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Comparison of absolute magnitude estimation and relative magnitude estimation for judging the subjective intensity of noise and vibration

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ABSTRACT

The method of magnitude estimation is used in psychophysical studies to obtain numerical values for the intensity of perception of environmental stresses (e.g., noise and vibration). The exponent in a power function relating the subjective magnitude of a stimulus (e.g., the degree of discomfort) to the physical magnitude of the stimulus shows the rate of growth of sensations with increasing stimulus magnitude. When judging noise and vibration, there is no basis for deciding whether magnitude estimation should be performed with a reference stimulus (i.e., relative magnitude estimation, RME) or without a reference stimulus (i.e., absolute magnitude estimation, AME). Twenty subjects rated the discomfort caused by thirteen magnitudes of whole-body vertical vibration and 13 levels of noise, by both RME and AME on three occasions. There were high correlations between magnitude estimates of discomfort and the magnitudes of vibration and noise. Both RME and AME provided rates of growth of discomfort with high consistency over the three repetitions. When judging noise, RME was more consistent than AME, with less inter-subject variability in the exponent, n_s. When judging vibration, RME was also more consistent than AME, but with greater inter-subject variability in the exponent, n_v. When judging vibration, AME may be beneficial because sensations caused by the RME reference stimulus may differ (e.g., occur in a different part of the body) from the sensations caused by the stimuli being judged.

1. Introduction

The method of magnitude estimation was developed to obtain quantitative judgements of the perceived magnitudes of stimuli [1–3]. A sensation produced by a stimulus is rated numerically by an observer using either any number (in the absolute method of magnitude estimation), or relative to a number associated with the sensation produced by a reference stimulus (in the relative method of magnitude estimation). Stevens' power law shows how the subjective magnitude, ψ, grows as a power of the stimulus magnitude, φ:

$$\psi = k\varphi^n \tag{1}$$

where k is a constant that depends on the units of measurement and the exponent, n, is the rate of growth of subjective sensations, which differs according to the sensation [3].

The absolute method of magnitude estimation was based on evidence that subjects tend to use absolute scales rather than ratio scales for judging stimuli [4]. Zwislocki and Goodman [5] argued that the absolute method of magnitude estimation was relatively free of biases due to contextual effects (such as the order of the presented stimuli, the range of stimuli, the range of numbers, the level of stimuli relative to the reference), and that it could provide an 'absolute' scale of sensory magnitudes. Mellers [6] argued that removing the constraints of a standard (the reference stimulus) and the modulus (the numerical value of the reference, for example '100') did not yield an 'absolute' scale of sensation, and that absolute scaling increased response variability and thereby lowered the statistical power of a subjective test.

Magnitude estimation has been used to determine methods of predicting how sound and vibration influence opinions of living, working, and travelling environments. Exponents for scaling the subjective magnitude of sound have been obtained using both the absolute method of magnitude estimation [3,5,7,8], and the relative method of magnitude estimation [8–10]. However, the scaling of the subjective magnitude of vibration has mainly used the relative method of magnitude estimation [11,12].

When comparing subjective magnitudes of the 'discomfort' produced by noise and whole-body vibration, the relative method of magnitude estimation has been used to judge noise relative to a vibration reference and to judge vibration relative to a noise reference [11,13,14]. The absolute method of magnitude estimation has not been used to compare noise and vibration stimuli.

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This study investigated the reliability of the two methods of magnitude estimation, ‘relative magnitude estimation’ (RME) and ‘absolute magnitude estimation’ (AME), in rating the ‘discomfort’ associated with noise and whole-body vibration. An experiment was designed to investigate whether the RME and AME methods yield the same relationships between the physical magnitudes of the stimuli (i.e., noise and vibration) and their subjective magnitudes. The reliability of RME and AME methods (i.e., degree to which they produce similar values when applied repeatedly) were compared based on their consistency (i.e., correlations between magnitude estimates when applied repeatedly) and inter-subject variability.

2. Methods

2.1. Subjects

Twenty healthy subjects (10 male and 10 female), with median age 24 years (range 22–29 years), stature 166.5 cm (range 160–196 cm), and weight 57.5 kg (range 41–103 kg) volunteered to take part in the experiment. The subjects were students of the University of Southampton.

The experiment was approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research at the University of Southampton. Informed consent to participate in the experiment was given by all subjects.

2.2. Apparatus

Subjects sat on a rigid horizontal flat surface secured to a rigid aluminium-framed seat mounted on the Human Factors Research Unit 1-m vertical vibrator (Fig. 1). The subjects sat upright without contact with a backrest, with their eyes closed and their feet resting on the vibrator table.

Fig. 1. Subject on the test rig.

The vibration stimuli were generated and controlled by a Pulsar digital controller (Servotest, Egham UK). A piezoresistive accelerometer (Entran Devices, NJ, USA, Model EGCS-10-/V10/L4M) secured to the seat monitored the vertical acceleration.

Sound stimuli were generated and controlled using Adobe Audition 3 software (Adobe Systems, CA, USA) and an E-MU 0404 USB 2.0 Audio/MIDI Interface (Creative, Singapore). Subjects experienced the sound stimuli via a pair of headphones (ATH M50) calibrated using a ‘Kemar’ (Knowles Electronics Manikin for Acoustic Research) artificial manikin. The Kemar incorporates an ear simulator (G.R.A.S. IEC 700) that houses a microphone (G.R.A.S. Type 40AG) to measure sound levels at the eardrum. A B&K calibrator (Type 4231) and a B&K sound level meter (Type 2250) were used to calibrate and measure the sounds. The sound pressure level, L_{Aeq}, was calculated using the diffuse field in BS EN ISO 11904-2 (2004) [15] and applying the A-weighting to the one-third-octave band spectra measured by the B&K 2250 sound level meter.

2.3. Stimuli

Thirteen levels of random noise, band-pass filtered between 50 and 500 Hz, were generated with L_{Aeq} levels ranging from 64 to 82 dBA in 1.5 dB steps [16]. Thirteen magnitudes of random vibration, band-pass filtered between 5 and 10 Hz, were generated at 0.05, 0.063, 0.079, 0.100, 0.126, 0.158, 0.199, 0.251, 0.315, 0.397, 0.500, 0.629, 0.792 m s^{-2} r.m.s. acceleration (a_{rms}), using frequency weighting W_b [17]. The vibration and sound stimuli had durations of 4 s with a cosine taper applied to the first and last 0.2 s. The background vibration was not perceptible and the background noise level measured at the ear when wearing the headphones was around 50 dBA.

2.4. Procedure

Judgments of ‘discomfort’ were obtained using the two magnitude estimation methods: the AME method and the RME method. The experiment was implemented in two sessions. Each session was implemented in two parts. In session A, subjects first rated the 13 magnitudes of vibration using the AME method, and then rated the 13 levels of noise using the RME method. In session B, subjects first rated the 13 levels of noise using the AME method, and then rated the 13 magnitudes of vibration using the RME method. The subjects experienced the two sessions on separated days, with 10 subjects commencing with session A (Group 1) and 10 subjects commencing with session B (Group 2).

When rating vibration using the RME method, subjects were presented with a ‘reference vibration’ at 0.199 m s^{-2} r.m.s. followed by a ‘test vibration’ and asked to state the discomfort caused by the test vibration, assuming the discomfort caused by the reference vibration was 100. When rating noise using the RME method, subjects were presented with a ‘reference noise’ at 73 dBA followed by a ‘test noise’ and asked to state the discomfort caused by the test noise, assuming the discomfort caused by the reference noise was 100. When rating vibration or noise using the AME method, subjects were presented with the vibration or noise stimuli and asked to give any numerical values they wished to quantify their discomfort.

With both the RME method and the AME method the 13 test stimuli were presented in independent random orders. In both sessions, all stimuli were judged using the AME method three times prior to starting with the RME method, which was also repeated three times. The duration of each session of the experiment was around 15 min.