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The effect of aircraft seat pitch on comfort

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Abstract

This study explores the relationship between seat pitch and comfort, and the influencing factors, like space experience and anthropometric measurements. Two hundred ninety-four participants experienced economy class seats in a Boeing 737 with 28-inch, 30-inch, 32-inch and 34-inch seat pitches. Anthropometric measurements of the participants were measured. Participants completed a questionnaire on comfort (10-scale), discomfort (CP-50) and space experience and the results were analysed using SPSS 24. This study showed a significant relationship between seat pitch and comfort as well as discomfort. Additionally, it was found that the mean rank of discomfort of each pitch size for the middle seat was higher than the window and aisle seat, though seat pitch did affect the (dis)comfort more compared with seat location. It was also found that anthropometric sizes significantly affect the (dis)comfort on smaller pitch sizes, and all space experience questions had a correlation to the pitch sizes.

Keywords: *Seat pitch, Comfort, Discomfort, Space experience, Anthropometric measurements*

1 Introduction

Approximately 3.6 billion passengers flew in 2016. This number continues to increase through the years (ICAO, 2017). To fulfil this emerging market, airlines are increasing the number of rows in an aircraft by placing them closer to each other. Due to this increasing demand, the distance of the rows has decreased 2 to 5 inches through the last 30 years (McGee, 2018). In 2015, Flyers' Rights, an airline consumer organisation, filed a petition to the Federal Aviation Organization on the "Case of the Incredible Shrinking Airline Seat" regarding this issue (Morris, 2017).

Today's seat pitch sizes vary from 28 inches to 38 inches for economy class flights (TripAdvisor, 2017). The seat pitch itself is measured from a point in a seat to the exact same point of the seat in-front/behind it (Vink, 2016). The arrangement of the seat pitch will affect the legroom or knee space. Legroom, as a result of seating row arrangements, is an important factor in passenger comfort (Vink et al., 2012). Minimal legroom is calculated from adding 2.5 cm to the 95th or 99th percentile of the buttock-to-knee length of the population (Porta et al., 2019). Providing sufficient legroom enables passengers to stretch legs which result in a changing body posture as a way to prevent discomfort (Vink, 2016). Research also shows that legroom is an important factor for frequent flyers' level of satisfaction. Vink et al. (2012) also showed that legroom (r=0.718) has a high correlation with comfort. The same study also found a strong correlation (r=0.730) between comfort and "fly again with the same airlines." Despite this importance, Blok et al. (2007) found after studying the 291 passengers' trip reports and interviewing 152 subjects that the knee space is the lowest rating item, followed by the personal space and

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seat width, especially knee space was seen a problem by taller passengers for the long-haul flight.

Some research indicates that comfort is related to pitch. Li et al. (2017) found that there is a relationship between seat pitch and sitting comfort. Moerland (2015) made a hypothetical model on the relationship of seat pitch, seat width and comfort. Kremser et al. (2012) found the influence of seat pitch to passenger well-being. “Space experience” a psychological factor on comfort related to seat distances was found to be related to human anthropometry (Anjani et al., 2019). There are different causes of comfort, such as psychological (Ahmadpour et al., 2016), physiological (De Looze et al., 2003; Zhao et al., 2020) and emotional causes (Bazley et al., 2015).

There are indications that comfort and discomfort are two different entities rather than extremes of one scale (Helander and Zhang, 1997). Zhang et al. (1996) made a model where comfort is driven by well-being and plushness, while discomfort comes from poor biomechanics and tiredness. Vink et al. (2016) also defined comfort as a “feeling and discomfort as a state of the human body”. Discomfort is related to physical feelings of pain, soreness, and so on. Comfort is established by the feeling of relaxation and well-being. Both comfort and discomfort were included in this study.

The aim of this study is to investigate the relationship between seat pitch and comfort, and its influencing factors, such as space experience and anthropometrics. The first hypothesis of this study is that comfort is correlated significantly with pitch size based on the hypothetical model of Moerland (2015). Second, that space experience and anthropometrics influence comfort. Space negative experience questions are assumed to lead to discomfort, while positive questions lead to comfort (Helander and Zhang, 1997). A correlation is also assumed between buttock-to-knee length and discomfort, as the minimum seat is based on the buttock-to-knee length of the population (Porta et al., 2019). The correlation between eye-height seated and comfort is also tested as comfort is derived from psychological well-being which is affected by visual perception (Vink and Brauer, 2011; Zhang et al., 1996).

2 Method

2.1 Participants

To study this relationship, 294 participants (135 males, 159 females, aged 17-23 years) sat on the tested aircraft seats in 8 groups of approximately 45 participants. The participants were first-year students studying at Delft University of Technology. All participants were asymptomatic for low back pain and had not any musculoskeletal injury. Before the experiment, all participants were asked to give informed consent that we were allowed to use the data in research. Participants who did not give consent were excluded from the data. Each participant took approximately 2 hours to complete the study.

2.2 Protocol

This study was conducted in a Boeing 737 airplane located at the campus of Delft University of Technology. It had a 3-3 configuration, the seat setup in the first nine rows is shown in Figure 1. All seats have the same form with different pitches. Four pitch sizes were chosen: 28 inches, 30 inches, 32 inches and 34 inches. The seats used were economy class seats (for dimensions see Figure 2). The hip-to-knee space (a) is recorded horizontally 10 cm above the seat pan. During the experiment, the seat on the first row was not allowed to be occupied, since the pitch could not be controlled.

Sizes of the body parts were measured according to the DINED method (Molenbroek et al., 2017). The sizes taken were: stature, sitting height, eye height seated, buttock-knee length and popliteal height sitting with shoes. These sizes were taken as Kremser et al. (2012) found that eye height seated and buttock-to-knee was related to comfort. Stature, sitting height, and popliteal height seated were added to find other possible correlations. These measurements were added to find possible seat design solutions based on anthropometry.

Before the participants entered the aircraft, they were given a verbal explanation of the research protocol. Every group of participants needed to finish four rounds in the experiment to enable a within-subject design, and every round lasted 10 minutes. When they first board the airplane, they can freely choose the seat from the second row to the ninth row. However, if a participant chose a middle, aisle or window seat, they had to take the same seat in the next rounds to prevent the effect of the position in the row. For each round, they were instructed to sit down for 10 minutes and complete the questionnaire after 10 minutes sitting while still sitting in the seat. There was a paper version and an online version to be completed using the smartphone. Participants were allowed to talk to each other and to choose their position freely. They were not allowed to use the tray table and not allowed to recline their seats. The seats were divided into four sections to ease participant rotation (Figure 1). When a round is finished, participants move to the seat directly in front of them. When they reach the front row of each section, they would need to move to the last row of that section. This rotation order is made to eliminate the influence of order in this study.

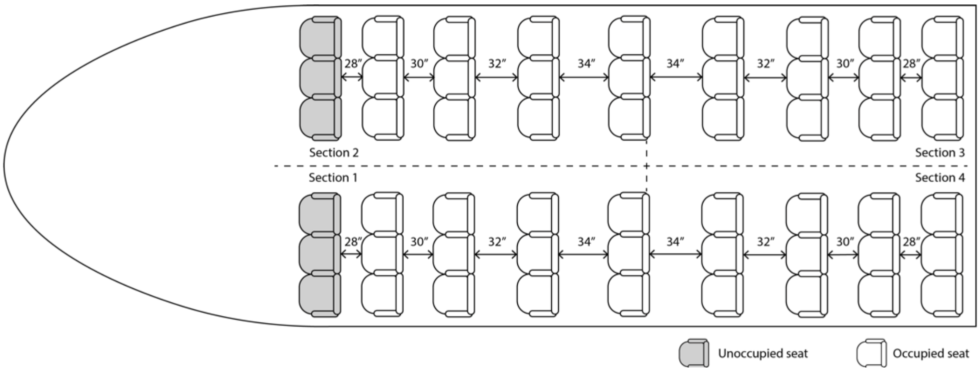
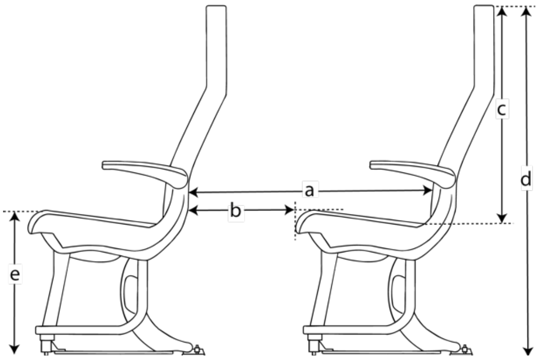


Figure 1. Seat layout in the test aircraft.



Dimensions	28"	30"	32"	34"
a	64 cm	69 cm	74 cm	79 cm
b	20 cm	25 cm	30 cm	35 cm
c	71 cm			
d	111 cm			
e	44 cm			

Figure 2. Dimensions of Seat Used

2.3 Measuring methods

The questionnaire consists of three parts: a comfort scale, discomfort scale and space experience. To measure the discomfort level of each participant, a CP-50 scale (category partitioning scale) was included in each questionnaire. This subjective rating scale is found to be reliable and most valid for rating perceived discomfort on sitting and also was preferred more than other discomfort scales (Shen and Parsons, 1997). A 10-point comfort scale was used as well to make a comparison with the study of Moerland (2015) possible (1=least comfortable, 10=most comfortable). Questionnaire items for space experience were gathered from studies of Kremser et al. (2012), and Menegon et al. (2017). These questions on space experience shown in Table 1 (Anjani et al., 2019) were included to learn more on the psychological effect of seat pitch on (dis)comfort. Only questions related to seat pitches are included in this study. Half of the questions were made using a positive descriptor leading to comfort and the other half using a negative descriptor leading to discomfort with a 9-scale Likert (from not at all to extremely) to enhance the intensity of each descriptor. This setting is based on a study of Helander and Zhang (1997) which assumes that sitting comfort and discomfort are independent entities influenced by different factors.

All data were imported in SPSS version 25 and analysed with Spearman-rank correlation and Kruskal Wallis H test. Nonparametric statistical methods were chosen because comfort and discomfort data are not normally distributed (Groenensteijn, 2014). Each participant was given a number, and all data were coupled to that number. Averages and standard deviation were calculated over participants. A Spearman's correlation was calculated between some body-measurements and (dis)comfort and between space experience, pitch and (dis)comfort. Significance of the correlation was calculated as well. Kruskal Wallis H tests was performed on comfort and discomfort between pitch sizes and also seat location to find whether there is significant effects. The results of the participants who did not complete the whole experiment or did not follow the order of the experiment were excluded in the analysis. The number of subjects for each analysis is stated with the results.

Table 1. Space Experience Questions (Anjani et al., 2019)

Question number	Question
Q1	I feel restricted by the distance of the seating rows
Q2	I feel like sitting in front of a wall
Q3	I feel lost because the distance of the seating rows
Q4	I feel stressed out because of the distance of the seating rows
Q5	I was able to stretch my legs without difficulty
Q6	The backrest was able to support my needs
Q7	There was enough room to get in and out of the seat
Q8	I can change easily from one sitting posture to another

3 Results and Discussion

3.1 Comfort and discomfort on seat pitch size

The results of the questionnaires of 166 participants were used to calculate the relationship of overall comfort to discomfort. Figure 3 and Figure 4 shows the relationship of mean overall comfort and overall discomfort for the different pitches. This graph shows that there is a positive relationship between pitch size and the mean overall comfort and a negative relationship between overall discomfort and pitch sizes. The Spearman's correlation of pitch with overall comfort is found significant p=0.000 with an r=.719, and pitch with overall discomfort is also found significant p=0.000 with an r=-.525. A Kruskal Wallis H Test was performed to see the effect of comfort and discomfort between pitch sizes. Both tests had significant results with H(3)=348.442, p=.000 for comfort and H(3)=184.74, p=.000 for discomfort.

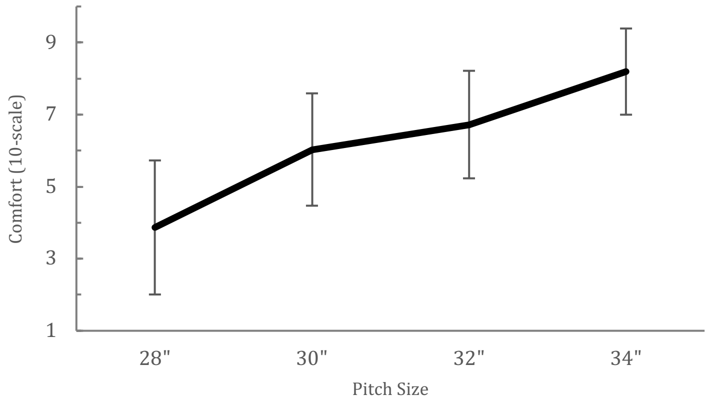


Figure 3. Mean Overall comfort (10-scale) by Pitch Sizes (inches)

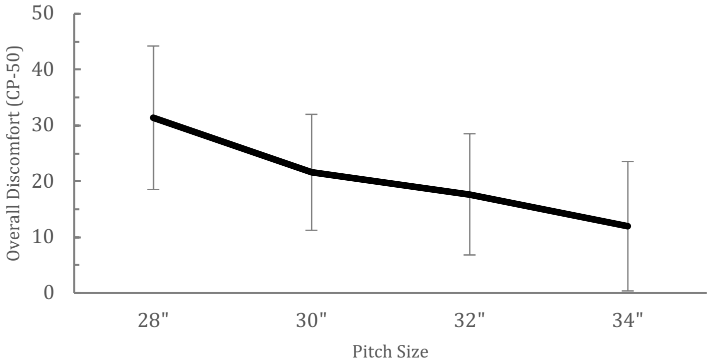
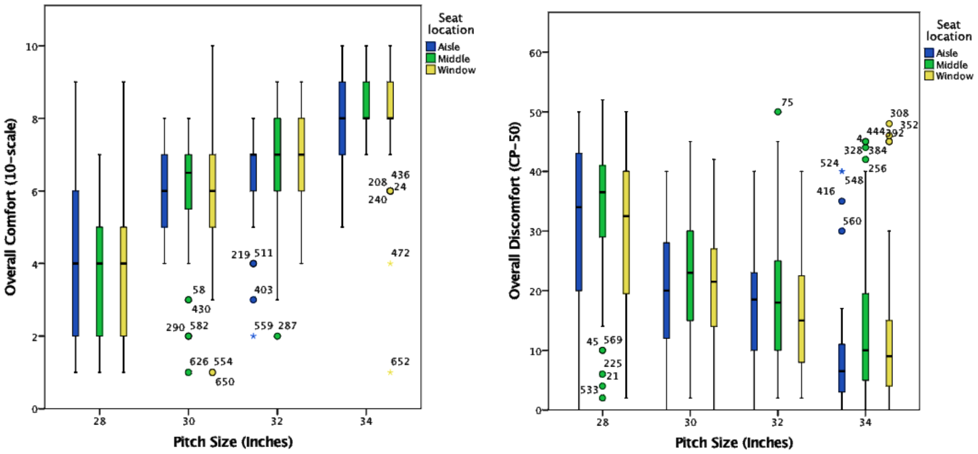


Figure 4. Mean Overall Discomfort (CP-50) by Pitch Sizes (inches)

All the seats in the rows tested were filled, so each participant had a neighbouring participant. Additionally, a both comfort and discomfort data were analysed by the location of the seats (aisle, middle, window). Figure 5 shows the comfort and discomfort for different locations. A Kruskal-Wallis H test was performed to show the effect of seat location on comfort and discomfort. Results show that it was significant for discomfort between the different seat locations with H(2)=6.170, p=.046 with mean rank score of 320.53 for aisle, 357.09 for middle and 317.46 for window seat.. However, results were not significant for comfort between different seat locations with H(2)=.382, p=.826 with mean rank score of 3207.12 for aisle, 330.37 for middle and 338.00 for window seat. Middle seat is found to have a higher mean overall discomfort in all pitches while the mean in comfort did not vary, though the effect on both comfort and discomfort on seat pitch was still higher than seat location.



(a) (b)

Figure 5 Comfort and Discomfort by Seat Location

3.2 Comfort and discomfort on anthropometric measurements

This study measured anthropometric data of participants (Table 2). The relationship between anthropometric data, comfort and discomfort was also calculated (Table 3). The data shows that the correlation is higher the shorter the pitch is. In 28 inches seat pitch, all anthropometric measurements were found to be significantly correlated at p=0.01 with comfort. While only sitting height, eye height seated, and popliteal height with shoes on were found to be correlated with discomfort in the 28 inches setting at p=0.01. Popliteal height sitting with shoes were found to be significant at 0.05 level r=0.-194 with overall discomfort at 32 inches seat pitch. There was no significant correlation between all anthropometric measurements and both comfort and discomfort for the 34-inch setting and only one at p=0.05 at the 32 inches setting, namely popliteal height. Results did not show correlations between eye height seated and comfort, as well as buttock to knee and discomfort in the 34-inch seat pitch. What is interesting is that the difference between the effect of anthropometry on comfort and discomfort is not that large, which might perhaps indicate the statement of Ahmadpour et al. (2016) that in aircraft interiors the comfort and discomfort could be on one axis, but further research would be needed to support this statement, though it might also be due to the short time sitting in the seat. While Smulders et al. (2016) and Li et al. (2017) showed that discomfort increases clearly over time

These measurements were compared to the anthropometric measurements of the Dutch students (Molenbroek et al., 2017) and it was found that both measurements were similar (Anjani et al., 2019). Molenbroek et al. (2017) found the anthropometric measurements in the last 30 years did not change much, except for hip-width. This shows that these results will be still relevant for design in the future for most anthropometric values.

Table 2. Anthropometric Measurements of Participants

Anthropometric Measurements	n	p5	p95	mean
Sitting height (mm)	88	831	1003	906
Eye height seated (mm)	88	720	899	801
Buttock to knee (mm)	88	472	695	596
Popliteal height sitting with shoes (mm)	151	423	510	466
Stature (mm)	88	1600	1937	1762

Table 3 Spearman's Correlation of Anthropometric Measurements to Overall Comfort and Overall Discomfort.

Measurements	n	28 inches		30 inches		32 inches		34 inches	
		Comfort	Discomfort	Comfort	Discomfort	Comfort	Discomfort	Comfort	Discomfort
Sitting height	88	-.400**	.374**	-.215*	.379**	-.066	.196	.089	-.041

Measurements	n	28 inches		30 inches		32 inches		34 inches	
		Comfort	Discomfort	Comfort	Discomfort	Comfort	Discomfort	Comfort	Discomfort
Eye height seated	88	-.329**	.294**	-.266*	.342**	-.045	.068	.035	-.033
Buttock to knee	88	-.343**	.289**	-.271*	.217*	-.089	-.024	-.085	.027
Stature	88	-.510**	.318**	-.317**	.386**	-.153	.189	.026	-.011
Popliteal height sitting with shoes	151	-.460**	.282**	-.313**	.271**	-.116	.190*	-.047	.054

** p-value < 0.01 level (2-tailed)
* p-value < 0.05 level (2-tailed)

Kremser et al. (2012) showed a surface plot on the relationship of buttock-to-knee length, seat pitch and well-being (Figure 6). This study tried to replicate this graph of buttock-to-knee length, seat pitch and comfort (10-scale) and found similar results for seat pitch 28-34 inches. However, the effect of anthropometry seems higher in our study. This could be due to the fact that in our study, a larger range of anthropometric variation is included.

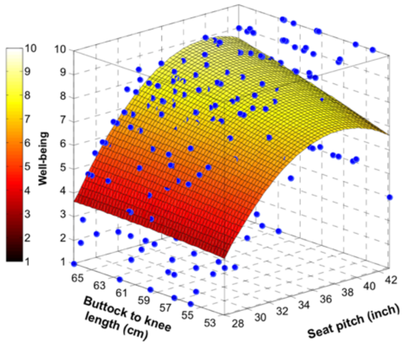


Figure 6 Relationship of buttock-to-knee, seat pitch and well-being (Kremser, 2012)

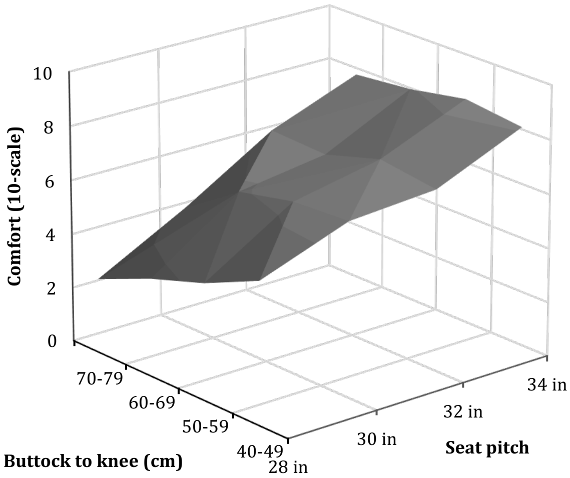


Figure 7 The overall comfort, buttock-to-knee by seat pitch size found in this study.

3.3 Space experience and (dis)comfort

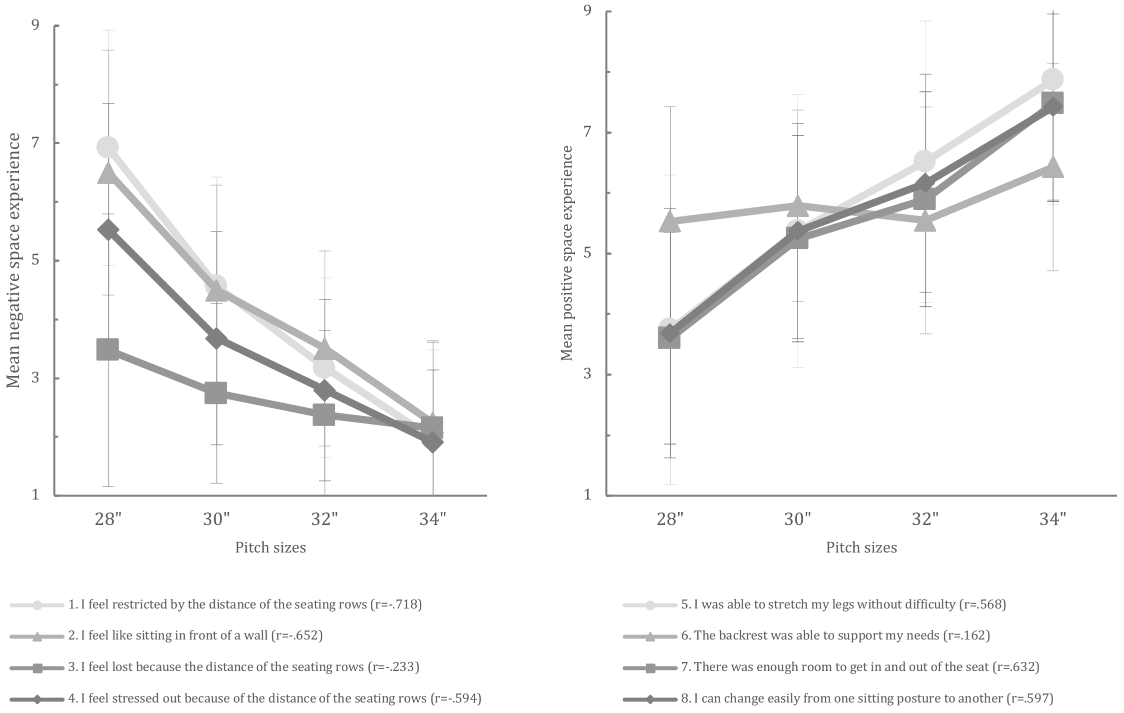
All positive descriptors (leading to comfort) were correlated significantly with overall comfort, and negative descriptors (leading to discomfort) was correlated significantly with overall discomfort shown in Table 4. The correlation of space experience descriptors was higher to overall comfort. This might indicate that comfort influenced more from psychological aspects regardless of whether the descriptors were positive or negative (Zhang et al., 1996). These space experience questionnaires were filled-in correctly by

167 participants. The questionnaire with missing answers were not included in the calculations.

Table 4. Spearman’s correlation of space experience descriptors, overall comfort and discomfort

Space experience descriptors	Overall Discomfort (CP-50)	Overall Comfort (10-scale)
1. I feel restricted by the distance of the seating rows	.601**	-.747**
2. I feel like sitting in front of a wall	.508**	-.682**
3. I feel lost because the distance of the seating rows	.275**	-.280**
4. I feel stressed out because of the distance of the seating rows	.482**	-.646**
5. I was able to stretch my legs without difficulty	-.515**	.623**
6. The backrest was able to support my needs	-.264**	.386**
7. There was enough room to get in and out of the seat	-.559**	.713**
8. I can change easily from one sitting posture to another	-.577**	.758**

** p-value < 0.01 level (2-tailed)



(a) (b)

Figure 8. The relationship of (a) negative and (b) positive space experience to seat pitch.

A Spearman’s correlation was also done to pitch size and all space experience statements. Results show all were significantly correlated to pitch size (p<.01). The question on the backrest was found to be less correlated (r=.162, p=.000) though it was significant. The highest correlation was found in the feeling of being restricted (r=.718, p=.000). These questions derived from the study of Kremser et al. (2012) and Menegon et al. (2017) were predicted to be correlated with seat pitch size for both comfort and discomfort. The results shown in Figure 8 indicate that these descriptors as psychological factors of comfort and discomfort did effect passengers seating in different pitch size.

This study is only for 10 minutes. As is shown by Smulders et al. (2016) studying a business class seat and Sammonds et al. (2017) studying a car seat discomfort increases in time and this could be the case in economy class seats as well. Future research is needed for long term studies to see the effect of time to (dis)comfort. Body movement/fidgeting and other objective measurements like HRV could be used to evaluate the (dis)comfort as an addition to having questionnaires for subjective measurements (Le and Marras, 2016).

Seat width as a factor that also adds to personal space in an aircraft should also be studied in the future as well, especially as hip width is increasing (Molenbroek et al., 2017). Moerland (2015) describes a relationship on seat pitch and its width on discomfort, which should be studied further. Also, sitting longer Li et al. (2017) found that the effect on seat pitch is larger in time. Blok et al. (2007) also found that personal space and seat width is also an important factor that ranked after knee space.

It is clear that anthropometric data, as well as psychological gathered data, have an influence on the discomfort and comfort of aircraft seats. The study also shows that a 28 inches pitch results in very low comfort scores (4 on a scale from 1-10), which is the agreement with the study of Moerland (2015) and Kremser et al. (2012). It is not only the physical hip-to-knee distance of the seat which causes this discomfort but also other physical and psychological factors play a role, which might be very relevant to airlines. Anthropometric measurements referring to width were not recorded although it might influence the perception of comfort, especially for the middle seat. Participants were allowed to talk to each other, which also potentially influences their decision in rating the seat. Participants involved belonged to a specific age range and nationality, which could not represent the whole group of airplane travellers.

4 Conclusion

The aim of this study was to investigate the relationship between seat pitch and (dis)comfort, and what the influencing factors are, like space experience and anthropometric data. This study has found a significant relationship between seat pitch and comfort as well as discomfort. An analysis was also done on the location of the seat, where it was found that the mean discomfort of each pitch size for the seat was higher than the window and aisle seat, though seat pitch did affect more the (dis)comfort in comparison to seat location.

We also found that anthropometric sizes significantly affect the (dis)comfort on smaller pitch sizes. In the 28 inches seat pitch setting the sitting height, eye height seated, buttock-to-knee, stature and popliteal height sitting with shoes were all found significant at 0.01 level. None of the anthropometric measurements were found significant on the 34 inches seat pitch. This shows that the comfort will rapidly decrease for people with larger body dimensions in shorter seat pitch.

All comfort and discomfort questions on space experience had a correlation to the pitch sizes. Where the question on feeling restricted had the highest correlation ($r=-.718$), and the question on the backrest support had the lowest correlation ($r=.162$). This shows that space experience as a psychological factor is relevant for comfort of passengers. The space experience questions were also significantly correlated to both comfort and discomfort. A stronger relationship was found between both negative and positive space experience descriptors to comfort. This might indicate that comfort is more related to psychological aspect regardless of the positive and negative sentences.

Future research is needed for long term studies to see the effect of time on (dis)comfort. Body movement and other objective measurements could be added as well to evaluate the (dis)comfort as an addition to questionnaires.

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