Aircraft Passenger Comfort Based on Muscle Activation and Perceived Discomfort During Long Flights

Huining Pei; Suihuai Yu; Man Ding; Zhonghang Bai

OBJECTIVE: The purpose of this study was to investigate the comfort of aircraft passengers during long flights and to determine the effects of the seatback angle and the seat pitch on passengers' upper body muscles (neck, shoulder, and lower back) and subjective comfort.

METHODS: All subjects sat on an aircraft seat for 2 h with different levels of seatback angle and seat pitch. Subjective discomfort scores and root mean square (RMS) and mean power frequency (MPF) values were used to evaluate muscle fatigue, and all data were calculated for every 15-min interval.

RESULTS: Significant increases of MPF for all three muscles were found at 30 min, along with significant increases in the perceived levels of discomfort (PLD) over 2 h. Besides, a 120° seatback angle and a 34″ seat pitch resulted in lower PLD values for the lower back and hip areas than smaller ones (significant difference).

DISCUSSION: It took around 30 min before pronounced discomfort in the upper body regions occurred during flight. The larger parameters of seatback angle and seat pitch may significantly contribute to the easing of subjective discomfort. Moreover, a decrease in MPF coupled with a concomitant increase in RMS does not appear to be a reliable indicator of discomfort rate. The need for further development of discomfort indicators which are more directly related to muscular activation is recognized.

KEYWORDS: ergonomics, muscle fatigue, aircraft seat, root mean square, median power frequency.

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In 2013, according to a report by the Air Transport Action Group (ATAG), over 3 billion passengers were carried by global airlines.[3] The sales volume of air travel will double in the next 15 yr, showing 4.7% annual growth between 2013 and 2033.[1] Additionally, a previous study reported that at least 35% of passengers chose an airline based on a previous comfortable experience in an aircraft cabin.[6] In other words, the business of airlines will be affected by passengers' subjective feelings and experience, so airlines should focus on the development of a comfortable aircraft environment to attract more passengers. These aspects directly affect the passengers' experience and willingness to travel.

Comfort and discomfort are defined as feelings or emotions that are subjective in nature.[11] Different methodologies are divided into subjective methods (e.g., Borg scale) and objective methods (e.g., pressure measurements, electromyography, and posture analysis) to measure sitting comfort. On one hand, previous studies stated that pressure distribution was considered the objective measure clearly related to seat comfort and discomfort.[11] For instance, Jackson et al.[14] suggested that no discomfort occurred while the time-averaged peak pressure on the buttocks was below 8.8 kPa. Kyung and Nussbaum[19] investigated several studies and concluded that preferred pressure levels were different between body parts, with human-seat pressure being more related to overall and comfort ratings. On the other hand, muscle activation is one of the common objective evaluations. Previous researchers have investigated the comfort or discomfort factors and response using electromyography (EMG). Lee et al.[21] demonstrated that

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increased muscle activation in the shoulders and back was significantly related to increased discomfort while performing a microscopic task on one seat. It has also been proven that prolonged sitting in a restricted posture is associated with negative health outcomes, such as lower back and neck pain.[24] In addition, in the amplitude domain, the root mean square (RMS) is considered to be more suitable to illustrate changes in the EMG signal caused by muscular fatigue.[23] However, the median frequency (MF) and the mean power frequency (MPF) are the most commonly used frequency domain features for EMG signal processing.[32]

Seat pitch (legroom) is seen as a critical comfort criterion by passengers and a discomfort indicator by ergonomists, especially during long-haul air travel, and the easiness of adopting a comfortable sitting posture is significantly influenced by the seat pitch.[31] The seatback angle is also one the crucial factors affecting sitting comfort. Andersson et al. report that it is beneficial to angle the seatback to the rear, but if the increased seatback angle is combined with reduced legroom, passengers will be forced to extend their knees.[2]

It is noteworthy that there was a large source of information available from the U.S. Air Force where they measured pressure, surface EMG, and perceived levels of discomfort (PLD) over long time flight. For example, experiments were undertaken by Jackson et al. to evaluate the performance of different seat cushions in the task of glider flights. They found that the foam cushion with a layered structure played an important role in relieving peak pressure and discomfort.[14] Neck muscle activity in air force pilots wearing night vision goggles were also studied. The results demonstrated that the additional load of night vision goggles extends neck muscle strain in anterior stabilizing muscles.[26] Few studies, if any, have investigated the issue of (dis) comfort assessment based on the ergonomic exposures of aircraft passengers, although a considerable amount of studies have focused on physical environment factors, such as the thermal, vibration, noise, pressure, and air quality, of the cabin environment and the seat comfort of office chairs, automotive seats, and pilots' seats.[9,19] Consequently, the present study investigates the influences of the seatback angle and the seat pitch on the upper body muscles (neck, shoulder, and lower back) of aircraft passengers and the subjective discomfort in the relevant body regions.

METHODS

Subjects

Recruited for this the study were 15 healthy subjects, including 7 men (mean ± SD height, 174.6 ± 3.3 cm; sitting height, 93.1 ± 2.6 cm; mass, 76.7 ± 9.8 kg; age, 25.0 ± 2.9 yr) and 8 women (mean ± SD height, 167.1 ± 3.8 cm; sitting height, 88.4 ± 3.1 cm; mass, 53.6 ± 3.5 kg; age, 24.1 ± 1.1 yr). All subjects were free from any chronic or acute upper body pain in the previous 6 mo. All subjects provided informed written consent and had institutional review board approval for the present study.

Materials

The experiment was conducted in a laboratory environment with an adjustable aircraft seat. The experiment had a nested factorial design. Two independent factors were manipulated and three classes of dependent measures were recorded. Independent variables included the seatback angle (two levels, 90° and 120°) and the seat pitch (two levels, 30″ and 34″). The seatback angles (measured from the seatback to the horizontal) were described as 90° and 120° backrest inclinations. The seat pitch was defined as the distance from a point on the seat in one row to the same point on a seat in the next row.[18]

EMG acquisition was collected using MP150 Biopac Systems and AcqKnowledge Software (Biopac Systems Inc., Goleta, CA, USA). PLD were assessed using a modified Borg's perceived level of exertion scale.

Procedure

Subjects were encouraged to maintain a relaxed sitting posture and were allowed freedom to change postures. Subjects performed a 2-h experimental reading task while sitting in the seat for four trials over 4 d. These four trials were randomized and counterbalanced across participants, separated by at least 48 h to minimize fatigue effects. The dependent variables were the EMG amplitude and the discomfort experienced during sitting tasks.

Subjects completed a demographic questionnaire prior to data collection. The skin surfaces of the three muscles were abraded and cleaned with alcohol, and surface electrodes were attached. The electrode placement sites were marked with an indelible felt tip pen at the conclusion of each test session to ensure consistent placement between test sessions. Following a 15-min stabilization period, impedance was measured to ensure impedance below 10 kΩ. Prior to the commencement of the tasks, subjects were briefed about the tasks. Subjects were also asked to fasten their seat belt before the test.

Maximum voluntary contractions (MVCs) were performed and recorded to normalize the EMG signals. Resting EMG signals were sampled at 5 Hz for 5 s while the subjects were sitting straight in the aircraft seat with both feet flat on the floor. A 5-s ramp-up and ramp-down procedure was used to collect the MVCs. A cervical erector spinae (CES) contraction was captured by extending the neck and head against the resistant arm of a Kin/Com dynamometer (Chatanooga Group, Inc., Hixson, TN, USA), contacting at the subject's occipital bone.[29] An upper trapezius (UT) contraction was obtained by holding a 0.5-kg dumbbell in each hand, with the arm abducted at 90° in the frontal plane and parallel to the floor.[33] A lumbar multifidus (LM) contraction was captured by holding the hands on the neck and lifting the head, with the shoulders and elbows just off the examination table and the subject positioned prone, legs straight, and strapped in with a belt.[25] A minimum of two trials lasting 5 s each with a 30-s rest period between exertions were performed. The EMG value was measured with AcqKnowledge 3.9.1 software.

Ag/AgCl pregelled bipolar disposable electrodes were attached. Raw EMG signals were recorded and differentially amplified at a sampling rate of 2000 Hz and band pass filtered (10–500 Hz for surface recordings). For activation measurement, signals were smoothed (2000 samples/window) then rectified (400 samples/window) to calculate the amplitude at 5-s intervals. The electrodes were sited on the following muscles of the right side of the body focused on the shoulder and back: CES, 2 cm lateral from the C4 spinous;[7] UT, lateral to the halfway point of an imaginary line formed by the posterior aspect of the acromion and the spinous process of C7; and LM, L5 level and aligned parallel to a line connecting the posterior superior iliac spine and the L1-2 interspinous space.[10] Raw EMG signals were amplified and computed as MPF and RMS values at times of 15, 30, 45, 60, 75, 90, 105, and 120 min. Subjects were asked to verbally provide a rating of discomfort on the parts of neck (NE), left shoulder (LS), right shoulder (RS), left lower back (LLB), right lower back (RLB), left hip (LH), and right hip (RH) at the start of each test and every 15 min thereafter for the remainder of the experiment (9 times for each test).

Statistical Analysis

Two-way repeated measures analyses of variance was conducted to determine the effects of seat configurations (two levels of seatback angle and two levels of seat pitch) on subjective discomfort ratings, and EMG variables were analyzed with the Tukey's honestly significant difference test for post hoc analyses, where significant main effect differences were found. Significant interaction effects were further examined using a simple effect analysis. Line plots were portrayed to evaluate the trends of the RMS, MPF, and PLD over time. All statistical analyses were completed using SPSS (IBM SPSS Statistics, Version 22, Armonk, NY, USA) and all results were considered significant at an alpha level of 0.05. The RMS and MPF were calculated using a program developed by MATLAB (Mathworks Inc., Natick, MA, USA).

RESULTS

Descriptive statistics for dependent variables and ANOVA results are presented in **Table I**, which shows the main effects of the seat pitch and seatback angle and the seatback angle × seat pitch interaction effects on muscle activation and perceived discomfort. To clarify, the combinations of seatback angle/seat pitch were on behalf of different trials as follows: 90°/30″ (T1), 90°/34″ (T2), 120°/30″ (T3), and 120°/34″ (T4).

On the basis of RMS values, the analysis of the seatback angle effects yielded a significant result for the CES [$F(1, 12) = 9.05$, $P = 0.004$] and UT [$F(1, 12) = 28.05$, $P < 0.001$] muscle activity only (see Table I). However, the CES was significantly influenced by the factor of seat pitch [$F(1, 12) = 29.17$, $P < 0.001$]. No seatback angle × seat pitch interaction effects were found for the RMS data. No significant differences between each trial were found for RMS values of the three muscles (see Table I).

Fig. 1 shows an increasing trend of the RMS over time for all three muscular regions, especially for the UT, although the results revealed no statistically significant changes in the RMS over 2 h of sitting in the aircraft seat. The MPF values of the seatback angle × seat pitch interaction showed a significant result for CES muscle activity only [$F(2, 24) = 9.75$, $P < 0.001$] (Table I). Further Tukey's multiple comparison tests of CES indicated significance for T1 vs. T3 [$F(2, 24) = 0.23$, $P = 0.041$] and for T3 vs. T4 [$F(2, 24) = 0.17$, $P < 0.001$]. No seat pitch or seatback angle effects were found for any trials.

No statistically significant changes in MPF over 120 min are found in **Fig. 2**. Declining trends of MPF were seen over time for all three muscular regions. In general, for all three muscles, 30-min measurements were elevated in comparison with the MPF measurements at 15 min.

Table I reveals no significant difference in seatback angle, seat pitch, or seatback angle × seat pitch effects for the NE, LS, or RS (Table I). The mean PLD of the RLB was significantly different [$F(1, 12) = 5.04$, $P = 0.019$] and no differences were found between other body parts for the seatback angle. In general, fewer discomfort values were found for the angle level of 120°.

It was shown that the mean PLD of the RLB [$F(1, 12) = 1.67$, $P = 0.029$], LH [$F(1, 12) = 6.24$, $P = 0.029$], and RH [$F(1, 12) = 1.84$, $P = 0.010$] were significantly different between each seat pitch. The mean PLD of the LLB [$F(2, 24) = 2.11$, $P = 0.028$] and RLB [$F(2, 24) = 2.67$, $P = 0.007$] were significantly different and no differences were found between other body parts for four different trials. Tukey's multiple comparison tests revealed that the PLD values of the LLB [T1 vs. T2: $F(2, 24) = 3.21$, $P = 0.029$; T1 vs. T3: $F(2, 24) = 3.17$, $P = 0.025$] and RLB [T1 vs. T2: $F(2, 24) = 2.12$, $P = 0.003$; T1 vs. T3: $F(2, 24) = 2.94$, $P = 0.002$; T1 vs. T4: $F(2, 24) = 1.98$, $P = 0.008$] for T1 were higher than those of the other trials.

As shown in **Fig. 3**, there was a significant increase in the perceived discomfort over time. However, no significant differences between the four trials were detected. Increased slopes of perceived discomfort were seen over time for all seven body parts. More values of discomfort were recorded for the hip areas. Overall, the average ratings of PLD were less than 3.2 on a scale of 0 to 10 and the discomfort levels were moderate.

DISCUSSION

The RMS is an expression of the amplitude of the EMG signal and it consistently increases during a fatiguing contraction.[30] Only a few studies identified the reliability of the RMS in assessing the degree of fatigue, and there was a controversy among researchers regarding the reproducibility of the RMS.[17]

Strimpakos et al.[30] proposed that the RMS slope was poor to moderate, with a large between-session error limiting its utility in monitoring neck muscle fatigue. However, De Luca found that an increase in the RMS amplitude could be regarded as an indicator of localized muscle fatigue during repetitive lifting tasks.[12] Herein, we hypothesized that a decrease in one or more of the frequency domain parameters coupled with a concomitant increase in the time domain parameters would be a reliable

Table I. Descriptive Statistics For The Root Mean Square (RMS) And Median Power Frequency (MPF) Values of Muscle Activity and Perceived Levels of Discomfort (PLD) Values for Different Combinations of Seatback Angle and Seat Pitch (Standard Deviation), Along with the Statistical Results (*P*-Values) of the Seatback Angle, Seat Pitch, and Seatback Angle × Seat Pitch Interaction Effects.

DEPENDENT VARIABLE	COMBINATIONS OF SEATBACK ANGLE (DEGREES) AND SEAT PITCH (INCHES)				*P*-VALUES FOR THE MAIN FACTORS		
	90°/30″ (T1)	90°/34″ (T2)	120°/30″ (T3)	120°/34″ (T4)	SEATBACK ANGLE	SEAT PITCH	SEATBACK ANGLE × SEAT PITCH
RMS data (mV)							
CES	0.31(0.32)	0.14(0.11)	0.18(0.22)	0.07(0.05)	**0.004**	<**0.001**	0.378
UT	0.17(0.14)	0.16(0.12)	0.07(0.05)	0.07(0.05)	<**0.001**	0.451	0.861
LM	0.11(0.07)	0.10(0.01)	0.10(0.07)	0.067(0.02)	0.098	0.066	0.358
MPF data (Hz)							
CES	76.23(14.41)	81.13(13.54)	82.85(14.32)	76.38(13.96)	0.594	0.655	**0.001**
UT	77.14(12.03)	79.35(11.97)	80.04(14.37)	81.28(13.01)	0.134	0.285	0.766
LM	75.74(11.97)	76.08(13.71)	77.96(11.88)	79.56(13.78)	0.078	0.548	0.695
PLD data							
NE	1.15(1.37)	1.07(1.02)	0.97(0.91)	0.76 (1.16)	0.747	0.613	0.187
LS	0.76(1.16)	0.77(0.91)	0.75(0.71)	0.63(0.66)	0.371	0.562	0.434
RS	0.69(1.02)	0.67(0.91)	0.89(0.84)	0.67(0.77)	0.252	0.170	0.268
LLB	1.83(1.70)	1.29(1.33)	1.28(1.16)	1.36 (1.17)	0.075	0.107	**0.028**
RLB	2.00(1.68)	1.32(1.29)	1.31(1.18)	1.38(1.17)	**0.019**	**0.029**	**0.007**
LH	2.12(1.81)	1.66(1.41)	1.78(1.34)	1.60(1.26)	0.177	**0.029**	0.334
RH	2.24(1.79)	1.65(1.45)	1.79(1.37)	1.61(1.26)	0.093	**0.010**	0.172

Cervical erector spinae (CES), upper trapezius (UT), lumbar multifidus (LM); neck (NE), left shoulder (LS), right shoulder (RS), left lower back (LLB), right lower back (RLB), left hip (LH), right hip (RH).
Bold values indicate significant differences ($P < 0.05$).

indicator of the passenger's discomfort levels. Therefore, in the current study, the RMS and MPF methods were both used to identify whether the fatigue and discomfort could have occurred over the long-term flight. The RMS results of the CES, the UT, and the LM trended upward along with a general trend of decline in the MPF analysis over 120 min, with no significant differences observed. In other words, our hypothesis was only partly affirmed by the preceding results. From these results it can be concluded that the indicator of fatigue rate proposed by Balasubramanian et al.[4] does not appear to be a reasonable tool for evaluating the discomfort of neck, shoulders, and lower backs among aircraft passengers as the differences were not significant.

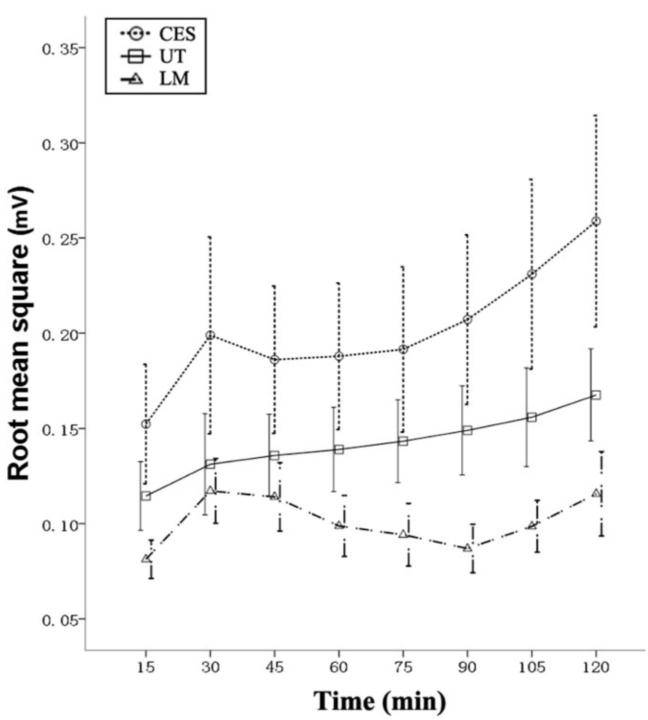

Fig. 1. Mean and standard error ratings of the root mean square for three muscles, including the cervical erector spinae (CES), the upper trapezius (UT), and the lumbar multifidus (LM), reported over 120 min sitting.

In the present study, only the CES and the UT were influenced by the factor of the seatback angle, and the CES was significantly affected by seat pitch; however, the 120° seatback angle did not cause significantly decreased RMS values compared with 90° in the LM. These findings were partly consistent with previous observations of an increased backrest angle being associated with reduced muscle activity in the back muscles when measured by EMG.[16] This may be because the area of placement of the electrode on the lumbar multifidus was in contact with the surface of the backrest and there could have been interference in the EMG signals to some extent.

The rating of perceived discomfort of the RLB was significantly influenced by the factor of the seatback angle. A 120° seatback angle was beneficial to the right lower back regions compared with an angle of 90°. This result is in agreement with studies done by Andersson et al.[2] and Harrison et al.,[26] who determined that the ideal backrest angle for reducing the EMG of the back during sitting or driving is 120°. Coincidentally, this result was in accordance with the results of the current study that a 120° seatback angle caused decreased RMS values and increased MPF; that is to say, a 120° seatback angle seems to play a role in discomfort relief compared with 90°. On the other hand, it supported the above result, in some sense, that no significant difference was found in LM muscle activation due to the unavoidable contact between the electrode and backrest.

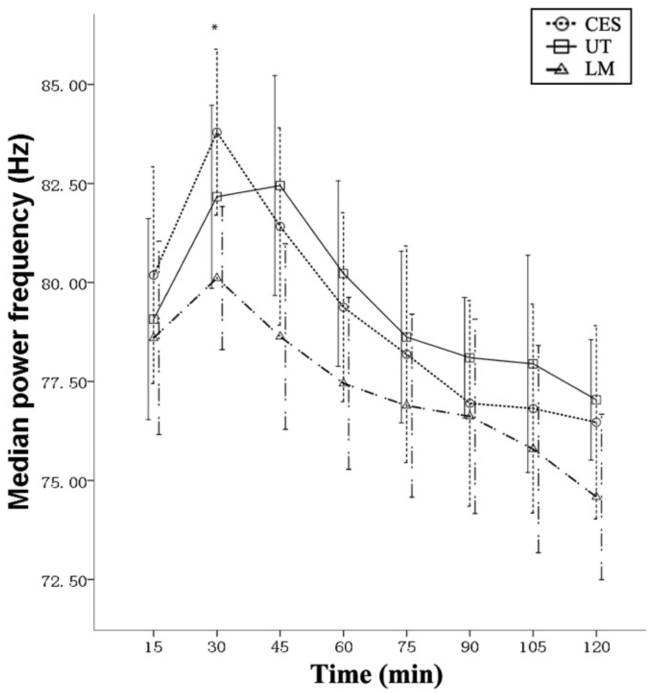

Fig. 2. Mean and standard error ratings of the median power frequency for three muscles, including the cervical erector spinae (CES), the upper trapezius (UT), and the lumbar multifidus (LM), reported over 120 min sitting. The asterisk indicates a significant difference.

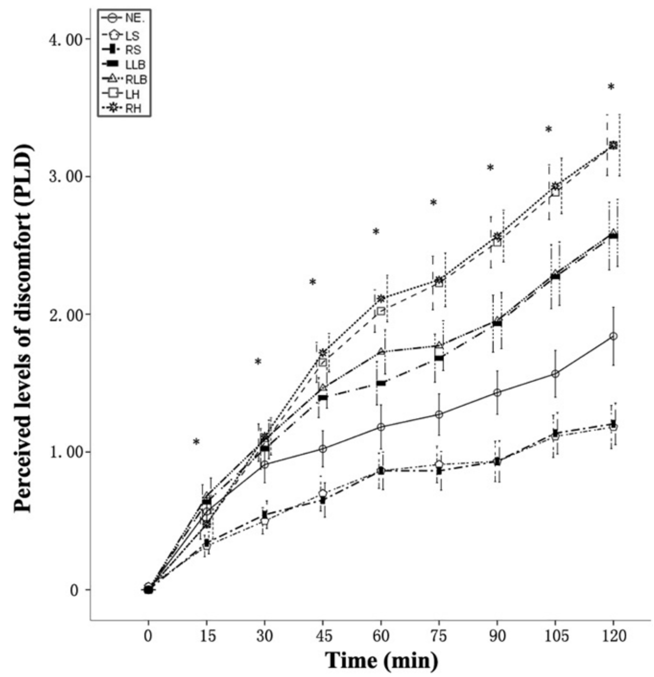

Fig. 3. Mean and standard error ratings of the perceived levels of discomfort (PLD) for seven body parts, including the neck (NE), left shoulder (LS), right shoulder (RS), left lower back (LLB), right lower back (RLB), left hip (LH), and right hip (RH), reported over 120 min sitting. An asterisk (*) indicates a significant difference.

In general, slight elevations in RMS levels and negative shifts in MPF values for the cervical, lower back, and hip regions were obtained over 120 min of sitting in the aircraft seat (see Fig. 1 and Fig. 2). This finding is consistent with the results reported by Kim and Chung,[15] who found that the MPF analysis for trunk muscular fatigue showed good compliance with the EMG amplitude analysis. Moreover, previous studies proved that muscle fatigue caused an increase in the RMS and a decrease in the values of the MPF.[5,28] Significant increases of MPF for all three muscles were found at 30 min and then the trend continuously shifted to negative. This phenomenon may be due to the 30 min of sitting, leading to perceived discomfort and frequent posture shifts, because a study reported that aircraft passengers adjust their body positions unconsciously when they feel discomfort.[8] This opinion was supported by previous research, which stated that it took between 30 and 45 min before discomfort or fatigue occurred.[20] In other words, muscle fatigue of the neck, shoulder, and lower back occurred at 30 min during flights.

In the present study, the MPF results demonstrated that only the CES was significantly influenced by the interaction efforts of seatback angle × seat pitch. Along with the RMS statistical results of the seatback angle × seat pitch interaction effects, this indicated that there were only a few relationships between EMG changes and the different combinations of seatback angle and seat pitch. This issue may need to be studied and discussed further.

Seat pitch is significantly influenced by the perceived discomfort of the lower back and hips. The larger seat pitch (34″) was more advantageous to the passengers' comfort than the smaller one (30″). Overall, the highest ratings of PLD in the lower back and hips were found in T1 (with a 90° seatback angle and a 30″ seat pitch). This indicated that, as outlined above, the wider seatback angle and seat pitch was conducive to relieving the perceived discomfort,[13,18] especially for the lower back and hips.

A line plot revealed that the PLD measurement was more sensitive than the EMG measurement for investigating discomfort in the temporal dimension (see Fig. 1, Fig. 2, and Fig. 3). This finding was in line with a previous study that showed that subjective analyses were more sensitive than parameters analyzed with the objective measurement recording by EMG and seat pressure distribution.[22] However, an indication of fatigue was found in the present study during a 2-h sitting session, as there was a slight increase in the EMG amplitude and a decrease in the EMG spectrum along with an increased perception of discomfort, although these changes were only partially significant. This finding was in line with Quigley et al.,[27] who indicated that the body discomfort of aircraft passengers was associated with the flight duration.

There are several limitations to the present study. First, the measurements were carried out under laboratory conditions without considering the factors of vibration, noise, cabin pressure, and so forth. Future studies may address comfort changes in vibration and noise. Second, only the EMG and PLD data of the upper extremity were examined. The muscular activation and perceived discomfort of other body parts, such as buttocks and lower limbs, should be an additional consideration in the future. Third, it remains unknown how muscle fatigue and discomfort develop during a long time sitting in an aircraft seat interspersed with short breaks (standing or walking the aisle).

Fourth, the small sample size may limit the generalization of the results and the trial needs to be repeated using a larger sample. Fifth, two levels of seatback angle and seat pitch were explored in this study, but the discrete nature of the configurations could have impacted the evaluation of passengers' comfort. Therefore, further investigation (e.g., 28″ to 33″ seat pitch and 90° to 130° seatback angle) should be devoted to understanding the above-mentioned issues. Sixth, the relationship between subject anthropometry (e.g., buttock-knee length and sitting height) and seatback angles and seat pitches should be taken into consideration. Finally, change of posture and joint angle would be an effective way to analyze physical exposure, so an electrogoniometer or a kinect camera should also be employed to identify muscle fatigue and subjective discomfort.

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