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Being in Control of Noise Levels Improves the Perception of Airplane Seat Comfort

Joyce Bouwens^{1,2}, Luisa Fasulo³, Suzanne Hiemstra-van Mastrigt¹, Udo W. Schultheis², Alessandro Naddeo³, and Peter Vink¹

¹Faculty of Industrial Design Engineering, Delft University of Technology, Delft, The Netherlands

²Department of Human Factors and Ergonomics, Zodiac Seats US, Gainesville, TX, USA

³Dipartimento di Ingegneria Industriale, Università Degli Studi di Salerno, Fisciano, SA, Italy

Abstract: The aviation industry is constantly making compromises when designing comfortable airplane cabins. Providing passengers with a pleasant acoustic environment without adding weight to the cabin structure is a field of tension that challenges cabin interior designers. The aim of this study was to investigate whether noise levels affect the comfort and physical discomfort experienced by airplane passengers, and whether control influences comfort perception. To this end, 30 participants experienced three conditions (silence, aircraft engine noise at 75 dB, and the same noise with the ability to use earplugs), and comfort and discomfort were measured using a questionnaire. It was concluded that aircraft engine noise negatively affected the airplane passengers' comfort experiences. Having the ability to control this noisy environment with earplugs resulted in the lowest reported physical discomfort.

Keywords: aircraft cabin noise, passenger comfort, discomfort, airplane seat, control

The control of noise in aircrafts and automobile interiors has received considerable attention (e.g., Tichy, 1991), because the presence of noise might have negative effects on human health and comfort, both physiologically and psychologically (Mellert, Baumann, Freese, & Weber, 2008).

Physicists describe sound as observable vibrations that travel through a medium (air, water, etc.; Rayleigh & Lindsay, 1998), while psychologists study sound as the perception of these vibrations by the brain (psychoacoustics). Sound is defined by volume (dB) and tone (frequency in Hz). The human hearing range lies between 20 and 20,000 Hz (Figure 1), and people are most sensitive to frequencies between 2,000 and 5,000 Hz. A volume of 0 dB is the hearing threshold for a child, and 150 dB corresponds to the volume of a rock concert when standing in front of the sound box.

The sound inside an airplane cabin predominantly originates from the aircraft power plant (propeller and engine) and the turbulent boundary layer (Wilby, 1996). It has an average level of 80 dB at cruise flight altitude (Figures 2 and 3) with a relatively low frequency (Hinninghofen & Enck, 2006; Ozcan & Nemlioglu, 2006; Smith, 1989). Although sound levels might vary between different seats inside the airplane depending on their location with regard

to the engines (Wilby, 1989, 1992), the discomfort threshold (approx. 120 dB depending on the frequency) will not be reached (Figure 3; Slater, 1985). Therefore, it is highly unlikely that aircraft cabin sound causes permanent hearing loss (Passchier-Vermeer, 1997), but sounds could still be perceived as annoying by airplane passengers.

On the one hand, Mixson and Powell (1985) indicate that sound with low frequencies (80–135 Hz) with a volume above 82 dB(A) result in annoyance among airplane passengers. On the other hand, Quehl (2001) states that annoyance caused by sound is based on individual preferences. Annoyance is significantly greater for sounds including tones than for noise alone (Mixson & Powell, 1985). Furthermore, the interpretation of sound is also influenced by cultural background (i.e., the sound of a car is perceived as sporty or luxurious; Noumura & Yoshida, 2003). Nevertheless, DeHart (2003) argues that noise and vibration are a cause of physical stress from which passengers should be protected.

Airplane passengers are exposed to a wide range of sounds during the flight that originate not only from the aircraft engine noise, but also from announcements by the crew, conversations of fellow passengers, or even crying babies (Lewis et al., 2016). The effect of these sounds on individual comfort perception can differ; however, when

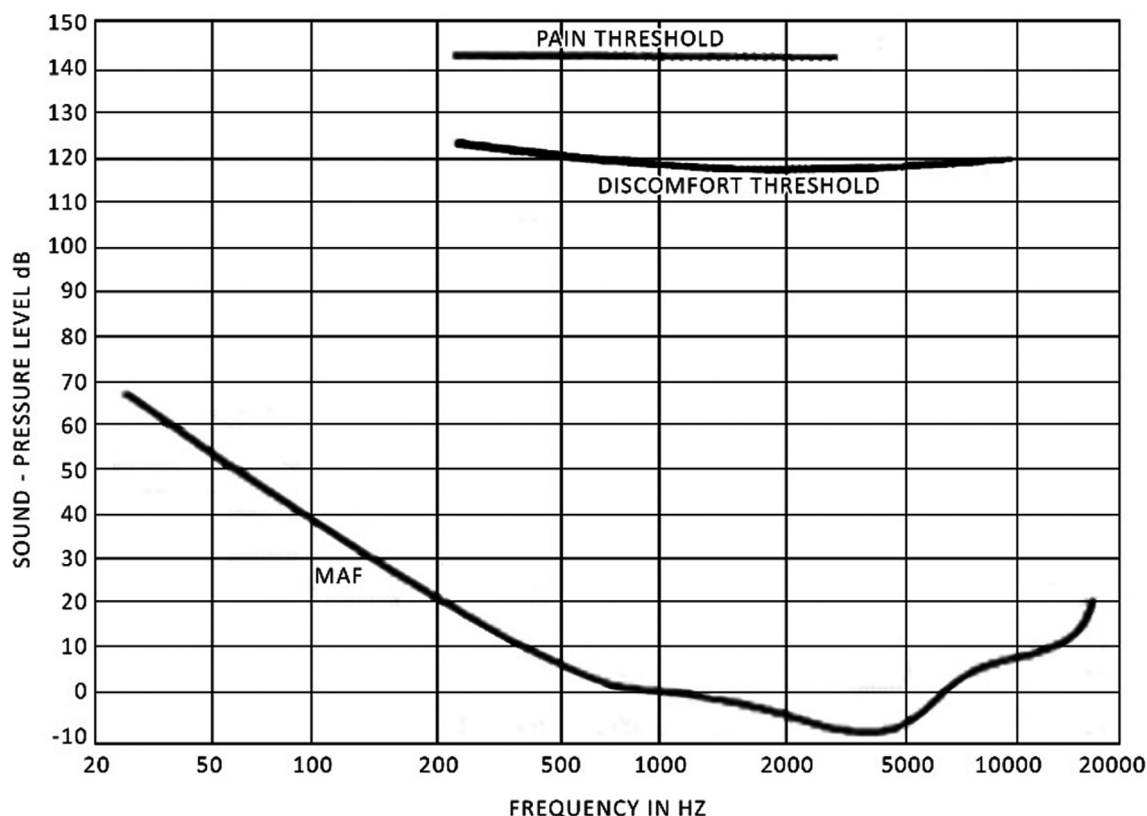


Figure 1. Human hearing range (Slater, 1985), showing the thresholds of discomfort and pain levels of hearing (MAF = minimal audible field) for every frequency with the corresponding sound pressure level (in dB).

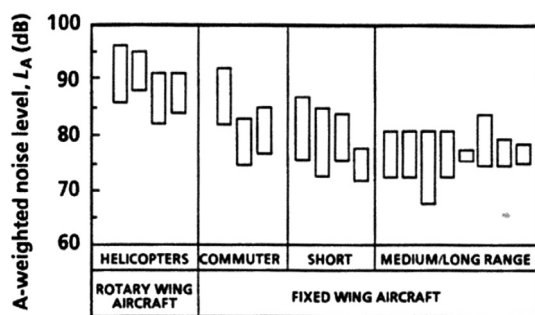


Figure 2. Typical ranges of interior sound pressure level in a fixed-wing aircraft and helicopter (in dB[A]; Smith, 1989).

recalling their last flight experiences, only 0.9% of surveyed airplane passengers mentioned noise, whereas 79% mentioned comfort and service (Vink, Bazley, Kamp, & Blok, 2012). This suggests that either passengers are not so aware of sound that they recall it, or that sound is a minor influencer of comfort.

However, real-time reported effects of noise indicate that sound can have a significant impact on airplane passengers' comfort experience, and that they might be unaware of this. The passenger's level of flight experience plays a role too: Novice fliers may become more alarmed by and be attentive to sudden changes in the aircraft acoustic environment

compared with experienced fliers (Västfjäll, Kleiner, & Göring, 2003). Weber et al. (2004) found that when noise increased (from 70 to 73 to 75 dB over 3 hr), cabin crew rated their annoyance level as significantly higher than when the noise decreased (from 75 to 73 to 70 dB). In line with this, Huang and Jiang (2016) suggest that subjectively measured discomfort increases with extended exposure duration. People in the airplane cabin are not always aware of the effect of noise. For example, Mellert et al. (2008) found that when the sound level increased during a flight, the crew was more aware of symptoms such as tiredness, difficulty concentrating, swollen feet, and headaches; by contrast, awareness of these symptoms was lowered when the noise level decreased. Besides Mellert et al. (2008), Pennig, Quehl, and Rolny (2012) also examined the effect of sound pressure levels (SPL) between 66 and 78 dB(A) on passengers' comfort experience and positive mood in the aircraft cabin. They suggest that aircraft interior noise could be optimized by reducing the SPL and high-frequency components (sounds described as "shrill" and "bright"), and reducing "irregular" sounds. However, total absence of noise might not be the solution, since the presence of a background noise masks other sounds, such as conversations between other passengers, and is therefore considered positive by train passengers (Khan, 2003). Similarly, in a

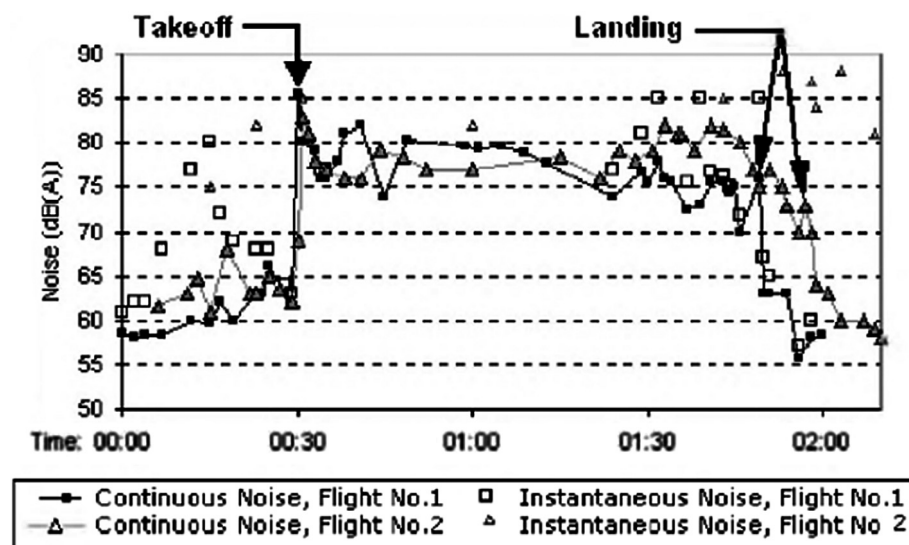


Figure 3. Recordings of noise levels during two flights (in dB[A]; Ozcan & Nemlioglu, 2006).

study conducted with 237 office workers, conversations were a source of irritation in the working environment, while overall background noise levels of 65 dB were not related to annoyance (Pierrette, Parizet, Chevret, & Chatillon, 2015). Lewis (2015) found that the extant sound of a crying baby is so annoying that airplane passengers can hardly be distracted from it by virtual reality, whereas the latter seems to be an effective distraction from the discomfort caused by a lack of legroom.

As sound is partly a psychological phenomenon, its perception can be influenced by several factors, of which “being in control” is one. Bazley (2015) states that people prefer to be in control of their environment and that this contributes to less stress and more comfort, for example, by adapting the temperature to their own situation (Ong, 2013) or having the ability to open the window (Leather, Pyrgas, Beale, & Lawrence, 1998). This theory (being in control benefits comfort) might also be applicable to noise.

Research Questions

Based on the aforementioned findings, it can be suggested that sound and noise have a considerable influence on the perception of comfort. Although many inventions offer solutions to escape from (monotonous) sounds, sound might also be applied to mask other sounds or even to distract from discomfort originating from other sources.

The aviation industry constantly makes compromises when designing comfortable airplane cabins. For example, a large, cushiony lounge chair might be very comfortable for the passenger, but too heavy and too laborious to maintain in the aircraft. Sound design for the airplane cabin has a similar field of tension, since the interpretation of sound might depend on age and gender, while sound-reducing solutions are highly likely to add weight to the cabin struc-

ture. Therefore, it is interesting to more closely examine the effect of sound in relation to the perception of comfort (of an aircraft seat). This study investigates the following research questions:

- Does noise level affect airplane passengers’ comfort and (physical) discomfort experiences?
- How do these (dis)comfort experiences change over time?
- Do noise levels influence the appreciation of the airplane seat?
- What is the influence of having (limited) control over sound on (dis)comfort perception?

Method

Participants

To answer these research questions, a comfort experience study was performed with 30 participants [(17 male, 13 female), aged 19–56 years (average = 25.9, $SD = 6.3$) with a mean weight of 68.2 kg ($SD = 13.4$) and mean height of 1.71 m ($SD = 0.097$)] with flying experience. All participants reported that they did not suffer from any hearing disability, and provided written informed consent preceding the study.

Set-Up and Procedure

The study took place in the audio laboratory at Delft University of Technology. The isolated audio cabin (Amplifon Silent Cabin Milano) was equipped with a decibel meter (Bruel&Kjaer 2270-S G4) and a sound box (Behringer Truth B2031A). A triple economy class passenger aircraft seat

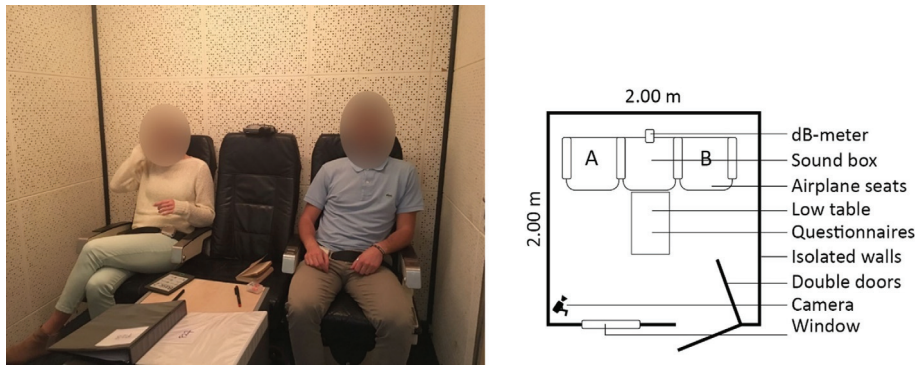


Figure 4. Set-up of the study in the audio laboratory.

(Zodiac Aerospace) was placed inside the cabin, with the seat backs fixed in a reclined position (see Figure 4). The sound cabin had a window, but participants could only see a wall through it; this window was used by the researchers to check on the participants and to inform them when it was time to fill out the next discomfort questionnaire, without opening the isolated door.

Two participants were tested simultaneously per session, sitting in either the left or the right seat. The middle seat was intentionally not in use to provide participants with private armrests and to minimize the effect of having direct neighbors. During the test, participants were not allowed to speak with each other, but were free to rest, sleep, or read a book.

The participants were exposed to three conditions:

- **Silence:** No sound was added to the audio cabin. The sound pressure level measured in the room was constantly 30 dB(A).
- **Sound:** In this condition, the constant aircraft cabin noise of a 777-300 (frequency between 20 and 16,000 Hz, with an emphasis on 20–500 Hz) was played in the cabin at an average level of 75 dB.
- **Earplugs:** The participants were provided with earplugs (Honeywell Howard Leight Quiet, noise reduction approximately 27.6 dB for frequency of 500 Hz according to AS/NZS 1270:2002) in the sound condition (aircraft cabin noise at 75 dB). Using the earplugs was optional and voluntary.

Each condition lasted for 45 min, followed by a 15-min break. The order of the conditions was systematically randomized per pair of participants.

Measurements

The effect of sound on the airplane passengers' development of comfort and discomfort experiences throughout the conditions was measured by means of questionnaires.

Mellert et al. (2008) found that higher noise levels caused increased muscle pain in the neck. Therefore, the development of physical discomfort was measured using the localized musculoskeletal discomfort (LMD) method (Van der Grinten & Smitt, 1992; see Figure 5). Participants ranked the level of their discomfort at the start of each condition and at every successive quarter of an hour (T0, T15, T30, T45), indicating the discomfort they experienced on an 11-point scale (ranging from 0 = *no discomfort at all* to 10 = *extreme discomfort*). In addition, a discomfort and comfort questionnaire was completed at the start and at the end of each condition (T0 and T45), where participants rated five factors related to comfort ("I feel relaxed," "The seat feels soft," "I feel fit," "I feel comfortable," "I like the seat") and five factors related to discomfort ("I feel stiff," "I feel uneven pressure from the seat pan or seat back," "I feel tired," "Parts of my body feel numb," "I feel uncomfortable") on a seven-point scale (ranging from 1 = *not at all* to 7 = *extremely*; Helander & Zhang, 1997).

The participants were video recorded (GoPro Hero) while they were in the cabin during all conditions to determine whether they used the earplugs.

Data Analysis

The LMD data were analyzed with a Wilcoxon and a Friedman test. The results of the comfort and discomfort questionnaires were analyzed using a reliability analysis followed by a Friedman test (IBM SPSS 22). Significance was accepted at $p < .05$.

Results

In this study, we observed that in the earplug condition, 87% of the participants used the earplugs, while 13% did not use them at all. No significant differences were found

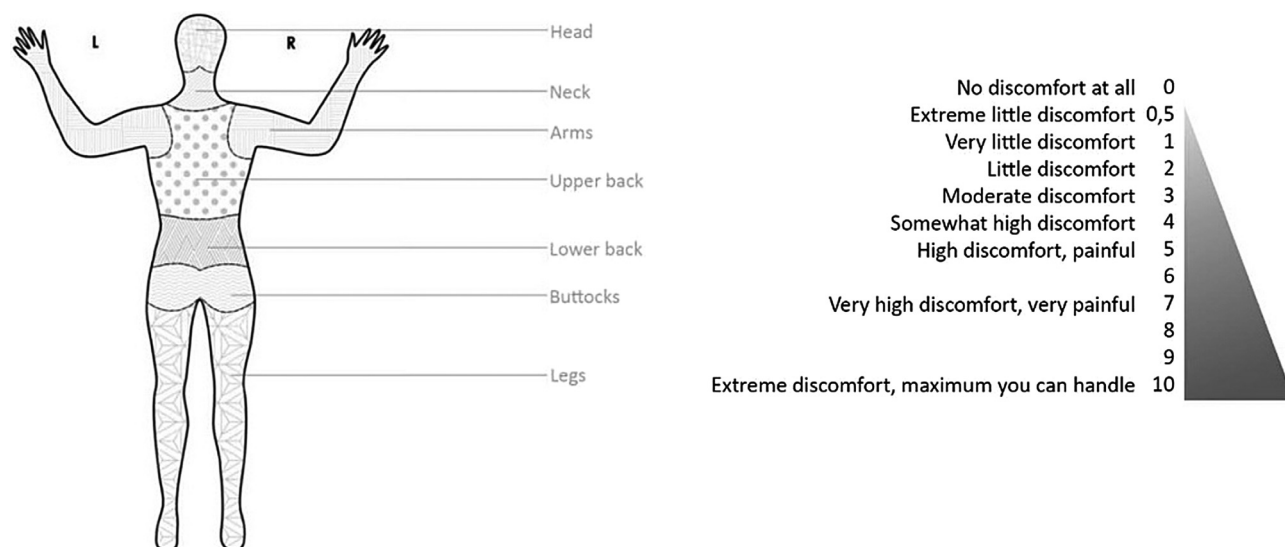


Figure 5. Localized musculoskeletal discomfort map (redrawn, based on Van der Grinten & Smitt, 1992).

between these groups in reported LMD, comfort, or discomfort. One participant did not understand how to fill out the LMD questionnaire (which resulted in LMD scores that were 3 standard deviations from the mean), and was therefore excluded from the LMD data analysis.

Localized Musculoskeletal Discomfort (LMD)

Figure 6 shows the averages of the LMD scores of all participants over time. Discomfort increased significantly over time (between T0 and T45) for all conditions (Wilcoxon signed rank test silence $p < .001$, $Z = -6.249$, sound $p < .001$, $Z = -8.042$, earplugs $p < .001$, $Z = -9.030$). Furthermore, LMD between the silence, sound, and earplug conditions differed significantly for T15 (Friedman, $p = .049$, $\chi^2 = 6.020$), T30 (Friedman, $p = .004$, $\chi^2 = 11.232$), and T45 (Friedman, $p = .008$, $\chi^2 = 9.740$), and not significant for T0 (Friedman, $p = .175$, $\chi^2 = 3.482$). The standard deviations belonging to this data are presented in Table 1.

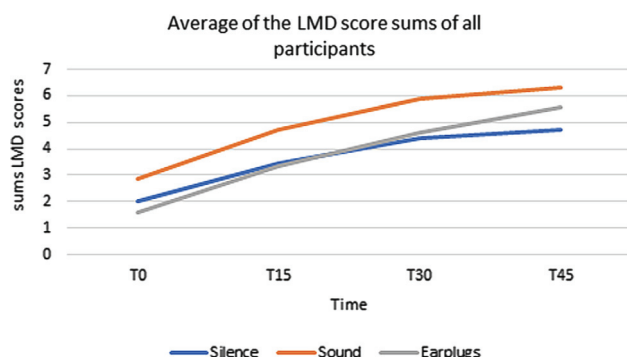


Figure 6. Average of the localized musculoskeletal discomfort (LMD) score sums of all participants for all body parts.

Table 1. Average of LMD score sums with standard deviations in parentheses

	T0 LMD mean (SD)	T15 LMD mean (SD)	T30 LMD mean (SD)	T45 LMD mean (SD)
Silence	2.0 (2.5)	3.4 (3.0)	4.4 (3.7)	4.7 (3.6)
Sound	2.9 (3.2)	4.7 (3.6)	5.9 (3.9)	6.3 (4.5)
Earplugs	1.6 (1.2)	3.4 (2.4)	4.6 (3.7)	5.6 (4.3)

Discomfort and Comfort Ratings

Discomfort Factors

Discomfort increased over time for all conditions (see Figure 7). Two reliability analyses with all discomfort-related factors at T0 and at T45 showed high internal consistency (Cronbach's $\alpha > .842$). Significant differences between the silence, sound, and earplug conditions were found for T0 (Friedman $p = .006$, $\chi^2 = 10.101$) and T45 (Friedman $p = .002$, $\chi^2 = 12.722$).

Comfort Factors

Reliability analyses between the comfort-related aspects indicated that the different factors were highly internally consistent (Cronbach $\alpha > .901$) at T0 and T45. A Friedman test was performed on the comfort-related aspects and indicated that there were significances between the silence, sound, and earplug conditions for T0 ($p = .046$, $\chi^2 = 6.166$) and T45 ($p = .002$, $\chi^2 = 12.399$) (see Figure 8).

Discomfort and Comfort Factors Addressing Seat Appreciation

Three aspects in the comfort/discomfort questionnaire directly referred to the seat ("I feel uneven pressure from the seat pan or seat back," "The seat feels soft," "I like the seat"). A Friedman test was performed on these aspects

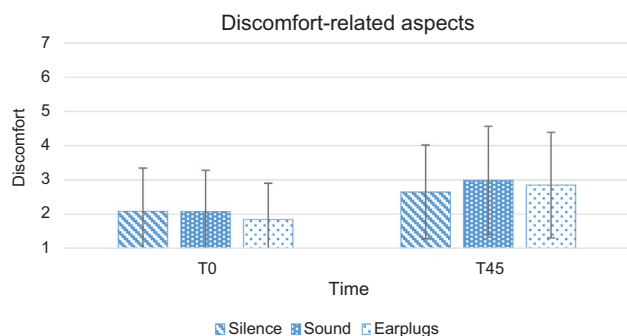


Figure 7. Average of discomfort-related aspects in all conditions.

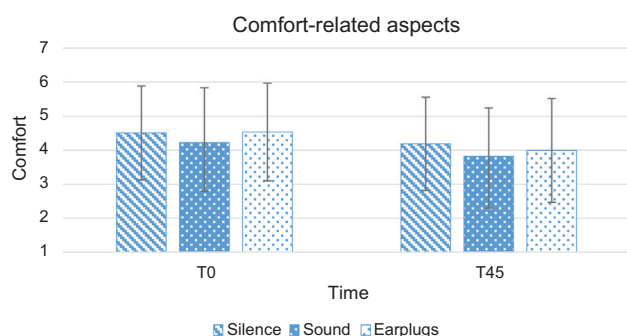


Figure 8. Average of comfort-related aspects in all conditions.

and indicated that there were no significant differences between the silence, sound, and earplug conditions for T0 ($p = .870$, $\chi^2 = 0.265$) and T45 ($p = .682$, $\chi^2 = 0.616$).

Discussion

The aim of this study was to investigate whether noise levels affect airplane passengers' comfort and (physical) discomfort experiences differently. This section first answers the research questions, and then evaluates the general limitations of this study.

Research Questions

How Do Discomfort and Comfort Experiences Under Different Noise Conditions Change Over Time?

Self-reported LMD increased over time in all three conditions (silence, sound, and earplugs). The sound condition resulted in the highest physical discomfort, and the earplug condition in the lowest perceived physical discomfort after 45 min. Self-reported discomfort based on discomfort-related statements also showed an increase in discomfort over time for all conditions, whereas the comfort-related

statements were given lower ratings over time for all conditions.

Given these points, no habituation effect (i.e., where the effect of the presence of noise on discomfort flattens out over time, and discomfort values will reach similar values for either noisy or silent conditions) was found in this study. This is in line with the findings of Banbury and Berry (2005) in their study of noise in office spaces.

Examining the individual conditions, the LMD scores were highest for the noise condition. This seems to be in line with the findings of Mellert et al. (2008) that more sound resulted in increased awareness of physical discomfort. However, the lowest LMD scores were not found in the silent condition, but in the earplug condition; hence, it can be suggested that the absence of noise in an airplane cabin does not automatically result in the most comfortable environment.

Do Noise Levels Influence the Appreciation of the Airplane Seat?

Three aspects in the comfort/discomfort questionnaire directly referred to the seat ("I feel uneven pressure from the seat pan or seat back," "The seat feels soft," "I like the seat"). The scores on these aspects did not show significant differences between the three conditions, which implies that noise levels did not influence direct appreciation of the airplane seat. However, the design of the seat might have indirectly caused physical discomfort, and since the LMD scores obtained here indicate that the noise level did influence discomfort experience, sound might have made a poorly designed seat feel even worse.

What Is the Influence of Having (Limited) Control Over Sound on Comfort Perception?

The findings of this study suggest that the relationship between sound level and comfort is not linear. Comfort levels reached in the silent condition were similar to those in the earplug condition. In the latter, the 87% of participants who did use earplugs experienced sound that was approximately 17 dB higher than the sound experienced during the silent condition. Thus, reducing noise did not necessarily lead to better comfort experience, which is in line with Khan's (2003) findings. On the other hand, a condition in which passengers were offered earplugs in a silent surrounding was not studied in this experiment. A combination of control and a quiet environment could possibly lead to even higher comfort levels. Given these points, aircraft cabin designers should focus on finding an optimal balance between implementing noise reducing solutions and offering control to passengers to optimize their comfort experience, which has also been suggested by Bazley (2015).

This study described the effect of aircraft cabin noise caused by the engines on passengers' comfort and

discomfort perception. However, it is highly likely that passengers on a flight will be exposed to sounds from other sources as well, such as conversations between other passengers, spoken crew instructions, or the sound of a crying baby. Although not all of these sounds will be perceived as bothersome, Lewis et al. (2016) suggest that it is difficult to distract airplane passengers from the sound of a crying baby.

Limitations

Since this study was performed in a laboratory setting, it was not feasible to simulate a complete airplane cabin environment while flying. Passengers in an airplane cabin are also subjected to vibrations caused by the airplane motor or turbulence caused by the weather. In this laboratory setting, it was unfeasible to simulate such physically perceptible vibrations; however, Dempsey, Leatherwood, and Clevenson (1979) suggest that noise and vibrations could be studied independently, which indicates that the absence of physical vibrations did not affect the results of the present study. Furthermore, the set-up of this study did not allow for an extra row of seats to be added in front of the participants to simulate restricted legroom and to provide them with a foldable tray table. However, this should not have affected the difference in comfort experiences between the conditions.

Future Research

The outcomes of this study suggest that noise caused by airplane engines influences comfort and discomfort experiences. However, previous studies have shown that sound (or lack thereof) might also be used as an effective tool to steer passengers' mood. Västfjäll et al. (2003) reported that sound can affect the valence and activation level of the passenger. According to Thompson, Schellenberg, and Letnic (2012), loud and fast music results in a low reading comprehension, while an instrumental and vocal background has no influence on verbal learning (Jäncke, Brügger, Brummer, Scherrer, & Alahmadi, 2014). Furthermore, tasks that require creativity prosper with a moderate ambient noise of 50–70 dB (Mehta, Zhu, & Cheema, 2012), comparable with the environmental sound in a coffee bar. Classical music is a sound that calms down passengers, and Harmat, Takács, and Bodizs (2008) suggest that this intervention even helps to reduce sleeping problems. The effect of noise on consuming behavior is another well-researched field (Spence, 2014): loud music in a bar (88–91 dB), results in higher drink consumption compared with a quiet bar (72–75 dB; Guéguen, Le Guellec, & Jacob, 2004); loud surroundings make food taste less salty or less sweet compared with the same food in a quiet environment; and crunchy

food is perceived as crunchier in a noisy environment (Woods et al., 2011). Another condition that could be considered for future research is the use of noise-cancelling headphones instead of earplugs, since such headphones are readily available (and used by airplane passengers). It might also be possible that the perception of noise in relation to comfort is influenced by age or gender, or is even culturally dependent; however, the data gathered in this study can neither confirm nor deny this.

All in all, future research is needed to investigate how sound can be applied in aircraft cabins to establish an optimal comfort experience for each individual passenger by providing him or her with the right amount of control.

Conclusion

Aircraft engine noise negatively affected airplane passengers' comfort experiences in this study. When experiencing aircraft engine noise at 75 dB, significantly more physical discomfort (LMD) was experienced and less comfort was perceived than when experiencing silence after 15, 30, and 45 min. Different noise levels did not affect the appreciation of the aircraft seat differently.

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Suzanne Hiemstra-van Mastrigt

Faculty of Industrial Design Engineering
Delft University of Technology
Landbergstraat 15
2628 CE Delft
The Netherlands
s.hiemstra-vanmastrigt@tudelft.nl



Suzanne Hiemstra-van Mastrigt (PhD) is a researcher and teacher at TU Delft's Faculty of Industrial Design Engineering. After obtaining her PhD, she helped develop innovative designs for future airports and aircrafts within the EU-H2020 research project PASSME (2015–2018). Currently she is the director of the Seamless Personal Mobility Lab, where researchers and students closely work together with transport operators, mobility companies, government and technology developers to get a better understanding of the (future) wants, needs, and behavior of travellers.



Joyce Bouwens (PhD) is an industrial design engineer with a special interest in human factors. During her PhD project at Delft University of Technology (completed in 2018), she worked at the company Zodiac Aerospace, where she was involved in the development of new airplane seats.



Alessandro Naddeo (PhD) is Associate Professor at University of Salerno, Italy, in Industrial Design Methods. From 2001 to 2002 he worked at Elasis S.c.p.A. vehicle-research center as Product Development Methodologist. His research activity is focused on Virtual prototyping, Industrial Design Methods and Human factors and Ergonomics.



Luisa Fasulo (MA) is currently a consultant at Ferrari S.P.A where her role is Process Engineering for new projects. Prior to that position, she worked with TU Delft and Zodiac Aerospace. In that period, she was involved in 2 amazing projects on aircraft interior and was working on Continuous Improvement projects at Yangfeng Automotive Interior.



Peter Vink (PhD) is Professor of Environmental Ergonomics at the Faculty of Industrial Design Engineering at the TU Delft. His main research interests are interior design, comfort and vehicle seat design and their applications in mobility. One of Peter's current projects is the interior of the Flying V. Peter has written more than 250 papers and books in the field of comfort, performance and design of interior designs.



Udo Schultheis (PhD) is currently Human Factors Scientist at J.S. Held LLC (Michigan, US). Having worked in research and leadership positions for Flight Safety International, the National Institute for Aviation Research, Zodiac Aerospace, the Civil Aviation Medical Institute and GM, he is now expert in Psychology and Human Factors associated with personal litigation, commercial and passenger land, air, and water vehicle accidents, safety and personal protective equipment, product failure analysis, warning and alarm signaling and labeling.