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# Ranking of Human Senses in Relation to Different In-flight Activities Contributing to the Comfort Experience of Airplane Passengers

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When booking a flight, passengers seek comfort and are willing to pay higher prices in exchange for increased seat comfort (Airbus, 2013). A pleasant and comfortable experience also increases the likelihood that customers will return to an airline for future travel (Vink et al., 2012). Based on this, it makes sense for some airlines to invest in the design of a comfortable airplane interior. Many factors influence passengers' comfort, such as expectations and environment (De Looze et al., 2010; Vink & Hallbeck, 2012). According to Krist (1993) and Bubb et al. (2015), comfort is established through six factors: anthropometry, climate, sound, vibrations, light and smell. These factors have been applied to airline travel in the following subsections.

## Literature Review

### Anthropometry

Anthropometry is the scientific study of measurements of the human body. When designing products such as aircraft seats, anthropometric data can be a valuable source of information. For instance, a study by Hiemstra-van Mastrigt (2015) comparing the dimensions of economy class aircraft seats to anthropometric measurements from a database demonstrated that current seats are not suitable for up to 21% of passengers due to the distance between armrests, which is too narrow to accommodate the hip width of some passengers. If the dimensions of the aircraft seat, such as width of the seat or the seat pitch (distance between two seats), are not well suited to the passenger, this will have an effect on the individual's perceived (dis)comfort.

### Climate

Ranging from 20°C to 27°C on intercontinental flights and 21°C to 31.7°C on continental flights, the temperature in an airplane cabin varies significantly (Pang et al., 2014). A self-controlled heated and cooled office seat contributes to maintaining neutral body temperature, however the perceived comfort is higher when using a heated seat in a cold environment than when using a cooled seat in a warm environment, as suggested by Pasut (2013). Therefore, providing passengers with the right means to control their body temperature might contribute to a better comfort experience.

### Noise

Aircraft interior sound levels depend on different factors, such as flying speed, altitude, and seat position (Quehl, 2001). The sound level (75 dB) inside an

aircraft at cruise flight altitude (Ozcan & Nemlioglu, 2006) mainly originates from the aircraft engines and does not cause permanent hearing loss (Mixson & Powell, 1985) or reach the discomfort threshold (Slater, 1985). However, the noise levels in the aircraft cabin can result in annoyance (Mellert et al., 2008). Despite this, Quehl (2001) has suggested that annoyance caused by sound is based on individual preferences. Therefore, providing passengers with the right means to cancel or control the environmental noise (earplugs, noise cancelling headsets) might contribute to a better comfort experience.

## Vibrations

Compared to other vehicles such as trains and cars, passengers in an aircraft at cruise flight altitude experience minor vibrations unless turbulence occurs. For instance, when passengers travel by train they experience significant lateral movement, which affects activities such as writing, eating and drinking (Bhiwapurkar & Saran, 2010; Corbridge & Griffin, 1991; Khan & Sundstrom, 2007; Khan & Sundström, 2004; Krishna Kant, 2007; Nassiri et al., 2011). In comparison, the vibrations experienced by most aircraft passengers are sufficiently minor that they do not affect most in-flight activities.

## Light

Light and color are well-studied environmental factors that influence human beings. In the literature review by Sokolova and Fernández-Caballero (2015) it was found that color influences emotions and is applied in numerous fields (e.g. psychology, medicine, design and architecture). Although the authors indicated that there are global trends in color perception, the use of specific colors for different socio-demographic groups (i.e. cultures and ages) should be exercised with caution, since people might react differently to the same stimuli. For example, kids like the colors yellow and red, but when they grow older this preference will change to blue or green (Sokolova & Fernández-Caballero, 2015). This should also be considered in the design of lighting in the airplane cabin, since the composition of passengers is diverse.

## Smell

Majid and Kruspe (2018) found that hunter-gatherer tribes in the tropical rainforest of the Malay Peninsula could name odors as easy as colors. However, the reduced importance of recognizing smells in modern (and sedentary) life has led to a reduced ability to communicate about smell using words (Engen, 1982; Majid & Kruspe, 2018). Despite its decreased importance, people do react to smell; odors


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can affect mood, physiology and behavior (Cardello & Wise, 2008; Herz, 2009; Holland et al., 2005). Therefore, it is important to be aware of this when designing airplane cabin interiors.

Although many studies have been conducted focusing on individual factors, the relationship and hierarchy between different human senses remains under-examined in scientific literature. Research by Quehl (2001) on the effects of aircraft interior sound and vibration on passenger comfort demonstrated that the sound pressure level contributed to approximately 70% of the comfort evaluation while the vibration magnitude contributed to about 30%. This was in line with the commonly reported dominance of noise in relation to subjective annoyance responses.

To indicate their relative significance, Bubb et al. (2015) proposed a generic hierarchical model of six discomfort sensations. In descending order, these are anthropometry, climate, sound, vibrations, light and smell. This model is established based on a study by Krist (1993). In this study participants were asked to indicate relevant factors that contribute to comfort experience. Anthropometry was mentioned most often by the interviewees, followed by climate, sound, vibration and light. Although smell was not mentioned by any of the participants, Bubb et al. (2015) suggested that smell must be a factor that contributes to comfort as well, because there is a direct connection between smell and the part of the brains that is responsible to emotion. Bubb et al. (2015) attributed the fact that smell is not mentioned by the participants to the unawareness of the participants, since they never experienced the effect of smell on comfort. Based on this, he suggested a hierarchical model, presented in a pyramid (see Figure 1). The base layer (smell) is most important, followed by other factors such as vibrations and climate. However, since the factors closer to the top of the pyramid were mentioned more often, Krist (1993) reasoned that it is less likely that these factors are accomplished yet.

In addition to this set of six environmental factors, more comfort factors have been described, such as expectations and time (Bazley, 2015). However, for the sake of manageable research not all factors influencing comfort are taken into account here, and only the influence of the six environmental factors smell, light, vibration, noise, climate and anthropometry are evaluated. The research question of this study is:

- What is the order of importance of the environmental factors as contributors to aircraft interior comfort experience, based on passenger expectations?

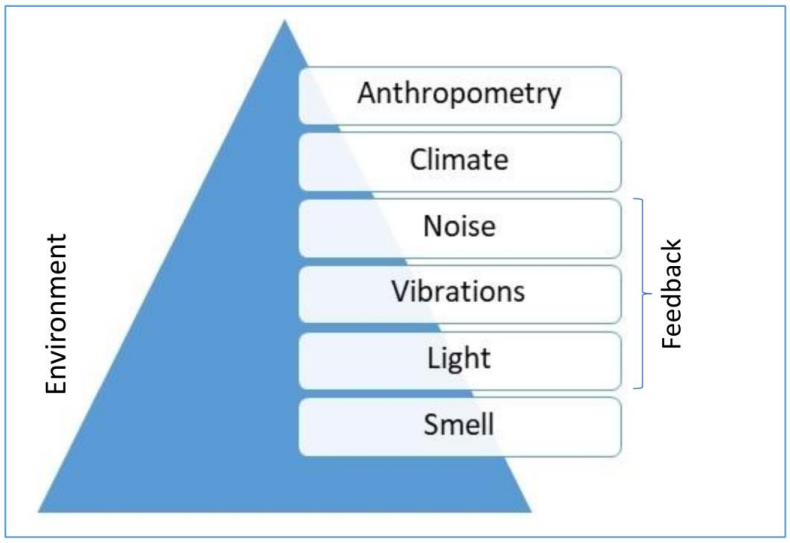


*Figure 1*. Hierarchy of environmental comfort factors represented in a pyramid (adapted from Bubb et al. (2015)). The environmental factors are ranked from most important (base of the pyramid) to least important (top of the pyramid).

## Study 1: Evaluation of Environmental Factors

### Method

In a questionnaire, respondents were asked to rank six different human senses: climate, vibration, light, noise, anthropometry and smell. These senses were presented to participants as 15 different "word pairs," and respondents were asked which element, according to their expectations, is the most important in experiencing a comfortable aircraft interior. For each of the environmental element pairs (Table 1) participants were asked to indicate which factor was more valuable to them. Respondents were recruited at the faculty of Industrial Design Engineering at Delft University of Technology. In total, 183 respondents between 19 and 64 years old (*mean*: 30.5, *SD*: 12.8), of which were 114 female and 66 were male (3 unknown), with flight experience completed the questionnaire. The scores for each environmental factor were analyzed with a Friedman test utilizing IBM SPSS Statistics 24, and significance was accepted at $p < 0.05$. When significance was found, a Wilcoxon signed rank test utilizing BM SPSS Statistics 24 was used to determine between which elements differences occurred. For the Wilcoxon signed rank test significance was accepted at $p < 0.05$. Additionally, respondents were allowed to provide comments on the questionnaire.

Table 1
*Environmental factors (each factor occurs five times)*

| Element 1 | Element 2 |
|---|---|
| **Climate** | Noise |
| **Vibration** | Light |
| **Light** | Climate |
| **Noise** | Light |
| **Anthropometry** | Smell |
| **Smell** | Climate |
| **Vibration** | Anthropometry |
| **Light** | Anthropometry |
| **Noise** | Vibration |
| **Vibration** | Smell |
| **Noise** | Smell |
| **Anthropometry** | Noise |
| **Climate** | Vibration |
| **Smell** | Light |
| **Anthropometry** | Climate |

## Results

The Friedman test found a statistically significant difference between the environmental factors, $\chi 2(5, N = 183) = 193.43, p < 0.001$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.01$. The average importance of anthropometry was 3.46 (*SD* = 1.54), noise 2.91 (*SD* = 1.38), smell 2.91 (*SD* = 1.65), climate 2.69 (*SD* = 1.50), and vibrations 1.91 (*SD* = 1.50), and light 1.11 (*SD* = 1.2). There were no significant differences between noise and smell ($Z$ = -.022, p = 0.982) and smell and climate ($Z$ = -1.238, $p$ = 0.216). However, there were significant differences between anthropometrics and noise ($Z$ = -.3220, $p$ = 0.001), climate and vibrations ($Z$ = -4.583, $p < 0.001$), and vibrations and light ($Z$ = -5.002, $p < 0.001$) (see Figure 2).

The element of anthropometry was, on average, indicated between 3 and 5 times as more important for experiencing aircraft interior comfort. The three elements of noise, smell and climate were indicated as more important approximately 3 times, the element of vibration twice and the element light just once. Three significant differences were found between anthropometry and noise, smell and climate, climate and vibrations and vibrations and light.

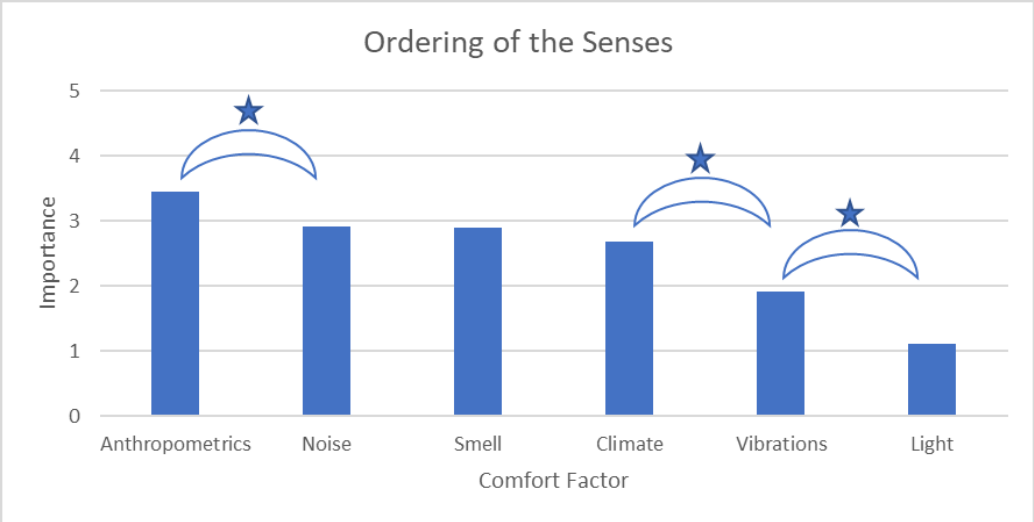


*Figure 2.* Ordering of the human senses from most important (5) to least important (0) for experiencing aircraft interior comfort (n = 183, the asterisk * indicates significance $p < 0.05$).

In 16% of the comments by respondents it was mentioned that their choice of most important factor is dependent on the situation. For example, one of the comments on climate stated, "Does climate refer to warm or cold air?" With regard to smell, one participant commented, "I hate a bad smell more than I love a nice smell."

## Discussion

This study illustrates that it is possible to create a hierarchy of environmental factors related to expected impact on comfort experience. The respondents indicated anthropometry as the most important factor, followed by noise, smell, climate, vibrations and finally light. This order differs from the discomfort pyramid proposed by Krist (1993) and Bubb et al. (2015). However, the respondents stated that the context of the factors was unclear, since the importance of each factor might depend on the performed in-flight activity (e.g. "I prefer a different temperature while sleeping than while walking"). Moreover, the factors were insufficiently explained (e.g. "Does climate refer to warm or cold air?"). Therefore, in order to provide reliable results, this study required repetition with a questionnaire that was clear and unequivocal, and which clarified context by adding an in-flight activity.

## Study 2: Evaluation of Environmental Factors in Relation to In-flight Activities

The study described in Section 2 of this article was repeated after improving the research design based on the feedback from respondents.

### Method

In a questionnaire, respondents were asked to rank six environmental factors of an airplane cabin for two activities, namely *sleeping* and *watching the in-flight entertainment (IFE) screen*. A general explanation of each factor was provided as follows:

- Seat: Adjustable seat to match personal body measurements
- Temperature: Manipulate temperature to personal preference
- Noise: Possibility to reduce cabin noise
- Vibrations: Control vibrations caused by the airplane
- Light: Control the intensity and color of the light
- Smell: Possibility to reduce bad odors in the airplane cabin

These senses were presented as 15 different "word pairs," and respondents were asked which factor, according to their expectations, is the most important in experiencing a comfortable aircraft interior for two different activities, sleeping or watching IFE. The survey was completed 168 times by respondents that did not participate in the first study. Respondents were recruited at the faculty of Industrial Design Engineering at Delft University of Technology. One response was not evaluated because the participant indicated that he did not have flight experience. The other 167 respondents were between 19 and 61 years old (mean: 26.6, SD: 9.0), of which were 98 female and 69 were male. The number of times each element was indicated as more important was recorded for each activity, and these scores were analyzed with a Friedman test (IBM SPSS Statistics 24). Significance was accepted at $p < 0.05$. When significance was found, a Wilcoxon signed rank test (IBM SPSS Statistics 24) was used to determine where differences occurred between elements. For the Wilcoxon signed rank test significance was accepted at $p < 0.05$.

### Results

Figure 3 and Figure 4 show the ranking of comfort aspects when sleeping and watching IFE.

There was a statistically significant difference in importance of each environmental factor, $\chi 2(5, N = 167) = 263.00$, $p < 0.001$ for the activity *sleeping*. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.01$. The average importance of the seat was 4.09 ($SD$ = 1.07), noise 2.86 ($SD$ = 1.29), temperature 2.80 ($SD$ = 1.38), light 2.01 ($SD$ = 1.34), vibrations 1.31 ($SD$ = 1.41), and smell 1.69 ($SD$ = 1.60). There were no significant differences between noise and temperature ($Z$ = -0.464, $p$ = 0.643), light and smell ($Z$ = -1.628, $p$ = 0.104) and smell and vibrations ($Z$ = -1.961, $p$ = 0.050). However, there were significant differences between the seat and noise ($Z$ = -7.135, $p < 0.001$), and temperature and light ($Z$ = -4.451, $p$ = 0.643).

For the activity *watching IFE*, a significant difference in importance of each environmental factor was found, $\chi 2(5, N = 167) = 219.04$, $p < 0.001$. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.01$. The average importance of the seat was 3.65 ($SD$ = 1.12), noise 3.43 ($SD$ = 1.42), temperature 1.87 ($SD$ = 1.37), light 2.47 ($SD$ = 1.16), vibrations 1.80 ($SD$ = 1.61), smell 1.45 ($SD$ = 1.64). There were no significant differences between the seat and noise ($Z$ = -1.374, $p$ = 0.170) temperature and vibrations ($Z$ = -0.523, $p$ = 0.601), and vibrations and smell ($Z$ = -1.788, $p$ = 0.074). However, there were significant differences between noise and light ($Z$ = -6.065, $p < 0.001$), and light and temperature ($Z$ = -3.577, $p < 0.001$).

The results for IFE and sleeping appear rather similar, except for temperature and light. Temperature was found to be more important than light for sleeping, while light was ranked as more important for IFE than temperature.

## Discussion

The results of the second study suggest that for the in-flight activities of watching IFE and sleeping, airplane passengers consider different human senses important (see Figure 5). Nevertheless, the seat (anthropometrics) is considered the most important factor for both activities. The first study shows anthropometry as the most important factor, noise as falling in the mid-range and vibration in the top, least important area. However, other factors appear to take different positions within the comfort pyramid. Therefore, it is possible that the way a factor is interpreted plays a role in the score it receives. The absence of light while sleeping has a different effect than watching a movie in the dark.


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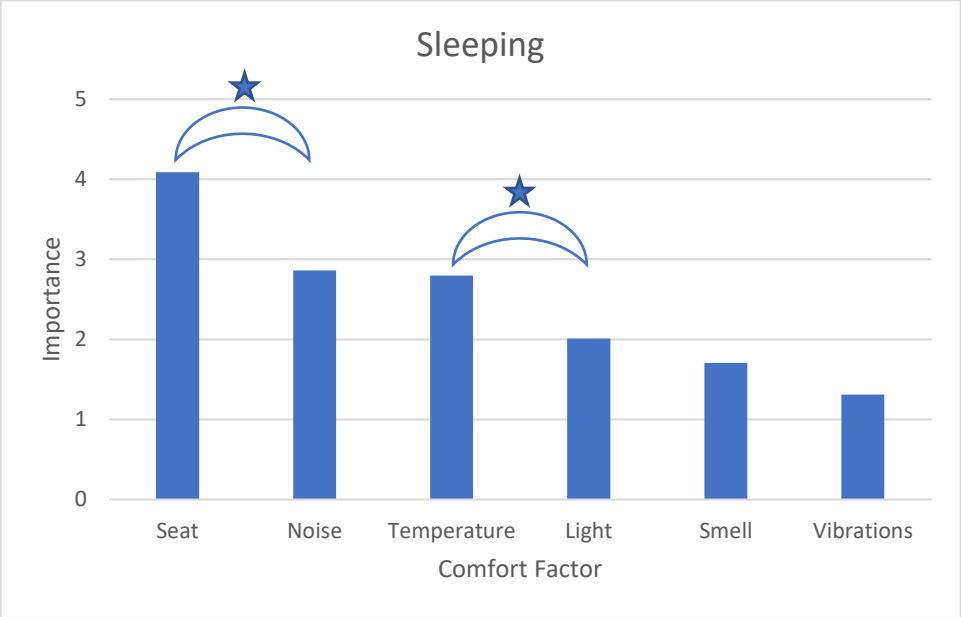


*Figure 3.* Ordering of the human senses from most important (5) to least important (0) for experiencing aircraft interior comfort while sleeping (n = 167, the asterisk * indicates significance $p < 0.05$).

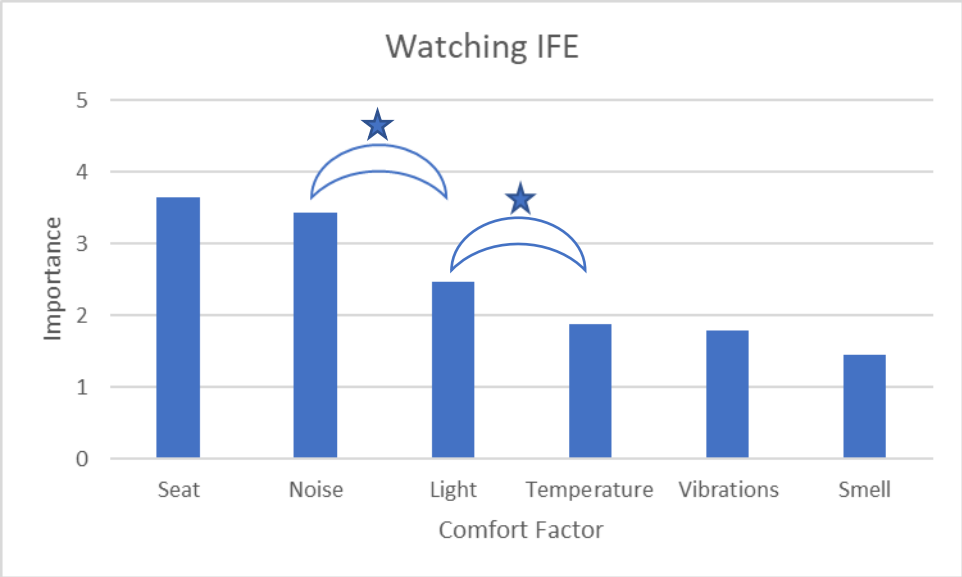


*Figure 4.* Ordering of the human senses from most important (5) to least important (0) for experiencing aircraft interior comfort while watching IFE (n = 167, the asterisk * indicates significance $p < 0.05$).

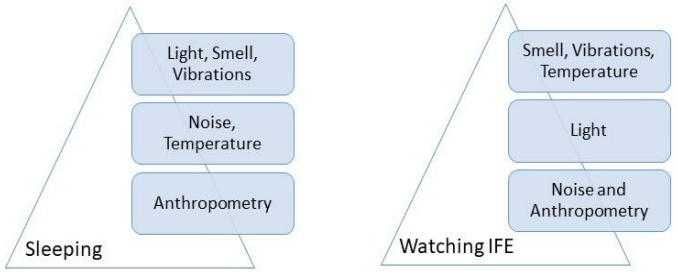


*Figure 5* The two new comfort pyramids for sleeping and watching IFE on the right (based on the outcomes of this research). The most important environmental factors are placed at the base, and the less important factors are placed at the top.

Anthropometry's importance is also seen in other studies. Kuijt-Evers (2007), for instance, demonstrated in hand tool research that while working with a screwdriver, the appearance of the tool (related to visual system) has almost no influence on comfort while the anthropometry (tool fit to the hand) has a strong influence.

There are some similarities between the findings of Krist (1993) and Bubb et al. (2015), since anthropometry is mentioned most in both studies. However, the position of this factor in the pyramids is different. Expectations and emotions influence passenger comfort (Ahmadpour et al., 2014; De Looze et al., 2010; Vink & Hallbeck, 2012), and might have influenced this order. For example, since passengers expect to have limited personal space in the airplane seat, they consider this aspect much more important than light or smell (since they have never experienced problems with these factors in the past). Also, passengers are not always aware of the influence of some of the environmental factors. For instance, noise does affect the human comfort experience unconsciously. A study by Mellert et al. (2008) found, for example, that more physical complaints were reported in a noisy airplane cabin. Similarly, the design of the airplane cabin ceiling affects the perceived seat comfort, air quality and temperature (McMullin, 2013). Therefore, passengers might consider some factors less important when in fact these factors have a considerable effect on actual comfort experience.

Although the outcomes of this research suggest a hierarchical order of factors that might give direction to prioritizing design efforts, Vink et al. (2016) discuss that optimizing every single element in the environment in order to optimize comfort is neither possible nor wise. Lewis et al. (2016) suggest that people can be distracted from sources of discomfort by a virtual environment. This technique


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appears to be more effective for distracting people from discomfort caused by restricted space than noise disturbances (such as a crying baby). Although rather counterintuitive, negative associations people might have with certain factors, such as noise, can also have positive side effects. For example, the presence of background noise is considered positive by train riders, as it masks other sounds like conversations between other passengers (Khan, 2003).

In the second questionnaire the environmental factors were clarified by providing definitions. Even though this was a major improvement on the initial questionnaire, respondents may still have interpreted the definitions differently (e.g. adjustable seat to match personal body measurements might refer to the adjustability of the width and/or the recline function). Therefore, more research is needed in order to define design requirements for each environmental factor that lead to an improved comfort experience. Future research is also needed to quantify the relationships between different factors of the comfort pyramid, and to research the generalizability of the outcomes to other fields (e.g. comfort of offices, car interiors).

## Conclusion

This study indicates that different in-flight activities require different environmental properties in order to facilitate passengers' comfort during their flight. The results from the second study (n = 167) suggest that a hierarchy of any comfort-related environmental factors depends on the performed in-flight activity.

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