The Influence Of Angle Of Attack On Passenger Comfort

Master Thesis by	Yayu Ping 5121280
	Integrated Product Design
Chair	Peter Vink
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Date	July 8th, 2021

Introduction

This master thesis consists of three parts. The original design brief, a scientific paper submitted to the journal Applied Ergonomics and the appendix I & II. The appendix I includes reports of the design made during the process, experiment protocol and ethical issues. The appendix II is the personal reflection of this graduation project. The original design brief is presented in the beginning of the thesis.

Original Design Brief

At the beginning of this master thesis a design brief was formulated. It was the planning of the research. The outcome will be described in the paper.

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Project team, Procedural checks and personal Project brief

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- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

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Your master programme (only select the options that apply to you):

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SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Peter Vink — dept. / section: AED

** mentor: Yu Song — dept. / section: MD

2[nd] mentor:

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Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

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Master electives no. of EC accumulated in total: ______ EC

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List of electives obtained before the third semester without approval of the BoE

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- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

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The influence of the angle of attack on comfort of passengers

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 25 - 02 - 2021

15 - 07 - 2021 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Context backgrounds

Passengers' experience of comfort in flights is one of the key elements in selecting airlines (Balcombe, Fraser, & Harris, 2009). Previous studies have analysed many factors, e.g. space of the seat, on-flight service, noise (Brindisi & Concilio, 2008; Mellert, Baumann, Freese, & Weber, 2008) regarding comfort/discomfort. However, most discussions focused on the seat comfort during the cruising stage of the flight, and only a few paid attentions to comfort of the passengers in the take-off and climbing phases. During these two phases, which may account for up to 30 minutes, the plane needs a larger inclination angle (angle of attack, AOA) to climb to the cruising height. According to the procedure recommended by Boeing, the climbing angle of a 737 plane varies between 15-18 degree with a rotation rate of 2-3 degree per second (Wakefield & Dubuque, 2009). This angle changes the seat inclination angle regarding the ground, and therefore changes the direction of the gravitational force of passengers' body against the seat. Furthermore, in these two phases, the backrest of the seat is put upright and the seat belt is fastened, which might make it difficult for passengers to seek for a comfortable posture themselves.

Previous research

Literature suggested that there was a relationship between pressure distributions and the comfort/discomfort experiences (Smulders et al., 2016). Besides, previous research also indicated that the inclination of the trunk may affect respiratory mechanics (Mezidi & Guérin, 2019), muscular activities (Munoz & Rougier, 2011), as well as posture mobility (Cherng, Lin, Ju, & Ho, 2009). However, these studies were mostly conducted in clinical environments regarding patients. The combined effects on comfort/discomfort of healthy passengers in the take-off and climbing phases of a flight are to be explored.

Opportunities and challenges

Opportunities of this study is to help researchers gain a better understanding of the perceived comfort/discomfort of passengers during the take-off and climbing phases in a flight and, thereby provide designers, aircraft seat manufacturers and airlines with useful information for designing and providing the seat and the service, respectively. Challenges come together with opportunities. The topic passengers' comfort experience of AOA is very new so that few researches pay attention to this, which makes it challenging to reveal the relation based on theoretical references.

Stakeholder and current situation

This is a research project within TU Delft, no external clients involved. This project is based on my work in my research elective. Initial literature research is finished and the experiment setup has been designed (shown in figure 1).

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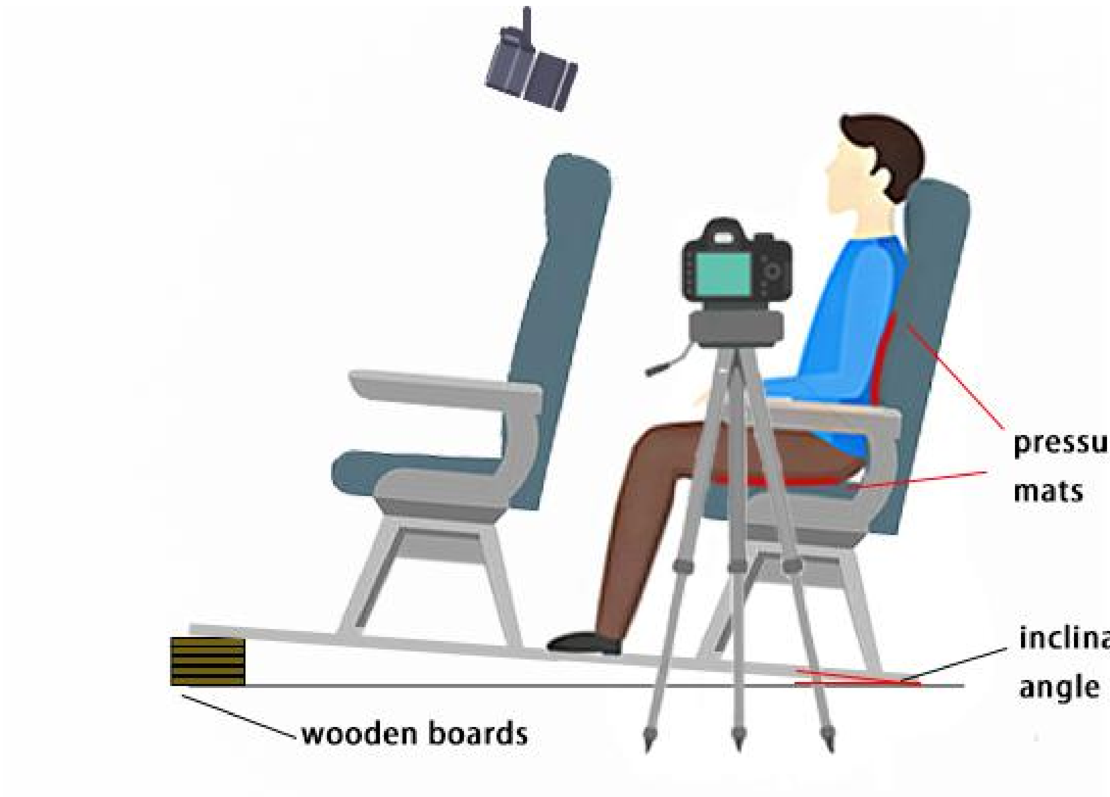

image / figure 1: Illustrator of experiment setup

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PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The aim of this research is to fill in this knowledge gap by identifying the influence of the inclination angles of the plane on the perceived comfort/discomfort of passengers.
The research question is: What is the relationship between the comfort/discomfort experience of the passengers regarding the AOA of the plane during the take-off and climbing phases of a flight.

The scope of this project is answering the research question by doing the experiment and analyzing the data from the experiment, and writing a paper of the procedure.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

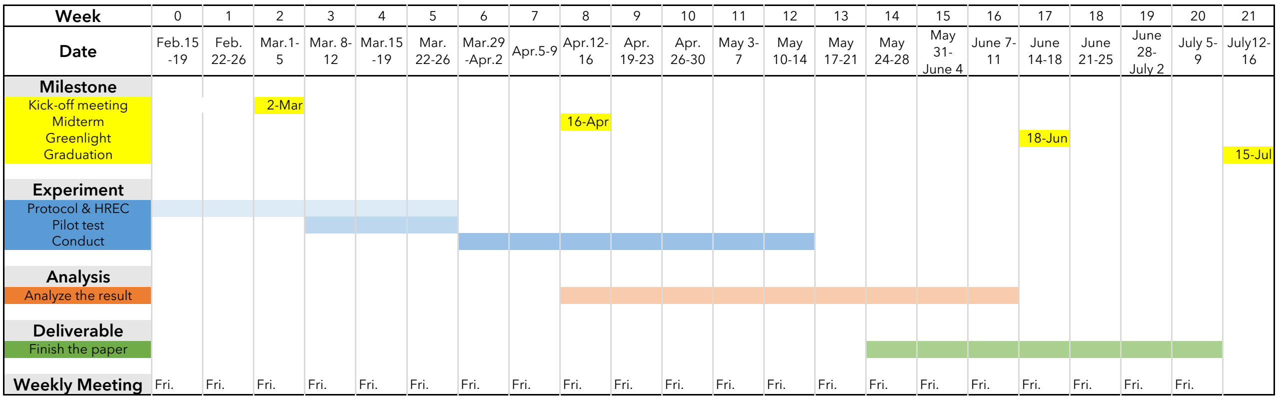
The physiological changes, pressure distribution and subjective feelings caused by seat inclination are main aspects to research. By analying these data it is expected to answer the research question.

Expected results
The results of this experiment are pressure distributions in different setups, the movements of the subjects, the corresponding physiological measures as well as the subjective comfort/discomfort measures. Using statistical tools, it is expected that the relations between comfort/discomfort and the inclination angles can be established.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 25 - 2 - 2021   15 - 7 - 2021 end date



Previous work
In the Research elective course before, I did some literature review regarding this topic. So in the graduation project, I will start with designing the experiment protocol in details.

Experiment
It is planned that an integrated experiment will be conducted within the whole research group, and my topic is part of the integrated experiment from one perspective. So, the experiment protocol needs to be made and discussed with other researchers in the group.

Analysis and writing the paper
This phase is the key procedure for a research project, and that's why I plan most of time here. I will use some data managing tools, such as SPSS, to analyze the data gathered from the experiment. Further research and experiment may be needed regarding specific topic in the phase.

Weekly meeting
In the first several weeks, I have a weekly meeting with my experiment group to finish the protocol. Every two weeks, I report to my supervisory team about my progress via email. Every four weeks, I present my work to my chair and mentor and ask for feedback.
Graduation presentation
It is expected to have my final presentation at mid-July.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Why this project
I did the research elective last semester and during that time I set my mind to apply for a PhD program. The research was to investigate relations between seat inclination and comfort. I chose to do this research for the reasons:
1. I have an interest in ergonomics. I consider ergonomics as a bridge connecting emotion and science, subject and object. Ergonomics tells designers the secrets behind various personal feelings and make those feelings measurable, which is a charming area I would like to go deeper. During my research work so far, I had a brief understanding of comfort/discomfort definition and measurement and would like to do further research if I get admitted to a PhD program.
2. I think people's experience on transportation vehicle is a promising field. In my previous design experiences, I did many projects about different means of transportation, such as: bike, scooter, automatic delivery car. And this time I had a chance to do research on aircraft. No matter what means of transportation, I feel that the exterior appearance of vehicles is no longer the most important part of their competitiveness, but passengers' experience instead. ThereforeI hope to make a difference in improving passengers' experience with my research.

Competences
I always consider myself as a design researcher or a research-base designer, who would prefer solid argumentation than gut feelings when designing something.
In my first year master courses I had chances to do some ergonomics research on specific products. In the ACD scooter project, I did tests on different riding postures. From those I learned how to do tests with participants and how to compare the results. The experience gave me some hints to prevent possible mistakes when communicating with participants. In my AED patient monitoring device project, I learned how to read scientific papers critically which I benefited a lot.
To improve my research skills, I did many research-related electives last semester. In Health Psychology course, I learned to make test plan and design scientific questionnaires. Those are really helpful for designing the experiment in this graduation project. In Capita Selecta Medisign course, some current PhD students shared their experiences so I got to know the differences between master-level research and PhD research and also had a picture of what PhD's life was like. I also practiced my literature reading and writing skills in other courses such as Consumer Behavior.
With this graduation project I can practice and prove what I learned from my previous master courses.

My ambitions
As I mentioned my plan is to do a PhD program. So the abilities I want to obtain are those which can help me conduct my own scientific research in the future. The abilities includes:
1. Designing and doing experiment. I'm always happy to get my hands dirty through design process. However, making design prototypes and doing scientific experiments are not the same way in 'making hands dirty'. The latter requires more patience and rigorous thinking.
2. Writing skills. I think it is the most important skills for a PhD student. As a non-native English speaker, it is a big challenge to overcome. I didn't have much experiences before so I definitely need to put more time on it.
3. Planning a research. I would like to gain in-depth knowledge on comfort so that I can form a research framework for my future work. Currently I am practicing it while writing research proposal for CSC.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

The influence of the angle of attack on passenger comfort

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Abstract

The angle of attack (AOA) of an airplane changes the direction of the gravitational force on passengers and this thereby might influence passengers' flying experience. However, the contribution of the AOA regarding comfort/discomfort is not fully explored. In this paper, we aim to fill this knowledge gap by identifying the relationships between the perceived comfort/discomfort of passengers and the AOA of the plane during the take-off and climbing phases of a flight. An experiment is conducted in a Boeing 737 fuselage where 26 participants were recruited. Each participant experiences 3 setups of seats with different AOAs (3, 14 and 18 degrees) for 20 minutes, respectively. Participants were asked to complete questionnaires during each session, and their heart rate and the pressure on the seat and the backrest were recorded as well. Experiment results indicated that participants experienced 14 degrees as the most comfortable angle with the lowest discomfort, which might be useful for airlines in setting up the take-off and climbing procedure. It would be good to check the findings in real flights.

Keywords

Seat inclination; comfort; take-off/climbing

Introduction

Passengers' comfort experience in flights is one of the key elements in selecting airlines (Balcombe et al., 2009). Previous studies have analyzed many factors influencing comfort/discomfort, e.g. space of the seat, in-flight service and noise (Brindisi & Concilio, 2008; Mellert et al., 2008). However, most discussions focus on the sitting comfort during the cruising stage of the flight, and only a few paid attentions to comfort of the passengers in the take-off and climbing phases. During these two phases, which may take up to 30 minutes, the airplane has an inclination angle (angle of attack, AOA) to climb to the cruising height. According to the procedure recommended by Boeing, the AOA of a Boeing 737 varies between 15-18 degrees (Wakefield & Dubuque, 2009) in these phases. This angle changes the seat inclination angle with respect to the ground, and therefore changes the direction of the gravitational force of passengers' body against the seat. Furthermore, in these two phases, the backrest of the seat is put upright and the seat belt is often fastened, which might make it difficult for passengers to seek for a comfortable posture.

The changed direction of the gravitational force influences the human body, but it may also influence the pressure distribution between the body and the seat. Literature suggests that there is a relationship between pressure distribution and the discomfort experience (e.g., Smulders et al., 2016). A large contact area between the seat pan and the human body often reduces discomfort. It is also confirmed by research that a lower mean pressure and an even pressure distribution is associated with more comfort (Zemp et al., 2015). Besides, many studies have investigated that the inclination of the trunk may affect the physical state, muscular activities (Munoz & Rougier, 2011) as well as posture mobility (Cherng et al., 2009). However, these studies consider mostly patient research in clinical environments. The combined effects on the comfort/discomfort of healthy passengers in the take-off and climbing phases of a flight are still to be explored.

The relationship between heart rate variability (HRV) and comfort has lately received attention. The market growth of smart wearables has made the measurements of HRV easier with commercially available smart watches, i. e. Apple Watch with a non-intrusive manner (Beggiato et al., 2018). HRV refers to the beat-to-beat alteration in cardiac cycle length (Shaffer & Ginsberg, 2017). The analysis of HRV provides a quantitative marker of the autonomic nervous system (ANS) which reflects one's capacity to generate physiological responses of emotion, stress or pain. Therefore, researchers believe that HRV might have a relationship with comfort/discomfort. Anjani et al., 2021 suggested that the HRV features SDNN, HF and SD2 might be interesting to apply because of their strong correlation with comfort and discomfort.

The aim of this research is to fill in the knowledge gap regarding the influence of inclination of the seat on comfort. The research question is: *What is the relationship between the comfort/discomfort experience of the passengers regarding the AOA of the plane during the take-off and climbing phases of a flight.*

Methods

Setup

An experiment was set up in the Boeing 737 fuselage at the Delft University of Technology (Fig.1). To simulate the scenario in a realistic context, two rows of seats were used in this experiment while the participants occupy the middle of the second row. The seats were mounted on a large platform which can be adjusted to different inclination angles. The width of the seat was 17 inch and the pitch was 30 inch. Three inclination angles were set in this experiment. The 3-degree was chosen to simulate the cruising stage, and the 14-degree and 18-degree were selected to simulate the minimal and maximal AOAs as mentioned in the introduction. The backrest was adjusted to the upright angle and the seat belt was fastened. The experiment setup and the protocol were approved by the Human Research Ethical Committee (HREC) of Delft University of Technology.

Figure 1: The setup of the experiment

Figure 2: The measurement stool

Participants & Measurements

26 international participants (14 male and 12 female) joined the experiment. The mean age of all participants is 25.5 years old. To acquire the anthropometric data, we used the measurement

approach as described in DINED (Huysmans & Molenbroek, 2021) which includes the use of a stool (see Fig.2). Besides, the height and weight of participants were measured by a measuring tape and a weighing scale, respectively. The measurement results and the calculated BMI values are presented in Table 1.

Table 1: Anthropometric measurements of subjects

	Male	**Female**
Age	25.6±2.7 year	25.3±2.4 year
Height	173.7±7.3 cm	164.0±6.2 cm
Weight	73.2±12.7 kg	56.9±6.2 kg
BMI	24.2±3.6	21.2±1.9
Hip breadth	389.5±29.9 mm	381.1±18.1 mm
Popliteal height	494.9±25.1 mm	456.0±24.1 mm
Buttock-popliteal depth	496.2±32.1 mm	476.2±26.3 mm

Two pressure mats (Brand: Xsensor) were placed on the seat pan and backrest to measure pressure distribution data between seat and buttock and back of the subject. The pressure mat consists of 48 by 48 measuring cells; each has a size of 12.7 by 12.7 mm. Cameras were installed in the front and at the side of (lateral to) the participants to record the scenario as well as the movements of the subjects during the experiment. All participants wear a Scosche Rhythm24 armband at the left forearm. Their heart rate and the RR intervals were logged throughout the experiment.

A set of questionnaires, which includes a 10-point likert scale for overall comfort and discomfort and a local postural discomfort (LPD) questionnaire, was asked several times in the experiment (Anjani et al., 2021). In the comfort and discomfort questionnaire, participants are able to rate the perceived comfort and discomfort regarding the overall experience at a given time span. The LPD questionnaire consists of a body map, in which participants evaluate the perceived discomfort for different areas of body. In this experiment an addition is made of a body map of the front of the body. Thereby participants are also able to rate the discomfort levels regarding different regions in the front of the body. For completing the questionnaire, participants were instructed that for a region(s) that she/he feels no discomfort, nothing needed to be noted on the body map. To avoid the effect on short term memory and to avoid the confusion of the word comfort and discomfort in different languages and cultures (Vink et al., 2021), we asked the question on comfort in the beginning, followed by the LPD questionnaire, and at the end of the questionnaire, we asked the question regarding the overall discomfort while still in the seat. Besides this set of questionnaires, participants were also asked to rank the 3 setups regarding comfort/discomfort levels after the experiment, i.e. after experiencing all of them.

Protocols

Two researchers hosted each experiment where they welcomed the participants first. After a short introduction of the setup and the procedure of the experiment, the participants signed an informed consent. Then the Scosche Rhythm24 armband was applied on the left forearm, and the participants took the seat with the first setup and the safety belt was fastened. Before the start of the timer, the participant had several minutes to adapt to the setup as they usually do while travelling. During this time, he/she completed questionnaire set 1 (incl. Comfort/discomfort questionnaire and LPD). As the AOA were adjusted to 3, 14 and 18 degrees in 3 setups, the sequence of the setups that the participant experienced was in a Latin square order. After finishing questionnaire 1, she/he sat for 20 minutes in total to simulate the duration of the take-off and climbing phases of a normal commercial flight. During this period, the participant completed questionnaire set 2 (same as the first set) after about 10 minutes. This took approximately 1 minute. Another 10 minutes after finishing the second set of questionnaires, she/he completed questionnaire set 3, which was the same as previous sets. In this period, the pressures on her/his buttock and the back were recorded in a 1 HZ frequency and her/his heart rate was continuously monitored and logged as well.

After finishing the first setup, he/she left the seat and took a 7-10 minutes break before experiencing the next setting. During the break, she/he was asked to walk along the aisle and had some water and snacks to "reset" the comfort/discomfort status. After a participant experienced all the 3 settings, her/his anthropometric data were measured by a researcher using the methods described in the previous section. Meanwhile, she/he was asked to rank the 3 setups regarding comfort levels. Figure 3 illustrates the complete procedure of the experiment in a chronological order regarding a participant.

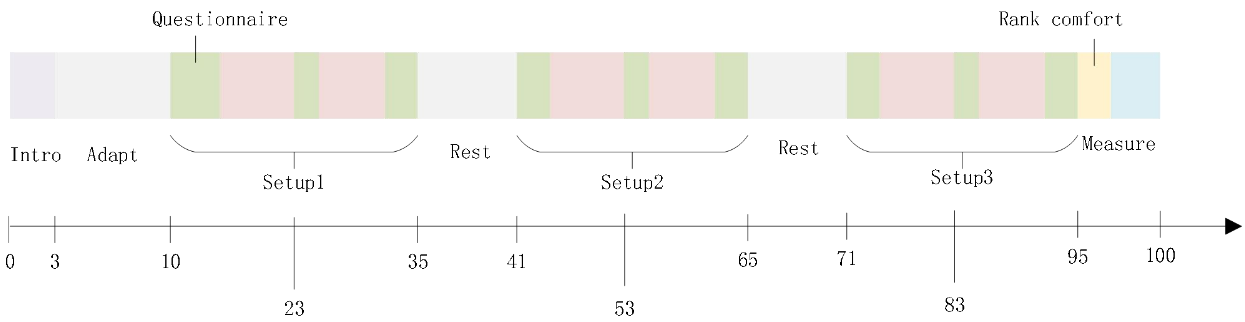

Figure 3: Experiment procedure in time (minutes)

Data analysis

The collected data on heart rate, pressure (distributions), anthropometrics and results of the questionnaires were further analyzed. For all logged RR intervals, a one-minute window was used to extract all HRV features using a self-developed Python program. The values of HRV features for each setting were computed with a 1-minute interval and averaged over 20-minutes to identify the correlations between the HRV features and comfort/discomfort ratings in 3 conditions The HRV features include time domain parameters (i.e., SDNN, pNN50), frequency domain parameters (i.e., LF, HF) and non-linear parameters (i.e., CSI, SD2). Pearson's correlation was used to identify relations between the mean of each HRV features and the corresponding subjective comfort/discomfort rating. The metrics of those parameters are shown in Table 2. Paired t-test was used to check significance between each two conditions for those features.

Table 2. HRV parameters and metrics

HRV features		Metric
Time domain	SDSD	Standard deviation of differences between adjacent NN intervals (ms)
	SDNN	Standard deviation of the time interval between successive normal heart beats (NN intervals)(ms)
	pNN50	Proportion of number of intervals differences of successive RR-intervals greater than 50ms
	pNN20	Proportion of number of intervals differences of successive

		RR-intervals greater than 20ms
	rMSSD	Root mean square of successive RR-interval differences (ms)
	mean NN	Mean normal-to-normal (NN) interval (ms)
	mean HR	Mean heart rate
Frequency domain	LF	Low frequency of the heart rate, range .04 to .15 Hz(ms^2)
	HF	High frequency of the heart rate, range .15 to .40 Hz(ms^2)
	LF/HF ratio	Ratio of LF/HF
	LF norm	Normalized LF
	HF norm	Normalized HF
Non-linear domain	CSI	Cardiac Sympathetic Index
	CVI	Cardiac Vagal Index
	SD1	Standard deviation of projection of the Poincare plot on the line perpendicular to the line of identity (ms)
	SD2	Standard deviation of projection of the Poincare plot along the line of identity (ms)
	SD2/SD1 ratio	Ratio of SD2/SD1

The pressure recordings were processed by a self-developed program for calculating the mean pressure and the contact areas on the seat and the backrest, respectively. The graphs of averaged pressure map were used to identify pressure distribution.

All anthropometric data and the results of questionnaires were placed in an Excel file where empty answers in the LPD questionnaires were filled in 0 by default. The mean values of the ratings of all subjects were calculated and the Wilcoxon signed rank test (using SPSS) was used ($P<.05$) to identify if there are differences between any two of the three conditions.

Results and discussion

Overall comfort and discomfort

Table 3 shows the calculated p values. It indicates that the perceived comfort and discomfort between 3-and 14-degrees AOA are not significantly different. While 3- and 18-degrees comfort and discomfort differ significantly. Comparing the 14-degree and 18-degree conditions, perceived comfort does not differ significantly, while participants' perceived discomfort differs significantly.

Table 3 p value calculation between two conditions averaged of three recording time over all comfort and discomfort values per condition

	3- and 14-degree	**3- and 18-degree**	**14- and 18-degree**
Perceived comfort	0.131, NS	0.031, $p<0.05$	0.261, NS
Perceived discomfort	0.284, NS	0.006, $p<0.05$	0.040, $p<0.05$

Figure 4 presents the mean scores of overall comfort and discomfort of the 3 conditions over time (0 minute, 10 minute and 20 minute). For all three conditions in general, comfort score decreased and discomfort increased during 20 minutes sitting on the seat. Compared with the control group (3-degrees), the participants' perceived comfort levels decreased slightly in reclined conditions. As the AOA gets larger, the perceived discomfort levels are higher. It is interesting to notice that when sitting on the 3-degree seat, participants gain a bit more comfort in the first 10 minute. Participants' comfort is probably not linear in time.

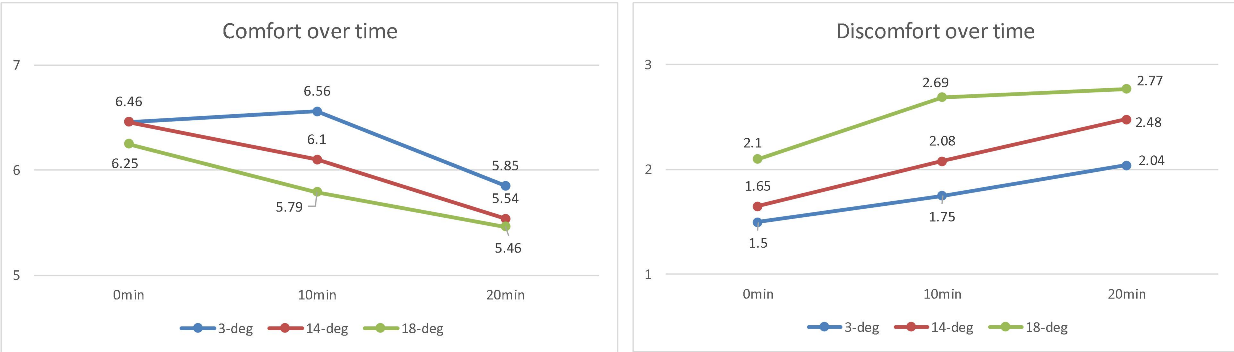

Figure 4: overall comfort/discomfort ratings over time under 3 settings

LPD questionnaire

Regarding the different body parts, results from the LPD questionnaires (Figure 5) show the highest discomfort score at the back of the neck and the lower waist in all three conditions. With a larger AOA, more body parts of the participants get higher levels of discomfort.

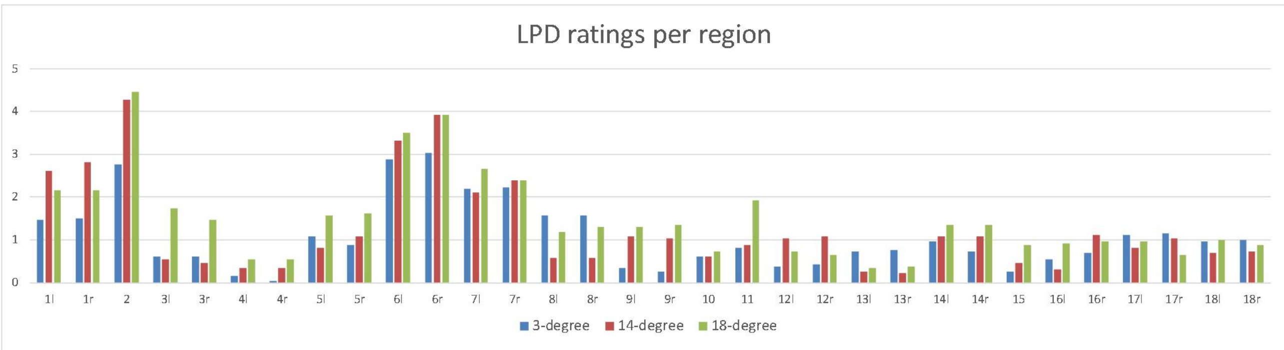

Figure 5: Average discomfort ratings in LPD questionnaires for 3 settings

HRV

The averaged values of HRV features for each condition are presented in Table 4. The 3-degrees condition had the lowest mean values of pNN50, pNN20, Mean NN, HF and HF norm compared with the other two conditions. PNN50, pNN20 and HF were found to have positive correlation with mental stress.(Castaldo et al., 2015) It can be inferred that participants have less stress and less physical pain under 3-degree AOA. Mean HR was the highest at the 3-degree condition. Yet for most features the differences were not significant among the three conditions.

Table 4 HRV features averaged of 26 participants per condition

HRV features		**3-deg**	**14-deg**	**18-deg**
Time domain	SDSD	47.2	46.8	47.8
	SDNN	56.8	55.2	55.3
	pNN50	24.6	24.8	26.0
	pNN20	60.2	60. 7	60. 7
	rMSSD	47.2	46.8	47.8
	mean NN	800.6	820.4	824.2
	mean HR	77.0	74.9	74.5

Frequency domain	LF	1363.7	1181. 3	1162.0
	HF	671.0	679.8	705.0
	LF/HF ratio	2.6	2.1	2.4
	LF norm	62.8	58.8	58.3
	HF norm	37.2	41.2	41.7
Non-linear domain	CSI	2.2	2.2	2.1
	CVI	4.5	4.5	4.5
	SD1	33.6	33.3	34.0
	SD2	72.5	70.1	69.9
	SD2/SD1 ratio	2.2	2.2	2.1

Table 5 shows the Pearson's correlation analysis between the scores of subjective comfort/discomfort and corresponding conditions. For time-domain features, the results indicate that Mean NN were significantly correlated to both the comfort ($r=-0.232$, $p<0.05$) and discomfort ($r=0.425$, $p<0.01$). This is in accordance with previous studies, where it was found that the mean NN was correlated to physiological stress and physical pain (Terkelsen et al., 2005). This indicates that both stress and pain are linked to the constructs of comfort and discomfort. Mean HR was found to be significantly correlated to discomfort (higher HR related to lower discomfort), but not correlated to comfort. It differs from the results of the study by Beggiato et al. 2018 who did not find a correlation. SDNN was found to be positively correlated to comfort (higher SDNN relates to higher comfort), which is different from the study of Anjani et al 2021, who found that SDNN has a high negative correlation with comfort. Terkelsen's study mentioned SDNN was not related to fatigue or physical pain, which may explain why SDNN is not correlated to discomfort.

For frequency domain features, both LF and HF was found to have weak positive correlation with comfort ($r=0.256$, $p<0.05$, $p=0.242$, $p<0.05$). These findings were also not accordance to Anjani's study, who found LF and HF were both negatively correlate to comfort. The non-linear feature SD2 was also found to have correlation to comfort. Previous researchers found SD2 probably had relation with mental stress, though the exact effect had not been deeply studied yet.

The mean NN shows the highest correlation and is most in line with the literature and supporting that passengers' experience most comfort and least discomfort under 3-degree AOA.

Table 5 Pearson' correlation of values of HRV features and subjective comfort/discomfort ratings at corresponding conditions (*, $p<.05$; **, $p< .01$)

		Discomfort	Comfort
Time domain	SDSD	0.1902	0.2033
	SDNN	0.1474	0.2249*
	pNN50	0.218	0.1829
	pNN20	0.2217	0.1694
	rMSSD	0.1903	0.2033
	Mean NN	0.425**	-0.2318*
	Mean HR	-0.3778**	0.1998
Frequency domain	LF	0.0304	0.256*
	HF	0.101	0.2417*
	LF/HF ratio	-0.0938	-0.0421
	LF norm	-0.1339	0.0283
	HF norm	0.1339	-0.0283

Non-linear domain	CSI	-0.1225	0.011
	CVI	0.1977	0.2087
	SD1	0.1913	0.2023
	SD2	0.1333	0.2264*
	SD2/SD1 ratio	-0.1225	0.011

Pressure distribution

Table 6 presents the contact areas and mean pressure of the three conditions, which are visualized in Figure 6. In the figure, the horizonal axis and the vertical axis stands for the index of the cells (48x48) in two directions and the colour represents the amplitude of the pressure (the lighter the more pressure). As expected, the contact area increases and the mean pressure on the backrest increased as well when the angle becomes larger, while this decreases on the buttock (fewer light colours). It can be observed from the graph that as the AOA increases, the pressure was gets less (gets darker). The finding that there is more pressure on the cushion in the three degrees condition is in accordance with the results of LPD questionnaire, where thighs got highest discomfort ratings under 3-degree AOA.

The contact areas on the backrest increased as the inclination angle gets larger. It can be inferred that people tend to sit more to the back of the seat and more weight is carried by the backrest in an inclined configuration, which results in larger contact areas. Previous studies said that a larger contact area may decrease discomfort (e.g., Zemp et al 2015). It may not be true in this case when the larger contact area is caused by a too much backward inclined seat.

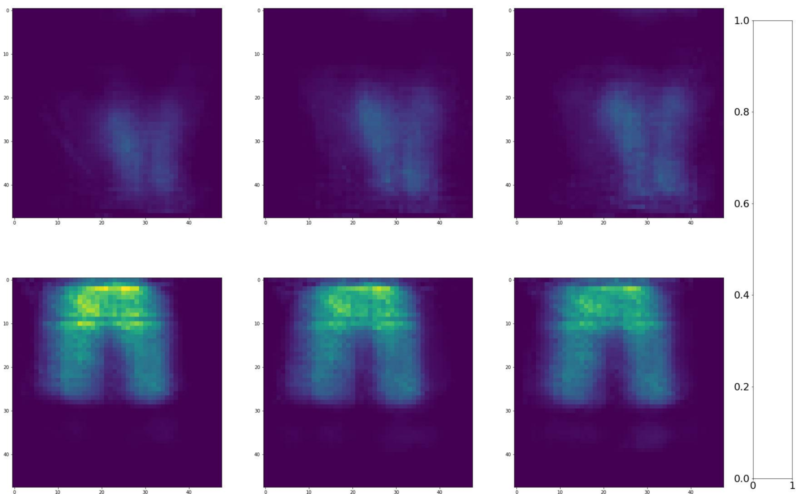

Figure 6: Averaged pressure map over 26 participants (left to right: 3-deg, 14-deg, 18-deg)

Table 6: Contact area (cm^2), mean pressure (N/cm^2) and total force (N) averaged over 26 participants

AOA	Back rest			Seat pan		
	Contact area	Mean Pressure	Total	Contact area	Mean Pressure	Total
3-deg	759.7	0.157	119.3	1190.3	0.434	516.6
14-deg	1054.8	0.161	169.8	1191.9	0.394	496.6
18-deg	1061.2	0.181	192.1	1241.9	0.369	458.3

Subjective ranking of comfort

After experiencing all three conditions, participants were asked to rank their comfort feelings among the three different AOAs. The comfort rankings given by participants showed that they experienced the 14-degrees setting as most comfortable. Previous research found that sitting on a backward tilting seat may have benefits on pressure relief and increase blood flow (Sonenblum & Sprigle, 2011), which might be a possible explanation of this phenomena. 18 degrees might be too extreme, discomfort ratings are highest here, the pressure on the backrest is high and mean NN (which links to physical discomfort) is also the highest among three conditions.

Limitations

This study was done in an aircraft which was not flying. It could be due to other sensations, like 'the journey starts' that in a real flight the experience is different. Bouwens et al, 2018 show that the take-off is relatively a nice experience. Although they do not describe if it is the climbing. It could also be the moment getting off the runway. Further research in a real flight is needed to see if the comfort and discomfort findings in this paper are found as well. On the other hand, data on pressure distribution and mean NN found in this study support the comfort and discomfort findings.

Conclusion

In this research, 26 participants experienced three angles of attack (AOA) for 20 minutes. Questionnaires and measurements indicated that the AOA is not linearly related to perceived comfort and discomfort of passengers. After analysis of multiple parameters, it can be concluded that a certain degree of inclination might improve the feeling of comfort, or at least will not increase the feelings of discomfort. It was found that 14-degree AOA is experienced as more comfortable than 18 degrees, which might be useful for airlines in setting up the take-off and climbing procedure.

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