

## The effect of 17-inch-wide and 18-inch-wide airplane passenger seats on comfort

Anjani, Shabila; Song, Yu; Hou, Tao; Ruiter, Iemkje A.; Vink, Peter

**DOI**

[10.1016/j.ergon.2021.103097](https://doi.org/10.1016/j.ergon.2021.103097)

**Publication date**

2021

**Document Version**

Accepted author manuscript

**Published in**

International Journal of Industrial Ergonomics

**Citation (APA)**

Anjani, S., Song, Y., Hou, T., Ruiter, I. A., & Vink, P. (2021). The effect of 17-inch-wide and 18-inch-wide airplane passenger seats on comfort. *International Journal of Industrial Ergonomics*, 82, Article 103097. <https://doi.org/10.1016/j.ergon.2021.103097>

**Important note**

To cite this publication, please use the final published version (if applicable). Please check the document version above.

**Copyright**

Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

**Takedown policy**

Please contact us and provide details if you believe this document breaches copyrights. We will remove access to the work immediately and investigate your claim.

# The effect of 17-inch-wide and 18-inch-wide airplane passenger seats on comfort

Shabila Anjani\*, Yu Song, Tao Hou, Iemkje A. Ruiter, Peter Vink

Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628CE Delft, the Netherlands

\* Corresponding author

Email addresses: S.Anjani@tudelft.nl (S. Anjani), Y.Song@tudelft.nl (Y. Song), T.Hou@tudelft.nl (T. Hou), I.A.Ruiter@tudelft.nl (I. A. Ruiter), P.Vink@tudelft.nl (P. Vink)

## Abstract

The pitch and width of airline seats are crucial factors on the comfort of passengers. The aim of this study is to measure the comfort feeling of passengers regarding different widths and together with data from a previous study, to offer suggestions on the aircraft interior design. 311 participants were recruited and were asked to sit in 17-inch-wide and 18-inch-wide aircraft seats in a Boeing 737 fuselage for 10 minutes, respectively. Questionnaires on psychological comfort and overall discomfort, as well as an additional questionnaire on the discomfort of different body parts, were used to evaluate the comfort and discomfort experience of participants. Experiment results indicated that the comfort scores were significantly higher, and the discomfort scores were significantly lower for sitting in the 18-inch-wide seats than that of sitting in the 17-inch-wide seats. It was also found that rather than the buttock, the shoulders, knees, lower legs and feet contributed significantly to the reduction in overall discomfort by providing more space for movements. Regarding anthropometric measurements, participants with smaller hip-breadth felt more comfort while sitting the 18-inch-wide seat, which highlights the importance of the freedom of movement. By synthesizing the results of a previous study on the relations of the seat pitch and comfort, it was found that given the same amount of additional floor area, widening the seat is more effective on comfort than increasing the pitch.

Relevance to industry: This discovery might be useful for the airline industry for a more effective and efficient usage of floor area.

Keywords: Comfort, seat, width, airplane

## 1. Introduction

The selection of carriers for air travellers are influenced by many factors. Besides the basic needs such as the convenience of the route, the departure time and the price, comfort is one of the most important criteria, especially for business travellers (Kurtuluşoğlu et al., 2016; Teichert et al., 2008).

Passengers experienced different activities during air travel. Among those activities, they spend most of their time sitting during the flight (Li et al., 2017). Offering the comfort seating experience is therefore crucial for airlines for attracting customers. An earlier study of 861 passengers by Richards and Jacobson (1977) found that seat width was linearly correlated to the level of satisfaction of passengers based on a comparison of data collected from 4 different airlines. Hinninghofen and Enck (2006) further identified that seat comfort was associated with seat pitch, seat width, legroom, quality of upholstery, and possibly, the angle of recline. Vink et al. (2012) also found that seat width was

important for passenger comfort provided that bigger armrests should not reduce the space for sitting. Besides, the width and pitch of the seat were also primary factors for passengers to upgrade to the premium economy class based on their previous experience (Kuo and Jou, 2017).

Body dimension is an important aspect to consider in the designing for large populations, e.g. having both the small man (P5) and the large man (P95) fit in the airplane seat (Roebuck et al., 1975). Besides, the changes of anthropometric measurements of populations over the past decades should also be considered, as Molenbroek (2017) found a 2% increase per decade in hip breadth of the Dutch population in 30 years' time and recommended a new standard for designers regarding the width of the seat. Quingley (2001) also proposed the need to update the minimum seat pitch requirements, as the UK Airworthiness Notice 64 requirements made in 1989 currently only fits P88 British, P77 European and P80 World population. Porta (2019) measured 547 participants in Spain and concluded that it is necessary to increase both the minimum seat pitch and the seat width in the economy class. The increments in both/either pitch and width would surely bring more comfort to the passenger. However, due to the limited floor areas, the priority of increasing the pitch or widening the seat remains a question.

In summary, literature study indicated that widening the seat will improve the comfort of passengers. However, space is valuable in an aircraft. While airlines try to accommodate more passengers of an airplane for profits, offering comfort experience in a given limited floor area is always a challenge. This leads to the research questions of this paper: 1) What is the comfort experience of widening a seat from 17 inches to 18 inches on comfort? and 2) Whether widening the seat or increasing the pitch is more effective in floor planning regarding the comfort feeling of passengers?

## 2. Materials & Method

An experiment was designed to study the comfort of passengers regarding the widths of seats. Fourteen 17-inch-wide seats and fourteen 18-inch-wide seats were installed in a Boeing 737 fuselage. The pitches of all seats were kept the same (30 inches). 311 participants were invited to the experiment in 12 sessions, which were held consecutively in 3 days. Prior to the experiment, participants measured their anthropometric data which included shoulder breadth, hip breadth, elbow to elbow breadth, waist breadth, sitting elbow height, sitting shoulder height, and stature of participants following the DINED procedure (Molenbroek et al., 2017). Weight of the participants were also measured for calculating their Body Mass Index (BMI). At the beginning of each session, the protocols of the study were explained to the participants and participants were asked to sign the consent form. Participants who did not want to share their data were excluded from the study. Then, half of them started by sitting in the 17-inch-wide seats and the other half with the 18-inch-wide. After 10 minutes, the two groups switch their seats for sitting another 10 minutes. The complete session lasted for approximately 30 minutes. In the experiment, the location of each participant was kept the same in both scenarios, e.g. if a participant first sat on a 17-inch-wide window seat at the left, he/she also sat on the 18-inch-wide window seat at the same side.

All seats were adjusted to an upright position. Therefore, the inclination angles of seats were the same. Participants were instructed to maintain the upright posture, though the actual posture was freely chosen. Every time after 10 minutes sitting in the seat, participants were asked to complete three questionnaires, i.e. a questionnaire on psychological comfort, a CP-50 scale on discomfort (Shen and Parsons, 1997) and a Local Perceived Discomfort (LPD) body map (Li et al., 2017). The reason of using

these three types of questionnaires is that discomfort is more related to physical factors and for comfort, besides physical factors, psychological and social factors should be considered as well (De Looze et al., 2003; Kremser et al., 2012; Li et al., 2017; Menegon et al., 2017; Zhang et al., 1996).

Eight statements used in the psychological comfort questionnaire (listed in Table 2) were derived from studies of Kremser et al. (2012), Menegon et al. (2017) and The Future Lab (2014), and the positive and negative descriptors suggested by Helander and Zhang (1997) were adopted. A “Not Applicable” option was added as an option for each question to see whether a question(s) fits the condition well. The CP-50 discomfort scale was selected as this two-stage questionnaire is able to give an holistic view of the discomfort of the subject (Shen and Parsons, 1997), where for evaluating discomfort regarding different regions of the body while sitting, the LPD body map with the Numerical Rating Scale (NRS) introduced by Li et al. (2017) was used.

The validity of answers of questionnaires was checked first. The number of valid datasets is reported in each analysis where incomplete datasets were excluded. The anthropometric measurements were compared to the database of Dutch populations (Molenbroek et al., 2017) as the participants were from the same population. These results were then correlated to the comfort and discomfort results of the questionnaires. Additionally, comfort and discomfort scores of regarding two hip width groups were compared, as Molenbroek et al. (2017) indicated that human with 434 mm hip width or less is suitable for 17.1” seat width.

Groenensteijn (2014) indicated that the feelings of comfort and discomfort were not always a normal distribution regarding the population. A Shapiro Wilk test were conducted to validate the data distribution for selecting proper statistical tools. The Wilcoxon Signed Rank tests were therefore selected to evaluate the differences (IBM SPSS 25) of the feeling of comfort/discomfort regarding different seat widths as this method is suitable for analysing data that is not normally distributed. A Spearman’s correlation was conducted to explore the relations between comfort/discomfort and the dimensions of each body dimensions regarding the seat widths. The significance and correlation of LPD results were calculated individually on each body part. Furthermore, the linear regression method was used to associate the discomfort of each body part to the 10-scale overall comfort and the CP-50 discomfort, respectively. The coefficients of the regression models were then analysed to highlight the importance of discomfort of each body part regarding the overall feeling of comfort/discomfort.

Finally, the results of comfort and discomfort of the two types of seats (17-inch-wide and 18-inch-wide) were synthesized with the results of a previous study (Anjani et al., 2020), which evaluated the feeling of comfort/discomfort of passengers regarding the pitch lengths of 17-inch-wide seat in the same Boeing 737 fuselage with a similar age group. The comfort and discomfort results of all seat arrangements were normalized and placed into a single graph. The synthesized results of these two experiments casted a new view on the comfort/discomfort regarding the seat pitch and width.

## 3. Results

### 3.1. Participant demographic characteristics

Out of 311 participants that participated in the study, 1 person did not wish to share the data for research and the data was excluded in the analysis, resulting in 310 datasets. Among 310 datasets, 193 valid anthropometric measurements were identified where 78 are males and 118 are females. The

mean age of the participants is 18.33 years with a standard deviation of 0.74. Details of anthropometric measurements are presented in Table 1 together with the reference database (Molenbroek et al., 2017). It can be found that the measurements of participants are very close to that of the reference with a mean absolute error of 3.9%.

*Table 1 Anthropometric measurements and comparison to the reference data.*

Average anthropometric measurements	This study		Reference (Molenbroek et al., 2017)		Difference	
	Male (n= 78)	Female (n= 115)	Male	Female	Male	Female
Shoulder breadth (mm)	442	414	457	418	-3.3%	-1.0%
Hip breadth (mm)	364	386	438	382	-16.9%	1.0%
Elbow to elbow breadth (mm)	452	428	438	402	3.2%	6.5%
Waist breadth (mm)	446	412	-	-	-	-
Sitting elbow height (mm)	250	261	260	259	-3.8%	0.8%
Sitting shoulder height (mm)	626	617	-	-	-	-
Stature (mm)	1818	1655	1821	1698	-0.2%	-2.5%
BMI (kg/m <sup>2</sup> )	21.95	21.33	-	-	-	-

### 3.2. The effect of an increase of seat width on comfort and discomfort

The results of the questionnaire indicate that the scores of participants on comfort is higher when they were sitting in the 18-inch-wide seats ( $7.72 \pm 1.13$ , n=263) than that when they were sitting in the 17-inch-wide seats ( $5.90 \pm 1.48$ , n=263). The results of the CP-50 discomfort rating also show that the average overall discomfort for participants sitting in 18-inch-wide seats were in the medium discomfort category ( $23.09 \pm 9.64$ , n=263), which was higher than that of the 17-inch-wide seats which resulted in the low discomfort category ( $14.44 \pm 9.70$ , n=263).

A Shapiro Wilk test was done to test the normality of the data. It was found that the results were not normally distributed for comfort ( $p=0.000$ ) and discomfort ( $p=0.000$ ) at both widths. Furthermore, a Wilcoxon Signed Rank test was used to identify the significances of the effect of widening seat regarding comfort/discomfort. It was found that the comfort scores of using the 18-inch-wide seats are significantly higher than using the 17-inch-wide seats ( $Z=-12.224$ ,  $p=0.000$ , n=263). The results of the discomfort rating also show a significant difference ( $Z=10.184$ ,  $p=0.000$ , n=263)

### 3.3. The psychological effect of the increase of seat width

The results of the questionnaires (n=263) are shown in Table 1. A Wilcoxon Signed Rank test was done and statistical significance was found in all statements ( $p<0.001$ ) regarding the Z-value respectively (-11,009, -10.072, -11.355, -10.033, -3.608, -8.955, -6.741 and -10.785). The questionnaires included a “Not Applicable” option in the statements. This enables participants to eliminate statements that do not match their psychological condition. It was found that 14.9% of participants thought that the “The seat was wide enough for my body to fit” was “Not Applicable” in determining their psychological comfort, while for other statements, the “Not Applicable” rates were within the range of 0.5%~3.9%.

*Table 2 The feeling of comfort of participants sitting in 17-inch-wide and 18-inch-wide seats.*

Psychological comfort statement	17-inch-wide (9-scale*)	18-inch-wide (9-scale*)
1. I feel restricted by the seat-width	4.35 ± 2.05	2.36 ± 1.54
2. I feel restricted by the distances of the armrests	5.20 ± 2.25	2,99 ± 1.81
3. I feel restricted by my seatmate	5.03 ± 2.25	2,54 ± 1.81
4. I feel stressed out because of the seat-width	3.45 ± 2.08	1,97 ± 1.42

5. The seat was wide enough for my body to fit	7.04 ± 2.32	7.38 ± 2.54
6. I can change easily from one sitting posture to another	4.99 ± 2.32	6.54 ± 2.24
7. The seat-width enhances my productivity	4.07 ± 1.98	5.08 ± 2.15
8. The width of the seat makes me relaxed	4.20 ± 2.00	6.49 ± 2.06

\*1: extremely disagree; 9: extremely agree

### 3.4. The physical effect of the increase of seat width

The anthropometric measurements were correlated to the scores of comfort and discomfort using the Spearman's correlation method. Table 3 presents the results.

Table 3 Spearman's correlation of anthropometric measurements to comfort and discomfort.

Anthropometric measurements (n=194)	Comfort		Discomfort	
	17-inch-wide	18-inch-wide	17-inch-wide	18-inch-wide
Shoulder breadth	-.070	-.154*	.043	.092
Hip breadth	-.172*	-.092	.052	.183*
Elbow to elbow breadth	-.133	-.121	.167*	.087
Waist breadth	-.098	-.121	.093	.073
Sitting elbow height	-.038	.055	-.019	-.036
Sitting shoulder height	-.231**	-.187**	.044	.045
Stature	-.192**	-.262**	.048	.185*
BMI	-.121	.125	.148*	-.076

\*\*Correlation is significant at the 0.01 level (2-tailed).

\* Correlation is significant at the 0.05 level (2-tailed).

Generally, the mean scores of the LPD body map were low for each body part both in using the 17-inch-wide and 18-inch-wide seats (Table 4). Wilcoxon Signed Ranks tests (n=294) were conducted to compare the differences between using two types of seats regarding each body part. Test results indicate that there are significant differences between using the 18-inch-wide seats and using the 17-inch-wide seat for all body parts except for the lower back (Z=-.127, p=.899), where participants felt less uncomfortable sitting in 18-inch-wide seats.

To explore the relations of the results of the LPD and the overall comfort/discomfort, a linear regression model was used to fit scores of each item in the LPD to the overall comfort and discomfort, respectively. Here  $c_i$  are coefficients of component  $i$  of the LPD and  $c_0$  is the intercept of the regression model. Table 5 presents all coefficients regarding comfort/discomfort of two types of seats. Regarding comfort, for the narrower 17-inch-wide seat, the absolute value of  $c_2$ ,  $c_5$ ,  $c_8$ ,  $c_9$  are larger than the rest, which indicates the importance of discomfort of the shoulder, the lower back, the knee and the lower leg and foot to the overall comfort in this situation. For the 18-inch-wide seat, the discomfort of the arm, the upper and middle back, the lower back and the knee were found to be of importance. In both cases, the signs of those large coefficients are negative, which indicates that discomfort in those areas is inversely correlated with people's perception of comfort. For discomfort of sitting in the 17-inch-wide seat, the most important factors on the overall discomfort are the discomfort of the upper and middle back, the lower back, the shoulders and the lower legs and feet and for the 18-inch-wide seat, they are the arms, the lower back, the buttocks and the shoulders. The signs of those large coefficients in both seats are positive, which highlights the positive correlations between local discomfort and overall discomfort.

Table 4 Discomfort Scores of the LPD body map.

Body part	17-inch-wide (5-scale*)	18-inch-wide (5-scale*)	p-value
1. Head & Neck	2.64 ± 0.96	2.18 ± 0.92	.000
2. Shoulders	2.31 ± 0.97	1.99 ± 1.02	.000
3. Arms	2.55 ± 1.08	1.93 ± 1.03	.000
4. Upper & Middle Back	2.35 ± 1.06	2.19 ± 1.09	.090
5. Lower Back	2.43 ± 1.13	2.42 ± 1.13	.899
6. Buttocks	2.36 ± 1.12	2.07 ± 1.12	.002
7. Thighs	2.11 ± 1.06	1.80 ± 1.06	.000
8. Knees	2.54 ± 1.33	1.99 ± 1.21	.000
9. Lower legs & feet	2.30 ± 1.16	2.04 ± 1.14	.003

\*1: not uncomfortable; 5: extremely uncomfortable

$$\text{Overall comfort/discomfort} = c_0 + \sum_{i=1}^9 c_i LPD_i$$

Table 5 Coefficient of regression.

No.	Body Part(s) . $LPD_i$	Comfort		Discomfort	
		17-inch-wide	18-inch-wide	17-inch-wide	18-inch-wide
C <sub>0</sub>	-	0.780	0.860	0.149	0.014
C <sub>1</sub>	Head and neck	-0.001	0.0001	0.007	-0.002
C <sub>2</sub>	Shoulders	-0.014	-0.001	0.023	0.030
C <sub>3</sub>	Arms	-0.004	0.010	0.015	0.024
C <sub>4</sub>	Upper and middle back	-0.006	-0.016	0.017	0.001
C <sub>5</sub>	Lower Back	-0.020	-0.014	0.019	0.025
C <sub>6</sub>	Buttocks	0.005	-0.007	0.007	0.026
C <sub>7</sub>	Thighs	0.011	0.003	-0.006	0.007
C <sub>8</sub>	Knees	-0.016	-0.010	0.015	0.022
C <sub>9</sub>	Lower legs and feet	-0.036	-0.008	0.032	0.004

The coefficients of comfort regarding sitting in two types of seats were found to be strongly correlated ( $r=0.99$ ), which indicates the consistency of the relations between the scores of the LPD body map and comfort in two scenarios. Regarding the overall discomfort, we did not find correlations between coefficients of the regression model in two scenarios. The comfort and discomfort scores were further categorized to 2 groups based on the 17-inch-wide seat width where 432 mm was used as the threshold based on the width of the seat and data from the literature (Molenbroek et al., 2017). The mean values and the standard deviation were calculated for both groups regarding comfort and discomfort (Table 6) and compared. The stature and sitting shoulder height were found to be significantly correlated with comfort, most probably due to the fact that the average height of Dutch is tall (1818 mm for male and 1655 mm female). The group with a larger hip breadth benefited more by the widening of the seats (Table 6). Even though the seat is still smaller than their hip breadth, adding an inch did make a difference for this group.

Table 6 Means and standard deviation of hip breadth groups.

Hip Breadth Category	Comfort (1-10 scale)		Discomfort (0-50 scale)	
	17-inch-wide	18-inch-wide	17-inch-wide	18-inch-wide
> 432 mm = 17" (n=178)	6.0 ± 1.5	7.6 ± 1.1	22.3 ± 10.0	14.9 ± 9.8
≤ 432 mm = 17" (n=15)	5.6 ± 1.5	7.8 ± 0.9	25.8 ± 7.0	13.2 ± 8.8
> 457 mm = 18" (n=196)	6.0 ± 1.5	7.6 ± 1.1	22.3 ± 9.9	14.9 ± 9.8
≤ 457 mm = 18" (n=10)	4.9 ± 1.4	7.8 ± 1.0	27.5 ± 6.8	11.8 ± 7.4

### 3.5. Comparison of increasing width and pitch

In a previous study (Anjani et al., 2020), the comfort and discomfort of participants regarding sitting in a 17-inch-wide seat with different pitches were studied in a similar setup with a similar population. Comparing the results of this experiment to the results of the previous study (Figure 1 and Figure 2), it was found that the comfort scores of the 17-inch-wide wide and 30-inch-pitch were similar (6.00±0.09 vs 6.03±0.12). The one-inch increment of seat width resulted in an increase in comfort score of 2.0 (in a scale of 1-10) and a decrease in the discomfort of 8.7 (in a scale of 0-50). This result is a lot higher compared to increasing the seat pitch of two inches, which increased the comfort 0.7 and decreased the discomfort 4.0.

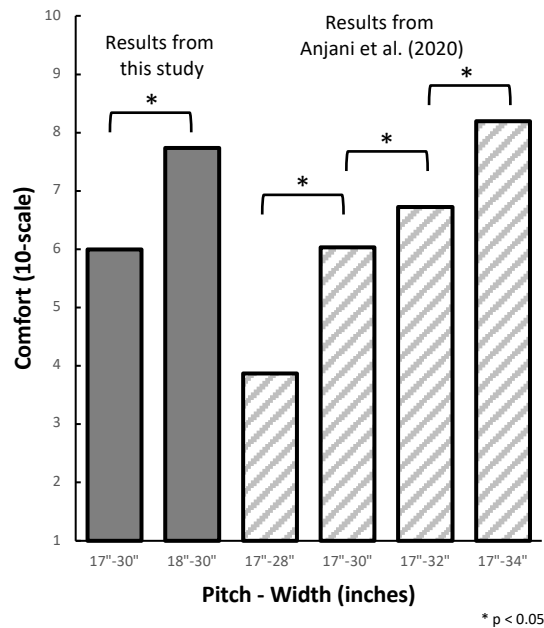


Figure 1 Comfort vs seat width and pitch



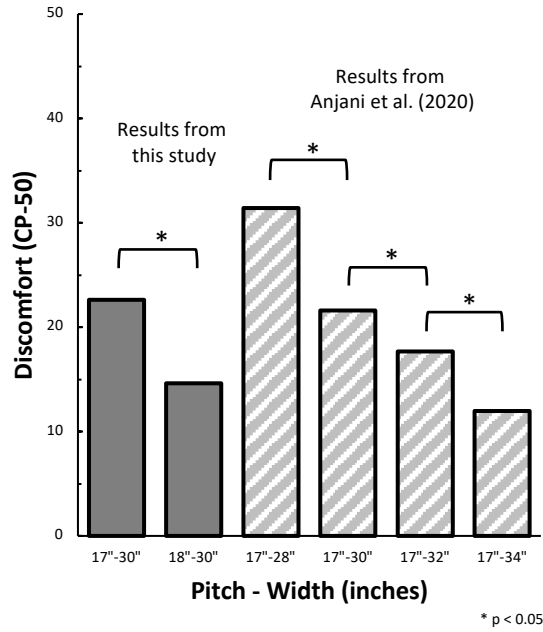


Figure 2 Discomfort vs seat width and pitch

The overall comfort and discomfort were normalized to 1 and plotted in Figure 3 to show the relationship between comfort and discomfort regarding the pitch and the width of seats. The figure shows that there is an overlap between comfort and discomfort of all scenarios, i.e. the sum of normalized mean values of comfort and discomfort is always larger than 1.

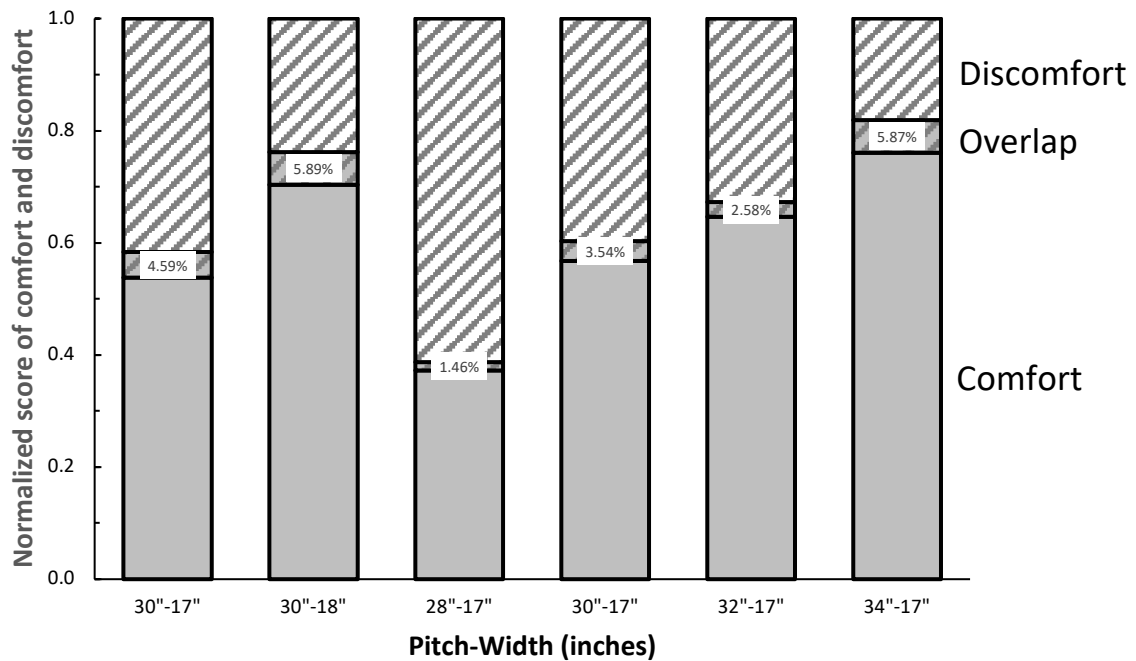


Figure 3 Normalized Averaged Comfort and Discomfort Scores vs seat width and pitch

## 4. Discussion

Three hundred eleven participants joined this study, which focused on comparing (dis)comfort of participants sitting in seats with different widths for 10 minutes. Questionnaires were given to explore the influence of seat widths on the overall psychological and physical feeling of comfort/discomfort as well as discomfort regarding different parts of the body. In addition, the results were synthesized with the outcomes of a previous study where 297 participants experienced sitting in 17-inch-wide seats with different pitches for 10 minutes (Anjani et al., 2020),

This study collected data of psychological perception of comfort using 8 statements with a 9-scale Likert (similar to Kremser et al. (2012)). Responses to all statements differed significantly between using the 17-inch-wide and the 18-inch-wide seats. It was also found that one statement had a higher “Not Applicable” rate than other statements, which was “The seat was wide enough for my body to fit”. The reason might be that the interpretation of the “fit” is not only based on physical measures, but also on psychological factors, e.g. people need more space to move around and change postures.

A Shapiro Wilk test was done to test the normality of the comfort and discomfort data. It was found that the data for this study was not normally distributed, therefore all data were analysed using a non-parametric statistical analysis. This result was in-line with literature indicating that comfort and discomfort data is not normally distributed (Groenensteijn, 2014).

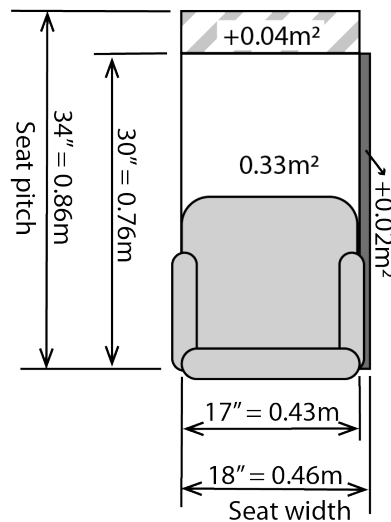
This anthropometric measurements taken are highly comparable to the data of Molenbroek et al. (2017) (e.g. Female/Male elbow-to-elbow breadth average = 429/455 mm vs 402/438 mm). It was found that for the 17-inch-wide seat, the wide hip groups had a lower comfort score and such situation did improve by adding 1-inch to the width.

For people with a wider elbow-to-elbow breadth and shoulder breadth, the width of a seat is important regarding the comfort (Molenbroek et al., 2017; Roebuck et al., 1975). This study did not find the correlation between comfort and discomfort scores of the participants to those anthropometric measurements. This might be that for a short-term study, the psychological factors are more important. However, such an impression could be changed after experiencing physical factors in the long run (Bouwens et al. 2018).

Regarding the LPD, it was found that all body parts except for the buttocks were significantly influenced by the seat width. This indicates that buttock discomfort is not related to seat width, but perhaps more to the quality of the seat cushion. Furthermore, a linear regression on comfort and LPD was made and showed that in the area of shoulders, knees, and lower legs and feet, there were increments on comfort from sitting in a 17-inch-wide to 18-inch-wide seats. Same as the discovery before, a wide seat may facilitate the feeling of comfort and decrease the feeling of discomfort by providing more spaces for movement.

According to Li et al. (2017) “The overall discomfort was the average of the all parts' discomfort ratings... based on an assumption that all body parts' discomfort have the same weight for the overall discomfort.” In our case, we asked discomfort per body part and additionally the total discomfort. It was interesting to see that the head and neck, shoulders, buttock, and thighs were affected by the seat width on the total discomfort, and the total discomfort was not related to the average of the LPD results. This indicates that discomfort has different relations regarding different parts of the body.

In answering the research questions, it was found that there is an increased feeling of comfort and decreased feeling of discomfort by widening the seats from 17 inches to 18 inches. Moreover, the level of comfort of sitting in an 18-inch-wide seat was nearly the same as sitting in a 17-inch-wide seat with 4 inches extra pitch. Therefore, to achieve the same level of comfort, it is more efficient for airlines to increase the width than the pitch regarding a 17-inch-wide seat, as the additional floor area ( $0.02\text{m}^2$ ) of widening 1 inch of the seat is the same as increasing the seat pitch for 2 inches ( $0.02\text{m}^2$ ) as shown in Figure 4. To achieve the same increased level of comfort, 4-inch additional pitch is needed, which



will cost 200% ( $0.04\text{m}^2$ ) as

Figure 5) extra floor area. Figure 6 presents a hypothetical relationship between pitch, width and comfort (Vink, 2016) based on literature. Results from this paper and the previous study were plotted on the graph as well. The experiment results of this paper, in which 30-inch seat pitch with 17-inch-wide and 18-inch-wide width were used, partly affirmed this hypothetical relationship. On the other hand, the results from the previous study did not fit well the hypothetical relationship. This might indicate that the relationship between pitch and comfort is not linear.

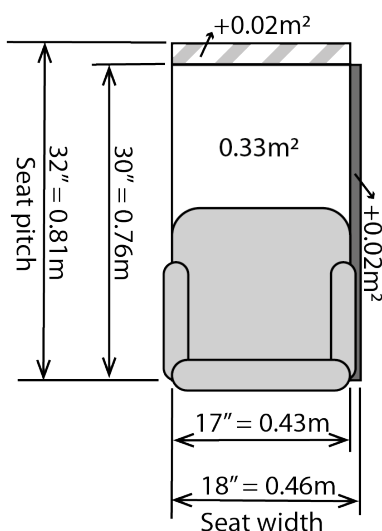


Figure 4 Increasing the pitch and width for the same floor area.

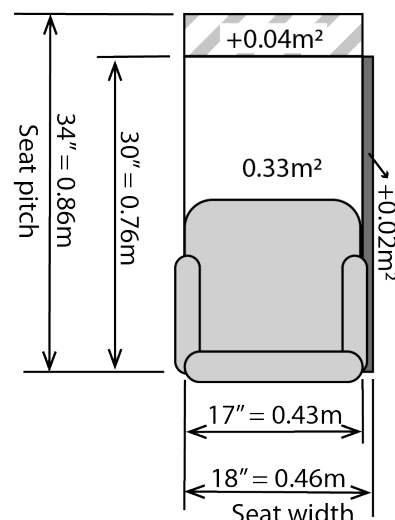


Figure 5 Increasing the pitch and width for the same level of comfort.

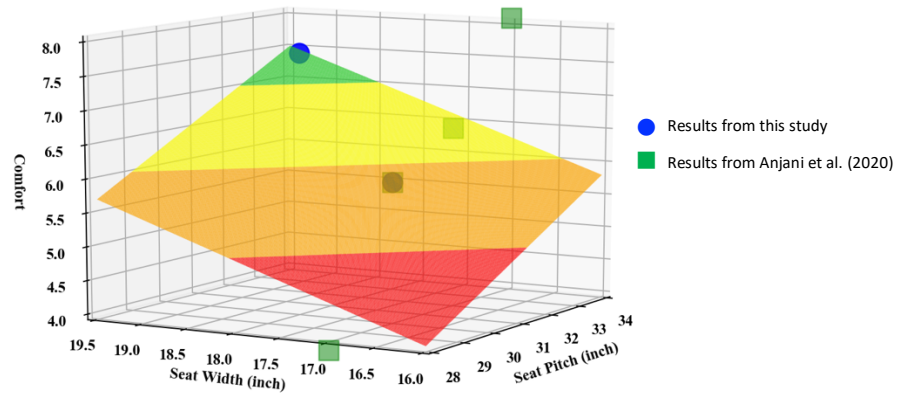


Figure 6 Experiment results and the hypothetical relationship of seat pitch and width graph proposed by Vink (Vink, 2016)

Ahmadpour et al. (2016) indicated that “discomfort and comfort could be used on one scale”. In this research, we normalized the scores of comfort and discomfort and projected the mean values to the span of 0 and 1. It was identified that there are consistent overlaps between mean scores of comfort and discomfort of each pitch (or width) variation (Figure 3), i.e. comfort is not as simple as 1 - discomfort. This might be explained by that comfort and discomfort scales are two different factors rather than one single entity and there is a transition phase between comfort and discomfort as Figure 7 (courtesy of Zhang et al. (1996). Vink and Hallbeck (2012) also stated that comfort is “a pleasant state or relaxed feeling of a human being in reaction to its environment” and discomfort as “an unpleasant state of the human body in reaction to its physical environment”, which indicate that the feeling comfort might not only based on human body reaction but consist more psychological and social factors.

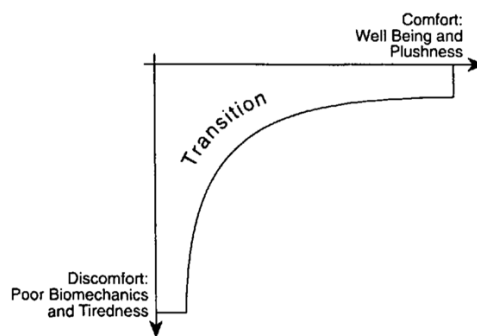


Figure 7 Comfort model of Zhang et al. (Zhang et al., 1996)

One of the limitations of this study is that the experiment was conducted in a relatively short period (10 minutes sitting in each type of seats), which is not comparable with regular flights. Smulders et al. (Smulders et al., 2016) indicated that even after 90 minutes that comfort continuously decreases while discomfort increases. Similarly, Li et al. (2017) discovered a constant increase of discomfort over 3 hours. So, it might be that the difference between the two widths would have been larger in a long test. Further studies are needed to test this hypothesis. Besides, in a long-haul flight, sleeping is an activity that most passenger will experience. Airbus indicated that a wider seat is preferred for better sleeping (Airbus, 2013) however, only 6 participants participated in the experiment. It is hard to

compare that with this study as 10 minutes comfort experience is different from 6 hours sleeping. On the other side, visual aspects that play a role in short term judgments could not be eliminated in this study since the difference in width is clearly noticeable. Such visual experience might be beneficial for short-haul flights regarding the feeling of comfort for passengers.

The participants in this study were young (17-21 years old) which does not represent average air travellers, on the other hand, these are the travellers of the futures and according to Mohn (2014), they will travel more. Therefore, the collected data is also relevant for designing future aircraft interiors for making efficient use of the space while creating the comfort experience at the same time.

## 5. Conclusion

This study aimed to compare the comfort and discomfort feelings regarding sitting in 2 different seat widths in a Boeing 737 fuselage, and to investigate the psychological and physiological factors that influence those feelings. The results of psychological statements indicated that participants felt more comfort and less discomfort when sitting in the 18-inch-wide seats than that of sitting the 17-inch-wide seats. Regarding the discomfort of different parts of the body, the results of LPD also indicated significantly reduced discomfort while using an 18-inch-wide seat except for the buttocks. Further analysis using linear regression models revealed that the lower discomfort scores of shoulders, knees, and lower legs and feet contributed to the reduced discomfort, which highlighted the importance of passengers' freedom of movement facilitated by the extra width provided by the 18-inch-wide seat.

By synthesizing the data of a previous study on various pitch sizes, it was found that to reach a similar level of comfort, increasing the width of a 17-inch-wide seat might be more efficient than increasing the pitch regarding the usage of floor areas. This discovery might be useful for airlines in designing a more effective and efficient floor planning of future aircraft.

## 6. Acknowledgement

The authors would like to thank Mr. Alex Visser for helping conduct the experiment. Funding: This work is part of a PhD research that is fully funded by Lembaga Pengelola Dana Pendidikan Republik Indonesia (Indonesian Endowment Fund for Education) under contract No. PRJ- 7071/LPDP.3/2016 for Shabila Anjani.

## References

- Ahmadpour, N., Kühne, M., Robert, J.-M., Vink, P., 2016. Attitudes towards personal and shared space during the flight. *Work* 54, 981–987. <https://doi.org/10.3233/WOR-162346>
- Airbus, 2013. Airbus calls on aviation industry to set a new standard for long-haul comfort [WWW Document]. URL <https://www.airbus.com/newsroom/press-releases/en/2013/10/airbus-calls-on-aviation-industry-to-set-a-new-standard-for-long-haul-comfort.html> (accessed 1.13.20).
- Anjani, S., Li, W., Ruiters, I.A., Vink, P., 2020. The effect of aircraft seat pitch on comfort. *Appl. Ergon.* 88, 103132. <https://doi.org/10.1016/j.apergo.2020.103132>
- Bouwens, J.M.A., Schultheis, U.W., Hiemstra-van Mastrigt, S., Vink, P., 2018. Expected versus experienced neck comfort. *Hum. Factors Ergon. Manuf. Serv. Ind.* 28, 29–37. <https://doi.org/10.1002/hfm.20721>
- De Looze, M.P., Kuijt-Evers, L.F.M., Van Dieën, J., 2003. Sitting comfort and discomfort and the

- relationships with objective measures. *Ergonomics* 46, 985–997.  
<https://doi.org/10.1080/0014013031000121977>
- Groenensteijn, L., 2014. Seat design in the context of knowledge work. Delft University of Technology, Delft. <https://doi.org/10.4233/uuid:19060a11-6d6c-46dd-9f47-8583d1610b94>
- Helander, M.G., Zhang, L., 1997. Field studies of comfort and discomfort in sitting. *Ergonomics* 40, 895–915. <https://doi.org/10.1080/001401397187739>
- Hinninghofen, H., Enck, P., 2006. Passenger well-being in airplanes. *Auton. Neurosci.* 129, 80–85.  
<https://doi.org/10.1016/j.autneu.2006.07.018>
- Kremser, F., Guenzkofer, F., Sedlmeier, C., Sabbah, O., Bengler, K., 2012. Aircraft seating comfort: the influence of seat pitch on passengers' well-being. *Work* 41 Suppl 1, 4936–4942.  
<https://doi.org/10.3233/wor-2012-0789-4936>
- Kuo, C.-W., Jou, R.-C., 2017. Willingness to pay for airlines' premium economy class: The perspective of passengers. *J. Air Transp. Manag.* 59, 134–142.  
<https://doi.org/10.1016/j.jairtraman.2016.12.005>
- Kurtuluşoğlu, F.B., Can, G.F., Tolon, M., 2016. A voice in the skies: Listening to airline passenger preferences. *J. Air Transp. Manag.* 57, 130–137.  
<https://doi.org/10.1016/j.jairtraman.2016.07.017>
- Li, W., Yu, S., Yang, H., Pei, H., Zhao, C., 2017. Effects of long-duration sitting with limited space on discomfort, body flexibility, and surface pressure. *Int. J. Ind. Ergon.* 58, 12–24.  
<https://doi.org/10.1016/j.ergon.2017.01.002>
- Menegon, L. da S., Vincenzi, S.L., de Andrade, D.F., Barbetta, P.A., Merino, E.A.D., Vink, P., 2017. Design and validation of an aircraft seat comfort scale using item response theory. *Appl. Ergon.* 62, 216–226. <https://doi.org/10.1016/j.apergo.2017.03.005>
- Mohn, T., 2014. The Rising Wave Of Millennial Travelers. *Forbes*.
- Molenbroek, J.F.M., Albin, T.J., Vink, P., 2017. Thirty years of anthropometric changes relevant to the width and depth of transportation seating spaces, present and future. *Appl. Ergon.* 65, 130–138. <https://doi.org/10.1016/j.apergo.2017.06.003>
- Porta, J., Saco-Ledo, G., Cabañas, M.D., 2019. The ergonomics of airplane seats: The problem with economy class. *Int. J. Ind. Ergon.* 69, 90–95. <https://doi.org/10.1016/j.ergon.2018.10.003>
- Quigley, C., Southall, D., Freer, M., Moody, A., Porter, M., 2001. Anthropometric Study to Update Minimum Aircraft Seating Standards. Report Prepared for Joint Aviation Authorities 157.
- Richards, L.G., Jacobson, I.D., 1977. Ride Quality Assessment III: Questionnaire Results of a Second Flight Programme. *Ergonomics* 20, 499–519. <https://doi.org/10.1080/00140137708931659>
- Roebuck, J.A., Kroemer, K.H.E., Thomson, G.W., 1975. Engineering anthropometry methods. John Wiley & Sons, Inc.
- Shen, W., Parsons, K.C., 1997. Validity and reliability of rating scales for seated pressure discomfort. *Int. J. Ind. Ergon.* 20, 441–461. [https://doi.org/10.1016/S0169-8141\(96\)00068-6](https://doi.org/10.1016/S0169-8141(96)00068-6)
- Smulders, M., Berghman, K., Koenraads, M., Kane, J.A., Krishna, K., Carter, T.K., Schultheis, U., 2016. Comfort and pressure distribution in a human contour shaped aircraft seat (developed with 3D scans of the human body). *Work* 54, 925–940. <https://doi.org/10.3233/wor-162363>

Teichert, T., Shehu, E., von Wartburg, I., 2008. Customer segmentation revisited: The case of the airline industry. *Transp. Res. Part A Policy Pract.* 42, 227–242. <https://doi.org/10.1016/j.tra.2007.08.003>

The Future Lab, 2014. *The Future of Comfort: Asia*. London, United Kingdom.

Vink, P., 2016. *Vehicle Seat Comfort and Design*. Boekenbestellen, Delft.

Vink, P., Bazley, C., Kamp, I., Blok, M., 2012. Possibilities to improve the aircraft interior comfort experience. *Appl. Ergon.* 43, 354–359. <https://doi.org/10.1016/j.apergo.2011.06.011>

Vink, P., Hallbeck, S., 2012. Editorial: Comfort and discomfort studies demonstrate the need for a new model. *Appl. Ergon.* 43, 271–276. <https://doi.org/10.1016/j.apergo.2011.06.001>

Zhang, L., Helander, M.G., Drury, C.G., 1996. Identifying factors of comfort and discomfort in sitting. *Hum. Factors* 38, 377–389. <https://doi.org/10.1518/001872096778701962>