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EFFECT OF AIRPLANE PASSENGER SEAT ARMREST HEIGHT ON HUMAN NECK COMFORT WHEN USING A SMARTPHONE

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Abstract
Objectives: The objective of this study was to explore the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight. **Material and Methods:** The authors used a wireless angle-measuring instrument and subjective comfort scale to evaluate the changes of head flexion angle and neck comfort level of 24 young smartphone users in an aircraft simulated cabin. **Results:** The study results indicated that using a smartphone while sitting on a passenger seat during the flight would pose a larger discomfort to the neck, and the discomfort would be higher for gaming than reading tasks. Seat armrest height is related to the comfort level of the neck when using a smartphone, increasing the height of the armrest can effectively alleviate discomfort in this state. **Conclusions:** Considering the prevalence of passengers using smartphones in aircraft, a seat armrest that can be properly adjusted in height, which can effectively reduce the risk of passenger head flexion angle and neck discomfort. Int J Occup Med Environ Health. 2022;35(2)

Key words:
smartphone, airplane, armrest height, head posture, neck comfort, flexion angle

INTRODUCTION

Smartphones, as ubiquitous communication and entertainment tools in people's daily life, have been widely used, and it has become an indispensable smart device to help people get information and engage in recreational activities quickly [1]. Because the smartphone needs to be held by hand while using, and people usually do not lift the phone to a position parallel to the line of sight of the human head, this directly increases the fatigue burden on the neck muscles [2–5]. In recent years, some studies also have shown a correlation between changes in the angle of the human head and neck comfort in the use of smartphones [3,6–8]. Lee et al. mentioned in the paper that changes in head posture have an important effect on pain caused by neck muscle pressure [9]. At the same time, several previous studies have shown that prolonged neck flexion due to the use of smartphones increases the likelihood of neck pain [5,6]. In some circumstances, the network communication function of the smartphone will be disabled (the network cannot be accessed on

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Table 1. Characteristics of the participant of the study on the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight, Xi'an Shaanxi, China, October 2019

Variable	Participants (N = 24)
Age [years] (M±SD)	24 (2.8)
Height [cm] (M±SD)	168.25 (8.2)
Arm length [cm](M±SD)	65.87 (4.4)
Weight [kg] (M±SD)	57.3 (9.5)

the aircraft). In this time, people usually use the phone as an entertainment tool (for reading and gaming activities). Due to airline deregulation [10] and the lack of other entertainment activities, the use of time on smartphones will further boost [11–13].

Previous studies have shown that maintaining the line-of-sight position with the eye when the height of a traditional desktop computer monitor and providing effective arm and wrist support can reduce the fatigue burden of the muscles involved [14–16]. Findings of Syamala et al. indicated that a chair with adequate support can be an effective intervention to reduce the biomechanical exposures and associated muscular pain in the neck and shoulders during mobile phone use [8]. Due to cost considerations, the armrest height of mainstream cabin seats is currently not adjustable. Based on the studies mentioned above, such armrest designs may cause neck pain when passengers use smartphones for a long time. This also reflects the growing concern about neck diseases caused by using smart devices in recent years [17–20].

Research by Vasavada et al. investigated head and neck postures that were adopted to view a tablet computer positioned at various angles and located at about elbow height. Resulting postures were estimated to place 3–5 times more strain on the neck muscles than neutral neck postures [21]. Correcting the awkward head and neck posture is an important way to prevent users from neck pain while using smartphones. However, in order to provide users with a healthy environment for using smartphones, further research is needed to find out what degree of structural threshold does not overload the user's neck [22]. Nevertheless, few studies have systematically assessed the correlation relationship of neck discomfort and armrest height from an ergonomic perspective when passengers use their smartphones in aircraft cabin seats [23,24]. Therefore, the objective of this study was to measure the effect of different armrest heights on passengers' head angle and neck comfort.

To achieve the study goals, the authors tested two primary hypotheses:

H1. Compared with rest, read and play game with a smartphone will result in neck discomfort.

H2. In the process of participants using smartphones for entertainment, compared with fixed seat armrests, increased armrest height will reduce the discomfort of the participants' neck.

The findings could be used to develop ergonomic aircraft cabin seats to help passengers reduce the risk of neck pain that may occur when using a smartphone.

MATERIAL AND METHODS

Participants

Twenty-four adult participants with an equal sex distribution (12 males, 12 females) were recruited from the university community (participants information were shown in Table 1). The sample size satisfied the minimum number of samples to achieve the statistical power of 0.80. All of them were experienced smartphone users (at least five years of smartphone use experience) without left-hander, neck pain symptoms and physical difficulties in using their smartphones while sitting. Each participant provided informed consent before participating in the experiment. This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board at Northwestern Polytechnical University Institute of Industrial Design.

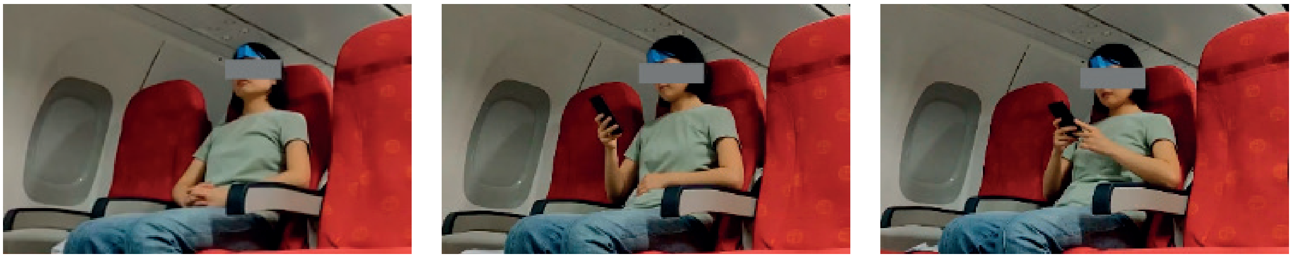


Figure 1. Status during 3 tasks: a) resting, b) reading novel, and c) playing game, in the study on the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight

Figure 2. Experimental protocol schematic in the study on the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight: a) seat armrest height increased by 5 cm and b) wireless Inertial Measurement Unit Sensors (IMU) placed on the forehead

Experimental protocol

In repeated laboratory experiments, participants were asked to sit in a simulated cabin seat of an unlisted aircraft (room temperature 25°C). The experiment included 3 independent variables:

– 2 types of backrest angles (90° upright and 120° tilted);
– 3 tasks (rest, hold a smartphone with one hand to read a novel and hold the smartphone with both hands to play a game) (Figure 1);
– 3 types of seat armrest height (according to the Chinese aviation industry-standard "HB8496-2014 civil aircraft passenger seat design requirements" armrest height demands, using a 1 cm thick shock-resistant EPE pearl cotton foam board stack, each increased by 0 cm, 5 cm and 10 cm, as shown in Figure 2a and Figure 3).

A total of 18 different experimental conditions (2×3×3). Each experimental condition was recorded separately for 10 min, and there was a 2 min break between consecutive trials. Previously, several related research articles have used sampling times of around 10 min for single experimental tasks, so for the experiments in this paper, the sampling time for single experimental tasks is sufficient [25–27]. Each participant can determine the gaze distance between the mobile phone and the eyes under different experimental conditions. The dependent variables of the experiment were the angle of flexion of the head.

a) b) c)

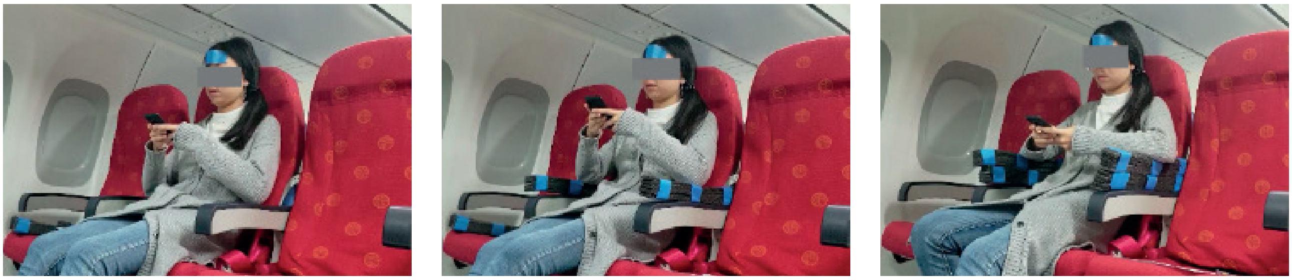


Figure 3. Comparison of arm and armrest contact position in the study on the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight – seat armrest height increased by a) 0 cm, b) 5 cm, and c) 10 cm

To avoid the potential systematic deviation of 18 different experimental conditions during the test, the test order is random. It should be noted that participants' head flexion angles were recorded after they were in a stable motion state, so the captured posture is relatively static.

Before starting the experiment, each participant fully understood the details of the entire experimental procedure through written informed consent. To eliminate potential accidents caused by different device sizes and settings, all participants were given sufficient time (≥10 min) to learn about the smartphone (Microsoft Lumia 530) required for the experiment and to settle into the condition before data collection began. At the same time, participants were asked to read the same chapter of the same novel and play the same part of the same game. During the rest task, the participants were asked to look straight ahead or to rest with their eyes closed. The height of the armrest above the seat pan is 20 cm. To minimize the fatigue effects caused by the previous stage of the experiment, a 2-minute rest will be given between each experimental session. A questionnaire measuring the participant neck discomfort according to the 5-point Likert scale was also delivered to confirm the results of the measures. For more details, please go to section 3.3.

Kinematic data

Previous studies have used camera optical motion capture systems to measure the human head flexion angle [8,21,28], but using inertial measurement unit sensors (IMU) has better portability and in many site measurement scenarios their accuracy will just fit the need [7,29].

Therefore, to accurately measure the data of participants' head flexion angle when using smartphone on the aircraft simulated cabin seat, the authors taped the wireless IMU sensor (model: WIT-BWT61CL, Wit-Motion Inc., Shenzhen, China; data sampling rate is 100 Hz; embedded Kalman Filter filter; attitude measurement accuracy is 0.05°) to participants in the middle of the forehead (Figure 2b) and continuous recording head motion data during the experiment. IMU performed a coordinate system correction before each experiment, and the experimental head flexion angle data were given as the difference relative to a fixed global reference system. Participants' head flexion angle data was transmitted to the computer database via wireless bluetooth. Because the head flexion angle did not change much during the experiment, the angle data's mean value was finally used.

Subjective assessment

To further study the impact of seat armrest height changes on neck comfort, based on the reference to the local musculoskeletal discomfort (LMD) method [30], according to the experimental conditions, the experiment uses a 5-point Likert scale designed an improved subjective questionnaire of human neck comfort. The values of the Likert scale in the questionnaire from -2-2 indicate extreme discomfort, discomfort, general, comfort, and extreme comfort.

Data analysis

All statistical analyses were conducted using Excel and Minitab. The dependent variables of the experiment were the angle of flexion of the head. For all dependent variables, the mean and standard deviation are calculated and used as the measurement results for each experiment. The experiment used repeated measures 2-way analysis of variance (ANOVA) to assess the effects of "task," "backrest angle," and "seat armrest height" on head flexion angle and neck comfort level data.

RESULTS

The data in Table 2 are the ANOVA results of all individual data, which showed significant differences in the head flexion angle and the subjective assessment of the neck in all tasks. For the following ANOVA results, significant main effects and interaction effects were tested. The mean data of head flexion angle and neck comfort are shown in Table 3.

Head posture

The variation range of the participant's head flexion angle is as follows: the authors performed an ANOVA test analysis of participants' head activity data, which showed significant differences in each task, backrest angle, seat armrest height and body height ($p < 0.05$). The interaction between height and other factors is significant, but the interaction between other factors is not significant. Participants in the resting state, increasing the height of the armrest, caused the head flexion angle to slightly decrease, but the overall change was not outstanding. Compared with rest, when the armrest height was not increased, and the participants read the novel while hold-

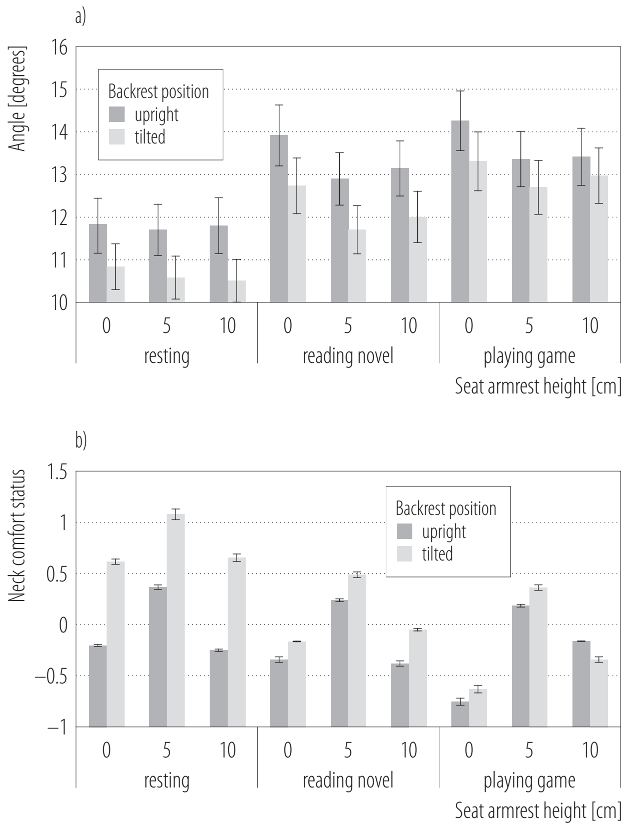
Table 2. Statistical analysis results (N = 24) in the study on the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight, Xi'an Shaanxi, China, October 2019

Variable	p	
	head flexion	subjective assessment
Task	<0.001	<0.001
Backrest angle	<0.001	<0.001
Seat armrest height	<0.001	<0.001
Body height	<0.001	<0.001
Task × backrest angle	0.190	<0.001
Task × seat armrest height	0.263	0.101
Seat armrest height × backrest angle	0.970	0.995
Task × body height	<0.001	0.001
Seat armrest height × body height	0.004	0.110
Backrest angle × body height	0.006	0.008

Table 3. Head flexion angle and neck comfort status value (N = 24) in the study on the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight, Xi'an Shaanxi, China, October 2019

Variable	Seat armrest height								
	while resting			while reading novel			while playing game		
	0 cm	5 cm	10 cm	0 cm	5 cm	10 cm	0 cm	5 cm	10 cm
Head flexion angle [degrees] (M)									
backrest angle – upright	11.83	11.69	11.85	13.92	12.87	13.14	14.24	13.34	13.40
backrest angle – tilted	10.83	11.56	10.5	12.72	11.68	12.00	13.31	12.69	12.97
Neck comfort status[a] (M)									
backrest angle – upright	–0.20	0.37	–0.25	–0.33	0.25	–0.37	–0.75	0.20	–0.16
backrest angle – tilted	0.62	1.08	0.66	–0.16	0.50	–0.04	–0.62	0.37	–0.33

[a] Subjective measurement data of neck comfort status.



Data given as mean value and error bar marked with 95% CI.

Figure 4. a) Head flexion angle and b) neck comfort status in the study on the relationship between seat armrest height and human neck comfort when using a smartphone while sitting on a passenger seat during the flight, Xi'an Shaanxi, China, October 2019

ing the smartphone with 1 hand, the head flexion angle increased dramatically to 13.92° (0 cm, backrest upright) and 12.72° (0 cm, backrest tilted).

However, when the armrest was increased to 5 cm and 10 cm, the head flexion angles of the participants were reduced to 12.87° (5 cm, backrest upright), 13.14° (10 cm, backrest upright) and 11.68° (5 cm, backrest tilted), 12.00° (10 cm, backrest tilted). When the height of the armrest did not increase, and the participants held the smartphone with both hands to play the game, the head flexion angle continued to increase markedly to 14.24° (0 cm, backrest upright) and 13.31° (0 cm, backrest tilted). Nevertheless, when the armrest was increased to 5 cm and 10 cm, the head flexion angles of the participants were reduced to 13.34° (5 cm, backrest upright), 13.40° (10 cm, backrest upright) and 12.69° (5 cm, backrest tilted), 12.97° (10 cm, backrest tilted) (Figure 4a).

Subjective assessment

All 24 questionnaires collected were filled out by the above experimental participants at the time of the experiment. The Cronbach's α value of the questionnaire calculated using Minitab was 0.913. The authors performed ANOVA test analysis of participants' subjective assessment data, which showed significant differences in a various task ($p < 0.05$).

According to statistical data analysis, the main effects of TASK, BA, and SAH are significant. There is no interaction between TASK*BA, TASK*SAH and SAH*BA. Participants have a higher neck comfort level when the armrest is increased by 5 cm. Both too high (increased by 10 cm) and too low (increased by 0 cm) armrests will adversely affect the neck comfort. The tilted angle of the backrest also had a significant impact on participants' necks comfort. Participants have higher neck comfort when the backrest is tilted compared to upright. Participants' neck comfort also showed great differences in different tasks, and comfort during rest was always the highest (Figure 4b).

In summary, the neck subjective comfort questionnaire could reflect the overall impact of seat armrest height on participants' neck comfort. This conclusion is consistent with the head flexion angle experiment.

DISCUSSION

This study evaluated whether there was a difference in the effect of armrest height on participants' head flexion angles and neck comfort when using a smartphone in an aircraft cabin seat. The results show that the head flexion angle and the neck comfort were both affected by the seat's armrest height.

The analysis results of kinematic data show that when participants use smartphones, increasing the armrest height by 5 cm and 10 cm can significantly reduce the head flexion angle. This is consistent with the results of previous related studies, which show that proper seat armrest support can positively improve the posture of the head and neck, thereby helping to reduce neck fatigue caused by smartphone use [8].

However, in previous aircraft cabin seat related research, it was not mentioned that when using a smartphone, excessively increasing the armrest height will lead to increased head flexion angle and neck discomfort. In this study, when the height of the armrest was increased by 10 cm, the value of the head flexion angle of the participants increased.

After discussing with participants and analyzing the experimental images, the authors found that when the armrest height increased by 5 cm, participants used the elbow joint of their arms to contact the increased armrest surface; but when the armrest height increased by 10 cm, participants used the elbow joint of their arms to contact the armrest surface, which would cause discomfort of the upper arm and shoulder muscles, so participants would use the forearm muscles to contact the armrest surface when using the smartphone (Figure 3). This will lead to a reduction in the height of the smartphone held by the participants, which will affect the head flexion angle and comfort level of the neck. This phenomenon is involved in more complex biomechanical studies and will be further explored in the future.

The results of this study suggest that in the process of using a smartphone on a passenger seat, consider seat armrests that can be properly adjusted in height, which can effectively reduce the risk of passenger head flexion angle and neck discomfort. Considering the prevalence of passengers using smartphones in aircraft, the results of this study provide essential theoretical suggestions for the optimization of passenger cabin seats in the future.

Under normal circumstances, passengers might will adjust their posture appropriately when their necks are uncomfortable during the use of smartphones in airplanes. Therefore, it is a feasible experimental protocol to monitor the postural changes of subjects through a long time experiment. However, this paper is more concerned with the effect of armrest height change on participants' head flexion angle and neck comfort under different task situations. The authors found experimentally that the participants' head flexion angle would be relatively stable during the task performance, so they did not consider monitoring the postural changes for a longer period of time. Therefore, the experiments measured the head flexion and neck comfort of participants after maintaining the initial posture under different tasks with fixed time variables.

Although the experiment in this paper was carefully designed, they have some limitations.

Every single experimental task is relatively short, which is not a good representative for assessing the physical fatigue of users who use smartphones for a long time in aircraft cabin seats. Although the experiments in this paper did not consider the frequency or duration of participants' task posture maintenance, it is appropriate to explore the effects of smartphone use on head flexion angle and neck comfort when considering fixed time variables, since participants' posture while using smartphone was relatively fixed. The long-term effects of armrest design on neck muscle activity and fatigue will be further investigated in the future.

Although the authors controlled the models of the smartphones in the experiment, users tended to use phones of different sizes in real-world scenarios, so the actual neck comfort levels of passengers could not be further accurately measured.

The subjective discomfort assessment can further reflect the measurement accuracy of the participants in the experimental task based on the analysis of objective measurement data; however, the subjective discomfort assessment in this study has the potential for further improvement based on different population characteristics and experiments.

The study only measured the neck comfort level of participants and did not measure other related parts (such as the anterior deltoid muscle that is used to evaluate the primary supporting role in the use of smartphones). Future studies will consider including more body parts assessment indicators.

This study did not collect participants' vision data. Correcting vision may affect participants' sight distance when using mobile phones.

Based on different research tasks, this paper only conducted ANOVA analysis on height and head flexion Angle, and did not conduct optimization analysis on armrest height for subjects with different heights and weights. The authors will improve this issue in future research work.

Due to the limitation of experimental samples in the university community, data surveys of different age groups need to be further improved in future research. According to experimental analysis, there is a correlation between the head flexion angle and the height of the smartphone holding. But for people of different ages (such as children and the elderly), whether the perception of neck comfort is more sensitive will be further explored in the future.

Because arm length and height are generally positively correlated, the experiment only considered height differences among different genders. The effect of arms-length on the head flexion angle and neck comfort will be further explored in the future.

The article did not conduct further experimental analysis on the comfort and accessibility of adjacent passengers with raised armrests. However, in order to ensure the evacuation efficiency of the passengers in emergency situations, the proposed armrest raising strategy needs to be adjustable; too high and fixed armrests will hinder the emergency evacuation efficiency of the passengers.

CONCLUSIONS

This study examines the head flexion angle and neck comfort of the participants when using their smartphone on the aircraft's simulated cabin seat. The findings of this laboratory-based study indicate that using a smartphone in an aircraft seat will increase the head flexion angle, thereby increasing the risk of discomfort and injury to the neck area. Consider seat armrests that can be properly adjusted in height, which can effectively reduce the risk of passenger head flexion angle and neck discomfort. The results of this study could provide some references for future aircraft cabin seat design.

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