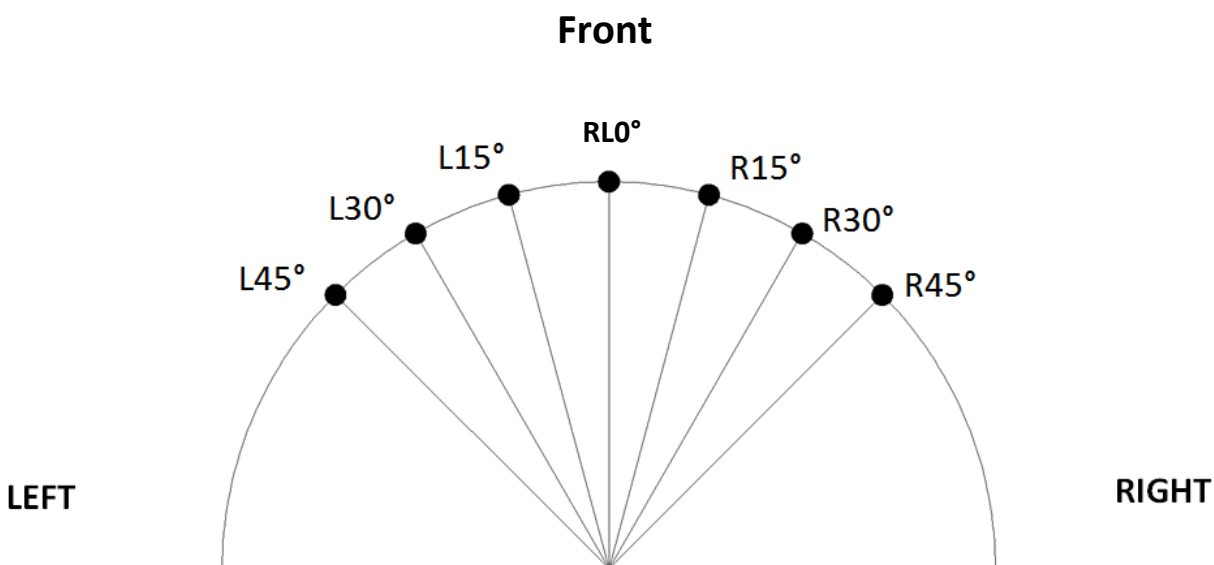


Figure 5.5 The schematic of defined angles for the head rotation angle apparatus in top view.

Experimental Procedure

For the calibration experiment, the SCM muscle was selected to measure the EMG value in different defined head rotation angles. The SCM muscle is the neck muscle relates to head rotation activity (Sommerich et al., 2000). The skin surface of the SCM was abraded and cleaned with alcohol and subsequently the surface electrodes were applied (Hermens et al. (1999); Hermens et al. (2000); Kallenberg and Hermens, 2008)). A pair of surface electrodes (Ag/AgCl electrodes; EL504-10;

10 mm diameter on a 25 mm square backing; Biopac Systems, Inc., USA) was placed in parallel with the muscle fibers of SCM with 20 mm inter-electrodes distance. The electrodes were placed at the lower 1/3 of the line connecting sternalnotch and mastoid process (Falla, 2002). The placement of the electrodes onto the SCM muscles is shown in Figure 5.6. The SCM muscle activity of the participants was recorded using a BioPac MP150 Systems (Biopac Systems, Inc., USA), and two EMG100C amplifiers. The EMG was recorded and analyzed with AcqKnowledge 3.9.1 (Biopac Systems, Inc., USA).

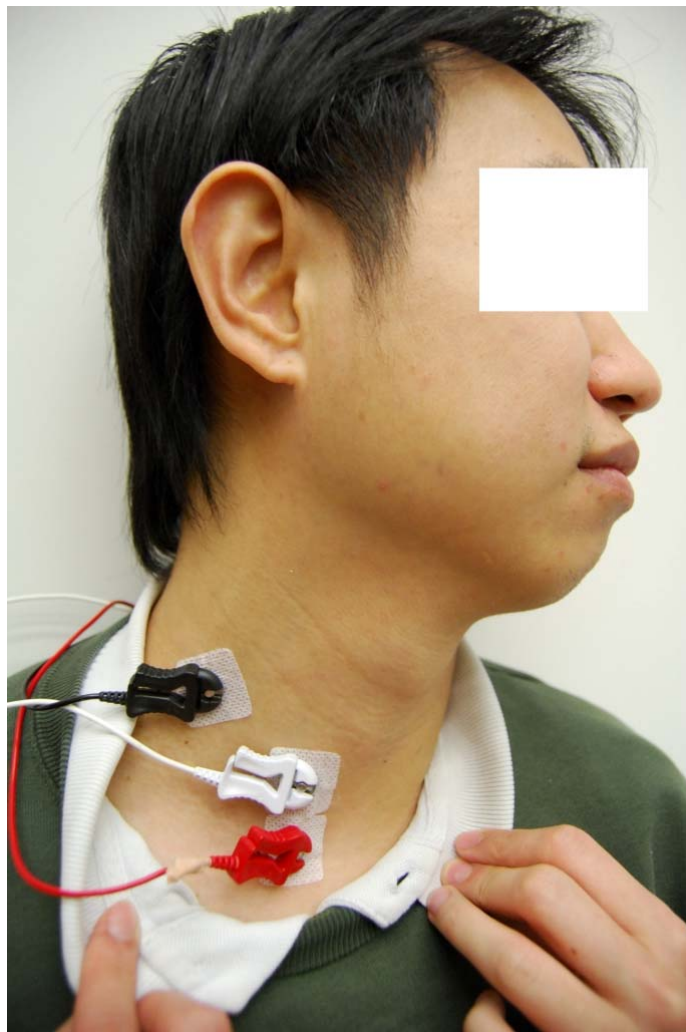


Figure 5.6 The SCM muscle with EMG electrodes.

Each participant was tested under the same experimental conditions. We started the experiment with 30 minutes of briefing to the participant and the attachment

of the electrodes on the SCM muscles. The participant performed maximal voluntary contractions (MVC) of the SCM by rotating the head to the left hand side and the right hand side. Each MVC lasted five seconds, with two minutes pause until the next MVC (Cheng et al., 2009). Next, the MVC information was input to the AcqKnowledge 3.9.1 software before measurement on head rotation angle.

Following a 10 minutes break, we positioned the participant inside the head rotation angle measurement apparatus wearing the headset with laser beam. Visual feedback of the participant was recorded and shown on the monitor. A participant who is positioned inside the head rotation angle measurement apparatus with 45° head rotation to his right hand side is shown in Figure 5.7.



Figure 5.7 A participant inside the head rotation angle measurement apparatus (45 degree condition).

Both right and left SCM muscles were evaluated in two head support conditions (with support and without support) and 7 rotation angles (L45°, L30°, L15°, RL0°,

R15°, R30°, R45°). The EMG value for rotation angle (RL0°) was used for both neck support conditions. The participant is tested in each angle for 10 minutes. A rest period of two minutes was scheduled between each angle to minimize the effect of fatigue (Cheng et al., 2009). After the measurement, the electrodes were detached from the participant and debriefing was conducted.

Signal Acquisition and Processing

The normalized EMG activity was analyzed. Normalization of EMG activity was performed for each participant individually. To measure the MVC of the SCM muscle, the participant's head was turned to the maximum head rotation angle. For example, to measure the MVC for right SCM muscle, the participant's head needs to turn to the left hand side until the participant reached maximum head rotation angle. Next, the participant was instructed to stay in the maximum head rotation angle position for 10 seconds. The maximum EMG value was measured with the AcqKnowledge 3.9.1 software (Biopac Inc, USA). The max EMG was normalized to MVC by computing the scaling factor (Biopac Systems, Inc., 2010).

After the normalization of EMG value for both SCM muscles, data were continuously recorded for 10 minutes. In the time domain, the EMG signals were collected at 1000 Hz sampling rate, band-pass filtered between 20 Hz and 350 Hz, full-wave rectified and smoothed with a low-pass filter (Cheng and Lin, 2009). The high-pass cutoff frequency at 20 Hz was used to reduce motion artifacts and electrocardiography (ECG) artifacts with minimal impact on the total power of EMG (Clancy et al. 2002).

Data Analysis

For each experiment, the average normalized EMG value was used for statistical analysis. For the statistical analysis, the time domain was divided into 10 time intervals with one time interval represents one minute. The normalized EMG values were then averaged over five seconds in each time interval. The average normalized EMG value was further analyzed with statistical method.

A statistical method was used to analyze the question data. The statistical analysis was carried out with SPSS® version 17.0 for Windows®. A one-way multivariate analysis of variance (MANOVA) with repeated measures was used to examine differences between neck support conditions: with support and without support, head rotation angles and durations.

5.3.3 Results

First, we present the questionnaire results and then the experimental results. The results from the questionnaire showed that all participants reported no neck pain in the last three months. Three out of four participants (75%) travelling mostly 6 to 10 hours per flight and all participants (100%) travelled with economy class. For the questions about the neck support during air travel, we conducted frequency tests. For the statement about 'I always feel neck discomfort during air travel' ($M = 1.00$, $SD = 0.00$), 75% answered 'agree' and 25% answered disagree. For the statement about 'I always bring neck support apparatus and use it during air travel' ($M = -1.50$, $SD = 1.00$), 50% answered strongly disagree; 25% answered disagree and 25% answered neutral. Next, for the statement about 'I always use neck support that is supplied during air travel' ($M = 0.75$, $SD = 0.96$), 25% answered strongly disagree; 25% answered neutral; 25% answered agree and 25% answered strongly agree. Lastly, for the statement about 'I always use the neck support that is attached to the seat' ($M = 0.50$, $SD = 1.73$), 25% selected strongly disagree; 25% answered disagree; 25% answered agree and 25% answered strongly agree. Table 5.2 shows the descriptive information of the questionnaire results (See also Appendix A.8).

Table 5.2 Descriptive statistics of questionnaire result.

No.	Description	M	SD	N
1.	Neck pain in last three months (1 = 'yes', 2 = 'no')	2.00	0.00	4
2.	Flight duration (1 = 'less than 1 hour', 2 = '2-5 hours', 3 = '6-10 hours', 4 = '11 hours or more')	2.75	0.50	4
3.	Flying class (1 = 'first', 2 = 'business', 3 = 'economy')	3.00	0.00	4
4.	I always feel neck discomfort during air travel (-2 = 'strongly disagree', -1 = 'disagree', 0 = 'neutral', 1 = 'agree', 2 = 'strongly agree')	1.00	0.00	4
5.	I always bring neck support apparatus and use it during air travel (-2 = 'strongly disagree', -1 = 'disagree', 0 = 'neutral', 1 = 'agree', 2 = 'strongly agree')	-1.50	1.00	4
6.	I always use neck support that is supplied during air travel (-2 = 'strongly disagree', -1 = 'disagree', 0 = 'neutral', 1 = 'agree', 2 = 'strongly agree')	0.75	0.96	4
7.	I always use the neck support that is attached to the seat (-2 = 'strongly disagree', -1 = 'disagree', 0 = 'neutral', 1 = 'agree', 2 = 'strongly agree')	0.50	1.73	4

The experimental results are described according to our hypothesis.

Hypothesis 1

H₀: The mean ratings of SCM EMG value for a sitting person with support condition are equal to without support condition.

H₁: The mean ratings of SCM EMG value for a sitting person with support condition are unequal to without support condition.

A MANOVA with repeated measurement (with Greenhouse-Geisser correction) was conducted to assess whether there are differences between the test conditions (with support and without support). Results indicated that there is a significant difference of the neck support condition, $F(1, 83.44) = 51.74, p < 0.001$. The test within subjects' effects for neck support condition is shown in Table 5.3. The means of the EMG value for the 'with support' condition ($M = 2.10, SD = 1.28,$

N = 4) is lower than the EMG value of the ‘without support’ condition (M = 2.65, SD = 1.46) over all head rotation angles. The means and standard deviations of the SCM normalized EMG value related to neck support conditions are shown in Table 5.4. Polynomial contrasts indicate there is a significant linear trend, $F(1, 83.44) = 51.74, p < 0.001$, reflecting the higher rating of normalized EMG values for without neck support than with support. The mean scores of normalized EMG value of neck support condition for four participants related to all three head rotation angles are shown in Figure 5.8.

Therefore, these results validated hypothesis 1 that H_1 is selected because the mean ratings of SCM EMG value with support condition are significantly unequal to without support condition.

Table 5.3 The test for within-subjects effects for neck support condition (with support and without support).

Source		Type III Sum of squares	df	Mean square	F	Sig.
	Sphericity Assumed	83.44	1.00	83.44	51.74	0.001
Neck support condition	Greenhouse-Geisser	83.44	1.00	83.44	51.74	0.001
	Huynh-Feldt	83.44	1.00	83.44	51.74	0.001
	Lower-bound	83.44	1.00	83.44	51.74	0.001

Table 5.4 The normalized SCM EMG value related to neck support condition.

Neck support condition	M	SD	N
Without support	2.65	1.46	280
With support	2.10	1.28	280

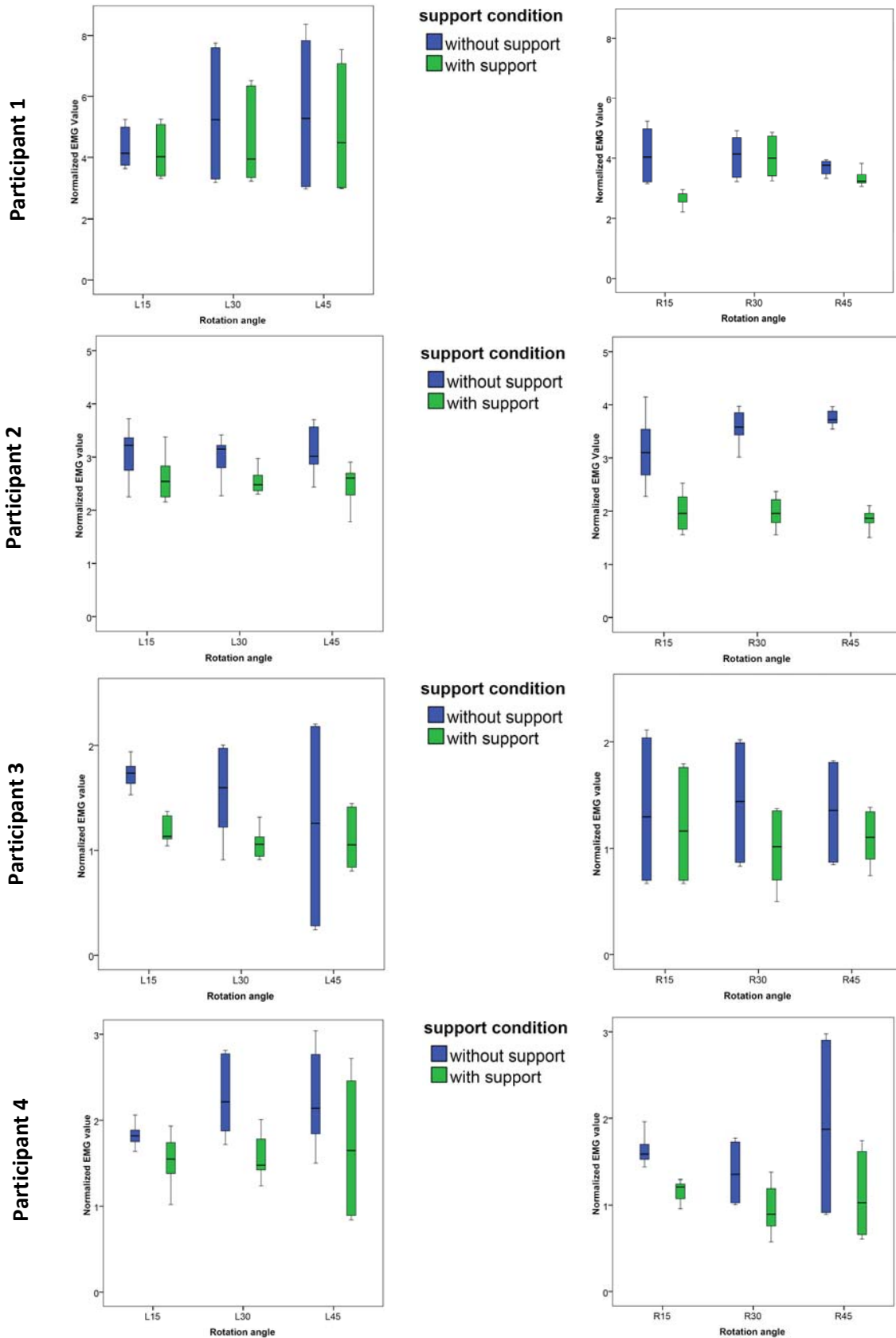


Figure 5.8 The box plots of normalized EMG value for both test conditions split by head rotation angles for each participant separately.

Hypothesis 2

H_0 : The mean ratings of SCM EMG value for a sitting person are equal over the increase of time.

H_1 : The mean ratings of SCM EMG value for a sitting person are unequal over the increase of time.

A MANOVA with repeated measurement (with Greenhouse-Geisser correction) was conducted to assess whether there are differences of the SCM EMG values for a sitting person between time intervals. The test within subjects' effects for neck support condition is shown in Table 5.5. There is a significant difference for time interval during the experiment, $F(1.64, 0.71) = 4.84, p < 0.05$. The means and standard deviations for the normalized EMG value listed in order from 1st time interval to 10th time interval are presented in Table 5.6. The means of normalized EMG value increased over time. The normalized EMG value of time interval no. 10 ($M = 2.46, SD = 1.44$) is higher than the normalized EMG value of time interval no. 9 ($M = 2.45, SD = 1.43$). The box plot of the 10 normalized EMG value over time interval for neck support condition related to head rotation angle R30° is shown in Figure 5.9. Polynomial contrasts indicate there is a significant linear trend, $F(1, 0.91) = 5.32, p < 0.05$. In addition, we can find a significant quadratic trend, $F(1, 0.16) = 6.14, p < 0.05$ and a significant cubic trend, $F(1, 0.07) = 4.84, p < 0.05$, reflecting the normalized EMG value was increased over time interval.

Therefore, H_1 is selected for hypothesis 2 and H_0 can be rejected.

Table 5.5 The test for within-subjects effects between SCM EMG value and time interval.

Source	Type III Sum of squares	df	Mean square	F	Sig.
Sphericity Assumed	1.17	9.00	0.13	4.84	0.001
Greenhouse-Geisser	1.17	1.64	0.71	4.84	0.010
Huynh-Feldt	1.17	3.40	0.34	4.84	0.001
Lower-bound	1.17	1.00	1.07	4.84	0.040

Table 5.6 The normalized EMG value over time interval.

Time interval (minute)	M	SD	N
1	2.23	1.29	56
2	2.29	1.34	56
3	2.33	1.38	56
4	2.37	1.42	56
5	2.38	1.43	56
6	2.40	1.43	56
7	2.41	1.44	56
8	2.43	1.43	56
9	2.45	1.43	56
10	2.46	1.44	56

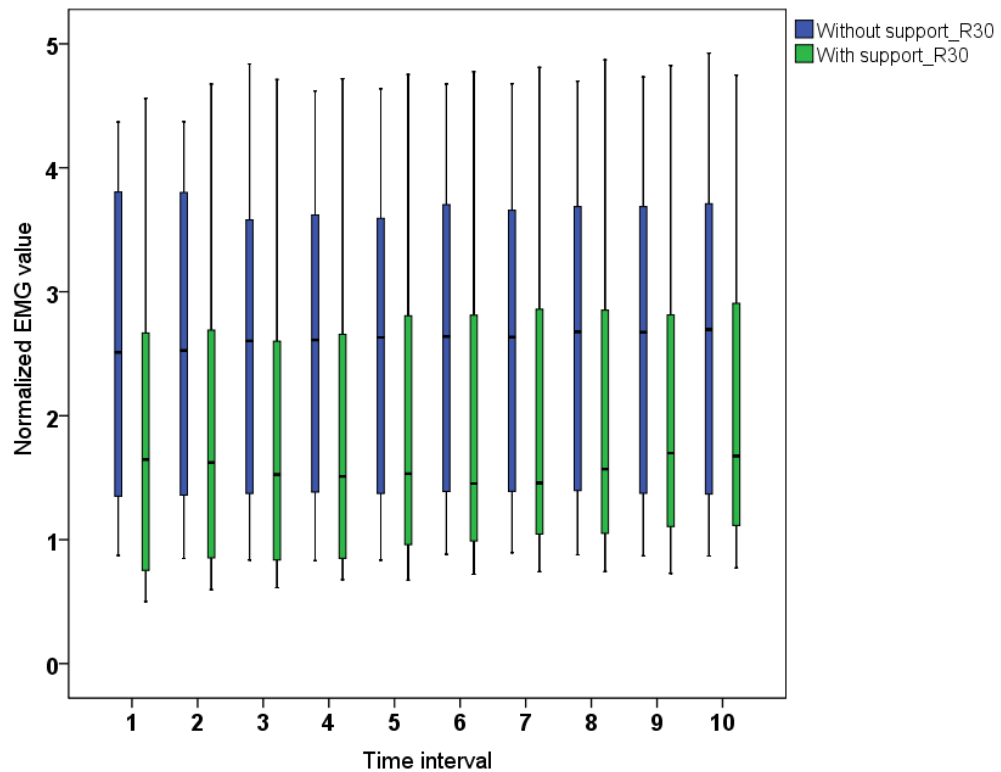


Figure 5.9 The box plot of normalized EMG value split by time intervals and neck support conditions for head rotation angle R30°.

Hypothesis 3

H₀: The mean ratings of SCM EMG value for a sitting person are equal over the increase of head rotation angles.

H₁: The mean ratings of SCM EMG value for a sitting person are unequal over the increase of head rotation angles.

A MANOVA with repeated measurement (with Greenhouse-Geisser correction) was conducted to assess whether there are differences of SCM EMG value for a sitting person between head rotation angles. Statistical results indicate that there is a significant difference for head rotation angle, $F(1.49, 73.08) = 3.86, p < 0.05$. The test within subjects' effects for neck support condition is shown in Table 5.7. Polynomial contrasts showed that there is a significant quadratic trend, $F(1, 50.86) = 21.67, p < 0.01$, reflecting that higher normalized EMG value of L45° than L30° for left SCM as well as right SCM. The means and standard deviations of normalized EMG value in different head rotation angle related to neck support condition are shown in Table 5.8. As referring to Table 5.8, the normalized EMG value of head rotation angle L45° (without support condition: $M = 3.186, SD = 1.918$; with support condition: $M = 2.562, SD = 1.841$) is higher than L30° (without support condition: $M = 2.923, SD = 1.953$; with support condition: $M = 2.444, SD = 1.543$). The box plot of normalized EMG of head rotation angles related to both neck support conditions is shown in Figure 5.10. The EMG value of head rotation angle (RL0°) is same for both neck support conditions.

Therefore, H_1 is selected for hypothesis 3 and H_0 can be rejected.

Table 5.7 The test for within-subjects effects between SCM EMG value and head rotation angles.

Source	Type III Sum of squares	df	Mean square	F	Sig.
Sphericity Assumed	108.61	6.00	18.10	3.86	0.001
Greenhouse-Geisser	108.61	1.49	73.08	3.86	0.060
Huynh-Feldt	108.61	3.34	32.48	3.86	0.020
Lower-bound	108.61	1.00	108.61	3.86	0.090

Table 5.8 The normalized SCM EMG value in different head rotation angles related to both neck support conditions.

Head rotation angle	N	Without Support Condition		With Support Condition	
		M	SD	M	SD
RL0°	80	1.61	0.64	1.61	0.64
R15°	80	2.55	1.29	1.76	0.71
R30°	80	2.61	1.32	2.00	1.34
R45°	80	2.67	1.20	1.85	0.97
L15°	80	2.74	1.13	2.39	1.28
L30°	80	2.92	1.95	2.44	1.54
L45°	80	3.19	1.92	2.56	1.84

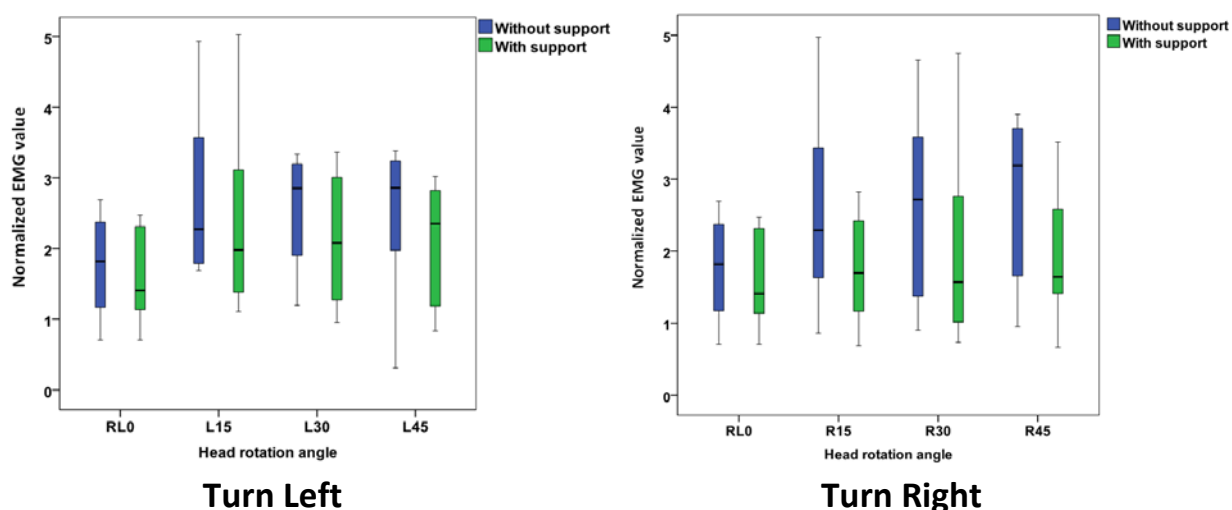


Figure 5.10 The box plot of normalized EMG value split by head rotation angles for both neck support conditions.

Hypothesis 4

H₀: The mean ratings of SCM EMG value of SCM muscle for a sitting person are not significantly different between both SCM muscles.

H₁: The mean ratings of SCM EMG value of SCM muscle for a sitting person are significantly different between both SCM muscles.

A MANOVA with repeated measurement (with Greenhouse-Geisser correction) was conducted to assess whether there are differences between both SCM muscles in relation to SCM EMG for a sitting person. The statistical result indicates that EMG value for both right SCM and left SCM are significantly different, $F(1, 135.68) = 19.29, p < 0.001$. The test within subjects' effects for neck support condition is shown in Table 5.9. The means and standard errors of normalized EMG value for SCM muscle of both rotation directions for both neck support condition is shown in Table 5.10. The mean ratings of right SCM muscle (without support: $M = 3.00, SD = 1.73$; with support: $M = 2.39, SD = 1.54$) and left SCM muscle (without support: $M = 2.30, SD = 1.05$; with support: $M = 1.84, SD = 0.91$) are significantly different. The boxplot for normalized EMG value over SCM muscle related to neck support conditions are shown in Figure 5.11.

Therefore, H_1 is selected for hypothesis 4 and H_0 can be rejected.

Table 5.9 The test for within-subjects effects between SCM muscles.

Source	Type III Sum of squares	df	Mean square	F	Sig.
Sphericity Assumed	135.68	1.00	135.68	19.29	0.001
Greenhouse-Geisser	135.68	1.00	135.68	19.29	0.001
Huynh-Feldt	135.68	1.00	135.68	19.29	0.001
Lower-bound	135.68	1.00	135.68	19.29	0.001

Table 5.10 The normalized SCM EMG value for both rotation directions related to neck support conditions.

SCM Muscle	Without support			With support		
	M	SD	N	M	SD	N
Right	3.00	1.73	561	2.37	1.54	560
Left	2.30	1.05	561	1.84	0.91	560

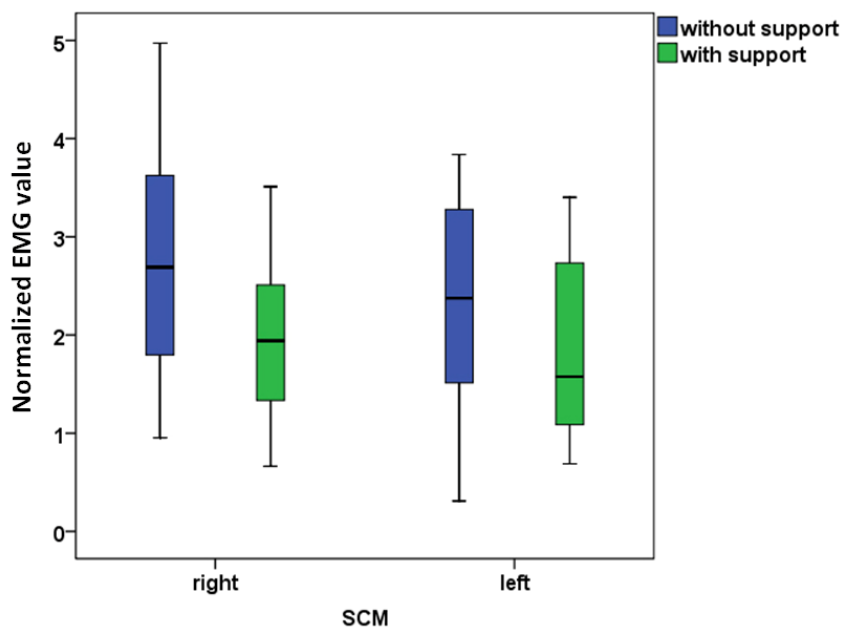


Figure 5.11 The box plot of normalized EMG value over SCM muscle for both rotation direction split by neck support conditions.

5.3.4 Discussion and Conclusions

Our calibration experiment explored the EMG value of the SCM muscle related to both neck support conditions, changes in head rotation angles and duration. The first result shows that when the neck is under the support condition, both SCM muscles showed a lower EMG value than under the without support condition. It is shown that when the neck is supported, the SCM muscle stress is lower than without support. Next, the mean rating of EMG values for a sitting person was increasing over time for both SCM muscles. The result showed that the EMG values for a sitting person in both neck support condition and without support condition were increasing over time. In the third finding, the mean rating of EMG value is increasing with the increase of head rotation angle. The finding is in line with the studies by Ylinen et al. (2003), Bexander et al. (2005), Moon et al. (2003) and Lin and Huang (2008). Lastly, there is a significant difference between right SCM muscle and left SCM muscle related to EMG value.

In this section, we describe the calibration experiment to determine the difference of SCM muscle stress related to neck support conditions, time and head rotation angles. To do this, we developed the head rotation angle measurement apparatus with the support of the headset with laser beam and MP150 Biopac Systems to measure the SCM muscle stress of four participants. Based on the calibration experiment results, we concluded that the SCM muscle stress showed a significant difference related to neck support conditions, time and neck rotation angles. The right SCM muscle and left SCM muscle should be evaluated differently based on both SCM muscle showing significant differences.

The main information gained from the calibration experiment is:

- 1) A sitting person in support condition demonstrated significantly lower mean ratings of SCM EMG value than under without support condition.
- 2) A sitting person in support and under without support condition presented significantly higher mean ratings of SCM EMG value over the increase of time.

- 3) A sitting person under support and under without support condition showed higher mean ratings of SCM EMG value over the increase of head rotation angles for both rotation directions.

The results from the calibration experiment act as important input to calibrate our neck support design and validate our developed smart neck support system.

5.4 VALIDATION EXPERIMENT

In this subsection, a validation experiment is reported. The validation experiment is to validate the developed smart neck support system (SnS²) in a simulated 'real life' setting. The design knowledge about SnS² was acquired from literature review findings as well as our survey results. Next, a functional prototype of SnS² was developed. The aim of SnS² is to support the passenger's head and reduce passenger neck muscle stress during air travel adaptively and autonomously. An aircraft cabin simulator was utilised to conduct the validation experiment. The calibration experiment was conducted to gain information to be used for the validation experiment. The validation is an important process of SnS². A similar validation process is also described by Rauterberg (2006) and Abrazhevich et al. (2009).

5.4.1 Research Question

There are two research questions related to the validation experiment. The first question is to examine subjectively about the comfort experience of the participants with or without the smart neck support system based on the questionnaire. The second question is to examine objectively whether the SnS² is able to reduce the SCM muscle stress when supported by our SnS². Both questions are applicable to our treatment group in the validation experiment.

The first question is to examine subjectively about the comfort experiences of the participant with or without the smart neck support system by answering the questionnaire after each experiment (control experiment and treatment

experiment). The first question used the comfort factors selected from Section 2.3.2.

The second question is to examine whether the SCM EMG values of the participant supported by SnS² are lower than without support condition. The result from this hypothesis is important information used to validate the developed smart neck support system subjectively and objectively.

5.4.2 Methods

Participant

Three participants (N = 3) with no neck pain over the last three months were recruited in this experiment. The group consisted of one female and two males aged between 27 and 32 years old (mean 29.67 years). They were informed regarding the experiment which involved questionnaires, sat inside the aircraft cabin simulator for one hour with SCM electromyography measurement and video recording. The participants were invited for the experiment and were given Euro 20 after completion. The demographic details of the participant are shown in Table 5.11.

Table 5.11 Demographic details of participants.

Variable	M	SD	N
Age (years)	29.67	2.52	3
Weight (kg)	64.67	4.51	3
Height (m)	1.72	0.07	3
BMI (kg/m ²)	21.77	0.55	3

Experimental Setup

We conducted two experiments inside the aircraft cabin simulator. The location of the experiment is in the simulation lab in the main building of Eindhoven

University of Technology. The first experiment was done with the control group where there is no installation of the SnS² and the participants had attached EMG electrodes. The first experiment was conducted from 7:00 PM to 8:00 PM on 5th February 2010 (Friday). The second experiment was done with the treatment group where there is installation of the SnS² to the economy class aircraft passenger seat and the participants had attached EMG electrodes. The second experiment was conducted from 7:00 PM to 8:00 PM on 12th March 2010 (Friday). Both experiments recruited the same participants and tested under the same experimental conditions. The duration of both experiments is about one hour. The experimental setup for the treatment group in the aircraft cabin simulator is shown in Figure 5.12.

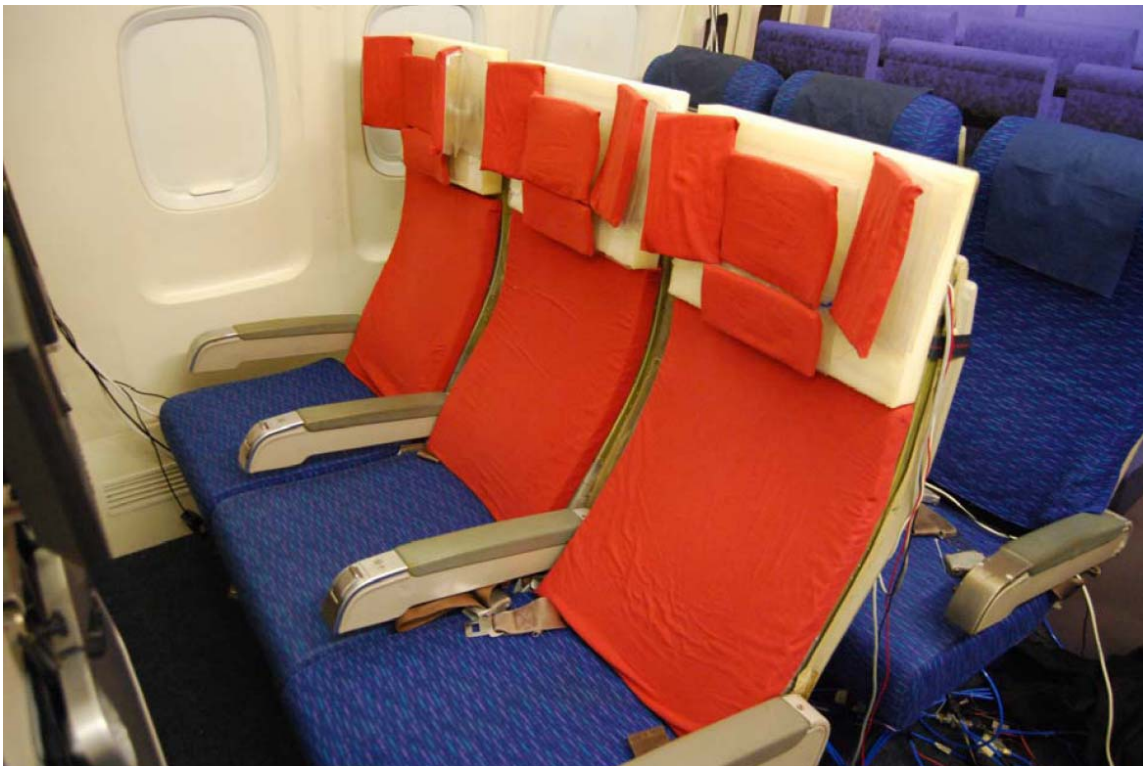


Figure 5.12 The installation of three SnS² prototypes in the aircraft cabin simulator for validation experiment with the treatment group.

For observational purposes, CCTVs were installed inside the aircraft cabin simulator. There were two CCTVs used to monitor each participant's activities separately. One CCTV is located in front of the participant and another CCTV is located directly above the head of the participant. There is a CCTV that monitored the overall activities in the cabin.

Questionnaire

A questionnaire (Appendix A.9) was distributed after the experiment with the control group and the experiment with the treatment group. The questionnaire consisted of two sections: (1) questions regarding the comfort factors of the neck support (without SnS² in control group, with SnS² in treatment group) during the experiment; (2) questions about demographic background. The comfort experience was based on the comfort descriptor in Section 3.2 in Chapter 3. The primary goal of our investigation is to understand the smart neck support effects to the participant after the experiment. The questionnaire had two main parts:

1. The first part examined the comfort factor of the neck support of the economy class aircraft passenger seat during the experiment. It contained 10 questions that evaluated the comfort feeling of the participants during the experiment. Participants could indicate their degree of comfort based on a nine point Likert scale (1 = 'not at all'; 5 = 'moderately'; 9 = 'extremely').
2. The second part assessed demographic variables of the participants, such as gender, age, height and weight.

Apparatus and Data Recording

For the first experiment with the control group, the following hardware was used:

- MP150 Biopac system with EMG module (MP150WSW with EMG100C)
- Aircraft cabin simulator (refer to Chapter 4)
- Personal computer (Intel Pentium Dual Core)
- CCTV (VZOR VMP311)

The specification of the second hand aircraft passenger seats used in both experiment is as follows:

Product name: Recaro Air Comfort

Model no.: 3010-3

Weight: 29.349 kg

Date of manufacture: 14 July 1981

Next, in order to gather EMG value of the SCM muscle and observe the activity of the participants during the second experiment with the treatment group, different hardware was used. The hardware used during the second experiment is as follows:

- MP150 Biopac system with EMG module (MP150WSW with EMG100C)
- Smart neck support system (SnS²) (refer to Chapter 3)
- Aircraft cabin simulator (refer to Chapter 4)
- Personal computer (Intel Pentium Dual Core)
- CCTV (VZOR VMP311)

Three smart neck support systems were installed on each aircraft passenger seat inside the aircraft cabin simulator. The computer was used for data logging and video recording. The CCTVs were installed at the front as well as above each participant.

Experimental Procedure

Before the experiment with the control group, 15 minutes of briefing was conducted. Next, the participants were positioned inside the aircraft cabin simulator. The acquisition of EMG signals and procedures are the same as the experimental procedure in Section 5.3.2. After that, the light in the aircraft cabin was dimmed and the participants were advised to rest during the one hour experiment. The EMG measurement and video recording was conducted on a real time basis. After one hour of experiment, the participants were given a questionnaire. The experiment procedure for the SCM muscle measurement is the same as the experimental procedure in Section 5.3.2.

For the experiment with the treatment group, we started the experiment with 45 minutes of briefing to the participants and the attachment of electrodes on the SCM muscles. The acquisition of EMG signals and procedures are the same as the experimental procedure in Section 5.3.2. After that, we positioned the participants on the economy class aircraft passenger seats. The aircraft passenger seat sitting positions were classified as aisle seat, center seat and window seat. Next, the light in the aircraft cabin was dimmed and the participants were advised to rest during the one hour experiment. The EMG signals of the participants were monitored and recorded in parallel with system logging and video recording. The validation experiment setup in the aircraft cabin simulator is shown in Figure 5.13. After the experiment, the EMG electrodes were detached from the participants and a questionnaire was given to each participant. Lastly, debriefing was conducted and each participant was paid Euro 20.

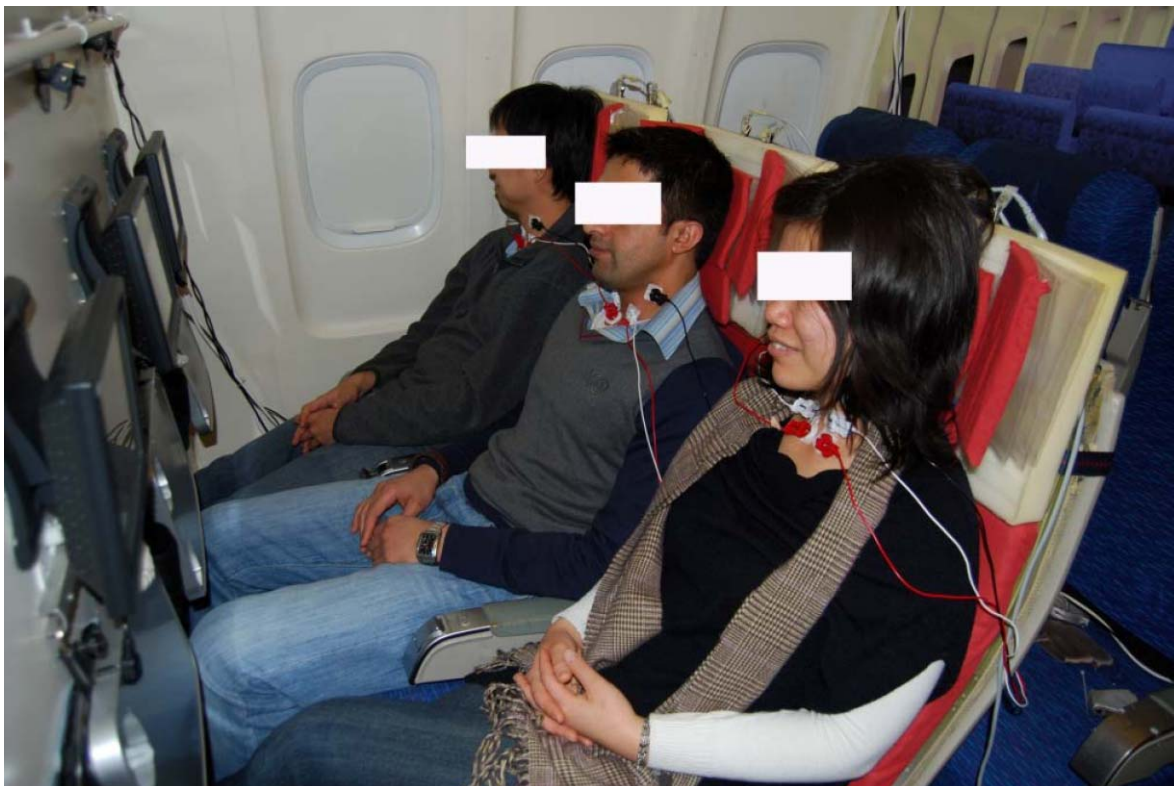


Figure 5.13 The experimental setup of participants for the treatment group in the aircraft cabin simulator.

Signal Acquisition and Processing

The normalized EMG activity was analyzed. Normalization of EMG activity was performed for each participant individually. To measure the MVC of SCM muscle, the participant's head was turned to the maximum head rotation angle. The procedure to normalize the SCM EMG value is the same as described in Section 5.3.2.

Data Analysis

For the recorded normalized EMG data, the data with the complete cycle were selected for further analysis. The complete cycle is the cycle from 1) SnS² detects the participant's head 2) the support of the participant's head and 3) the deactivation of SnS² when the participant's head is away. The selection of the normalized EMG data is based on the data log information. The data log is recording the time when the system is activated and the time when the system is deactivated. The data log with complete cycles of airbag activity will be selected for further analysis. The complete cycle was described as 1) the participant's head is in touch with the airbag 2) after t time the airbag is inflated and supports the participant's neck and 3) the participant is not in touch with the airbag, the airbag will be deflated. The data with incomplete cycles will be ignored. The selected average normalized EMG value was used for statistical analysis. For the statistical analysis, the time domain was divided into 10 time intervals where one time interval represents one minute. The normalized EMG values were then averaged over five second blocks in each time interval. Hence, each one minute time interval has 12 five seconds blocks. The average normalized EMG value was further analyzed with statistical method. A descriptive statistical method was used to analyze the questionnaire about comfort factors as well as to examine differences before support by SnS² and after support by SnS².

Limitation

The validation experiment was conducted on SnS² inside the aircraft cabin simulator. The experiment was conducted in the static aircraft cabin like environment. Thus, some important factors such as accelerations and air pressure like the real aircraft environment could not be addressed. In addition, the aircraft passenger seat used was a second hand aircraft seat which has been used for almost 29 years. Besides, there was no sleeping activity among the participants. For control group, only questionnaire data were available.

5.4.3 Results

The results from the questionnaire distinguished between the experiment with the control group and the experiment with the treatment group. The means and standard deviations of the questionnaire scores are shown in Table 5.12. Both groups use the mean score across the 10 questions. The mean scores from the statistical results showed that the means scores for the treatment group (M = 5.60, SD = 1.63) is higher than for the control group (M = 5.10, SD = 1.37).

Table 5.12 The questionnaire scores for the two groups (control and treatment).

Group	N	M	SD
Control	30	5.10	1.37
Treatment	30	5.60	1.63

The means and standard deviations of the comfort factor scores are shown in Table 5.13. We found that the comfort factors, such as ‘good neck support’ (control group: M = 3.67, SD = 2.31; treatment group: M = 5.67, SD = 3.22), ‘restful’ (control group: M = 4.67, SD = 1.16; treatment group: M = 5.00, SD = 1.73), ‘no stiffness’ (control group: M = 4.67, SD = 0.58; treatment group: M = 5.33, SD = 0.58), ‘no sore muscles’ (control group: M = 4.67, SD = 1.16;

treatment group: M = 5.3, SD = 1.16), 'no fatigue' (control group: M = 5.67, SD = 2.31; treatment group: M = 7.00, SD = 1.00), 'no strained' (control group: M = 5.00, SD = 1.73; treatment group: M = 6.00, SD = 2.00) and 'comfortable' (control group: M = 6.00, SD = 1.00; treatment group: M = 6.33, SD = 1.53) show the increase of mean ratings for comfort in the treatment group. Subsequently, there are three comfort factors that show the decrease of mean ratings, these are 'relax' (control group: M = 5.00, SD = 0.00; treatment group: M = 4.67, SD = 1.53), 'seat cushion firmness' (control group: M = 5.33, SD = 1.16; treatment group: M = 5.00, SD = 2.65) and 'fit' (control group: M = 6.00, SD = 1.00; treatment group: M = 5.67, SD = 0.58). The mean ratings on the comfort experiences for the experiment with control group and experiment with treatment group are shown in Figure 5.14.

Table 5.13 The comfort factor scores related to the control group and the treatment group.

No.	Comfort factors	N	Control group		Treatment group	
			M	SD	M	SD
1.	Good neck support	3	3.67	2.31	5.67	3.22
2.	Relax	3	5.00	0.00	4.67	1.53
3.	Seat cushion firmness	3	5.33	1.16	5.00	2.65
4.	Restful	3	4.67	1.16	5.00	1.73
5.	No stiffness	3	4.67	0.58	5.33	0.58
6.	No sore muscles	3	4.67	1.16	5.33	1.16
7.	No fatigue	3	5.67	2.31	7.00	1.00
8.	No neck strained	3	5.00	1.73	6.00	2.00
9.	Fit	3	6.33	0.58	5.67	0.58
10.	Comfortable	3	6.00	1.00	6.33	1.53
	Total		5.10	1.37	5.60	1.63

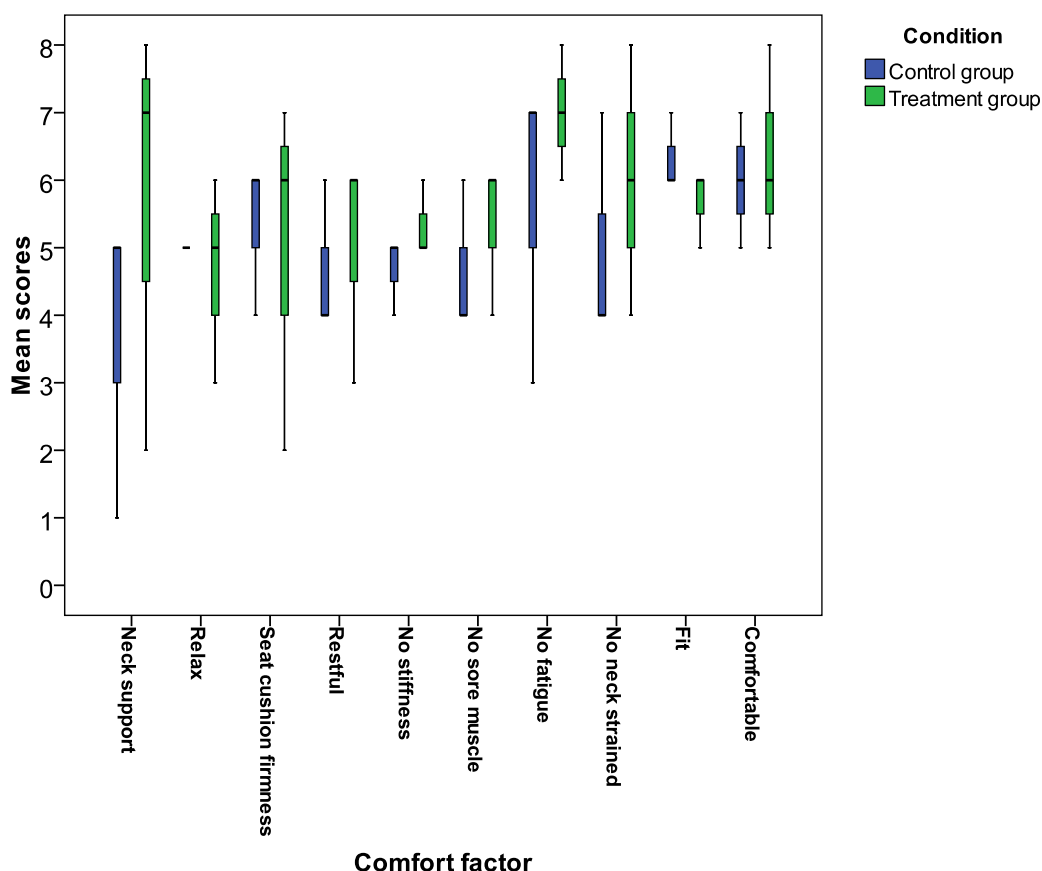


Figure 5.14 The box plot of comfort factors for the control group and the treatment group.

After the experiment with the treatment group, the results from EMG measurements were selected and analyzed. The mean scores of the normalized EMG value after supported by SnS² (M = 2.82, SD = 2.13) are lower than the mean scores of the normalized EMG value for before supported by SnS² (M = 3.03, SD = 2.31). The means and standard deviations of the normalized EMG value for the two test conditions are shown in Table 5.14. The mean scores of the normalized EMG value after supported by SnS² are also lower than the mean scores of the normalized EMG value before supported by SnS². The mean scores for each participant are shown in Table 5.15. The mean scores of the normalized EMG value for the participants in relation with neck support activity are shown in Figure 5.15.

Therefore, H₀ can be rejected and H₁ is selected for hypothesis 2.

Table 5.14 The normalized EMG values for the two test conditions.

Test condition	N	M	SD
Before supported by SnS ²	30	3.03	2.31
After supported by SnS ²	30	2.82	2.13

Table 5.15 The normalized EMG values for each participant separately.

Test condition	N	P1		P2		P3	
		M	SD	M	SD	M	SD
Before supported by SnS ²	30	4.93	1.39	3.56	2.81	1.41	0.35
After supported by SnS ²	30	4.38	1.21	3.37	2.68	1.37	0.35

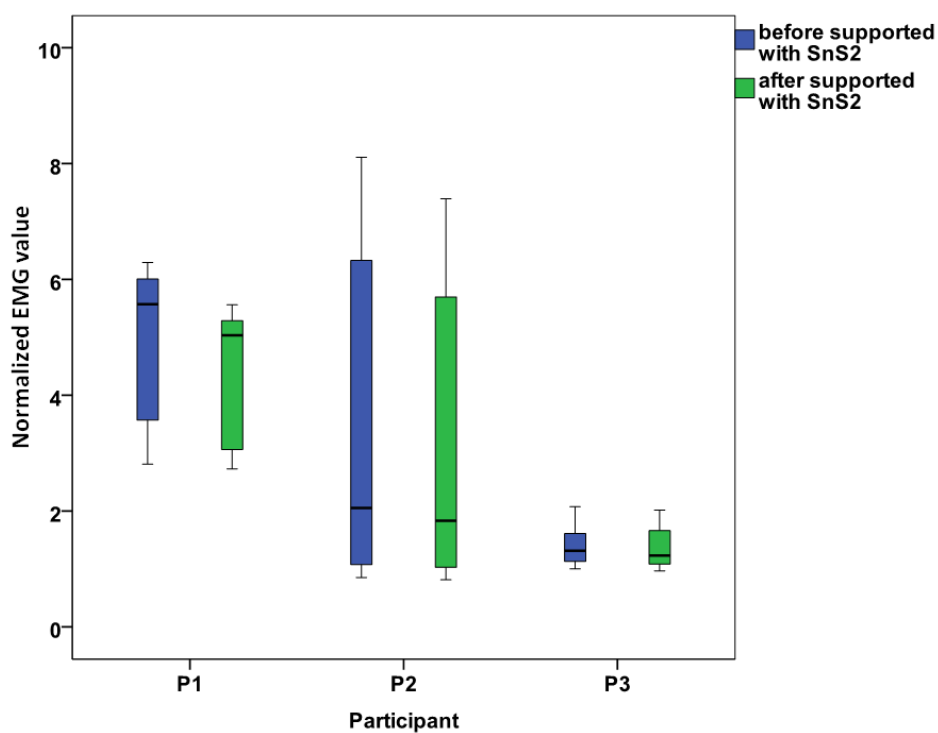


Figure 5.15 The box plot of normalized EMG value for the participants in relation to both neck conditions (before support with SnS² and after supported with SnS²).

5.4.4 Discussion and Conclusions

This experiment validated the developed SnS². The major findings from the validation experiment were:

- The mean ratings of a sitting participant in experience on the seat with SnS² demonstrate more comfort than without SnS².
- The mean ratings of a sitting participant SCM EMG value supported by SnS² are lower than without support condition.

The questionnaire was used for the experiment with the control group as well as the treatment group. The participants evaluated the SnS² based on their experience during the experiment. They evaluated the system based on 10 comfort factors selected from Section 2.3.2 in Chapter 2. The mean scores of comfort factors for the treatment group are higher than for the control group. The result shows that the seat enhanced with SnS² is able to improve the subjective comfort experience while sitting. Out of ten comfort factors, there were seven comfort factors that showed the increased of mean ratings such as 'good neck support', 'restful', 'no stiffness', 'no sore muscles', 'no fatigue', 'no neck strained' and 'comfortable'. Three comfort factors presented lower mean ratings i.e. 'relax', 'seat cushion firmness' and 'fit'. The developed SnS² prototype demonstrated comfort improvement in seven comfort factors and decrease of comfort experience in three comfort factors.

For the second result, we tested the SCM participants with EMG measurement to validate the SnS² objectively. The result from the experiment showed that the SnS² is able to reduce the SCM muscle stress. The developed SnS² is able to adapt to the participant's neck posture automatically and provides the necessary neck support to reduce the SCM muscle stress.

The EMG measurements of the SCM muscle demonstrated that the developed SnS² provides support to the participant's neck as well as reduces the SCM muscle stress. The experiment was conducted in the aircraft cabin simulator and tested in the same environment for both experiments. The result from the questionnaire proved that the participants feel subjectively more comfortable with a seat

equipped with SnS². For the experiment with the treatment group, the SCM EMG measurement showed that the SCM EMG value was reduced objectively when it is supported by SnS². The EMG value is lower when both SCM muscles are supported by SnS². The result from the validation experiment is in parallel with the findings in the calibration experiment. It can be proved that the developed SnS² is able to improve the comfort experience and to reduce the SCM muscle stress.

5.5 SUMMARY

In summary, the first part of this chapter examined the SCM muscle stress under different support conditions, time and head rotation angles. The results showed that SCM EMG value is reduced under support condition. The SCM muscle stress was increased in parallel with the increase of time as well as the increase of head rotation angles (0° to 45°). The result from the calibration experiment is an important input for the validation experiment. Next, the validation experiment examined the comfort experience and SCM muscle stress of the participants with the SnS². The results showed that the SnS² is able to reduce the SCM muscle stress adaptively and automatically. It is concluded that the developed SnS² demonstrates the ability to reduce the SCM muscle stress objectively and to improve the comfort experience of the participants subjectively.

CHAPTER 6

CONCLUSION

6.1 OVERVIEW

In this thesis, four key problems have been addressed. The first problem is how we can contribute to reduce the economy class aircraft passenger's seating discomfort during air travel. The second problem is whether a smart support system is able to reduce the economy class aircraft passenger's neck discomfort during air travel. The third problem is how to develop a smart system to reduce the economy class aircraft passenger seating discomfort during air travel. Finally, the fourth problem is how to use the design process to contribute to the development of a smart system for comfort improvement during air travel. To investigate the four key problems, in the previous chapters we have used the subjective method to define the body seating discomfort of aircraft passengers and proposed the smart neck support system (SnS²) to reduce sternocleidomastoid (SCM) muscle stress of economy class aircraft passengers during air travel. In this chapter, we summarize our work and the achieved results.

6.2 QUESTIONNAIRE ON SEATING COMFORT AND DISCOMFORT

Four surveys were conducted to study seating comfort and discomfort subjectively. The first survey identified comfort factors for an economy class aircraft passenger seat. We selected 41 factors to be rated by 82 respondents. Factor analysis was used to identify the underlying dimensions of the factors. The factors were divided into six factors viz. 'no irritation in sitting', 'body support', 'seat function', 'feeling in sitting', 'long hour sitting' and 'adaptability'. Next, the nonparametric Friedman test was used to study the mean rank of 41 comfort factors. The factors were ranked according to means ratings. The result showed that there are significant differences among the 41 factors. The 'spacious' factor was the top rank among the 41 factors, followed by 'adjustable', 'ergonomic', 'head rest', 'seat contour' and 'neck support'.

The second survey studied seating comfort and discomfort for truck drivers. The main focus of the survey is the body seating discomfort in relation to travel time for professional Dutch truck drivers. The body seating discomfort of truck drivers was evaluated based on data after one hour and after five hours travel. In total 217 out of 1000 questionnaires were received and analyzed. Univariate analysis of variance was used to find the differences of body discomfort level for truck drivers after one hour and after five hours travel. The result showed that there is a significant increase of body discomfort ratings after five hours travel. The non parametric Friedman test was used to test the mean rank of 16 defined body parts. Buttocks are the most discomfort body part, both after one hour and after five hours travel. After one hour travel, buttocks, lower back and shoulder were ranked as the top three most discomfort body parts. Subsequently, after five hours travel, the top three most discomfort body parts were buttocks, lower back and neck.

The third survey focused on the body discomfort for economy class aircraft passengers. The survey examined the relationship of body discomfort over time for economy class aircraft passenger during air travel. 104 self administered questionnaires were collected and analyzed statistically. Univariate analysis of variance was used to find the differences of body discomfort level for economy class aircraft passengers after one hour and after five hours travel. The result showed that there is a significant increase of body discomfort ratings after five hours travel. The nonparametric Friedman test was conducted to test the mean rank of 16 defined body parts of aircraft passengers from the same population. 16 body parts of aircraft passenger were ranked. The top three most discomfort body parts after one hour travel was shoulder, neck and right lower leg. After five hours travel, buttocks, shoulder and neck were the top three most discomfort body parts.

The fourth survey studied the relationship of sitting posture of economy class aircraft passenger and sitting location in the economy class section. The survey was conducted in a flight from Kuala Lumpur to Amsterdam and 12 passengers were being observed. Selected passengers were observed and

recorded based on seven pre-defined sitting postures. The Chi-square test showed that there is a significant correlation between sitting posture and seat location. In this observation survey we also found that six out of 12 observed passengers preferred the position where the head and body were facing the front.

The comfort factors such as adjustable, head rest and neck support can be used to represent the preferences of economy class aircraft passengers, which is important during the early stage of the design process. The survey on truck driver's body discomfort over time is a study used to compare with the body discomfort survey over travel time of economy class aircraft passengers. Both truck drivers and economy class aircraft passengers are spending most of their time sitting during travel. The truck driver is driving while sitting whereas the economy class aircraft passenger is resting while sitting. There are differences in body discomfort over travel time for truck drivers and economy class aircraft passengers. However after five hours travel, buttocks and neck are amongst the most discomfort body parts for both truck drivers and economy class aircraft passengers. Lastly, the survey found that there is a significant correlation between sitting location and sitting posture. Half of the observed passengers preferred head and body facing front during the observation process. The output from four surveys provides important information for the development of a smart neck support system (SnS²) in our whole design process.

6.3 A SMART NECK SUPPORT SYSTEM

The development of smart neck support system (SnS²) is to reduce sternocleidomastoid (SCM) muscle stress of economy class aircraft passenger during air travel. SnS² consists of a main central processor, a database, sensors and actuators. There are four conditions for SnS². To simulate air pressure changes in the airbag system, we developed the air pressure model. With the application of air pressure model, the airbag system is capable to detect the passenger's head posture and support the economy class aircraft

passenger's neck adaptively in an automatic manner. To ensure the reliability and to predict the behavior of the airbag system, we applied a mechanical model of the airbag. A systematic approach, namely total design, was used to develop SnS². Different methods were used to develop the concept for SnS². The total design method was used for the development of our SnS². Functional and working prototypes were built for visualization and validation purposes. The functional prototype consists of a head cushion, a neck cushion and two side airbags. Open source hardware (Arduino) and software (Arduino and Processing) were used to develop the control module for SnS² prototype.

In order to validate the developed SnS², two experiments were conducted. The first experiment is targeted as a calibration experiment. This experiment examined the right and left SCM muscle over different support conditions, time and head rotation angles. The results showed that the SCM muscle electromyography (EMG) values under the support condition are lower than under the without support condition. The SCM muscle EMG value was increased in parallel with the increase of time as well as head rotation angle (0° to 45°) for right and left side. The results from the calibration experiment, where the neck with support condition showed lower EMG values than the neck without support condition, are important inputs for the validation experiment. Secondly, the validation experiment examined the comfort experience and SCM muscle stress of the participants with SnS². In this one hour experiment in the aircraft cabin simulator, the results showed that SnS² is able to improve the subjective comfort experience as well as to reduce the SCM muscle stress.

6.4 AIRCRAFT CABIN SIMULATOR

The aircraft cabin simulator was constructed to validate the developed smart neck support system (SnS²). The total design approach was used for the development of our aircraft cabin simulator. The aircraft cabin simulator is capable to simulate the average economy class aircraft cabin environment.

The aircraft cabin simulator consists of an economy class section, a business class section, a lavatory, a galley and a gangway. The aircraft simulator was built on a motion platform which consists of four airbags and is controlled by state of the art automation technology. The developed aircraft simulator was considered as a low cost design in comparison with current commercially available aircraft simulators. The low cost aircraft cabin simulator was validated with twelve participants in two 10 hours experiments. The presence questionnaire was used to examine the perceived realism of the developed aircraft cabin simulator. The statistical result showed that our developed aircraft cabin simulator is sufficiently able to simulate the environment of an economy class aircraft cabin.

6.5 OVERALL CONCLUSIONS

The main conclusions are summarized as follows:

- From the literature study, the current available economy class aircraft seat is limited to passive comfort improvement technology and focuses on sitting space. The objective and subjective measurements need to be combined for better understand the seating comfort and discomfort as well as to evaluate the developed SnS².
- To understand the body back discomfort among economy class aircraft passengers and truck drivers, we designed four surveys. The results from the survey on seating comfort and discomfort showed that the neck is one of the main body parts negatively influenced by travel duration. Both truck drivers and economy class aircraft passengers showed the body part discomfort level was increased over travel time. The buttocks are the most discomfort body part after five hours travel. The sitting posture of the economy class aircraft passengers was determined by the seat location in the aircraft cabin. Half of the observed passengers preferred the position where the head and body are facing the front.
- With input from the survey on body discomfort of economy class aircraft passengers, we contribute to the development of a smart

system, namely the smart neck support system (SnS²) to reduce sternocleidomastoid (SCM) muscle stress adaptively during air travel. We developed an air pressure detection model for the implementation of SnS² and a mechanical model to predict the mechanical behavior of the airbag system of SnS². Total design method was used to develop the SnS². Prototypes were built to demonstrate the functionality and usability of SnS².

- To evaluate the developed SnS², we developed the low cost aircraft cabin simulator. The development of the aircraft cabin simulator is important to create an average aircraft cabin environment for experimental purposes. The aircraft cabin simulator is a low cost design which can simulate the general flight procedures with a motion platform. Experiments were designed to evaluate SnS² in the simulator. Experimental results showed that the SnS² is able to reduce SCM muscle stress adaptively.
- In the development of SnS², we applied the overall design process with requirements, conceptual design, prototyping and evaluation. We have developed the SnS² to reduce SCM muscle stress adaptively during air travel.

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APPENDICES

APPENDICES

APPENDIX A.1 Questionnaire on Seating Comfort Factors

The objective of the questionnaire is to test the relation between COMFORT and aircraft seat factors. Please rate the following factors by ticking (●).

	Very closely related to Comfort	Closely related to Comfort	Slightly related to Comfort	Not related to Comfort
Lumbar support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ergonomic	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Seat contour	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Spacious	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Side support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Firmness of backrest	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Breathability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adjustable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Seat cushion firmness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Restful	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Head rest	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fit	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Relax	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Adaptable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Arm rests	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Neck support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Functionality	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Leg support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Pleasurable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Well being	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Uneven pressure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Automatic adjustment	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Not Bouncy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Long duration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Massage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Reliable	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Short duration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Hardness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Intelligent	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Strained	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Fatigue	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Sore muscles	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Warm	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Stiffness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Vibration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Heavy legs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Safety	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Pressure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Not Tired	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
No Shock	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

No Uneasy

What is your age?

What is your gender?

Female

Male

What is your last educational level?

High School

Certificate

Diploma

Bachelor

Master

PhD

Other (please specify)

**WORKING TOGETHER,
WE CAN MAKE AIRCRAFT SEAT MORE COMFORTABLE.**

THANK YOU FOR YOUR COOPERATION

APPENDICES

APPENDIX A.2 The Means and Standard Deviation of Comfort Factors

No.	Factor	N	M	SD
1	Spacious	55	3.20	1.03
2	Adjustable	55	3.15	0.76
3	Ergonomic	55	3.12	1.23
4	Head rest	55	3.12	0.98
5	Seat contour	55	2.98	1.01
6	Neck support	55	2.95	1.05
7	Relax	55	2.80	1.19
8	Firmness of backrest	55	2.85	0.88
9	Seat cushion firmness	55	2.76	1.02
10	Restful	55	2.76	1.26
11	Safety	55	2.73	1.07
12	Adaptable	55	2.66	1.09
13	Arm rest	55	2.73	0.90
14	Lumbar support	55	2.34	1.51
15	No stiffness	55	2.56	1.03
16	Breathability	55	2.66	0.99
17	No sore muscles	55	2.46	1.31
18	No fatigue	55	2.51	1.25
19	Fit	55	2.49	1.08
20	Side support	55	2.59	0.92
21	Leg support	55	2.54	0.93
22	No hardness	55	2.34	0.94
23	No pressure	55	2.29	1.12
24	Not tired	55	2.22	1.29
25	No shock	55	2.17	1.30
26	No vibration	55	2.32	0.96
27	Reliable	55	2.34	1.02
28	Well being	55	2.07	1.39
29	Warm	55	2.24	1.07
30	No uneven pressure	55	2.12	1.25
31	Functionality	55	2.29	0.96
32	No uneasy	55	2.02	1.42
33	Massage	55	2.22	1.15
34	No heavy leg	55	2.10	1.24
35	No strained	55	2.07	1.31
36	Automatic adjustment	55	2.00	1.10
37	Long duration	55	1.98	1.33
38	Pleasurable	55	2.00	1.20
39	Intelligent	55	1.73	1.03
40	Not bouncy	55	1.51	1.14
41	Short duration	55	1.59	1.10

APPENDIX A.3 Truck Driver's Seat Uncomfortable Survey



TRUCK DRIVER'S SEAT UNCOMFORTABLE SURVEY

Dear Member,

We need your help to improve truck driver's seat comfort. Little is really known about truck driver's seat uncomfortable during driving. Technische Universiteit Eindhoven is concerned about the risks of truck drivers may encounter during driving. In cooperation with the BGZ Wegvervoer, we are conducting a survey to determine the uncomfortable indicators of truck driver's seat during driving. Results from this survey will help determine measures that could be taken to protect the member of BGZ Wegvervoer.

You have been randomly selected from the BGZ Wegvervoer membership list to participate in this survey. Only a small proportion of the BGZ Wegvervoer members has been selected to participate, so your experience and thoughts on the subject are very important. **You will be representing many members who are similar to yourself.**

Enclosed is a copy of the questionnaire that includes question about:

- your truck
- your driving experience
- your feeling
- your seat
- your body
- yourself

Please take the time to complete the questionnaire and return it in the enclosed self-addressed stamped envelope. It would be very helpful to have your completed questionnaire returned to us by **31 July 2008**.

Your responses are confidential. No names or individual information will be used or released to your employer. If you have any question or concerns about the survey, please feel free to call me at (040) 247 2514 or Wei Chen at (040) 247 3563.

Thank you for your cooperation.

Yours sincerely,

ir. CheeFai Tan
Promovendus

Designed Intelligence Group
Department of Industrial Design
Technische Universiteit Eindhoven
Tel: 040 247 2514
Fax: 040 247 3285
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ir. Marinka de Groot
Adviseur arbeid en gezondheid

BGZ Wegvervoer
Tielweg 3
2803 PK Gouda
Tel: 0182-596144
Fax: 0182-517740
Email: mgroot@bgz.nl

General Instruction

Please answer the following questions by **write** and **tick** (√) the answer you have chosen (see example below).

Example

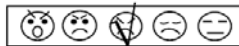
Please "TICK" (√) the answer that you select.

Is there any Cab Suspension with your truck?

Yes
 No

What do you think about your seat discomfort? Please rate your discomfort based on each part of your seat.

EXTREMELY UNCOMFORTABLE



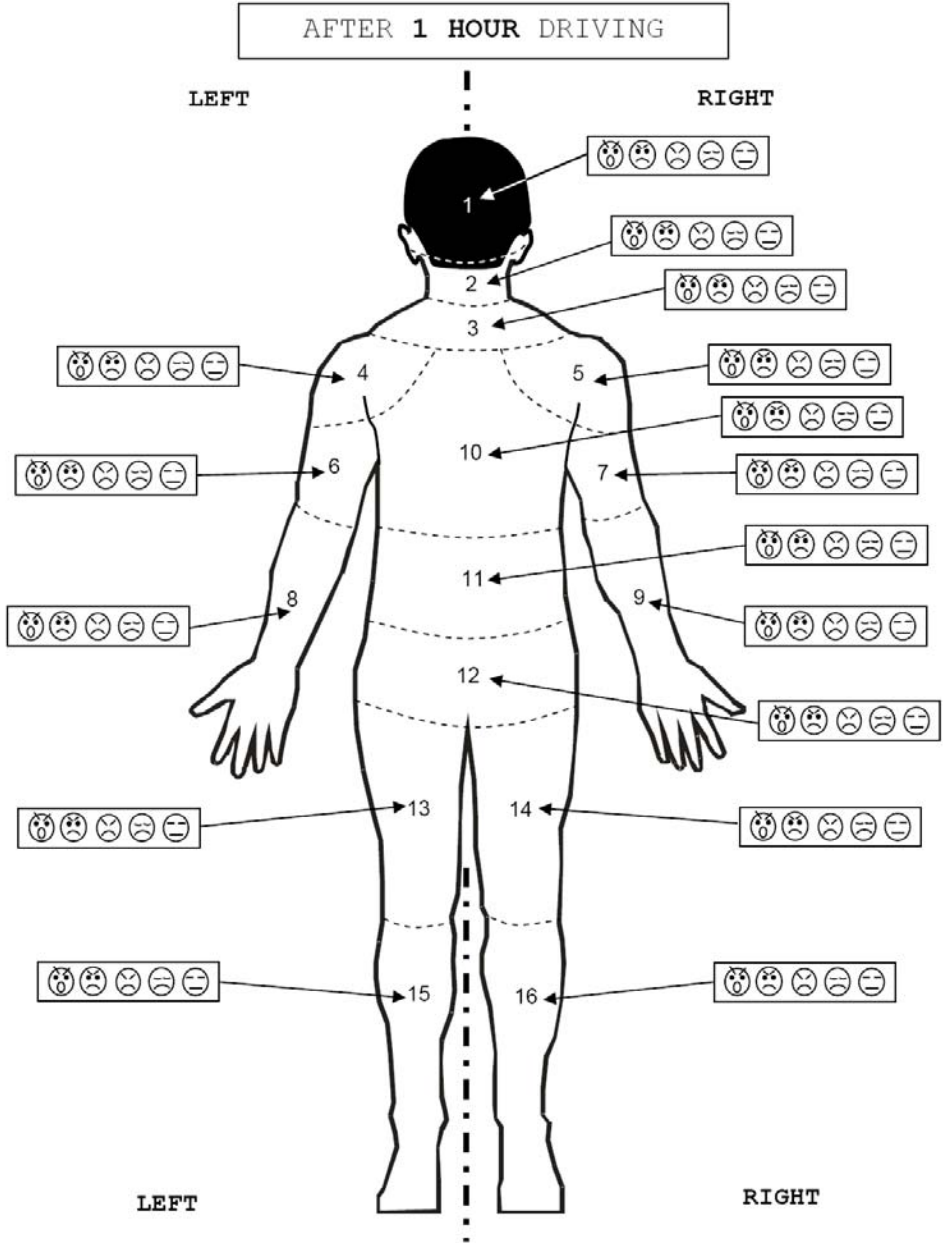
NORMAL

A. About Your Body

1. During driving, some parts of the body will be feeling uncomfortable. Please rate your **uncomfortable level** of each part of your body backside after **one (1) hour** driving. Please tick **all** legends.

Legend:

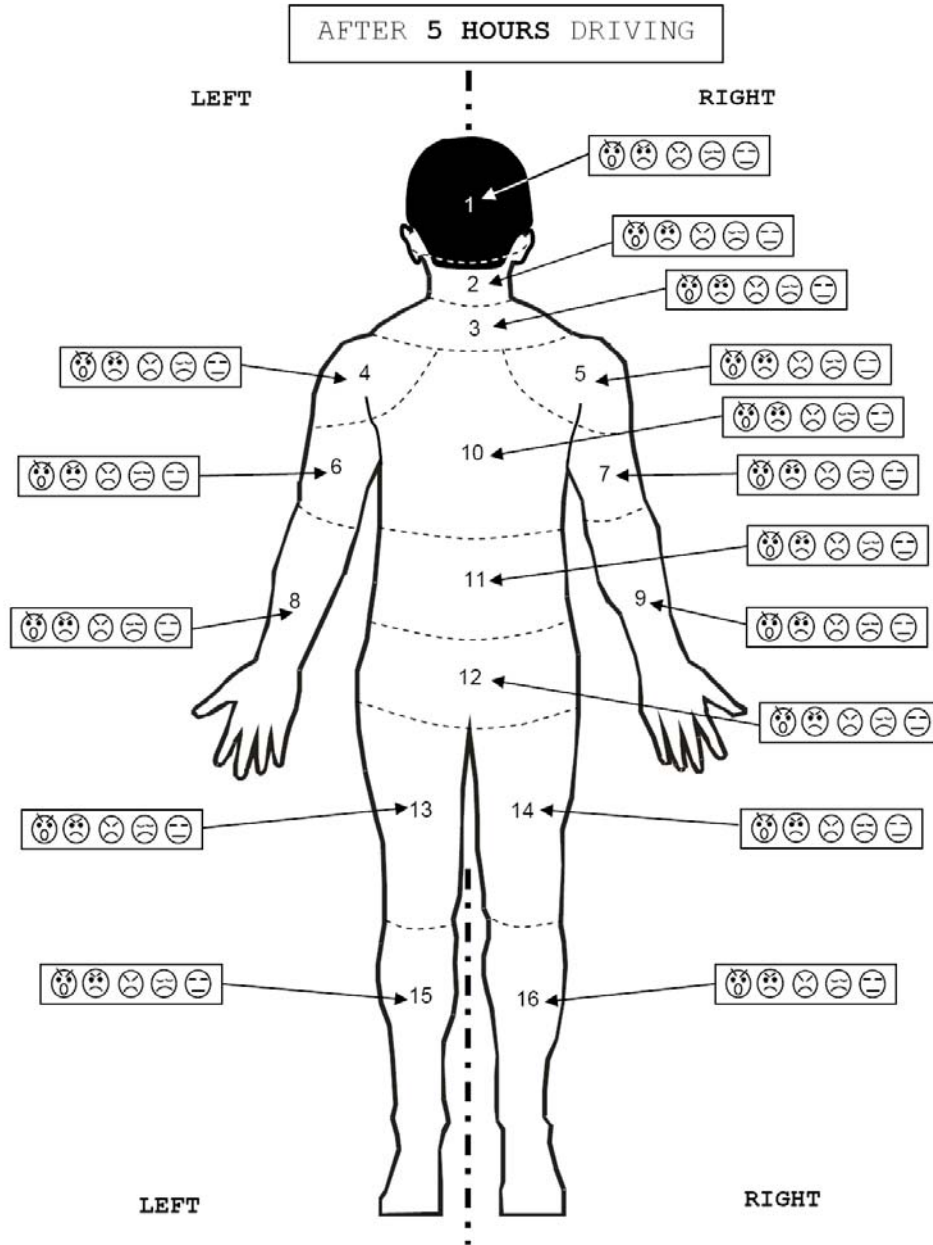
EXTREMELY UNCOMFORTABLE  NORMAL



2. During the long hour driving, some parts of the body will be feeling uncomfortable. Please rate your **uncomfortable level** of each part of your body backside after **five (5) hours** driving. Please tick **all** the legends.

Legend:

EXTREMELY UNCOMFORTABLE  NORMAL



F. About Yourself

3. What is your **gender**?
- Male
 Female
4. What is your **age**?
- years old
5. What is your **height**?
- meter
6. What is your **weight**?
- kg
7. What is your **educational level**?
- Primary education (Basisonderwis)
 Basic secondary education (Basisvorming)
 Pre-university education (VWO)
 Senior General Secondary education (HAVO)
 Pre-vocational education (VMBO)
 Secondary vocational education (MBO)
 Higher professional education (HBO)
 University education (WO)
 Other, namely.....

**You have completed the questionnaire.
Please take a moment to look through your answers.
Return the questionnaire to us in
the self address pre-paid envelope supplied.**

**ONCE AGAIN THANK YOU FOR YOUR TIME AND HELP
IN SUPPORTING MY PHD RESEARCH**

APPENDICES

APPENDIX A.4 The Mean Ranks, Means and Standard Deviation for Each Truck Driver Body Part After One Hour and After Five Hours of Travel

Truck Driver Body Discomfort											
Body discomfort after 1 hour travel						Body discomfort after 5 hours travel					
No.	Body part	MR	M	SD	N	No.	Body part	MR	M	SD	N
1	Buttock	10.75	2.24	1.34	215	1	Buttock	11.42	2.68	1.43	215
2	Lower back	10.49	2.21	1.37	215	2	Lower back	10.89	2.57	1.43	215
3	Left upper leg	9.23	1.89	1.20	215	3	Neck	9.37	2.17	1.26	215
4	Shoulder	9.22	1.89	1.17	215	4	Shoulder	9.37	2.15	1.27	215
5	Neck	9.12	1.89	1.23	215	5	Right upper leg	9.16	2.13	1.32	215
6	Right upper leg	9.11	1.87	1.20	215	6	Left upper leg	9.07	2.11	1.31	215
7	Upper back	8.30	1.70	1.12	215	7	Upper back	8.65	2.02	1.31	215
8	Left shoulder	8.28	1.68	1.09	215	8	Right shoulder	8.41	1.95	1.26	215
9	Right shoulder	8.26	1.69	1.12	215	9	Left shoulder	8.19	1.89	1.23	215
10	Right lower leg	8.18	1.66	1.11	215	10	Left lower leg	8.12	1.90	1.27	215
11	Left lower leg	7.96	1.60	1.07	215	11	Right lower leg	8.10	1.91	1.30	215
12	Right lower arm	7.66	1.60	1.14	215	12	Left lower arm	7.24	1.64	1.10	215
13	Left lower arm	7.54	1.54	1.09	215	13	Right lower arm	7.14	1.64	1.10	215
14	Left upper arm	7.46	1.49	1.02	215	14	Right upper arm	7.04	1.61	1.05	215
15	Right upper arm	7.32	1.49	1.02	215	15	Head	6.93	1.59	1.12	215
16	Head	7.24	1.50	0.99	215	16	Left upper arm	6.91	1.57	1.01	215

APPENDIX A.5 Economy Class Aircraft Seat Survey (Woman)



Ref. no.: QAM

ECONOMY CLASS AIRCRAFT SEAT SURVEY

Dear Sir,

We need your help to improve economy class aircraft seat comfort. Little is really known about aircraft seat comfort during air travel. Technical University Eindhoven is concerned about the comfort of economy class aircraft passengers may encounter during air travelling. Due to this reason, we are conducting a survey to determine the comfort indicators of economy class aircraft seat. Results from this survey will help determine measures that could be taken to improve the economy class aircraft comfort.

You have been randomly selected and only a small proportion of the economy class aircraft passengers have been selected to participate, so your experience and thoughts on the subject are very important. **You will be representing many economy class aircraft passengers.**

Enclosed is a copy of the questionnaire that includes question about:

- **your travelling habits**
- **economy class aircraft seat**
- **your body**
- **yourself**

Please take the time to complete the questionnaire and it would be very helpful to have your completed questionnaire.

Your responses are confidential. No names or individual information will be used or released.

Thank you for your cooperation.

Yours sincerely,

ir. CheeFai Tan
 Doctorate Candidate
 Designed Intelligence Group
 Department of Industrial Design
Technische Universiteit Eindhoven
 Tel: 040 247 2514
 Email: c.f.tan@tue.nl

General Instruction

Please answer the following questions by **cross** (X) or **write** the answer you have chosen (see example below).

Are you a frequent air traveler?

- Yes
 No

What do you think about your seat discomfort? Please rate your discomfort based on each part of your seat.

EXTREMELY UNCOMFORTABLE  NORMAL

A. About Your Travelling Habits

1. How many **time(s)** do you **travel by aircraft** in a year?
 - 1 time
 - 2 - 5 times
 - 6 - 10 times
 - 11 times or more
 - I Don't know


2. What is your most common flight **duration**?
 - Less than 1 hour
 - 2 - 5 hours
 - 6 - 10 hours
 - 11 hours or more
 - I Don't know

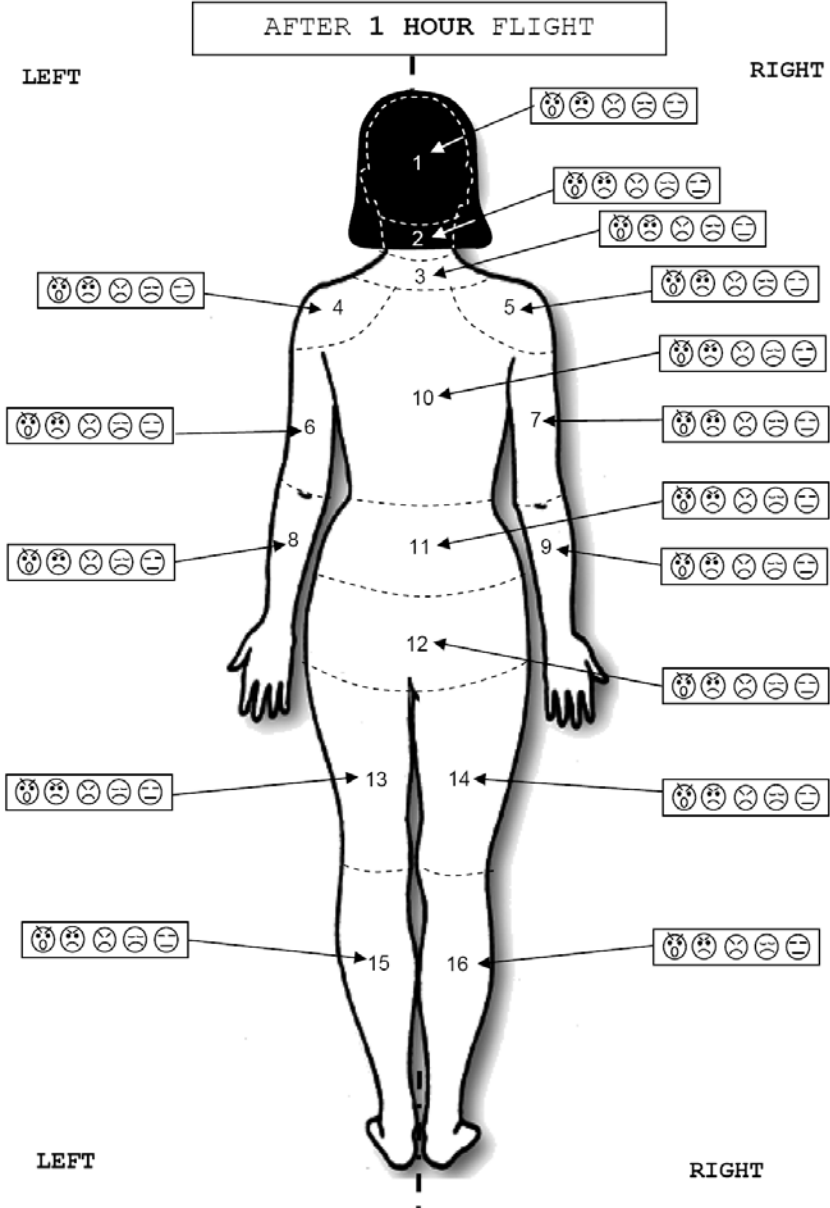
3. What **class** do you normally fly?
 - First
 - Business
 - Economy
 - I Don't know

B. About Your Body

4. During the flight, some parts of your body will be feeling uncomfortable. Please rate your **uncomfortable level** of each part of your body backside after **ONE (1) hour** flight. Please **select and tick (✓)** the appropriate "smiley" for your body part.

Legend:

EXTREMELY UNCOMFORTABLE  NORMAL



APPENDICES

5. During the long haul flight, some parts of your body will be feeling uncomfortable. Please rate your **uncomfortable level** of each part of your body backside after **FIVE (5) hours** flight. Please **select** and **tick (✓)** the appropriate "smiley" for your body part.

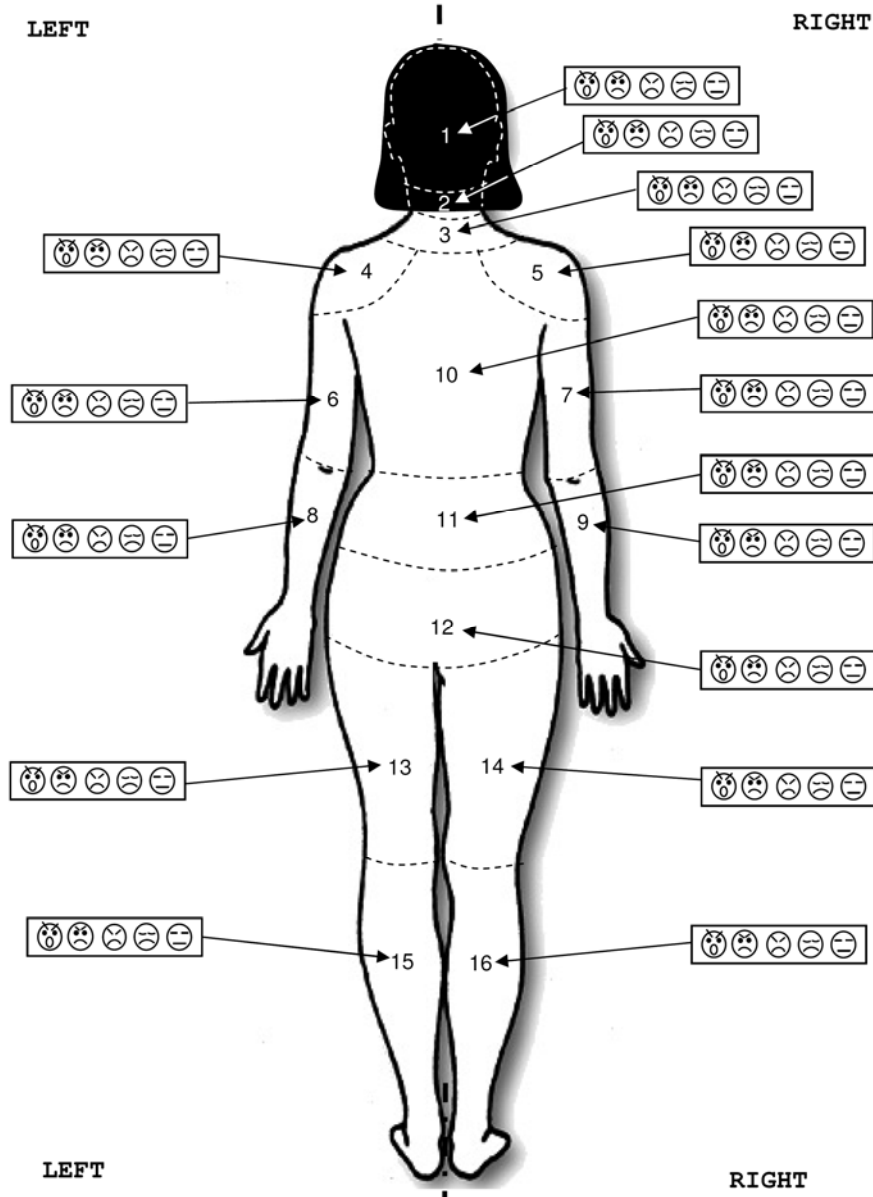
Legend:

EXTREMELY UNCOMFORTABLE  NORMAL

AFTER 5 HOURS FLIGHT

LEFT

RIGHT



LEFT

RIGHT

C. About Yourself

6. What is your **gender**?

- Male
 Female

7. What is your **age**?

..... years old

8. What is your **height**?

..... meter


9. What is your **weight**?

..... kg

You have completed the questionnaire.
Please take a moment to look through your answers.

ONCE AGAIN THANK YOU FOR YOUR TIME AND HELP
IN SUPPORTING
ECONOMY CLASS AIRCRAFT SEAT RESEARCH

APPENDIX A.6 Economy Class Aircraft Seat Survey (Man)

	Technische Universiteit Eindhoven University of Technology	Ref. no.: QAM
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ECONOMY CLASS AIRCRAFT SEAT SURVEY

Dear Sir,

We need your help to improve economy class aircraft seat comfort. Little is really known about aircraft seat comfort during air travel. Technical University Eindhoven is concerned about the comfort of economy class aircraft passengers may encounter during air travelling. Due to this reason, we are conducting a survey to determine the comfort indicators of economy class aircraft seat. Results from this survey will help determine measures that could be taken to improve the economy class aircraft comfort.

You have been randomly selected and only a small proportion of the economy class aircraft passengers have been selected to participate, so your experience and thoughts on the subject are very important. **You will be representing many economy class aircraft passengers.**

Enclosed is a copy of the questionnaire that includes question about:

- **your travelling habits**
- **economy class aircraft seat**
- **your body**
- **yourself**

Please take the time to complete the questionnaire and it would be very helpful to have your completed questionnaire.

Your responses are confidential. No names or individual information will be used or released.

Thank you for your cooperation.

Yours sincerely,

ir. CheeFai Tan
Doctorate Candidate
Designed Intelligence Group
Department of Industrial Design
Technische Universiteit Eindhoven
Tel: 040 247 2514
Email: c.f.tan@tue.nl


General Instruction

Please answer the following questions by **cross** (X) or **write** the answer you have chosen (see example below).

Are you a frequent air traveler?

Yes
 No

What do you think about your seat discomfort? Please rate your discomfort based on each part of your seat.

EXTREMELY UNCOMFORTABLE  NORMAL

A. About Your Travelling Habits

1. How many **time(s)** do you **travel by aircraft** in a year?
 - 1 time
 - 2 - 5 times
 - 6 - 10 times
 - 11 times or more
 - I Don't know


2. What is your most common flight **duration**?
 - Less than 1 hour
 - 2 - 5 hours
 - 6 - 10 hours
 - 11 hours or more
 - I Don't know

3. What **class** do you normally fly?
 - First
 - Business
 - Economy
 - I Don't know

B. About Your Body

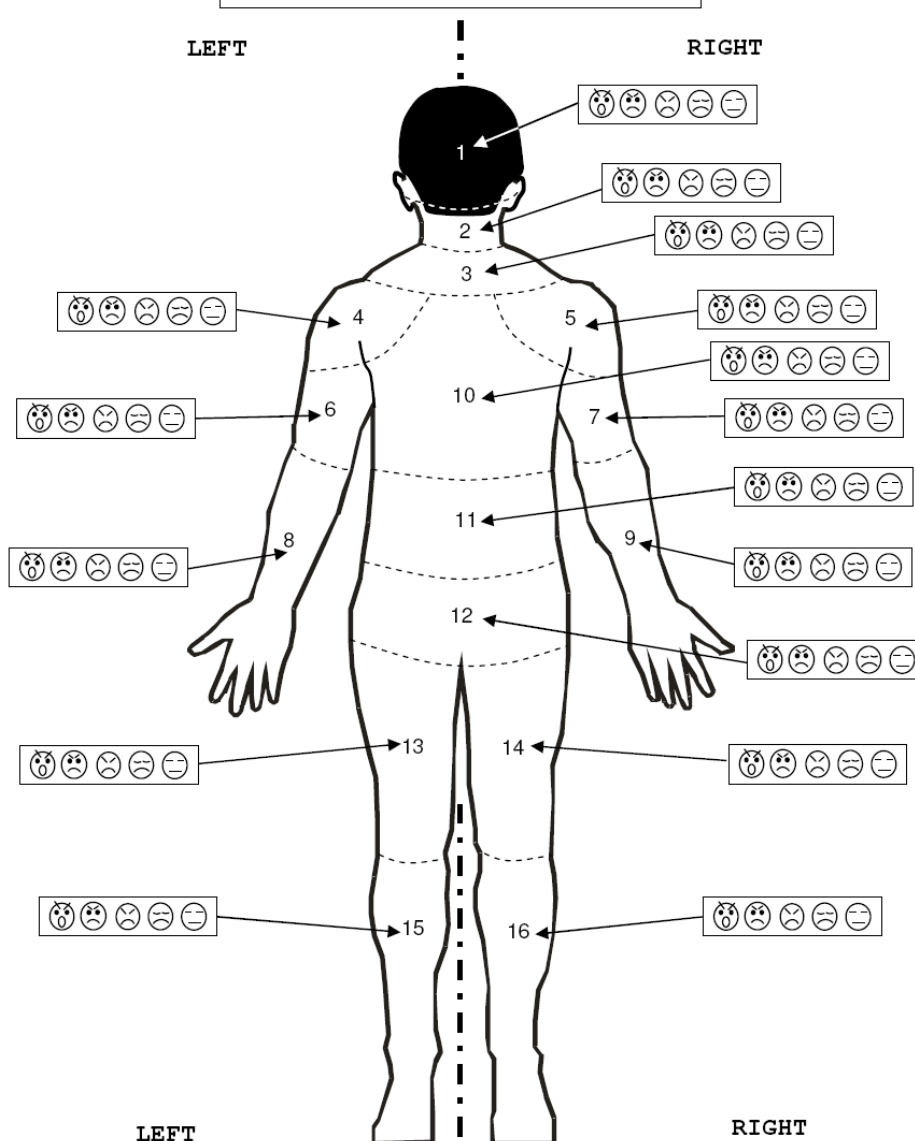
4. During the flight, some parts of your body will be feeling uncomfortable. Please rate your **uncomfortable level** of each part of your body backside after **ONE (1) hour** flight. Please **select** and **tick (✓)** the appropriate "smiley" for your body part.

Legend:

EXTREMELY UNCOMFORTABLE  NORMAL

AFTER 1 HOUR FLIGHT

LEFT RIGHT



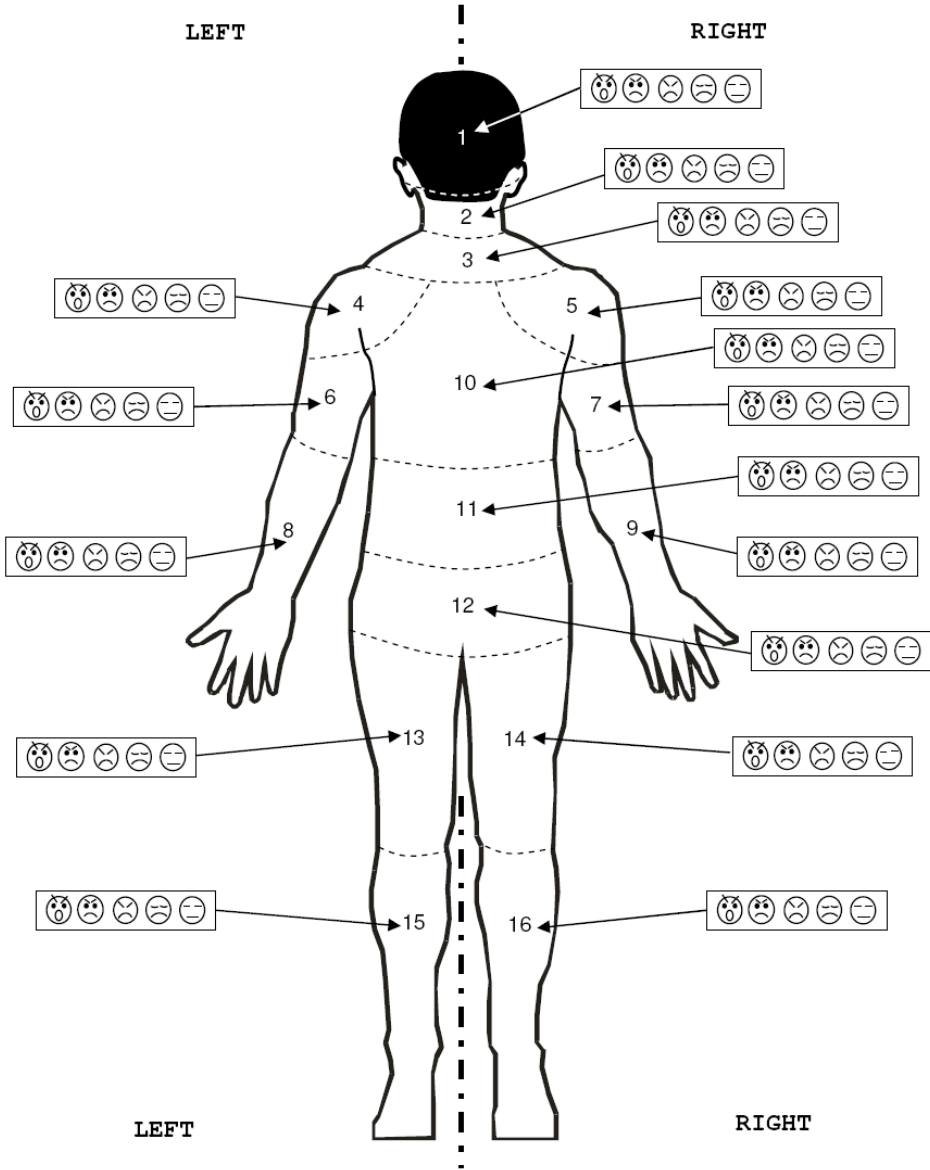
LEFT RIGHT

Detailed description of the diagram: The diagram shows the backside of a human figure from the neck to the ankles. A vertical dashed line runs down the center, separating the left and right sides. There are 16 numbered points (1-16) marked on the backside. Each point has an arrow pointing to a scale of five smiley faces. The smiley faces are arranged from left to right in each scale as follows: 1. extremely sad (frowny face), 2. sad (frowny face), 3. neutral (straight line), 4. happy (smiling face), 5. extremely happy (wide smiling face). The points are: 1. Head, 2. Neck, 3. Upper back, 4. Left shoulder, 5. Right shoulder, 6. Left upper arm, 7. Right upper arm, 8. Left lower arm, 9. Right lower arm, 10. Upper back, 11. Middle back, 12. Lower back, 13. Left leg, 14. Right leg, 15. Left leg, 16. Right leg.

5. During the long haul flight, some parts of your body will be feeling uncomfortable. Please rate your **uncomfortable level** of each part of your body backside after **FIVE (5) hours** flight. Please **select** and **tick (√)** the appropriate "smiley" for your body part.

Legend:
EXTREMELY UNCOMFORTABLE [smiley icons] NORMAL

AFTER 5 HOURS FLIGHT



C. About Yourself

6. What is your **gender**?

- Male
- Female

7. What is your **age**?

..... years old

8. What is your **height**?

..... meter

9. What is your **weight**?

..... kg

You have completed the questionnaire.
Please take a moment to look through your answers.

ONCE AGAIN THANK YOU FOR YOUR TIME AND HELP
IN SUPPORTING
ECONOMY CLASS AIRCRAFT SEAT RESEARCH

Appendix A.7 The Mean Ranks, Means and Standard Deviation for Economy Class Aircraft Passenger Body Part After One Hour and After Five Hours of Travel

Economy Class Aircraft Passenger Body Discomfort											
Body discomfort after 1 hour travel						Body discomfort after 5 hours travel					
No.	Body part	MR	M	SD	N	No.	Body part	MR	M	SD	N
1	Shoulder	10.57	2.50	1.44	104	1	Buttock	10.74	3.16	1.53	104
2	Neck	10.37	2.41	1.41	104	2	Shoulder	10.24	3.04	1.43	104
3	Right lower leg	10.29	2.28	1.38	104	3	Neck	10.15	2.99	1.38	104
4	Left lower leg	10.14	2.23	1.36	104	4	Lower back	10.07	2.90	1.45	104
5	Buttock	9.93	2.18	1.30	104	5	Right lower leg	10.04	3.04	1.43	104
6	Right upper leg	9.42	2.08	1.28	104	6	Left lower leg	9.88	2.98	1.43	104
7	Left upper leg	9.21	2.02	1.25	104	7	Right upper leg	9.68	2.87	1.46	104
8	Lower back	9.05	1.95	1.23	104	8	Left upper leg	9.57	2.83	1.44	104
9	Upper back	7.75	1.60	0.93	104	9	Left shoulder	8.14	2.44	1.34	104
10	Head	7.59	1.56	0.93	104	10	Right shoulder	8.12	2.43	1.35	104
11	Left shoulder	7.52	1.53	0.84	104	11	Upper back	8.03	2.34	1.32	104
12	Right shoulder	7.52	1.53	0.84	104	12	Head	7.41	2.20	1.24	104
13	Right lower arm	6.74	1.42	0.95	104	13	Right upper arm	6.09	1.91	1.22	104
14	Right upper arm	6.71	1.38	0.90	104	14	Left lower arm	6.01	1.87	1.25	104
15	Left upper arm	6.61	1.36	0.82	104	15	Left upper arm	6.00	1.87	1.11	104
16	Left lower arm	6.59	1.40	0.99	104	16	Right lower arm	5.83	1.82	1.24	104

Appendix A.8 Economy Class Aircraft Seat Survey (Before Experiment)



ECONOMY CLASS AIRCRAFT SEAT SURVEY

Subject code :

Date :

Time :

General Instruction

Please answer the following questions by **cross** (X) or **write** the answer you have chosen (see example below).

Are you a frequent air traveler?

- Yes
- No

1. Do you have **neck pain** in the last 3 months?

- Yes
- No

If "yes", describe your current injury:

2. What is your most common flight **duration**?

- Less than 1 hour
- 2 - 5 hours
- 6 - 10 hours
- 11 hours or more
- I Don't know

3. What **class** do you normally fly?

- First
- Business
- Economy
- I Don't know

4. Do you agree with the following statements?

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
a) I always feel neck discomfort during air travel	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
b) I always bring neck support apparatus and used during the air travel	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
c) I always used the neck support that supply during air travel	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
d) I always used the neck support that attached with the seat	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5. What is your **gender**?

Female

Male

6. What is your **age**?

..... years old

7. What is your **height**?

..... meter

8. What is your **weight**?

..... kg

You have completed the questionnaire.
Please take a moment to look through your answers.

ONCE AGAIN THANK YOU FOR YOUR TIME AND HELP
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ECONOMY CLASS AIRCRAFT SEAT RESEARCH

APPENDIX A.9 Economy Class Aircraft Seat Survey (After Experiment)



ECONOMY CLASS AIRCRAFT SEAT SURVEY

Seat No. :

Date :

Time :

1. Please rate the comfort factors of the neck support of the chair that you seated. Mark by **cross** (X) on each line at the point that best describes your feelings or impressions. Note: 1 = Not at all; 9 = extremely.

I feel good neck support	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I feel relax	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I feel seating firmness	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I feel restful	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I feel no stiffness	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I have no sore neck muscle	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I feel no neck fatigue	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I have no neck strained	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I feel fit	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		
I feel comfortable	Not at all					Moderately					Extremely
	1	2	3	4	5	6	7	8	9		

2. What is your **gender**?

Female

Male

3. What is your **age**?

..... years old

4. What is your **height**?

..... meter

5. What is your **weight**?

..... kg

You have completed the questionnaire.
Please take a moment to look through your answers.

ONCE AGAIN THANK YOU FOR YOUR TIME AND HELP
IN SUPPORTING
ECONOMY CLASS AIRCRAFT SEAT RESEARCH

LIST OF PUBLICATIONS

LIST OF PUBLICATION

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SUMMARY

Smart System for Aircraft Passenger Neck Support

Air travel is becoming increasingly more accessible to people due to the availability of low cost air travel. However, long distance air travel is not a normal activity for human. During air travel, people experience different levels of physiological and psychological discomfort. The discomfort may affect the passenger's health and feeling. With the rapid development of technology, the comfort of service has become an important issue. Nowadays, comfort is an attribute which is highly demanded by aircraft passengers. The comfort of aircraft passengers depends on different features and the cabin environment during air travel. Seat is one of the important features for the passengers and in which a passenger spends almost all their time during air travel. Different seat aspects have to be seen and taken into account in the comfort model. The research has five goals. First goal, literature research starts with the study on the state of the art and recent development of vehicle seat design which is available in current literature and products. The literature review gives a general idea about the research and the measurement method related to seating comfort and discomfort. Second goal, four surveys were conducted to identify the comfort factor of economy class aircraft passenger, body discomfort for truck driver, body discomfort for economy class aircraft passenger and relationship between seat location and sitting posture. The first survey is to identify and investigate the comfort factors for economy class aircraft passenger seat. Subsequently, survey on the body back sitting discomfort over travel time was conducted for truck driver and economy class aircraft passenger. The third survey is to investigate the relationship of the seat location and sitting posture of passengers in the economy class aircraft cabin. The postures of subjects were observed and recorded based on seven predefined sitting postures. Third goal, we contributed to develop a smart neck support system for economy class aircraft passenger. Our system aims to support and reduce neck muscle stress. A functional and working prototype was built to demonstrate the design concept and to perform experimental validation. Forth goal, we developed a low cost aircraft cabin simulator and we utilized it to validate our developed smart neck support system. The aircraft cabin simulator was built with motion platform and it is able to simulate a broad range of flight procedures. Next, a calibration experiment was conducted to investigate

SCM muscle stress in relation to different support conditions, time interval and head rotation angle. Fifth goal, a validation experiment was conducted in the aircraft cabin simulator to evaluate the smart neck support system. The objective and subjective results show that the smart neck support system is able to reduce SCM muscle stress adaptively in a fully automate manner.

CURRICULUM VITAE

Ir. CheeFai Tan was born in Kuala Lumpur, Malaysia on 8th April 1974. He received a full scholarship from Ministry of Higher Education, Malaysia and Universiti Teknikal Malaysia Melaka (UTeM), Malaysia for his PhD study at TU/e. He is a lecturer at Department of Design and Innovation, Faculty of Mechanical Engineering, UTeM, Malaysia. He is on study leave from Jan 2007 to Jan 2011. He graduated with Bachelor of Engineering (Mechanical Engineering) and Master of Science (Manufacturing Systems Engineering) from University of Putra, Malaysia. After graduation, he work as various post as mechanical engineer and academician. Most of his work is related to engineering design, automotive, industrial automation, CAD/CAM and industrial ergonomics. He is a registered professional engineer (mechanical discipline) with Board of Engineers, Malaysia. In 2003, he joined UTeM as lecturer and he has been awarded excellence service award in year 2006. He involved actively in teaching and learning activities as well as research and development. For the research experience, he is the principal researcher and co-researcher for various research projects. During the execution of the research project, he discovered that there were some shortages of the knowledge about technology integration in product development. It leads him to the Netherlands to pursue a PhD at Designed Intelligence Group, Department of Industrial Design, Eindhoven University of Technology. He has been working on European 6th Framework Project, namely, Smart tEchnologies for Stress free Air Travel (SEAT) to develop the aircraft cabin simulator and Microsoft Research supported project, ALICE. Subsequently, his PhD project works on smart system for comfortable air travel. The technological design of this thesis is the result from the research work in year 2007 to 2010.