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Adaptive Neck Support for Wellbeing During Air Travel

CheeFai TAN[a,b,*], Wei CHEN[b] and Matthias RAUTERBERG[b]
[a] *Universiti Teknikal Malaysia Melaka, Melaka, Malaysia*
[b] *Department of Industrial Design, Eindhoven University of Technology, Netherlands*

Abstract. Air travel is becoming increasingly more accessible to people both through the availability of low cost flights. Health problems may arise due to anxiety and unfamiliarity with airport departure procedures prior to flying, whilst during the air travel, problems may arise as a result of the food served on board, differences in the environmental conditions inside the cabin, the risk of cross-infection from fellow passengers, seat position, posture adopted and duration of the flight. These can be further compounded by changes in time zones and meal times, which may continue to affect an individual's health long after arrival at the final destination. The aircraft passenger comfort depends on different features and the environment during air travel. Seat comfort is a subjective issue because it is the customer who makes the final determination and customer evaluations are based on their opinions having experienced the seat. The aircraft passenger seat has an important role to play in fulfilling the passenger comfort expectations. The seat is one of the important features in the passenger aircraft and is the place where the passenger spends most of time during air travel. This chapter describes the development of adaptive neck support system to improve the wellbeing experience during air travel for economy class aircraft passenger. Design concept, prototyping, system implementation, experimental testing and design evaluation in an aircraft cabin simulator developed at Eindhoven University of Technology will be presented in the chapter.

Keywords. Adaptive, air travel, neck support

Introduction

Travel by air, especially long distance, is not a natural activity for human. Many people experience some degree of physiological and psychological discomfort and even stress during flying. Excessive stress may cause the passenger to become aggressive, over-reaction, and even endanger the passenger's health [2,6,24]. A number of health problems can affect flying passengers. Seat comfort is an attribute that demand by today's passenger. The results of seating comfort and discomfort survey [13,14,18] indicated 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, the 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

[*]Corresponding Author: CheeFai Tan, Senior Lecturer, Department of Design and Innovation, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia. E-mail: cheefai@utem.edu.my.

facing forward is the most comfortable head position [21]. Therefore, an adaptive support system prototype was developed that focuses on neck. The objective of an adaptive system is to reduce the neck muscle stress of the economy class passengers during air travel. This chapter describes the development of an adaptive neck support system for aircraft passenger wellbeing during air travel.

1. Current Neck Support for Vehicle Seat

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

1.1. 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 [9], polyester filled pillow [9], memory foam pillow [9], feather filled pillow [12] and the aircraft seat with mechanical neck support [3,7,16].

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 [9].

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 [9].

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 [9].

Figure 1. The luxury coach passenger seat with neck support (Photograph reprinted from [5]).

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 [12].

1.2. 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 [22]. 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 Fig. 1 was equipped with neck, side and leg support for their passenger's comfort during long distance bus travel.

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 Fig. 2. The neck support is a soft cushion attached to the seat with two strings.

1.3. 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 (Fig. 3) available in the

Figure 2. The German train ICE passenger seat with neck support.

Figure 3. The Cathay Pacific Airlines economy class aircraft seat with built-in neck suppor (Photograph reprinted from [3]).

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 [3]. Most of the headrests available in current aircrafts [3,7,11] are a mechanical system where the passenger needs to adjust the head rest manually to the required position.

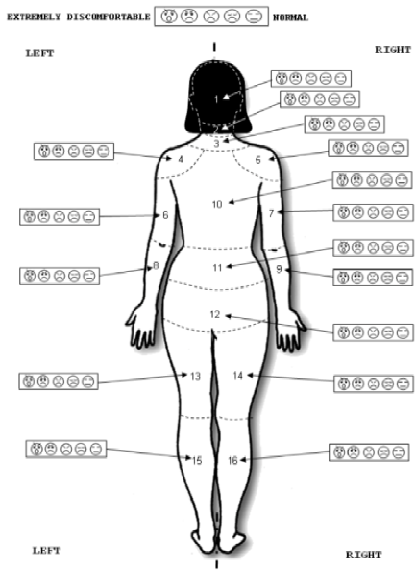
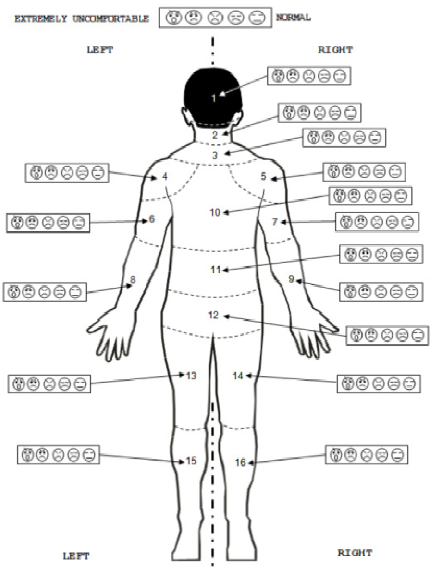
2. Survey of Body Discomfort for Economy Class Aircraft Passenger

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.

2.1. Methods

The objective of the questionnaire 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 dura-

Table 1. Body map and scales for body discomfort evaluation

Female body map	Male body map
	

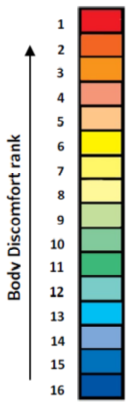
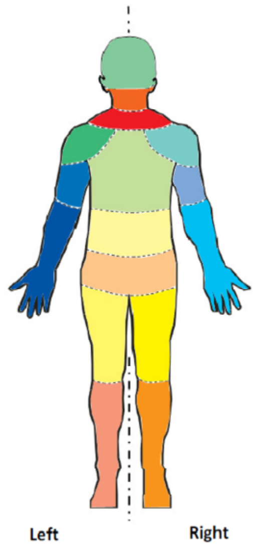
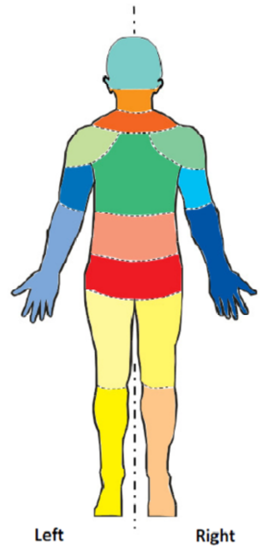
tion and the travel class; (2) questions about their discomfort level for each body part after one hour and five hours flight; (3) questions about demographic background of respondents.

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.

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 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 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 1.

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

Table 2. Body discomfort ranking of aircraft passengers after one hour and after five hours of travel

Ranking	Body discomfort after 1 hour travel	Body discomfort after 5 hours travel
		

map was distributed to female respondents and the questionnaire with male body map was distributed to male respondents. Approximately 90% of those approached accepted to participate. The questionnaire took between three to five minutes for self-completion.

2.2. Results

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 χ^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 χ^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.

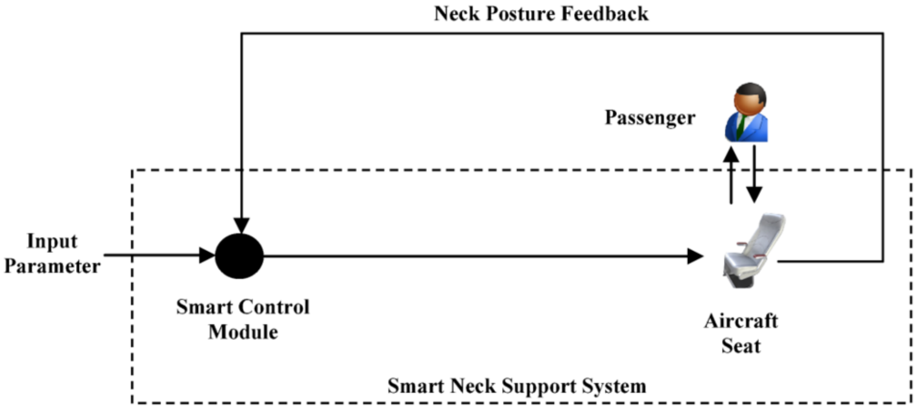


Figure 4. Feedback loop for smart neck support system.

2.3. Discussion and Conclusion

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 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 neck support system.

3. Adaptive Neck Support System

An adaptive neck support system is developed to reduce neck muscle stress during air travel for economy class aircraft passenger seat. Feedback loop for adaptive neck support system is illustrated in Fig. 4. 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:

- Providing support to the passenger's head based on his or her current head posture.
- 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 [21].

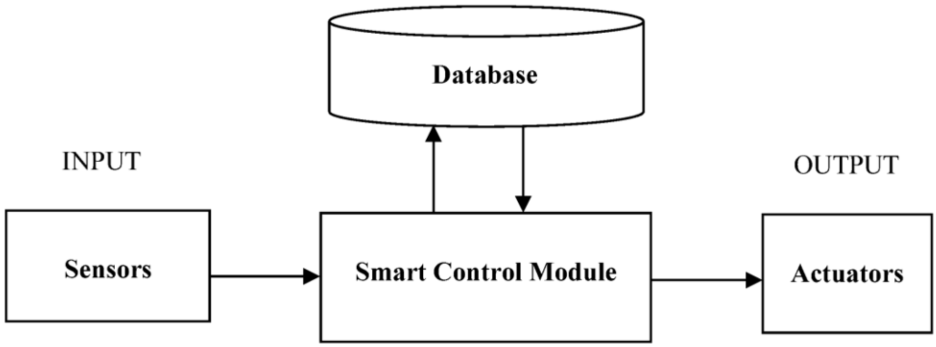


Figure 5. The simplified architecture of an adaptive neck support system.

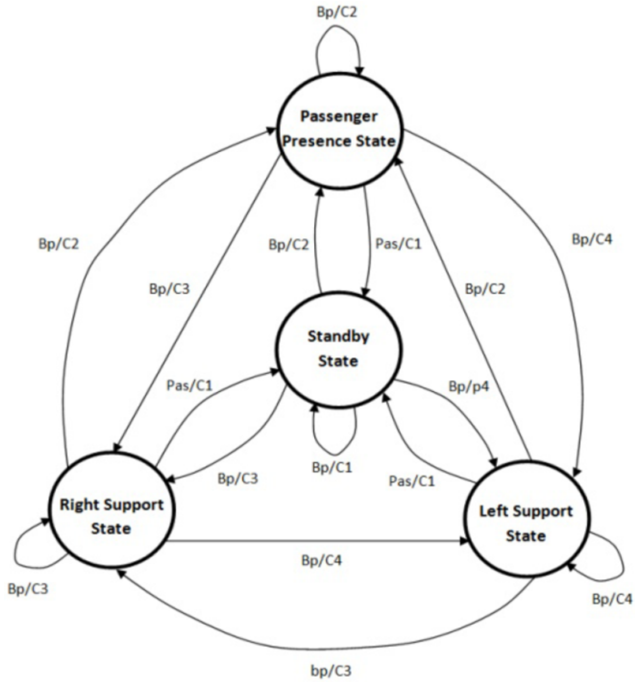
3.1. The Architecture of Adaptive Neck Support System

The architecture of an adaptive neck support system is shown in Fig. 5. 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.

3.2. System Design

State Transition Diagram

The state transition diagram (Fig. 6) is used to describe the behavior of an adaptive neck support system. 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 adaptive neck support system, the adaptive neck support system is in the initial airbag pressure condition (C1). For example, when the passenger head is in contact with the head cushion (Fig. 9) 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 SnS[2]

States:
Standby state
Passenger presence state
Right support state
Left support state

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

Figure 6. State transition of an adaptive neck support system.

State Transition Description for Smart Neck Support System

State transition is used to describe the behavior of an adaptive neck support system. There are four transition states of an adaptive neck support system. The description of the state transition for an adaptive neck support system 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 Fig. 7. Each airbag is equipped with an air pressure sensor and a potentiometer. The adaptive neck support system is in stand-by mode.

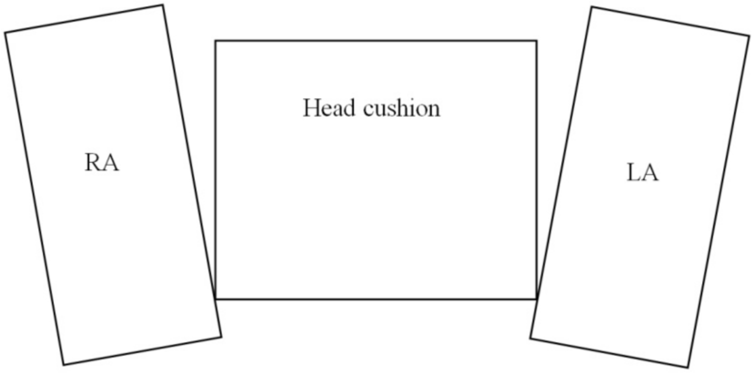


Figure 7. Schematic of 'Standby State'.

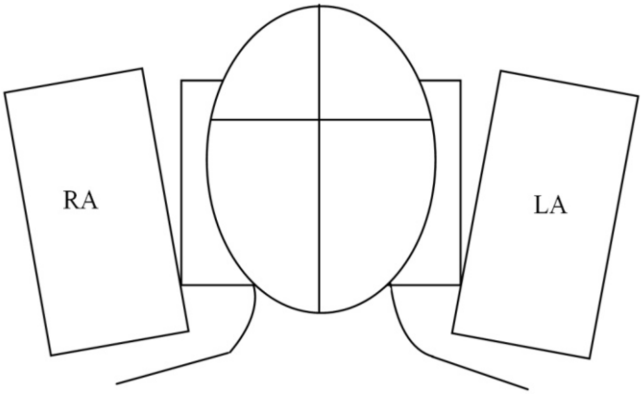


Figure 8. Schematic of 'Passenger Presence State'.

Passenger Presence State

The head cushion detects the presence of the passenger. As shown in Fig. 8, the passenger's head is perpendicular to the head support and it is not in touch with the right and left airbag.

Right Support State

In the 'Right Support State' (Fig. 9), 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 Fig. 10. When the system is activated, the airbag will be inflated from the initial position (45°) to the supported position (15°).

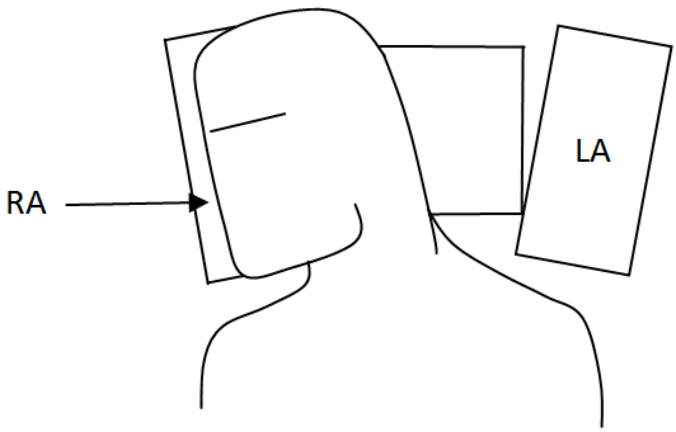


Figure 9. Schematic of 'Right Support State'.

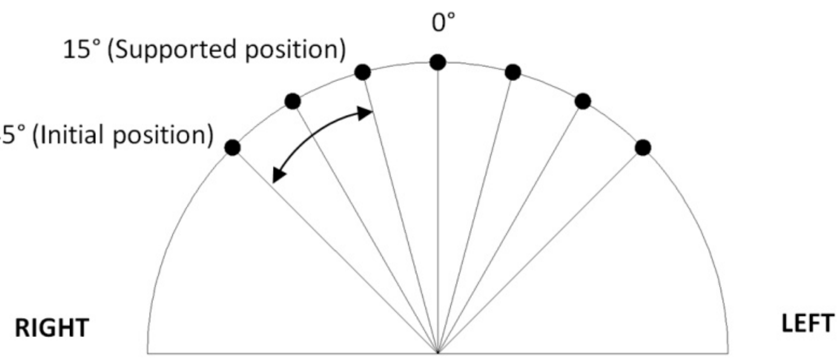


Figure 10. The schematic of example initial position and supported position for right airbag.

Left Support State

In 'Left Support State', the passenger's head is in touch with the left airbag (Fig. 11). 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 Fig. 12. During the activation of the system, the airbag will be inflated from initial position (45°) to supported position (15°).

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 re-

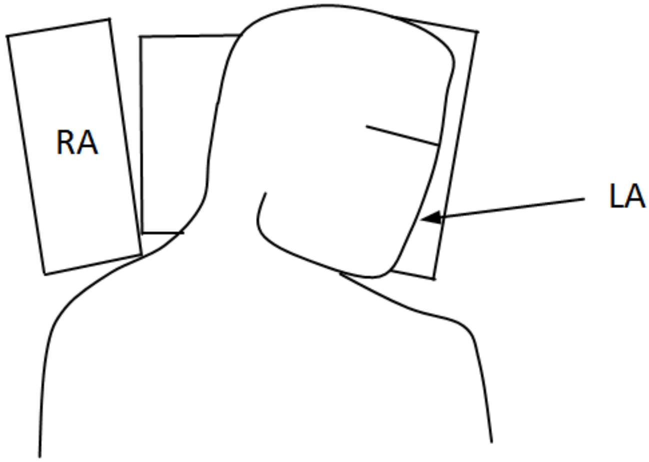


Figure 11. Schematic of 'Left Support State'.

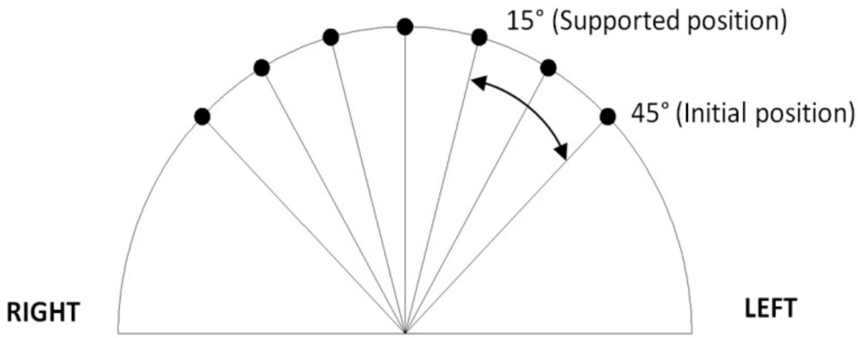


Figure 12. The schematic of example initial position and supported position for left airbag.

cording of air pressure takes place. This 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

$$P_{airbag} = P_{recorded} - P_{current} \tag{1}$$

P_{airbag} is used for data logging purpose.

Mathematically,

When passenger is in touch with the airbag,

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

If the current air pressure in the airbag is within the defined upper threshold and the lower threshold, the SnS^2 is activated.

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

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

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 SnS^2. The algorithm of air pressure detection model for the right airbag and the left airbag is shown in Fig. 13.

4. Prototype

The final prototype setup is an adaptive neck support system that contains a head cushion, a neck cushion, two side airbags, a microcontroller with sensors and actuators connected. The installation of an adaptive neck support system to the economy class aircraft seat in aircraft cabin simulator is shown in Fig. 14. The aircraft cabin simulator is a testbed used for experimental purposes as well as product evaluation purposes.

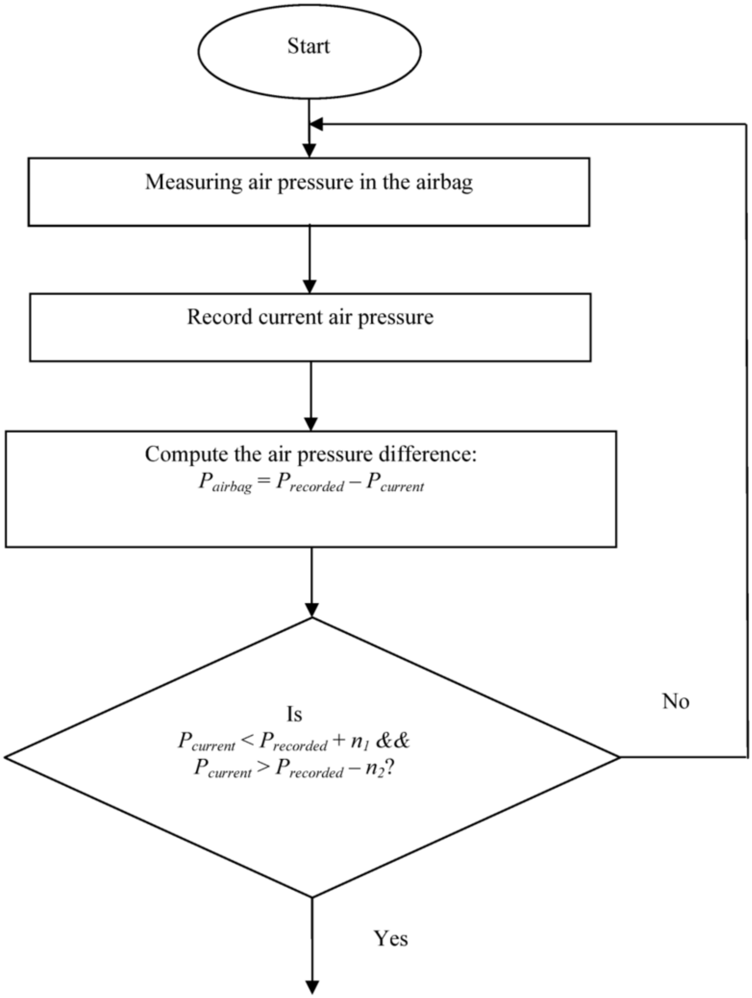
4.1. Hardware

Arduino Mega [1], transformer, air pressure sensor and proportional solenoid valve were used to build the control system for SnS^2. 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 air pressure sensor is a Phidget 1115 [8] 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 ±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 [4].

4.2. Software

The software is an integral part of an adaptive neck support system. 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



Adaptive neck support system is activate

Figure 13. Flowchart for the neck support state transitions when the passenger is touching the airbag.

system. The aims of the developed program are to control the right and the left airbag of an adaptive neck support system.

In term of programming implementation, two programming languages were used in the adaptive neck support system prototype. Arduino programming language [1] was used to program the Arduino microcontroller. The Arduino programming language is based on *Wiring* [23] and the Arduino development environment was based on Processing [10]. 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 [10] is an open source programming language and environment for prototyping purposes. Processing was used to log the sensors and actuators data.

Figure 14. An adaptive neck support system on economy class aircraft seat.

5. The Validation of Adaptive Neck Support System

The proposed adaptive neck support system was evaluated in an aircraft cabin simulator [15,17,20] as shown in Fig. 14 developed at Department of Industrial Design, Eindhoven University of Technology. Calibration experiments and evaluation experiments were carried out. The purpose of the calibration experiment [16,19] was to provide input such as the neck support condition, time factor and the neck rotation angle to validate the adaptive neck support system. In this section, details of the validation experiment are reported.

5.1. Participant

Four participants (2 females and 2 males) with no neck pain from the last three months were recruited. They were informed regarding the procedure of experiment such as sitting inside the aircraft cabin simulator for one hour, video recording and attachment of EMG electrodes on their sternocleidomastoid (SCM) muscle.

5.2. Experimental Setup

Two validation experiments were conducted in the aircraft cabin simulator. The location of experiment is in the simulation lab in the main building of Eindhoven University of Technology. The first experiment was the aircraft seat without smart system and the second experiment was the aircraft seat with smart system. Both experiments recruited same participant. The observation cameras used to monitor the activity of each participant.

5.3. Apparatus and Data Recording

The hardware used in experiment was MP150 Biopac Systems with (electromyography) EMG module, aircraft cabin simulator, a adaptive neck support system, computer and observation camera.

Two EMG module of MP150 Biopac system were used for each participant. The aircraft cabin simulator is a test bed was designed and built to simulate the average economy class cabin. Three adaptive neck support systems were installed in each aircraft seat. The computer was used for data logging and video recording. The cameras were installed at the front as well as above the participant. The acquisition of EMG signal and procedure are same as calibration experiment.

5.4. Experimental Procedure

We started the experiment with 30 minutes of briefing to participants and attachment of electrodes on SCM muscles. The participant was performed maximal voluntary contraction of the SCM by rotate the head to left hand side and right hand side for 10 seconds. After that, we positioned the participant on the economy class aircraft seat. The aircraft seat sitting position was classified as aisle seat, center seat and window seat. Next, light in the aircraft cabin was dimmed and the participant was advised to rest during the one hour experiment. The EMG signals for participants were monitored and recorded in parallel with system log and video recording.

5.5. Data Analysis

For each experiment, the average normalized EMG value was used for statistical analysis. A descriptive statistical method was used to analyze the questionnaire. A one-way analysis of variance with repeated measures was used.

5.6. Results

After the experiment, the results from EMG measurements were selected and analyzed. From the statistical result, the mean scores of normalized EMG value for after supported by adaptive neck support system ($M = 2.817$, $SD = 2.130$) is lower than the mean scores of normalized EMG value for before supported by adaptive neck support system ($M = 3.029$, $SD = 2.312$). The mean scores of normalized EMG value for the participant in relation with neck support activity are shown in Fig. 15.

6. Summary

This chapter presents the development of an adaptive neck support system to improve the neck comfort during air travel. The architecture of an adaptive neck support system described the structure of the system which consists of sensor, actuator, database and central processor. The framework showed that the behavior of the developed system

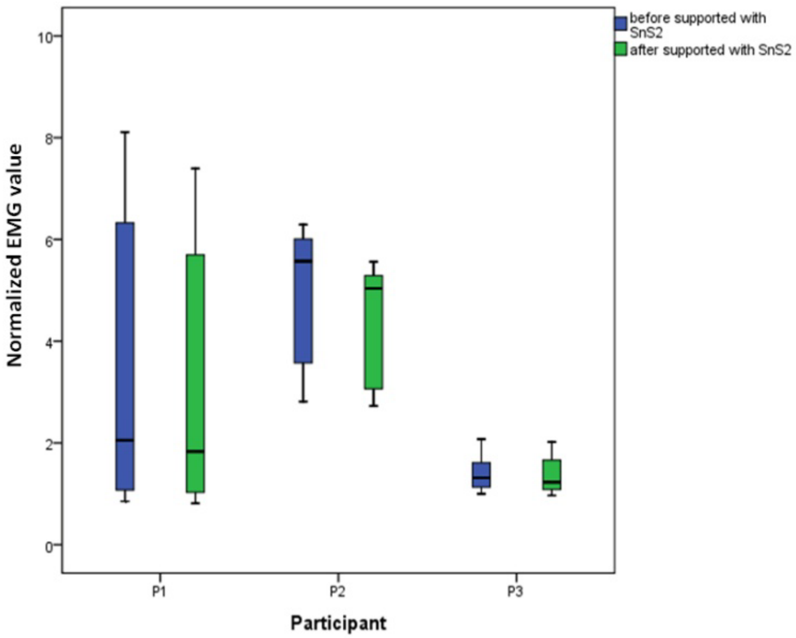


Figure 15. The mean scores of normalized EMG value for the participant in relation to neck support activity.

can improve the aircraft passenger neck comfort. The state transition diagram was used to describe the behavior of an adaptive neck support system. 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 an adaptive neck support system, the airbag is capable to detect the passenger's posture and support the passenger's neck adaptively. The final setup of an adaptive 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 the adaptive neck support system. For the experiment to validate the adaptive neck support system, the results showed that the developed system is able to provide the necessary neck support to reduce the SCM muscle stress.

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