Influence of frequency and magnitude on the perception of vertical whole-body vibration

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1 Introduction

The interest in human response to vibration becomes more and more public because number of mechanized sources of vibrations in daily life has enlarged and the number of exposed persons has increased. Existing standards, for example, ISO 2631-1/2 [1, 2], refer to sinusoidal excitation based on vibration perception in buildings. These standards address, i.e., perception thresholds of whole-body vibrations in all directions or equivalent-comfort contours. Existing data in literature on the perception of sinusoidal whole-body vibration show considerable differences to the present standards [e.g., 3]. However, data from different laboratories deviate from each other too, probably due to differences of the used psychophysical measurement method [3]. Additionally, incomplete details exist in the literature for basic experiments like difference thresholds in magnitude and frequency. Nevertheless, the benefit of more and better information and knowledge about the perception of vibrations admit of improving human response to vibration models (HRVM) so that 'well-being' would increase and the annoyance experienced from vibrations would be reduced.

Therefore, four basic experiments were carried out with new and reliable measurement methods: (i) perception threshold, (ii) and (iii) difference thresholds in level and frequency and (iv) equal-vibration level contours.

2 Experimental METHOD

2.1 Subjects

Up to 17 volunteers participated in the experiments. Their age ranged from 26 to 33 years. All subjects were free of injury or history of relevant illness. The posture of the subjects was normal and preferably comfortable on the seat [after existing guidelines 4]: feet on the rigid shaker-table of the vibrating system, sitting with an upstanding upper part of the body, leaning with the backside against the backrest and no existing armrests. All experiments were carried out after existing guidance on safety aspects of tests and experiments with people [5].

2.2 Apparatus and stimuli

Vertical sinusoidal whole-body vibrations were produced by using a vibration test plant, called "vibration-floor", which was developed at the University of Oldenburg in cooperation with the itap GmbH [6]. The test vibration frequency f_S varied between 5 to 200 Hz. The duration of the stimuli was 2 s (closed symbols) for $f_S \leq 12.5$ Hz and 1 s (open symbols) for higher frequencies. A signal duration of 2 s was used due to the finite integration time of the mechano-receptor at low frequencies and, therefore, to prevent an influence of the signal duration on the results [6]. The 'vibration-floor' is optimized to produce just vertical whole-body vibrations and simultaneously emits no or very low sound pressure levels. The system is located in a nearly silent measuring environment (L_{Aeq} =42.4 dB(A)). Signal generation and presentation during all experiments were computer controlled using the AFC software package for matlab from MATHWORKS, developed at the University of Oldenburg.

2.3 Procedure

A three-interval, 3-AFC paradigm was used to measure absolute and detection thresholds. A 2-down 1-up procedure was taken. Subjects had to identify the one randomly chosen interval containing the signal vibration. A two-interval, 2-AFC paradigm was used to determine the equal-vibration level contours with a one-down one-up procedure. The subjects had to identify the interval in which they felt the strongest vibration. The three or two observation intervals were separated by 500 ms non-vibrating intervals.

3 Results

3.1 Perception Threshold (PT)

17 subjects (5 female, 12 male) participated in this measurement. The results of (absolute) perception thresholds were similar for all subjects. Therefore, the averaged (mean) data are presented, Figure 1. The PT was measured for test vibration above 16 Hz with and without the presence of an audible masker (Gaussian noise at 69 dB(A)) to mask possible emitted sound from the vibration test plant. The audible masker has no influence on the PT therefore just the averaged results from measurements in presence of the masker are shown [6]. Additionally, several literature data (some are based on an illustration in [3]) and standard data of existing standards [2] are diagrammed in comparison to results of this study.

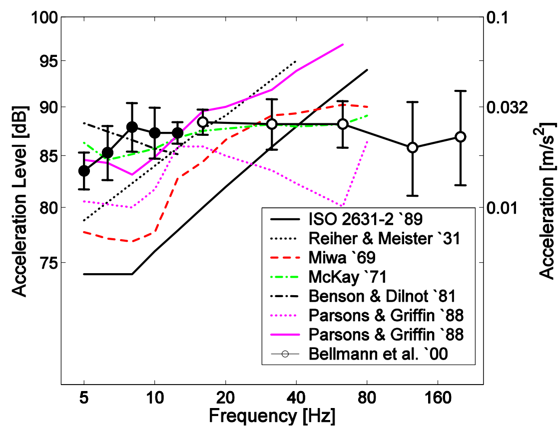

Figure 1: The averaged perception threshold of 17 subjects is shown in comparison to literature data (some are based on an illustration in [3]) and standard data [2].

3.2 Detection Threshold

In a second and third experiment detection thresholds of the test vibration magnitude and frequency were determined. The relative difference threshold in a stimulus magnitude or frequency can be derived from detection thresholds. These differences are often signified as just noticeable differences (JNDs).

Just Noticeable Differences in Level (JNDL)

The averaged results for JNDLs of 16 subjects (5 female, 11 male) are shown as a function of frequency. The reference acceleration level was 96 dB. However, four different types of mechano-receptors are found in human skin which are responsible for vibrotaction: slow adapting (SA I and II), rapidly adapting (RA) units and Pacinian corpuscles (PC). These mechano-sensitive units differ with regard to functional properties, especially in frequency range, Figure 2.

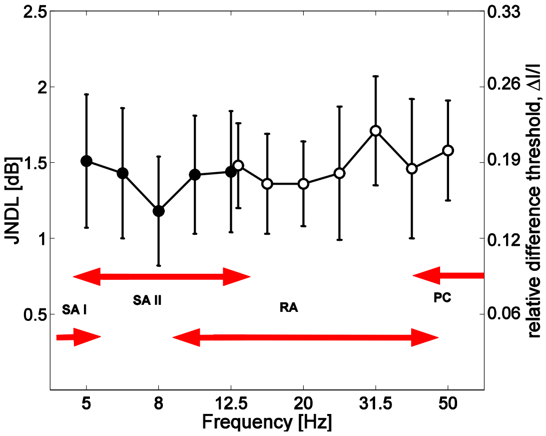

Figure 2: JNDLs are plotted as a function of frequency (left y-axis). On the right y-scale the relative difference thresholds (ΔI/I) are denoted. Additionally, the frequency ranges for the four vibrotactile units are diagrammed.

Just Noticeable Differences in Frequency (JNDF)

The individual (stars) and interindividual (diamonds) mean data of the JNDF are diagrammed for the 6 (male) subjects who participated. However, the individual results look similar therefore a linear regression curve is shown and a statistical analysis points out that there are no statistically differences between regression curve and results (r = 0.93***).

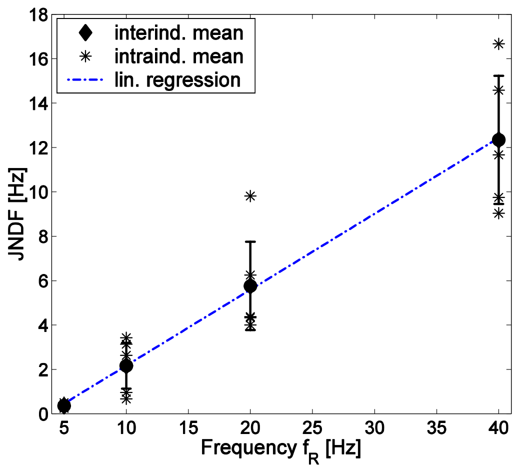

Figure 3: The averaged relative difference thresholds for six subjects in comparison to the interindividual mean data. Additionally, the linear regression curve is plotted as a function of frequency.

3.3 Equal-Vibration Level Contours (EVLC)

EVLC for 15 subjects (3 female, 12 male) were determined with a sinusoidal 20 Hz reference vibration at 100 dB, Figure 4. The EVLC characterize the vibration perception above the PT depending on vibration magnitude. In comparison to the EVLC the (averaged) PT is shown, as well.

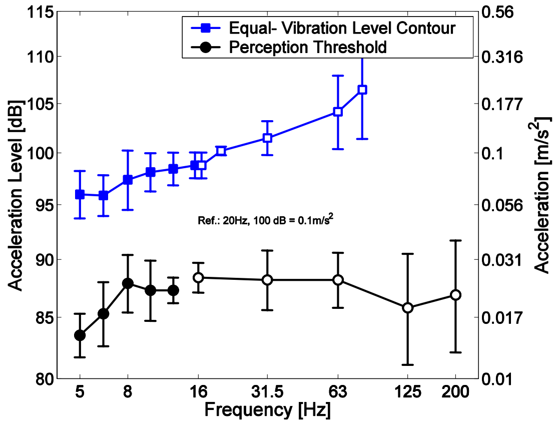

Figure 4: Measured equal-vibration level contours in comparison to determined perception threshold (Figure 1).

4 Summary and Conclusion

- The perception threshold is nearly constant between 8 and 63 Hz and decreases slightly for lower and higher frequencies. The results show no larger deviations to literature data (Figure 1), except for frequencies below 16 Hz. These data are often influenced by additional visual or audible cues [described in 3]. But presented thresholds (this study and literature) show considerable deviations to existing standards [2].
- Weber fraction (JNDL) of about 1.5 dB at a reference level of nearly 100 dB are perceivable. Furthermore, JNDLs are independent of frequency. Fine structures probably depend on different involved vibrotactile units.
- JNDFs increase from about 0.4 Hz at 5 Hz to nearly 12 Hz at 40 Hz.
- EVLC increases with 2.3 dB/octave from 6.3 to 63 Hz. For higher frequencies the slope increases slightly (with nearly 6 dB/octave). Considerable differences between the measured perception threshold and the EVLC exist, even though the EVLC is measured slightly above the perception threshold. These differences cannot be explained by frequency depending JNDLs.

5. References

[1] ISO 2631-1 Part 1 (**1997**) „Evaluation of human exposure to whole-body vibration - Part 1: General requirements“

[2] ISO 2631-2 Part 2 (**1989**) „Evaluation of human exposure to whole-body vibration - Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz)“

[3] Griffin, M. J. (**1991**) „*Handbook of human vibration*“, Academic Press, New York

[4] ISO 8727 (**1997**) „Mechanical Vibration and Shock - Human exposure - Biodynamic coordinate system“

[5] ISO 10326 Part 1 (**1992**) „Mechanical Vibration - Laboratory method for evaluating vehicle seat vibration - Part 1: Basic requirements“

[6] Bellmann, M.A. (**2002**) „*Perception of Whole-Body Vibrations: From basic experiments to effects of seat and steering-wheel vibrations on the passenger`s comfort inside vehicles*“, Dissertation, Shaker Verlag, Aachen