FEELING THE SOUND: AUDIO-TACTILE INTENSITY PERCEPTION

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In this study, an experiment was conducted to determine the influence of vibration on loudness perception. Vertical whole-body vibrations were produced using an individually calibrated electro-dynamic shaker. A pair of closed dynamic headphones was used for audio reproduction. A loudness matching experiment was carried out with 28 participants. In this experiment, sinusoidal sounds were presented in the absence and presence of simultaneous vibrations. Participants had to match the level of the acoustic stimuli while ignoring the tactile stimulation. The loudness matching experiment was carried out for four sinusoidal tones, at the frequencies of 10, 20, 63 and 200 Hz. Three different vibration levels (4, 8 and 12 dB above the vibration threshold for each participant) were used to study the influence of the vibration amplitude. Results indicate that whole-body vibration had a significant influence on loudness perception. When an acoustic stimulus was accompanied by vibration, the level of the acoustic stimulus was perceived one decibel higher on average.

INTRODUCTION

Perception is a multi-sensory phenomenon that involves the interaction of individual sensory modalities. Understanding this interaction is important for the design of virtual reality experiences, for consumer product design and for the automotive industry. First discussions about interaction between modalities appeared in as early as 1985, focusing on the interaction between vibration and sound in automobiles [1]. Nevertheless, whereas the mechanisms of single modalities are well understood today, the interactions between modalities have not been studied as extensively. To develop the best possible solutions that involve multiple modalities, the consideration of interactions between different modalities has become increasingly important. In this paper, we discuss one of these interactions: the influence of whole-body vibrations on loudness perception.

Sound and vibration are often coupled in real life. For example, when sitting in a car, a passenger not only hears the motor, but also feels vibration via his seat. Similarly, seats in a church vibrate during an organ concert. However, usually only one integrated event is consciously perceived. This raises the question whether the processing of sound and vibration is coupled in our brain. In our study, we examined the hypothesis that acoustic signals are rated as being louder in the simultaneous presence of whole-body vibration.

1. LITERATURE

Different neurological studies have revealed integration and interaction effects between auditory and tactile signals both in the auditory cortex of monkeys [2] and in the cerebral cortex of the human being [3]. In addition, tactile stimuli alone have been found to activate the auditory cortex [4,5]. These studies indicate an early interaction of the two modalities in our brain. However, the measurement of action potentials does not provide information about the influence of this interaction on a specific perceptual dimension, such as loudness.

Several psychophysical studies have investigated audio-tactile loudness perception. The direct influence of hand vibration on loudness perception has been demonstrated by Schürmann [6]. The results showed that audio-tactile stimuli were perceived 12.4 % louder than purely auditory stimuli, corresponding to a sound pressure level difference of 1.1 dB. Other studies did not find a significant influence of vibration on loudness perception. Specifically, Bellmann [7] determined only a slight difference while measuring the 60-phon loudness contour with and without simultaneous whole-body vibration. Using sinusoidal and broadband signals (automotive noises), Lange [8] also did not find an influence of whole-body vibration on loudness perception.

The conflicting results across the aforementioned studies, which differ from each other in terms of both the method and the stimuli, motivate the further investigation of the influence of vibration on loudness perception in the current study. Additional variables, including vibration frequency and vibration amplitude, will also be taken into account.

2. EXPERIMENT

2.1 SETUP

Figure 1 shows the general setup used to present sound and vibration. The audio signals were delivered through an external Hammerfall DSP Multiface II sound card, amplified by a Phone-Amp G93 and reproduced through a set of Sennheiser HDA 200 closed dynamic headphones. Masking pink noise was reproduced throughout the whole experiment at 74 dB(A).

Whole-body vibrations were generated vertically using an electro-dynamic shaker. The subject was asked to sit on a flat, hard, and wooden seat with both feet on the ground. The transfer characteristic of the vibrating chair was strongly dependent on the individual person [9]. This phenomenon is referred to as the body-related transfer function (BRTF). The BRTF of each subject was individually monitored using a vibration pad (B&K Type 4515B) and a Sinus Harmonie Quadro measuring board, and compensated using inverse filters in Matlab.

The participant was able to control the amplitude of a test stimulus using a rotary knob that was infinitely adjustable and did not possess any indicators, such as on or off markings (Griffin Technology, PowerMate). During the experiment, the control knob was used in the same way as the volume control of a stereo system.

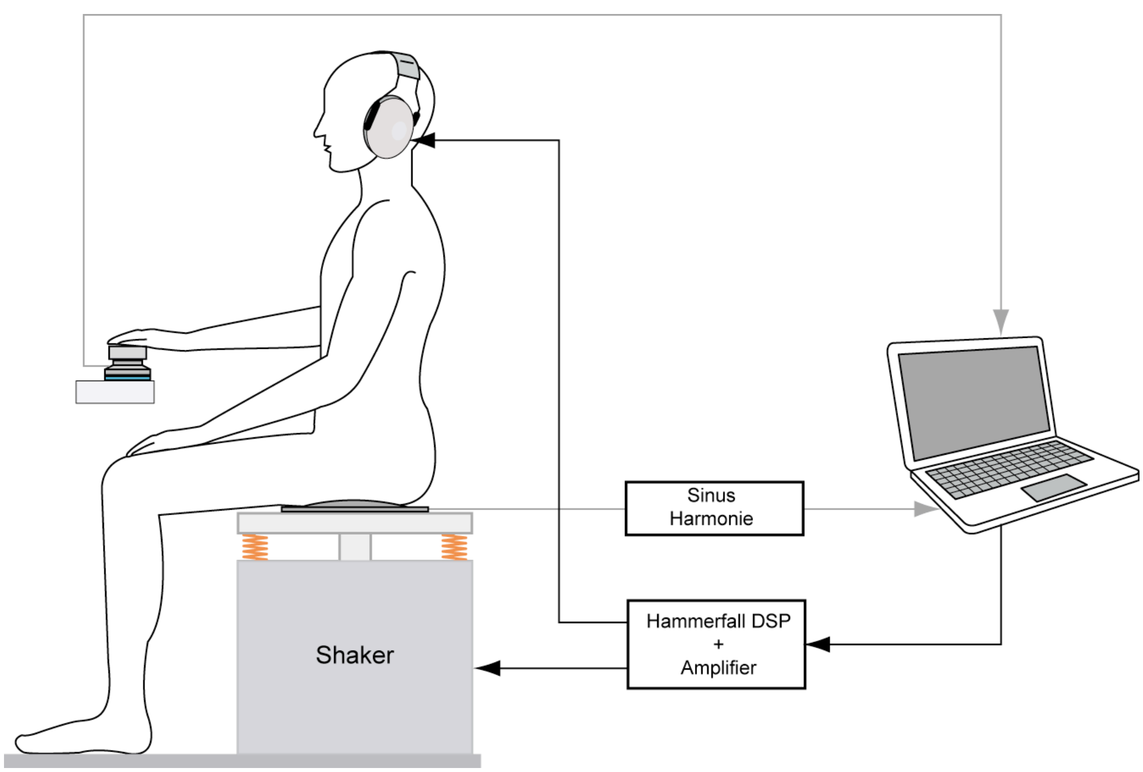

Fig.1. Experimental setup with subject sitting on a wooden vibration chair and wearing closed dynamic headphones (Sennheiser HDA 200). The vibrations were monitored using a vibration pad (B&K 4515B).

2.2 SUBJECTS

Twenty-eight subjects voluntarily participated in the experiment (16 male and 12 female). Most of the participants were students. Participants were between 19 and 52 years old (mean 27.3 years), had no any hearing or spinal damage and had not been previously involved in psychophysical experiments.

2.3 STIMULI

Sinusoidal stimuli were selected to investigate the influence of vibration frequency on loudness perception. The use of sinusoidal stimuli is ecologically valid, because acoustical and vibratory sinusoidal components are often perceived simultaneously, such as when driving a car or during a concert. The frequencies 10, 20, 63 and 200 Hz, which can be perceived by both auditory and tactile senses, were chosen. To analyze the influence of vibration level, vibration amplitudes were generated with 4, 8 and 12 dB above the individual tactile perception threshold for each subject.

The reference tone was chosen with a constant sensation level of 10 dB with reference to the individual detection threshold in 74 dB(A) pink noise.

2.4 PROCEDURE

The task was to compare a reference tone without vibration with a test tone reproduced simultaneously with a vibration. During this comparison, the volume level of the test tone could be adjusted using the rotary knob. Participants were instructed to focus solely on the loudness of the sound. A trial was complete when a participant judged both of the tones as equally loud. A diagram of a sample trial is shown in Figure 2. The reference tone without vibration and the test stimulus with vibration were played back in turns. Each tone was one second long and separated from adjacent tones via half-second breaks. The loudness matching trial was repeated ten times for each participant.

Additionally, a purely acoustical reference loudness matching was carried out, by having participants compare a test tone without vibration with a reference tone without vibration.

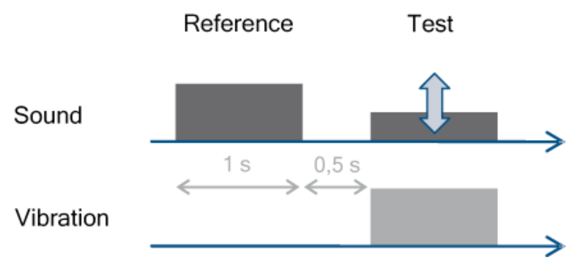

Fig.2. Experimental procedure: the reference and test tones were presented in alternation until a participant was satisfied with her/his loudness matching. The amplitude of the acoustical reference stimulus was fixed at a sensation level of 10 dB. The amplitude of the acoustical test stimulus could be adjusted using a rotary knob. Throughout each trial, the vibration amplitude remained constant at 4, 8 or 12 dB sensation level.

3. RESULTS AND DISCUSSION

The results can be seen in Figure 3. As expected, when no vibration was reproduced, a level difference of 0 dB between reference tone and adjustable test tone was observed. When the test tone was accompanied by vibration, its adjusted level fell, on average, 1 dB lower than the reference tone (ANOVA, $p < 0.05$). In other words, the simultaneous presence of vibration had a significant influence on loudness perception. Interestingly, as shown in a series of pairwise comparisons, there were no significant differences across vibration levels nor across frequencies. However, bigger standard deviations were observed at 63 Hz, though the reasons for this effect were unclear."

At first glance, a 1-dB difference in sound pressure level may appear relatively small. However, the dynamic range of the auditory system decreases with decreasing frequency. Thus, a small increase in sound pressure level can change the perceived loudness from barely perceivable to loud [10]. The increased loudness perception cannot be explained by bone conducted sound from the vibration chair. If this were the case, the value of the acceleration level should influence loudness matching. As this was not the case in our data, an integration effect provides a more likely explanation.

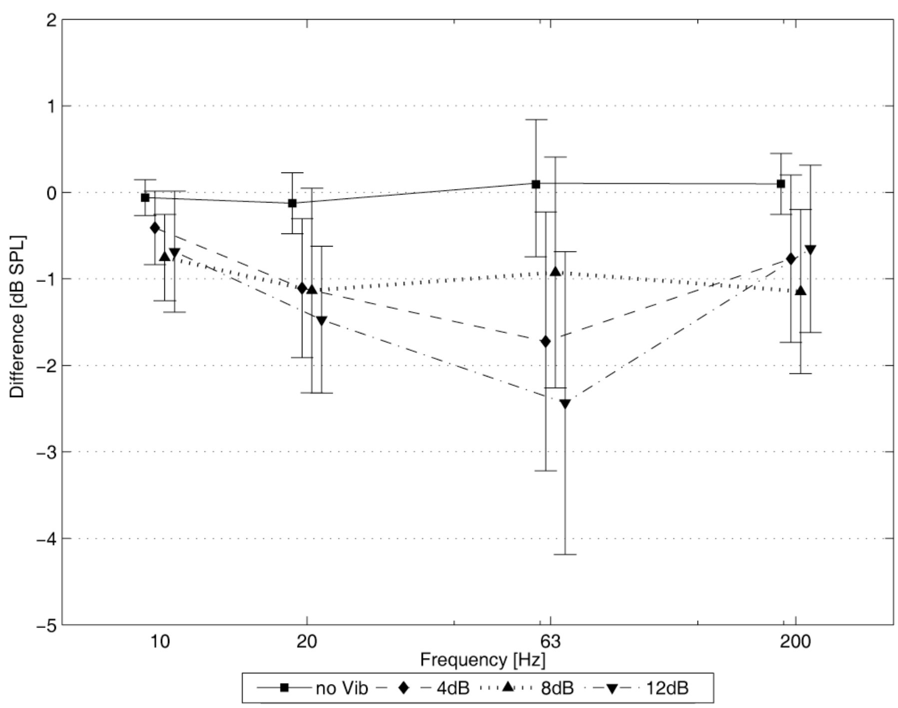

Fig.3. Results of the loudness matching experiment showing mean values and standard deviations. The difference between the adjusted level of the reference tone and the level of the test tone is presented for all vibration conditions.

The results of this study essentially deviate from the results of Bellmann [7] and Lange [8], who did not observe whole-body vibration to have an influence on loudness perception. At the same time, the observed effect in our study has the same order of magnitude as reported by Schürmann [6]. Several factors might explain the differences between our results and those in the literature:

- The participants in the Lange [8] study were more experienced than those in this study. This may influence study findings due to the tendency for experienced participants to judge loudness more critically than do inexperienced participants.
- In this study, to ensure clearly perceptible vibrations, the acceleration level was adjusted according to the perception thresholds of individual participants.
- Participants adjusted loudness using an infinite rotary knob with no markings, and were thus forced to rely solely on the rendered signals.

The consequences of using different psychophysical methods should be compared in detail in a subsequent study. Furthermore, the influence of higher acceleration levels on loudness perception is another interesting direction for future research.

REFERENCES

[1] Tamura, Yasushi; Hiraga, Masaharu; Usagawa, Tsuyoshi; Ebata, Masanao: *The Effect of Low Frequency Vibration on Sound Quality of the Automobile Audio System - Proposal of a New Automobile Audio System*, 1985.

[2] Kayser, C.; Petkov, C. I.; Augath, M.; Logothetis, N. K.: *Integration of touch and sound in auditory cortex*, Neuron 48, 10, Nr. 2, 2005, 373-384.

[3] Foxe, J. J.; Wylie, G.; Martinez, A.; Schroeder, C.; Javitt, D.; Guilfoyle, D.; Ritter, W.; Murray, M.: *Auditory – somatosensory multisensory processing in auditory association cortex: an fMRI study*, J Neurophysiol 88, 2002, 540-543.

[4] Foxe, J. J.; Morocz, A. I.; Murray, M. M.; Higgins, B. A.; Javitt, D. C.; Schroeder, C. E.: *Multisensory auditory – somatosensory interactions in early cortical processing revealed by high-density electrical mapping*, Cognit Brain Res 10, 2000, 77-83.

[5] Caetano, Gina: *Brain Mechanisms of Audiotactile and Audiomotor Interactions*, Helsinki University of Technoloy, Diss., 2007.

[6] Schürmann, Martin; Caetano, Gina; Jousmäki, Veikko; Hari, Riita: *Hands help hearing: Facilitatory audiotactile interaction at low sound-intensity levels*, J. Acoust. Soc. Am. 115, 2004, 830-832.

[7] Bellmann, Michael A.: *Wahrnehmnung von Schall und Vibrationen im tiefrequenten Bereich*, Carl von Ossietzky - Universität Oldenburg, diploma thesis, 1999.

[8] Lange, Simon: *Multimodale Einflüsse auf die auditorische Wahrnehmnung*, RWTH Aachen, diploma thesis, 2004.

[9] Altinsoy, M. E.; Merchel, S.: *BRTF - Body Related Transfer Functions for Whole-Body Vibration Reproduction Systems*, Proceedings of DAGA, 2009, Rotterdam, Netherlands.

[10] Møller, H.; Pedersen, C.S.: *Hearing at Low and Infrasonic Frequencies*, Noise & Health 4, 2004, Nr. 23, 37-57.