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Use pressure data below seat cushions to evaluate comfort

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ABSTRACT

During a flight, passengers spend most of their time sitting in their seats. Studying the comfort and discomfort while passengers are sitting is helpful to improve the overall comfort during a flight. Pressure mats are commonly used in studies to collect pressure distribution in order to research sitting comfort. Different from most past studies, in which pressure mats are placed on the top of the cushions, the focus of this paper is to show the potential of placing pressure mat below the seat cushion. Three identical cushions differing in stiffness were prepared. The pressure distribution of 12 sitting postures was collected from 33 subjects both at the top as well as at the bottom of the foam in a randomized order. After sitting on each cushion, the participant was asked to leave the seat and complete a sitting comfort and discomfort questionnaire. The results show that the softest cushion got the highest rank in short-term comfort and lowest rank in short-term discomfort. The recorded pressure distributions both on the top and at the bottom of the foam can influence comfort and discomfort. This indicates the potential to use pressure distributions under the foam to evaluate the perceived comfort and discomfort in sitting, which might reduce the intrusive feeling of the participants in comfort studies.

KEYWORDS

Sitting comfort, aircraft seat, pressure distribution

Introduction

The air transport industry has been growing rapidly (Schaefer, 2012). Though in the period of 2020-2021, due to the influence of Covid-19, there was a massive drop in the number of passengers, it is expected that the demand will return to the pre-Covid-19 in about 2.4 years (Gudmundsson et al., 2021). Passengers' perceived comfort plays a vital role in creating a pleasant experience during flight. In 1980, Richards highlighted the importance of comfort as it has a substantial impact on passengers' decision to fly again with the same airline (Richards, 1980). Hiemstra-Van Mastrigt also identified that the perceived sitting comfort and discomfort are of significant importance for passengers when choosing an airline since they spend most of their time sitting in a constrained space (Hiemstra-Van Mastrigt et al., 2016). The prolonged sitting can cause discomfort in the body and severe complaints such as venous thromboembolism (Gavish & Brenner, 2011).

Vink and Hallbeck defined comfort and discomfort as "comfort is seen as a pleasant state or relaxed feeling of a human being in reaction to its environment" and "discomfort is seen as an unpleasant state of the human body in reaction to its physical environment"(Vink & Hallbeck, 2012). As these are two subjective and independent perceptions (Hiemstra-van Mastrigt et al., 2017), the presence of sitting comfort and discomfort can be simultaneous and they are not linearly correlated. For instance, the reduction in sitting discomfort does not necessarily increase the sitting comfort (Helander & Zhang, 1997). Besides, sitting duration also plays an important role in the evaluation of comfort and discomfort (Vink et al., 2017).

The pressure distribution has a clear relation with discomfort (De Looze et al., 2003). When people are sitting, the hip joints are fixed and the weight is mainly sustained by the bony structure (Floyd & Roberts, 1958). In an ideal situation, the maximum level of comfort can be achieved by a design which support the weight mainly around the ischial tuberosities (Lay & Fisher, 1940). Soft tissues on the buttock and thigh cannot support the sitting body for a prolonged duration (Akerblom, 1949), as when they are compressed, numbness and tingling can happen due to improper pressure load on nerves and blood vessels (Floyd & Roberts, 1958). To avoid the risks of blocking the blood flow in vessels, the pressure should stay below 60mm Hg (Conine et al., 1994). Therefore, the hypothesis is that human will consciously, or unconsciously, move the body in a prolonged sitting. Such movements often lead to the change pressures underneath the buttocks.

Pressure distributions of people sitting in automobiles are studied to guide the seating designs in order to improve comfort of passengers and reduce potential health risks (Hartung, 2006)(Zenk et al., 2012)(Kilincsoy, 2019). In the study of Ebe and Griffin, it was found that a ‘bottoming feeling’ and a ‘foam hardness feeling’ were the two main factors influencing cushion comfort of a seat (Ebe & Griffin, 2001). Zemp et al. (2015) showed that the less discomfort and higher comfort are related to the lower mean pressure, the lower peak pressure, and larger contact areas. Another study of automotive seats also indicated the correlations between perceived comfort and the peak and mean pressure on the seat pan (Akgunduz et al., 2014), which implicitly addressed the importance the geometry of the seat pans. Besides the geometry, interface pressure can be strongly influenced by other factors of the seats (Vos et al., 2006). For instance, Zemp et al. confirmed that pressure distribution under the buttock is highly related to the materials and the mechanical configuration of the seat (Zemp et al., 2016)(Wegner et al., 2019).

Most of the existing studies on the pressure distributions focus on office chairs and car seats. Only a few studies investigated the seat of the aircraft (Dangal et al., 2021). Also, it is confirmed in previous studies that features of both the top and bottom layer of a cushion could influence sitting comfort in the short and long term (Moon et al., 2020) but in most studies, only the pressure distribution of the top interface of the seats are investigated. However, the airtight and slippery material may cause extra discomfort in long duration experiments. When people are seated, the body surface in contact with the seat requires a different material than the body parts in contact with the environment (Ferreira & Tribess, 2009). Airtight material can make the process of heat and humidity transfer very difficult. Also, the pressure mat can be shifted slightly due to the movement of the participants.

In this study, the pressure distribution was recorded on the top as well as at the bottom of the seat. Three types of aircraft seat pans were used and effects on comfort and discomfort were studied. Our target is to investigate the potential of evaluating the perceived comfort of participants in sitting position using pressure (distributions) measurements at the bottom. This leads the to the research question: is it possible to evaluate the perceived comfort and discomfort using pressure and pressured distributions measured at the bottom of the seat cushion?

Methods

A within-subject experiment was designed based on two rows of aircraft seats. Subjects of this experiment were 18 males and 15 females, aging from 23 to 37 years old. BMI of the participants varied from 17.6 to 41.3. Three cushions with the same shape, but different in foam hardness were evaluated in a randomized order. All cushions were supported by a self-designed seat pan on the frame of a Recaro BL3520 economy class passenger seat. The inclination angle of the seat pan is 12 degrees and the angle between seat pan and backrest is 96 degree. During the experiment, each participant was asked to perform 12 postures pre-selected by the researchers on each seat pan. Each posture lasted for about one minute. The pressure distribution of each posture on the top surface and bottom surface of seat pans was recorded by pressure mats LX210:48.48.02 developed by XSENSOR Technology Corporation. Each mat consists of 48 by 48 sensing cells, and the dimension of each cell is 12.7 mm by 12.7 mm. Transparent adhesive tape was used to fix the pressure mat on the top. After each cushion participants left the seat and completed the questionnaires. This was done for 12 postures. The questionnaires used in this study consisted of a comfort and discomfort questionnaire and a local postural discomfort questionnaire. In the local discomfort questionnaire, eight regions selected from the regions used in Hartung's study (Hartung, 2006) regarding sitting postures was used. The sequence of postures and cushions were different for each participant based on a randomized order as well. To exclude bias of visual perception, the appearances of different cushions were made the same for the participants. The complete protocols of the experiment can be found in Fig.1. Figure 2 shows the inner-structure of three types of cushions. Different types of foams and the combination of foams can be observed. Among them, cushion A is the softest of the cushions, and cushion C is the stiffest one. The bottom materials (the black layer) of cushion B and Cushion C are the same.

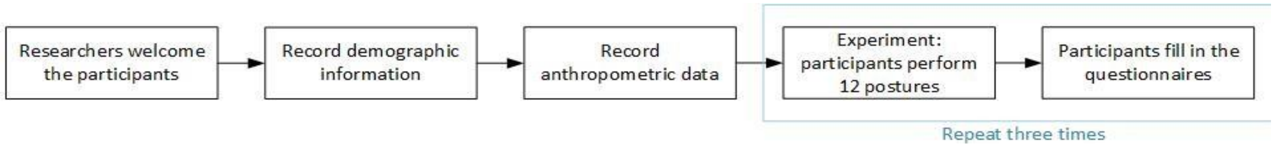


Figure 1:Experiment *protocols*

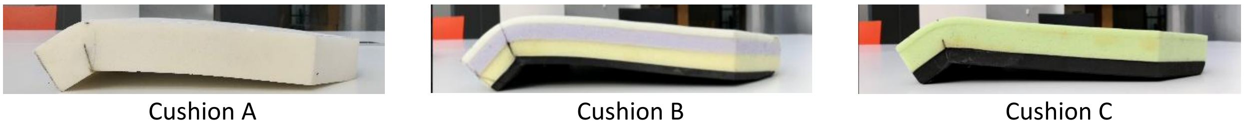


Figure 2: Three cushions used in the experiment

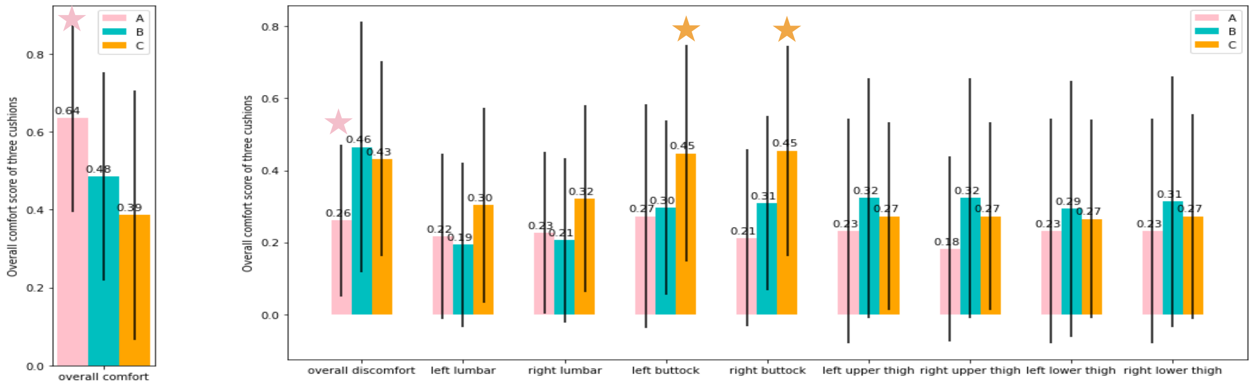
The data of the questionnaires were first normalized using the min-max scaler, and tested with a Shapiro Wilk test for normality. Since the results of questionnaires are not in the normal distribution, a Mann-Whitney U test was selected to find out the difference in perceived comfort and discomfort between the three cushions.

The missing data of the pressure mat were filled with the average value of its neighbours. The average pressure and contact area of each posture were calculated. To reduce noise, cells on the mat sensing less than 0.01 N/cm^2 were excluded.

Results

The mean values of the data regarding comfort and discomfort are presented in Fig.3. The items with a significant difference ($p<0.05$) from others are marked with a star. The softest cushion

(cushion A) scored the highest in comfort and the least in general discomfort. Regarding the different regions, the stiffest cushion (cushion C) showed most discomfort around the buttock regions. It also scored the lowest on perceived comfort. Significant differences were found between cushion A and other two cushions. There is also a significant difference between cushions with the same bottom layer materials. Though most of participants are right-handedness, we did not find difference between the left and the right regarding the subjective feelings.



(a) Comfort score

(b) Discomfort score

Figure 3: Scores of perceived comfort and discomfort (items with significant difference with other two cushions are marked with stars)

The mean pressures sensed by both pressure mats were calculated for each posture as presented in Fig.4 and Fig.5, respectively. The softest cushion has the smallest value regarding the mean pressure and the hardest cushion has the highest. Figure 6 and 7 show the average contact area of each cushion in different postures. The softer the cushion is, the larger the contact area between the human body and the cushion is. The mean pressures of three cushions were significantly different in most postures on the top layer, except for posture 5 (no significant difference between cushion B and cushion C) and posture 6 (significant difference were only found between cushion A and cushion C). For the bottom layer, the mean pressure of cushion A is significantly different from cushion B and cushion C. Significant differences between cushion B and cushion C were only found regarding posture 9 and 10. Contact areas on the top layer were different between all the cushions except for posture 11. In this posture, a significant difference was sensed between cushion A and the other two cushions on the bottom layer. A summary was made in Fig.8 to show whether significant differences are found both in pressure distribution, contact area and sitting comfort status regarding the top and the borrow layer.

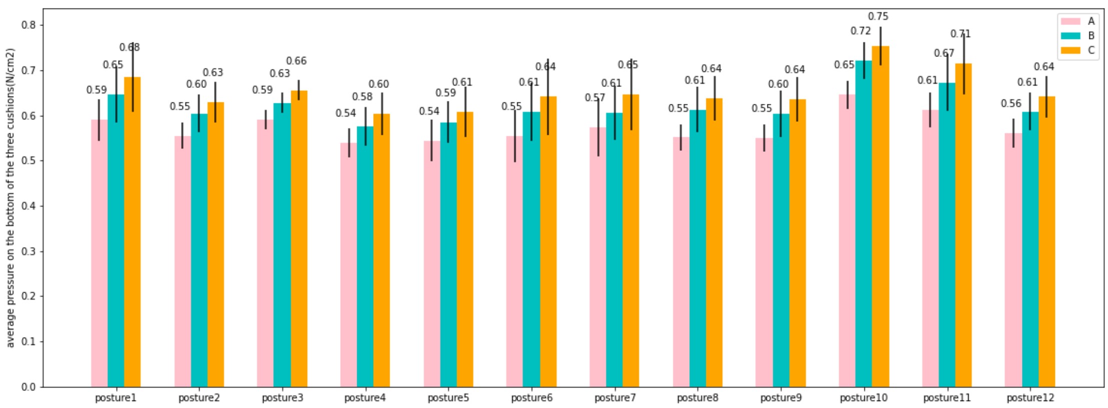


Figure 4: Mean pressure of each posture with different cushions(top layer)

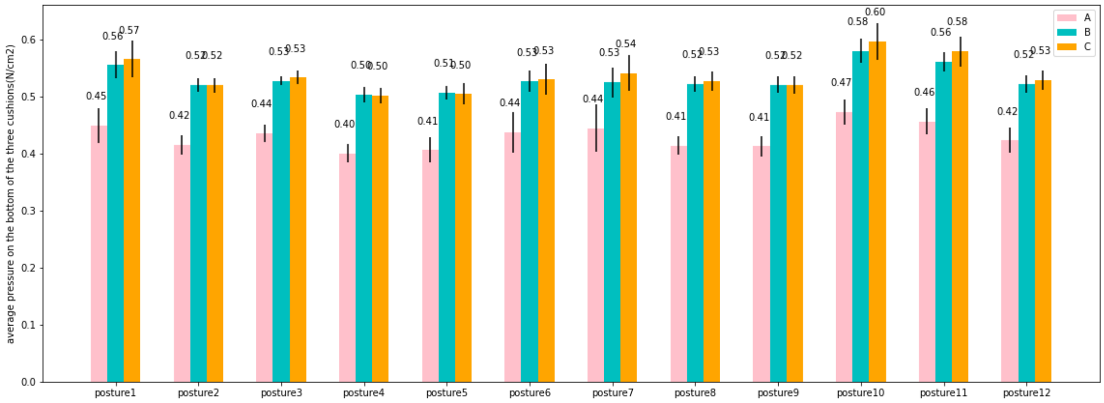


Figure 5: Mean pressure of each posture with different cushions (bottom layer)

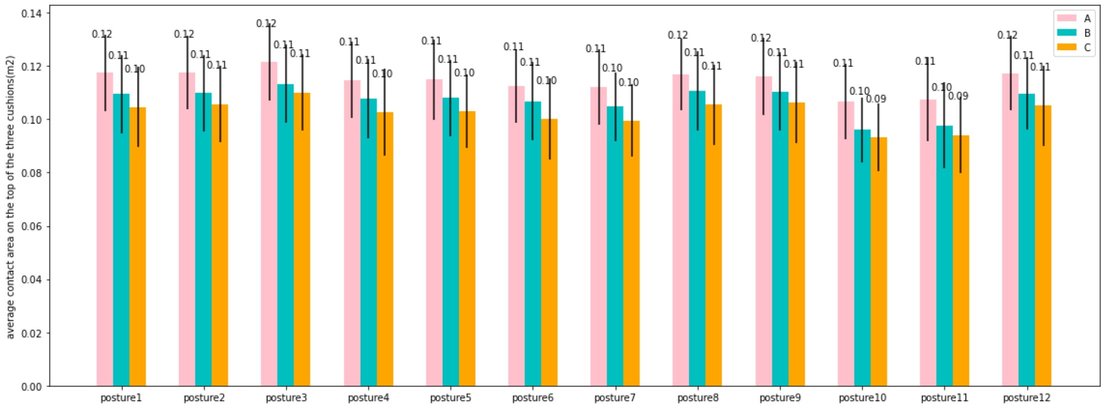


Figure 6: Mean contact area of each posture with different cushions(top layer)

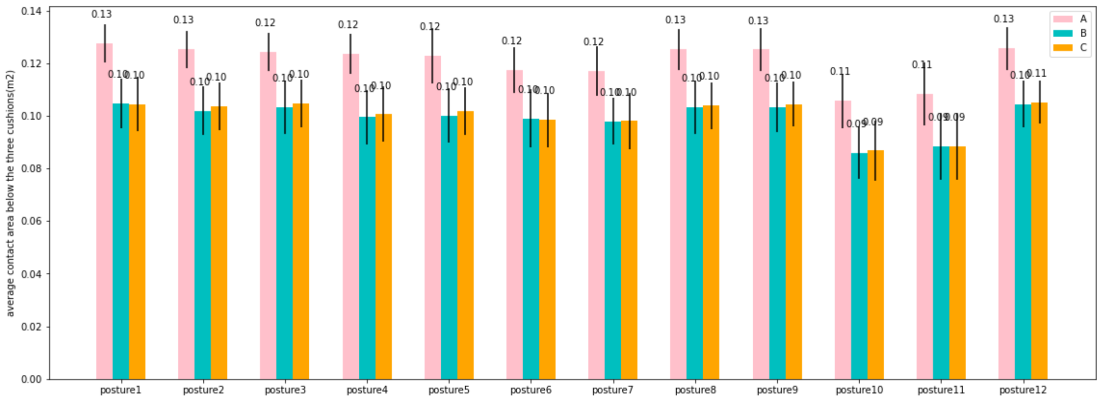


Figure 7: Mean contact area of each posture with different cushions (bottom layer)

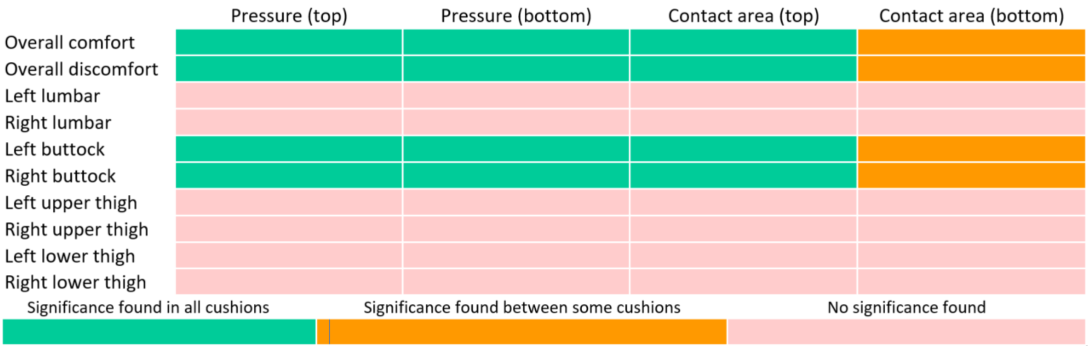


Figure 8: cross comparison of significant difference found in pressure distribution, contact areas and the comfort status

Discussion

In this study, the softest cushion, which has the lowest mean pressure and the largest contact area performed best on perceived comfort. A similar result can be found in the study of Dangal et al. (Dangal et al., 2021). Ebe and Griffin also found that compared to seats that create high pressure under the buttock, the ones that create less pressure beneath the ischial bones are considered as more comfortable (Ebe & Griffin, 2001). This can be a result of associating softness with luxury (Kamp, 2012). The most significant differences in pressure distribution were found between cushion A and the other two cushions but still, cushion B and cushion C performed different on discomfort. With different materials both on the top and bottom, cushion A performed different on comfort and discomfort.

Figure 8 show the coherent performance of the pressure distributions at the top and the bottom, which indicate the potential of using either of them as an evaluation tool for comfort/discomfort. It is not validated whether the stiffness on the top layer mainly influences discomfort and the stiffness of the bottom layer has a bigger influence on comfort but it is clear that the features of both surfaces of a cushion can be associated to sitting comfort/discomfort. This is in accordance with the work of Moon et al. (2020).

According to Stevens's power law (Stevens, 1957), the exponent of tactual hardness regarding the perceived amplitude is 0.8, but the exact difference of hardness of different cushions was not measured in this study. It is not sure whether the difference in hardness of the three cushions can be sensed very well.

The population age of this study is between 23 and 37. Both young children and the elderly were not included. However, the preference of these groups should still be studied. Also, during the experiment, the position of pressure mats could be shifted due to participants' movement, which may cause noise.

Conclusion

This study using three cushions which differ in hardness, shows that pressure data at the bottom of a foam cushion and at the top of a cushion are linked to each other and have a relationship with experienced comfort and discomfort. The lowest mean pressure and the largest contact area performed best on perceived comfort and had the lowest discomfort. Although the impact of pressure on the two surfaces may not be equal, the potential of using pressure data under the foam to evaluate the perceived comfort and discomfort of the user in different sitting postures is verified.

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