Interactions between visual, auditory, and tactile senses in product sound quality evaluation

Daniel Västfjäll

Department of Applied Acoustics, Chalmers University of Technology, SE-412 96 Göteborg, Sweden, Email: danie@ta.chalmers.se

Introduction

Most previous sound quality research has focused on perceived product sound quality or vibration quality separately. However, Blauert and Jekosch [1] suggested that factors such as input from other sensory modalities than hearing must be considered to reach a more complete understanding of sound quality. For aircraft ride comfort, hearing, vision, and tactile senses interact and jointly determine the overall judgment of comfort and quality [2]. It is therefore important to study the joint effect of sound, vibration and visual input on subjective reactions and sound quality evaluation. To accomplish this a "virtual" aircraft allowing for simultaneous exposure to binaural sound, stereoscopic 3-D vision, and lateral feet vibrations was constructed. Using this Virtual Environment an experiment was performed where 16 research participants rated 12 stimuli combinations. The present research both focused on the effect of vibrations and visual input on sound quality perception and the joint effect of all senses on overall reactions. From previous research it was hypothesized that both vibrations and picture stimuli could modify sound quality perception. In line with some previous research it was expected that visual input decrease negative reactions. Vibration combined with sound should influence subjective reactions, but previous research is however ambiguous on the direction (increase/decrease in annoyance) of the effect.

Method

Participants: 16 participants (13 men) participated on a voluntary basis. Their mean age was 26.2 years (SD 4.3). All participants reported having normal hearing. They had previous experience as aircraft passenger (median number of flights was 15), but none had previously participated in sound and vibration experiments. They were compensated for their participation by two movie vouchers.

The virtual aircraft: The Virtual Aircraft is an attempt to efficiently model the auditory, tactile, and visual characteristics of an aircraft interior. A visual model of a generic aircraft interior was created using Kinetix 3D Studio MAX. The model consists of approximately 40000 polygons. In order to achieve a realistic visual stimulus, a radiosity simulation performed in Autodesk Lightscape with 72 light sources enhanced the model. The illuminated surfaces were converted to textures by the "mesh to texture" utility and applied to the MAX-model. To reduce the number of polygons and thus enhance rendering performance, some of these textures were projected onto polygon-reduced surfaces. The radiosity enhanced model was then exported to EON Reality EON Studio 3.01, which is a PC-based real-time visual rendering software. A WinNT P3-workstation with a Creative GeForce 3 card was used to render the visual scene. With this, a frame-rate of at least 20 Hz, as measured by the frame-rate prototype in EON Studio, was obtained. To give the participants a sense of airplane movement, surfaces with cloud textures were animated outside the aircraft. The scene was presented monoscopically to the participants over a Sony Glasstron HMD, and head-movements were tracked with a Polhemus FASTRACK electromagnetic tracking device. A screen-shot showing the visual scene presented to the participants is shown in Figure 1.

Figure 1: Screen-shot from the interior visual model of the Virtual Aircraft.

To administer and control the tactile stimuli an aircraft vibration simulator was developed. The simulator utilizes an electro-dynamic shaker exciter for vibrations in the x-direction (lateral; left-to-right) on a foot plate and is used in conjunction with an aircraft seat. Vibrations are generated through a Bruel and Kjaer 1027 sine wave generator fed by a Dynaco 400 power amplifier that is connected to the shaker. Sounds are presented in an acoustically well-damped room over STAX electrostatic headphones or over loudspeakers by the use of binaural sound reproduction. For the present purpose headphone reproduction was used.

Tactile stimuli and presentation: Two frequencies of vibrations were chosen, 16 and 95 Hz sine waves. The choice of frequencies was based on previous research reporting that these two vibration frequencies are dominant in the vibration spectrum of turboprop aircraft, corresponding to the fundamental blade-pass frequency and harmonic [3]. The vibrations were presented at a constant acceleration of 2 mm/s^2.

Auditory stimuli and presentation: Two binaural recordings of interior aircraft sounds from different seats in both turboprop aircraft were used (taken from [4]). Recordings were made during in-flight conditions on a TEAC DAT recorder with calibrated Sennheiser KE 4-211-2 microphones using a sampling frequency of 44.1 KHz. One sound had strong tonal components (tonal sound) whereas the other sound had significantly less tonal content (random sound).

Rating scales: The annoyance measure was a 9-point unipolar scale with verbal endpoints 'not at all' (0) to 'very much' (8). Participants were thoroughly instructed to rate the overall annoyance caused by the whole situation, and not only the noise.

Results

The ratings were analysed using within-subjects Analysis of Variance (ANOVA). The ANOVA model used was a 2(sound: random sound/tonal sound) x 3, (vibration: no vibration/LF/HF) x 2(picture: no picture/picture). From such a model three main effects corresponding to the different factors can be assessed (sound, vibration, picture). In addition, all possible interaction terms can be assessed (sound x vibration, sound x picture, picture x vibration, sound x vibration x picture). Greenhouse-Geisser correction of the degrees of freedom was used to correct for possible unequal variances (violation of sphericity). Only the annoyance and sharpness ratings are reported here.

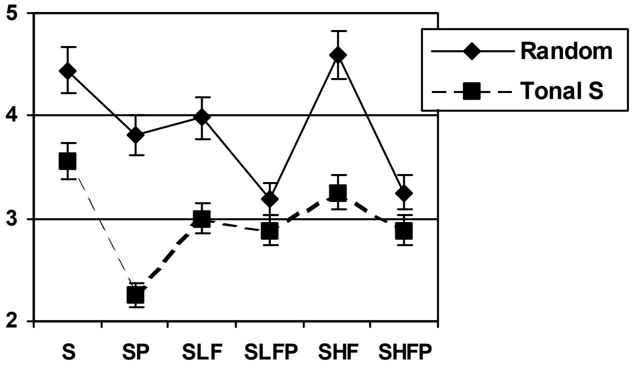

Figure 2: Mean ratings of overall annoyance for the 12 sound/vibration/picture combination. Note that S = sound only, SP = sound and picture, SLF = sound and LF vibration, SLFP = sound and LF vibration and picture, SHF = sound and HF vibration, SHFP = sound and HF vibration and picture.

Overall annoyance: The ANOVA for the overall annoyance ratings showed a significant main effect for sound F(1, 15) = 18.07, p<.001, where it was found that the random sound was generally perceived as more annoying than the tonal sound. A significant main effect was also obtained for picture, F (1,15) = 49.59, p<.001, where the presence of pictorial stimuli made the experience less annoying than in the no picture conditions. The three-way interaction between sound x vibration x picture was significant, F(1.59, 23.98) = 5.02, p<.05. As for valence the effect of the HF vibration more pronounced for the random sound than for the tonal sound. Also, as may be seen in Figure 2, the effect of picture was more pronounced for the tonal sound in the absence of vibrations, but stronger for the random sound in the presence of vibrations.

Conclusions

Overall, the present results suggest that multi-modal perception of an aircraft environment (e.g. auditory, visual, and tactile) differs from unimodal perception (auditory). These results are in agreement with both everyday perception as well as current theoretical and empirical findings that suggest that perceptual information from one sense (tactile) influences evaluation and perception of information in other senses (hearing) [5]. The present findings suggest that cross-modal integrations exists and are likely to influence subjective experience, evaluations, and judgments of aircraft comfort and quality. For subjective reactions to the different sound/vibration/pictorial combinations the present research showed that both sound and vibration decreased annoyance and increased pleasantness as compared to the sound only (substractive interaction).

The present research showed that a promising venue for future research and applications in passenger ride quality is to use virtual environments to mimic the cabin of an aircraft. Multi-modal systems like the virtual aircraft described here will help to minimize the difference between the laboratory and the real world. The continued use of such systems will provide new insights in interior aircraft cabin perception that pervious research focusing one a single modality not yet uncovered.

References

[1] Blauert, J., & Jekosch, U: Sound-quality evaluation – A multi-layered problem. Acta Acustica 83 (1997), 747-753.

[2] Griffin, M. J. *Handbook of human vibration*. Academic Press: London, 1990.

[3] Ingvarsson, I., & Västfjäll, D: A study on human response to vibrations in-flight and in the laboratory. In Proceedings of the 5th AIAA Aeroacoustics Conference, Seattle; WA. (1999), 1024.-1032.

[4] Västfjäll, D., Kleiner, M & Gärling, T: Affective reactions to interior aircraft sound quality. Acta Acustica 89 (2003), 693-701.

[5] Stein, B. E., & Meredith, M. A. *The merging of the senses*, Cambridge: MA. MIT press, 1997.