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Comparison of the perceived intensity of time-varying signals in the tactile and auditory domain

Sebastian MERCHEL; Jing DOU; M. Ercan ALTINSOY
TU Dresden, Lehrstuhl für Akustik und Haptik

ABSTRACT

Most natural signals vary with time. Impulsive sound and vibrations in cars are typical examples. The perceived intensity of such signals is time-dependent too. This study investigates the influence of the stimulus duration of sinusoidal vibration bursts on the perceived intensity of seat vibrations. The resulting tactile vibration magnitude is discussed in comparison with the auditive loudness perception. An experiment was conducted, using vertical seat vibrations with frequencies of 40 Hz, 80 Hz, 160 Hz and 320 Hz. The length of the test stimuli varied between 40 ms and 3000 ms. The task of the participants was to adjust the intensity of the test vibration to the perceived magnitude of a reference vibration with the same frequency. A stimulus duration of 1000 ms was chosen for the reference. The acceleration level of the reference vibration was set to 30 dB above the individual perception threshold. The results show a decrease of perceived vibration magnitude with decreasing burst duration if the stimulus is shorter than 320 ms. These data help to improve the modelling of tactile intensity perception. The final goal is to define a new perceptually motivated measurement for the perceived vibration magnitude M comparable to auditory loudness N.

Keywords: Vibration, Magnitude, Intensity, Perception, Loudness,
I-INCE Classification of Subjects Numbers: 49.1, 63.1

INTRODUCTION

Sound and vibrations often vary with time. It is well known from audition that the perceived loudness is a function of stimulus length for short signal durations. This study investigates the influence of the stimulus length of sinusoidal seat vibration bursts on the perceived vibration magnitude.

1. EXPERIMENTAL DESIGN

1.1 Setup

This study was conducted using an electrodynamic shaker (self-made, based on an RFT Messelektronik Type 11076 with an Alesis RA 150 amplifier). Seat vibrations were generated vertically, as shown in Figure 1.

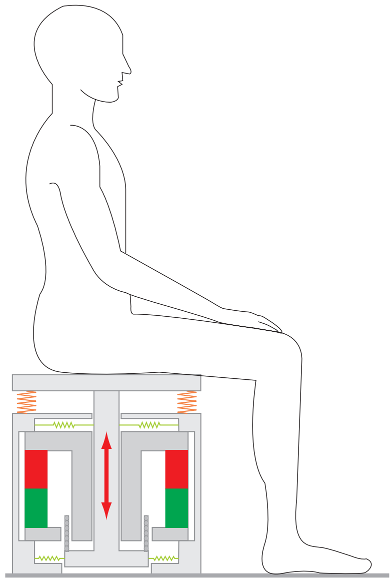

Figure 1 – Vibration chair with electrodynamic exciter.

The subjects were asked to sit on a flat, hard wooden seat (46 cm x 46 cm) with both feet flat on the ground. If necessary, plates were placed beneath the subjects feet. The transfer characteristic of the vibrating chair (relation between acceleration at the seat surface and input voltage) was strongly dependent on the individual person. This phenomenon is referred to as the body- related transfer function (BRTF). Differences of up to approximately 10 dB have been measured for different subjects [1]. The BRTF were compensated for using inverse filters in Matlab. This resulted in a flat frequency response over a broad frequency range (±2dB from 10 to 1000 Hz). A corresponding BRTF, with and without compensation, is shown in Figure 2.

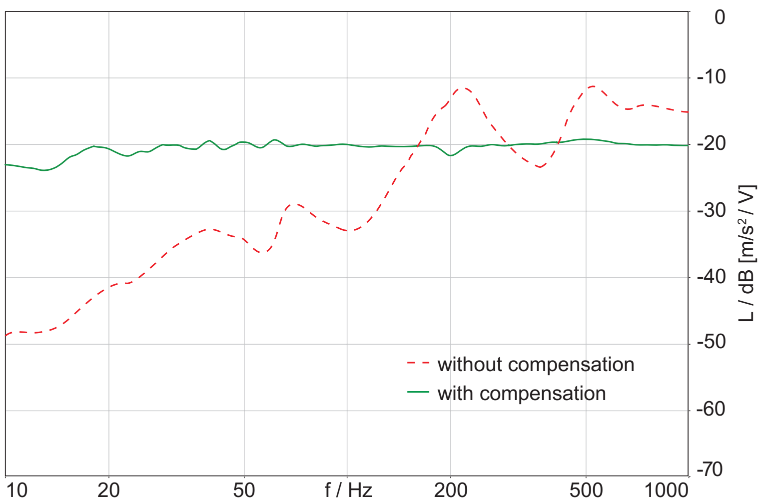

Figure 2 – Body-related transfer functions (FFT 65536, 1/24th octave intensity averaging) measured at the seat surface of the vibration chair, with and without compensation.

1.2 Subjects

Twenty subjects (eight male and nine female) voluntarily participated in the experiment. Most of the participants were students with a mean age of 25.4 years. The participants had no hearing impairments or spinal damage. Most of them never participated in a perceptual experiment before.

1.3 Stimuli and Procedure

The dependence between the duration of vertical seat vibrations and the perceived intensity should be examined. The task of the participant was to match the amplitude of a test vibration to the perceived intensity of a reference vibration. Both vibrations had the same frequency. Four sinusoidal frequencies were selected for this study from a broad frequency range: 40 Hz, 80 Hz, 160 Hz and 320 Hz. The duration of the test stimuli varied in seven steps between 40 ms and 3000 ms. The duration of the reference was chosen to be 1000 ms. All signals were faded in and out using ramps of 10 ms with the shape of half a Hann window. To ensure that all vibrations were clearly perceptible, the acceleration level of the reference vibration was set to 30 dB above the perception threshold (30 dB SL, sensation level). The selected reference stimuli are shown in Figure 3 together with perception thresholds for vertical seat vibrations.

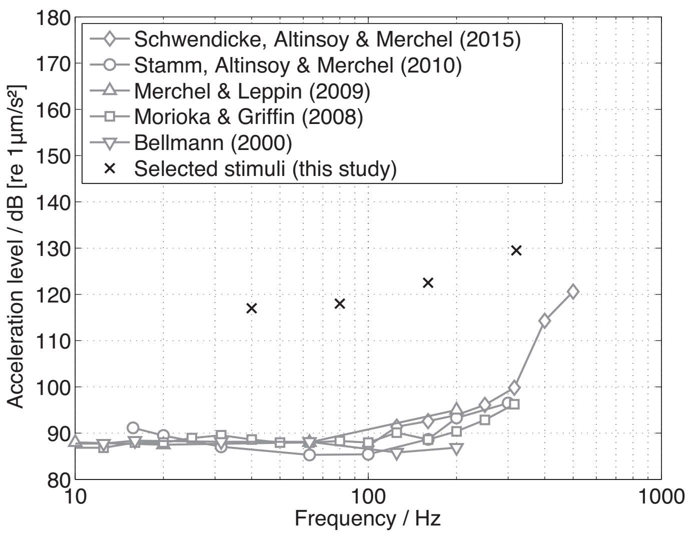

Figure 3 – Selected reference stimuli and perception threshold for vertical seat vibrations [2-6].

The subjects were able to adjust the intensity of the test vibration adaptively using a rotary control knob with a minimum step size of 0.25 dB. The knob was infinitely adjustable and did not possess any visual indicators, such as an on-or-off mark (Griffin Technology, PowerMate).

Figure 4 illustrates the temporal procedure of one experimental trial. The reference and test vibrations were presented in alternation. Between the stimuli a short break of 400 ms was inserted. A random offset was used for the initial acceleration level of the test vibration for each trial. The participant adjusted the amplitude of the test vibration until she/he was satisfied with her/his intensity match. By pressing the knob the trial was stopped. Each intensity match was repeated twice for each subject. This process resulted in a total of 56 trials (4 frequencies x 7 durations x 2 repetitions). The entire experiment lasted approximately 12-25 min per participant.

Figure 4 – Experimental procedure: the reference and test vibrations were presented in alternation until a participant was satisfied with her/his intensity matching. The amplitude of the reference stimulus was fixed at a level of 30 dB above the threshold. The amplitude of the test stimulus could be adjusted.

2. RESULTS

Figure 5 shows the mean values and the inter-individual standard deviations of the adjusted level difference between test vibration and reference vibration as a function of test stimulus duration for a frequency of 40 Hz. A test stimulus with 1000 ms duration corresponds to the reference. As expected, a level difference of 0 dB is observed in this case. Longer stimulus durations show the same behavior. A reduction of the test stimulus duration results in an increased level compared to the reference condition. This means that the perceived intensity of a vibration increases with increasing stimulus duration, although the acceleration level is kept constant. This hold true up to a certain threshold (approximately 320 ms).

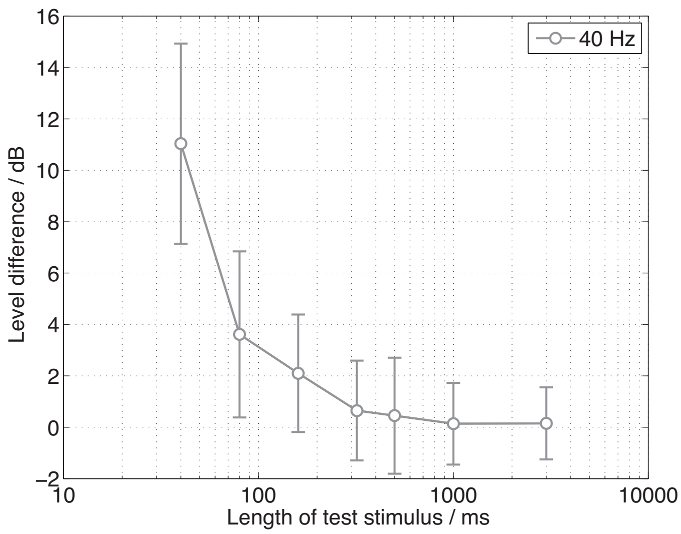

Figure 5 – Results of the intensity-matching experiment, indication the mean values and standard deviations. The difference between the adjusted level of the test vibration and the level of the reference vibration is presented as a function of test stimulus duration. The vibration frequency was 40 Hz.

A similar tendency can be observed in Figure 6 for all four frequencies. An increase of the slope for very short stimulus durations (< 80 ms) is noticeable. The effect is particularly strong at lower frequencies (40 Hz and 80 Hz). In this case, only few oscillation periods are contained in the stimulus. The truncation of the stimulus by windowing the signal results in spectral broadening, which might explain the increase.

Presumably, the data overestimates the effect for these short durations.
The variance is comparable for all frequencies. It increases with increasing difference between test stimulus duration and reference duration (one second). For clarity, standard deviations are plotted solely for 40 Hz.

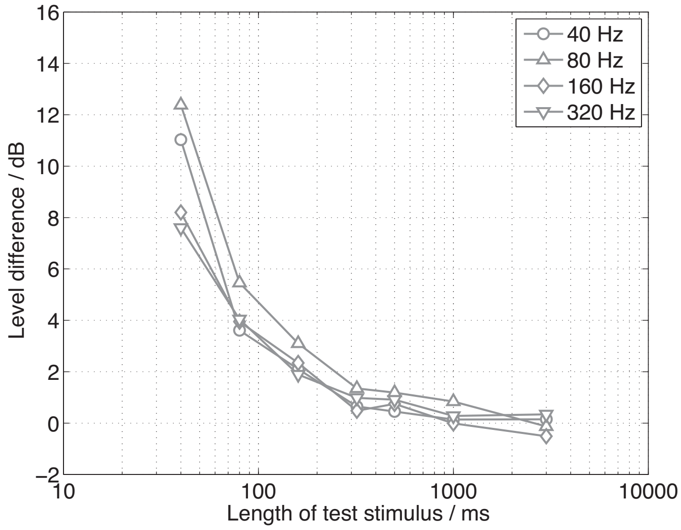

Figure 6 – Difference between the adjusted level of the test vibration and the level of the reference vibration (mean) as a function of test stimulus duration for all four frequencies.

A similar relation between stimulus duration and perceived intensity is known from audition. Several studies report that the auditory threshold of detection decreases with increasing duration. This relationship holds true for various types of stimuli over a broad frequency range [7]. Figure 7 presents data for an acoustic stimulus frequency of 250 Hz [8,9]. The curves follow approximately the prediction made by the theory of temporal summation, which was formulated by Zwislocki [10]. A similar trend can be seen in the current data which is plotted in Figure 7 for comparison.

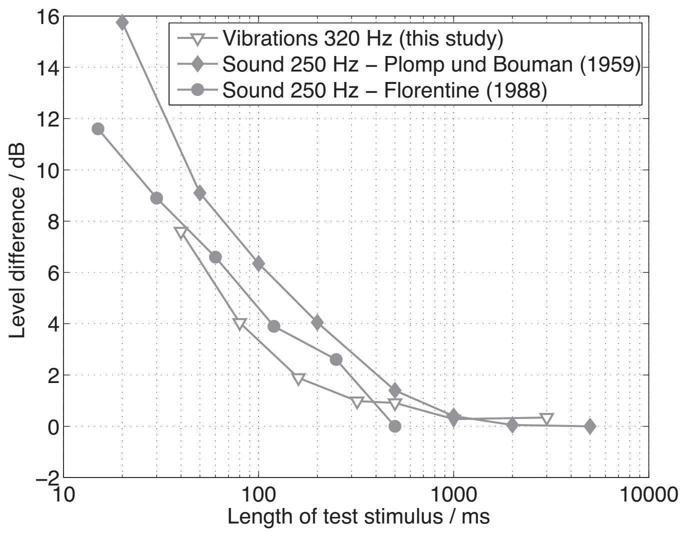

Figure 7 – Comparison of the results from this study for tactile perception of seat vibrations (frequency: 320 Hz) with literature data for audition [8,9]. Shown with closed symbols is the auditory threshold shift as function of stimulus duration at a frequency of 250 Hz.

3. SUMMARY AND OUTLOOK

The perceived intensity of sinusoidal seat vibrations was investigated for four frequencies between 40 Hz and 320 Hz with varying stimulus durations. The resulting data show an increase of perceived vibration magnitude with increasing burst duration up to a stimulus length of approximately 320 ms. The results agree well with other studies, which investigated vibration perception at the hand. Temporal energy integration has been reported for short vibration bursts in the Pacinian system [11]. The selected frequencies of the seat vibrations used in this study stimulate the Pacinian receptors too. No energy integration has been found for other tactile receptors [12,13].

The results from this study help to improve the modelling of tactile intensity perception. The final goal is to define a new perceptually motivated measurement for the perceived vibration magnitude M comparable to auditory loudness N [14]. For this purpose, other effects like masking or adaptation for prolonged stimulation have to be considered. In addition, the stimulation of other body parts with different contact areas or stimulation with different vibration directions is interesting.

REFERENCES

1. Altinsoy M. E. and Merchel S. *BRTF - body related transfer functions for whole-body vibration reproduction systems*. In Proceedings of NAG/DAGA, Rotterdam, The Netherlands, 2009.
2. Schwendicke A., Altinsoy M. E. and Merchel S. *Was fühlen wir noch? – Ganzkörperschwingungsfühl-schwellen für hohe Frequenzen*. In Proceedings of DAGA, Nürnberg, Germany, 2015.
3. Stamm M., Altinsoy M. E. and Merchel S. *Frequenzwahrnehmung von Ganzkörperschwingungen im Vergleich zur auditiven Wahrnehmung I*. In Proceedings of DAGA 2010 - 36th German Annual Conference on Acoustics, Berlin, Germany, 2010.
4. Merchel S., Leppin A. and Altinsoy M. E. *Hearing with your body: The influence of whole-body vibrations on loudness perception*. In Proceedings of ICSV - 16th International Congress on Sound and Vibration, Krakow, Poland, 2009.
5. Morioka M. and Griffin M. *Absolute thresholds for the perception of fore-and-aft, lateral, and vertical vibration at the hand, the seat, and the foot*. J. Sound and Vib., 314(1-2):357–370, 2008.
6. Bellmann M. A. *Perception of whole-body vibrations: From basic experiments to effects of seat and steering-wheel vibrations on the passengers comfort inside vehicles*. PhD thesis, Carl von Ossietzky - University Oldenburg, 2000.
7. Garner W. *The effect of frequency and spectrum on temporal integration of energy in the ear*. J. Acoust. Soc. Am., 19(5):808–815, 1947.
8. Plomp R. and Bouman M. *Relation between hearing threshold and duration for tone pulses*. J. Acoust. Soc. Am., 31(6):749–758, 1959.
9. Florentine M., Fastl H. and Buus S. *Temporal integration in normal hearing, cochlear impairment, and impairment simulated by masking*. J. Acoust. Soc. Am, 84(1988):195–203, 1988.
10. Zwislocki J. J. *Theory of temporal auditory summation*. J. Acoust. Soc. Am., 3(8):1046–1060, 1960.
11. Verrillo R. T. *Temporal summation in vibrotactile sensitivity*. J. Acoust. Soc. Am., 37(5):843–846, 1965.
12. Gescheider G. A. and Joelson J. M. *Vibrotactile temporal summation for threshold and suprathreshold levels of stimulation*. Perception & Psychophysics, 33(2):156–162, 1983.
13. Gescheider G. A. *Evidence in support of the duplex theory of mechanoreception. Sensory Processes*. 1(1):68–76, 1976.
14. Merchel, S. *Auditory-Tactile Music Perception*. ISBN: 978-3-8440-3161-4, Shaker Verlag, Germany, 2014.