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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 thirteen 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.

Keywords: discomfort, magnitude estimation, noise, vibration

1. Introduction

The method of magnitude estimation was developed to obtain quantitative judgements of the perceived magnitudes of stimuli [1, 2, 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, 9, 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.

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 to 29 years), stature 166.5 cm (range 160 to 196 cm), and weight 57.5 kg (range 41 to 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 (Figure 1). The subjects sat upright without contact with a backrest, with their eyes closed and their feet resting on the vibrator table.

FIGURE 1 ABOUT HERE

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 ms^{-2} r.m.s. acceleration (a_{rms}), using frequency weighting W_b [17]. The vibration and sound stimuli had durations of 4 seconds 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 ms^{-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 minutes.

Before commencing each part of the experiment, subjects were provided with written instructions and practiced magnitude estimation with the appropriate method (RME or AME) and noise or vibration stimuli having, successively, median, high, and low magnitudes until they felt confident with magnitude estimation.

After finishing the experiment, subjects responded to three forced-choice questions: “1. Which method was easier for you to rate – with reference, or without reference?”, “2. Overall, which did you feel more uncomfortable – noise or vibration?” and “3. Which stimulus was easier for you to rate – noise or vibration?”

According to Stevens’ power law [3], the subjective magnitude of noise, ψ_s, and the subjective magnitude of vibration, ψ_v, are related to the physical magnitude of sound, φ_s, and the physical magnitude of vibration, φ_v, by power functions:

$$\psi_s = k_s \varphi_s^{n_s} \tag{2}$$

$$\psi_v = k_v \varphi_v^{n_v} \tag{3}$$

where k_s and k_v are constants, and n_s and n_v are the rates of growth of subjective sensations produced by the sound and the vibration, respectively.

In terms of logarithms, the power law equations become:

$$\log_{10}(\psi_s) = \log_{10}(k_s) + (n_s/20) \times L_{Aeq} \tag{4}$$

where $L_{Aeq} \propto 20 \log(\varphi_s)$ is the equivalent continuous A-weighted sound pressure level [18], assuming φ_s represents the A-weighted sound pressure in equation (2), and

$$\log_{10}(\psi_v) = \log_{10}(k_v) + n_v \times \log_{10}(a_{rms}) \tag{5}$$

where $a_{rms} \propto \varphi_v$ is the W_b-weighted root-mean-square (r.m.s.) acceleration of the vibration stimulus [17].

Magnitude estimates obtained from each individual using the AME method were divided by the median of their magnitude estimates over all stimuli, and then multiplied by ‘100’ [19]. This ‘normalised’ the magnitude estimates so that the AME and RME data could be analysed using the same procedures and compared.

3. Results

3.1 General results

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From the questionnaire, 85% of subjects thought RME was easier than AME. Overall, 75% of subjects felt that the noise was more uncomfortable, but 75% of subjects thought the vibration was easier to rate.

The magnitude estimates of discomfort associated with the 13 levels of noise, and the magnitude estimates of discomfort associated with the 13 magnitudes of vibration, are shown for both RME and AME in Figure 2.

FIGURE 2 ABOUT HERE

For each individual, linear regression analysis was performed between the dependent variables, $\log_{10}(\psi_s)$ and $\log_{10}(\psi_v)$, and the independent variables, L_{Aeq} and $\log_{10}(a_{rms})$. Median and inter-quartile ranges of the exponents, n, the constants, k, and Spearman rank correlation coefficients, r, between ψ and φ are shown for the three repetitions in Table 1. Individual values of the exponents are shown in Figure 3 with medians and inter-quartile ranges.

FIGURE 3 AND TABLE 1 ABOUT HERE

There was no significant difference between the exponents of Group 1 (who attended session A first: AME with vibration and RME with noise) and the exponents of Group 2 (who attended session B first: with AME with noise and RME with vibration) (Wilcoxon, $p>0.07$).

3.2 Repeatability within methods

When judging the discomfort produced by vibration using RME, both the exponent, n_{vr}, and the constant, k_{vr}, varied over the three repetitions ($p<0.02$, Friedman), with a greater exponent and greater constant for the second repetition than the first repetition ($p<0.01$, Wilcoxon). Correlation coefficients between magnitude estimates of discomfort and the magnitude of vibration, r_{vr}, differed slightly over the three repetitions ($p=0.02$, Friedman; Table 1), with significantly higher correlations for the second repetition than the first repetition (0.99 compared with 0.97; $p=0.02$, Wilcoxon). With AME, there were no statistically significant changes in the exponent, n_{va}, the constant, k_{va}, or the correlation, r_{va}, over the three repetitions ($p=0.15$ for exponent, $p=0.71$ for constant, $p=0.39$ for correlation, Friedman).

When judging the discomfort produced by noise using RME, the exponent, n_{sr}, varied over the three repetitions ($p=0.04$, Friedman; Table 1), but there was no change in either the constant, k_{sr}, or the correlation coefficients between magnitude estimates of discomfort and the level of noise, r_{sr}, over the three repetitions ($p=0.12$ for constant, $p=0.29$ for correlation, Friedman). With AME, neither the exponent, n_{sa}, nor the constant, k_{sa}, showed statistically significant changes over the three repetitions

(p=0.69 for exponent, p=0.95 for constant, Friedman). The correlations, r_{sa}, differed over the three repetitions (p=0.02, Friedman), with correlations for the second repetition significantly greater than those for the first repetition (p<0.02, Wilcoxon), and the third repetition (p<0.05, Wilcoxon).

There was high consistency in individual judgements across repetitions, as indicated by significant correlations between the exponents, n, and the constants, k, between repetitions 1 and 2, between repetitions 2 and 3, and between repetitions 1 and 3, when judging the discomfort of either vibration or noise when using either RME or AME (in all cases, p<0.01; Table 2). Consistency tended to be greater when using the RME method, with 10 of the 12 correlations greater when using RME than when using AME.

TABLE 2 ABOUT HERE

3.3 Comparison between magnitude estimation methods

When judging the discomfort produced by vibration, the exponent, n_v, was greater with AME than RME during the first repetition (p=0.04, Wilcoxon, Table 1), but did not differ between the methods in the second and third repetitions (p>0.12, Wilcoxon, Table 1). Over all three repetitions, the constant, k_v, was greater with AME than RME (p<0.03, Wilcoxon; Table 1).

When judging the discomfort produced by noise, neither the exponent, n_s, nor the constant, k_s, differed between RME and AME in any repetition (for n_s, p>0.19; for k_s, p>0.20, Wilcoxon; Table 1).

The individual correlation coefficients between magnitude estimates of discomfort and either the magnitude of vibration or the level of noise were greater when using RME (i.e., r_{vr} and r_{sr}) than when using AME (i.e., r_{va} and r_{sa}) for all three repetitions (p<0.01, Wilcoxon; Table 1).

There was consistency in individual exponents, n, and constants, k, obtained when using RME and AME (Table 3). Subjects giving a high value for n or k with one method tended to give a high value with the other method. However, it may be seen that the correlations between repetitions within methods are greater than the correlations between methods within repetitions (compare Tables 2 and 3).

TABLE 3 ABOUT HERE

3.4 Independence of the sensations of noise and vibration

Correlations between the exponents, n_s and n_v, obtained by AME and RME are listed in Table 4. With both methods, correlations between the exponents tended to increase with increasing repetition and were highly significant for the third repetition (Table 4). This indicates that subjects having a high rate of growth of discomfort for noise are likely to have a high rate of growth of discomfort for vibration. At each repetition, the correlations were greater with RME than with AME.

TABLE 4 ABOUT HERE

4. Discussion

4.1 Repeatability of the two methods

All the correlation coefficients between magnitude estimates of discomfort and magnitudes of vibration or noise (i.e., r_{vr}, r_{sr}, r_{va}, r_{sa}; Table 1) have high values, with a tendency towards higher correlations in the second repetition. The high correlations in the exponents, n, and the intercepts, k, across repetitions within both RME and AME suggests a single run would have been sufficient to obtain reasonable estimates of both the exponents and the intercepts (Table 2).

Over the three repetitions, the absence of significant changes in the exponents, n, with AME, but significant changes in those obtained by RME, must be interpreted relative to the inter-subject variability in the n values with the two methods (Table 1). With inter-subject variability expressed as the ratio of the inter-quartile range to the median value, the variability in the n value of vibration in the first repetition was greater for RME than AME (0.638 compared with 0.468; Table 5). Over the three repetitions, the variability in n for vibration increased with RME but reduced with AME. So the significant changes in n for vibration over the three repetitions with RME but not with AME cannot be attributed to greater inter-subject variability with AME. The variability in the n value of noise in the first repetition was less for RME than for AME (0.359 compared with 0.600; Table 5). Over the three repetitions, the variability in n for noise increased with RME but reduced with AME. So the significant change in n for noise over the three repetitions with RME, but not with AME, seems to be associated with inter-subject variability initially being less with RME than with AME.

TABLE 5 ABOUT HERE

4.2 Comparison of the two methods

The majority of subjects judged RME easier than AME, consistent with higher correlation coefficients between magnitude estimates of discomfort and the magnitude of vibration or the level of noise when using RME (Table 1). Over the three repetitions, the exponent for noise, n_{s}, tended to be more consistent with RME than with AME, whereas the exponent of vibration, n_{v}, tended to be more consistent with AME than with RME (Table 2). The presentation of the reference stimulus with a given

Comparison of absolute magnitude estimation and relative magnitude estimation for judging the subjective intensity of noise and vibration
Huang, Y. & Griffin, M. J. Mar 2014 In : Applied Acoustics. 77, p. 82-88

sensation (a magnitude estimate of ‘100’) seems to have stabilised magnitude estimates when judging noise, but not when judging vibration.

When judging vibration, the exponent, n_v, differed between the RME and AME methods in the first repetition and the constant, k_v, differed in all three repetitions (Table 1). When judging noise, neither the exponent, n_s, nor the constant, k_s, differed between the RME and the AME methods (Table 1). Subjects are familiar with the sensations caused by sound and judging the discomfort (or annoyance) of a sound. Subjects are less familiar with the sensations in different parts of the body produced by low, medium, and high magnitudes of vibration. For the familiar stimulus (i.e., noise), subjects provided the same results using RME and AME. For the less familiar stimulus (i.e., vibration), RME provided a significantly lower value of n_v in the first repetition but this increased so that there was no difference between RME and AME in the second and third repetition. The constant, k_v, differed between RME and AME during all repetitions and increased progressively over the three repetitions with both methods (Table 3). It seems that with sufficient practice the two methods may provide similar values of n_v and k_v, with practice being more important with RME than AME and n_v stabilising before k_v. The greater practice needed with RME may have arisen because subjects initially tried to match sensations to those produced by the reference motion, but later realised that there were several sensations that change with the magnitude of the vibration (e.g., the locations in the body where discomfort is felt can vary with the magnitude of vibration). For such a stimulus, an overall judgement of sensation may be more appropriate that trying to match specific sensations.

When judging vibration, the inter-subject variability in n_v (i.e., ratios of inter-quartile ranges to median values) was less with AME than with RME. When judging noise, the inter-subject variability in n_s was less with RME than with AME (Table 5). It seems that when judging a specific sensation (i.e., noise), RME had less variability than AME, whereas when judging the various sensations produced by vibration, AME had less variability than RME.

There was greater variability in the magnitude estimates for low magnitudes of vibration with RME than with AME (Figure 2: left of right three graphs), consistent with greater inter-subject variability in n_v values with RME than with AME. This is also consistent with greater difficulty when the test vibration is most different from the reference stimulus. Subjects may have had greater difficulty judging low magnitude vibration stimuli that produce sensations that are different from those produced by the reference stimulus, and they may have been more likely to give ‘real’ subjective magnitudes to the stimuli when using AME without the constraint of the reference [5].

4.3 The values of n_v and n_s

Various values of the rate of growth of discomfort caused by vibration, n_v, have been reported: between 0.86 and 1.04 for frequencies in the range 3.5 to 20 Hz [20], 0.93 for frequencies from 5 to 80 Hz [13], 1.04 to 1.47 for frequencies from 4 to 63 Hz [11], 1.18 for frequencies of 10 to 50 Hz [10], and 0.626 to 0.897 for frequencies between 2 and 50 Hz [12]. In the present study with random vibration in the range 5 to 10 Hz, the median value of 0.77 over three repetitions with RME, and the median value of 0.81 with AME (Table 1) seem consistent with Shoenberger and Harris [20] and Morioka and Griffin [12] for vibration in the same frequency range.

In Figure 2, there is some evidence of a greater rate of growth of vibration discomfort, n_v, with low magnitude vibration stimuli. Consequently, the use of the corrected Stevens’ power law, with an additive constant, a_0, representing the threshold of perception, may be expected to improve the representation of sensation magnitudes [12]:

$$\log_{10}(\psi_v) = \log_{10}(k_v) + n_v \times \log_{10}(a_{rms} - a_0) \qquad (6)$$

The value of 0.017 ms^{-2} r.m.s. was used for the threshold, a_0, in accord with the median threshold for frequencies of vertical vibration from 5 to 10 Hz reported by Morioka and Griffin [12]. The corresponding median exponents over three repetitions were 0.69 with RME, and 0.73 with AME. The use of the modified Stevens’ power law resulted in slightly different values of n_v, but did not change the statistical significance of any of the reported analyses.

For sound, an exponent of 0.60, 0.64, or 0.68 was originally proposed to relate the subjective magnitude of loudness to the sound pressure of 1000-Hz tones [1, 2]. Although the value of 0.68 for the exponent is widely quoted and has been recognized as the standard value for the rate of growth of annoyance (discomfort), other values of n_s have been reported as 0.72 and 0.78 [10, 21] for 100- to 5000-Hz noise inside a house during the passage of a near-by train, and 0.38 to 0.72 [14] for 100- to 300-Hz noise inside a running car. Using category judgment, AME, and cross-modality matching to brightness, with 1000-Hz tone stimuli from 55 to 82 dB, Ward *et al.* found values of 0.411, 0.483, and 1.017, respectively [8]. In a study of the loudness and annoyance of noise-tone complexes using AME, Hellman [22] obtained exponents of 0.63 and 0.92 for loudness with a 1000-Hz tone and with a 3000-Hz tone added to low-pass noise, respectively, and exponents of 0.95 and 1.1 for annoyance

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Huang, Y. & Griffin, M. J. Mar 2014 In : Applied Acoustics. 77, p. 82-88

with a 1000-Hz tone and with a 3000-Hz tone added to low-pass noise. In the present study with random noise from 50 to 500 Hz, the median value of 0.78 over three repetitions with RME, and the median value of 0.80 with AME (Table 1) are greater than the originally proposed value of 0.68 but within the range of previous values for the exponent, which may be expected to vary with the spectrum of the noise and the experimental method.

5. Conclusions

When judging the discomfort produced by noise and vibration, both the method of absolute magnitude estimation (AME) and the method of relative magnitude estimation (RME) can provide rates of growth of subjective sensations with high repeatability. When judging noise, RME produced slightly greater consistency with less inter-subject variability in the exponent, n_s, over the three repetitions. When judging vibration, RME was slightly more consistent but had greater variability in the exponent, n_v, over the three repetitions than AME. When judging vibration, AME may be beneficial because, unlike RME, it does not require subjects to judge their sensations relative to the sensations caused by the reference stimulus, which may differ in their nature from the sensations caused by the test stimuli.

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Table 1 The exponents (n_v and n_s), the constants (k_v and k_s), and Spearman's rank correlation coefficients (r_v and r_s), obtained with RME and AME methods of magnitude estimation when judging the discomfort of noise and the discomfort of vibration. Medians and inter-quartile ranges for 20 subjects.

Vibration						
Repetition	RME			AME		
	n_{vr}	k_{vr}	r_{vr}	n_{va}	k_{va}	r_{va}
1	0.69 (0.37, 0.81)	263 (178, 309)	0.97 (0.93, 0.98)	0.77 (0.66, 1.02)	302 (257, 417)	0.87 (0.85, 0.91)
2	0.77 (0.45, 0.97)	295 (190, 347)	0.99 (0.96, 0.99)	0.84 (0.68, 1.07)	316 (275, 550)	0.88 (0.82, 0.91)
3	0.81 (0.34, 0.99)	288 (182, 363)	0.98 (0.95, 0.99)	0.81 (0.72, 1.03)	324 (275, 490)	0.85 (0.89, 0.93)
Noise						
Repetition	RME			AME		
	n_{sr}	k_{sr}	r_{sr}	n_{sa}	k_{sa}	r_{sa}
1	0.78 (0.68, 0.96)	0.13 (0.034, 0.35)	0.97 (0.94, 0.98)	0.80 (0.60, 1.08)	0.087 (0.012, 0.58)	0.89 (0.84, 0.92)
2	0.88 (0.68, 1.02)	0.060 (0.020, 0.34)	0.98 (0.97, 0.98)	0.88 (0.60, 1.12)	0.056 (0.0058, 0.60)	0.94 (0.91, 0.96)
3	0.78 (0.64, 1.10)	0.12 (0.010, 0.43)	0.98 (0.97, 0.99)	0.80 (0.62, 1.08)	0.13 (0.087, 0.46)	0.92 (0.86, 0.94)

Table 2 Correlation coefficients between exponents (n_v and n_s) and constants (k_v and k_s) in successive runs when judging the discomfort produced by vibration and the discomfort produced by noise (Spearman rank correlation; 20 subjects).

Vibration							
RME				AME			
n_{vr}	1	2	3	n_{va}	1	2	3
1	1.00	0.84**	0.79**	1	1.00	0.87**	0.87**
2	—	1.00	0.95**	2	—	1.00	0.87**
3	—	—	1.00	3	—	—	1.00
k_{vr}	1	2	3	k_{va}	1	2	3
1	1.00	0.91**	0.92**	1	1.00	0.87**	0.88**
2	—	1.00	0.97**	2	—	1.00	0.93**
3	—	—	1.00	3	—	—	1.00
Noise							
RME				AME			
n_{sr}	1	2	3	n_{sa}	1	2	3
1	1.00	0.95**	0.97**	1	1.00	0.85**	0.86**
2	—	1.00	0.94**	2	—	1.00	0.92**
3	—	—	1.00	3	—	—	1.00
k_{sr}	1	2	3	k_{sa}	1	2	3
1	1.00	0.93**	0.98**	1	1.00	0.85**	0.87**
2	—	1.00	0.93**	2	—	1.00	0.93**
3	—	—	1.00	3	—	—	1.00

**$p < 0.01$.

Table 3 Correlations between exponents (n_v and n_s), the constants (k_v and k_s) obtained using RME and AME methods in successive repetitions when judging the discomfort produced by vibration and the discomfort produced by noise. (Spearman rank correlation; 20 subjects).

Vibration							
n_{va} n_{vr}	1	2	3	k_{va} k_{vr}	1	2	3
1	0.48*	—	—	1	0.51*	—	—
2	—	0.50*	—	2	—	0.54*	—
3	—	—	0.56**	3	—	—	0.56*
Noise							
n_{sa} n_{sr}	1	2	3	k_{sa} k_{sr}	1	2	3
1	0.70**	—	—	1	0.71**	—	—
2	—	0.72**	—	2	—	0.72**	—
3	—	—	0.68**	3	—	—	0.72**

* $p < 0.05$, ** $p < 0.01$

Table 4 Correlations between exponents, n_v and n_s obtained when judging the discomfort produced by vibration and the discomfort produced by noise when using the RME and the AME method in successive repetitions. (Spearman rank correlation; 20 subjects).

RME				AME			
n_{sr} n_{vr}	1	2	3	n_{sa} n_{va}	1	2	3
1	0.39	—	—	1	0.28	—	—
2	—	0.44	—	2	—	0.32	—
3	—	—	0.68**	3	—	—	0.48*

* $p < 0.05$, ** $p < 0.01$

Table 5 The inter-subject variability (ratio of the inter-quartile range to the median value) for the exponents (n_v and n_s) obtained using RME and AME when judging the discomfort of noise and the discomfort of vibration. Data from 20 subjects.

Repetition	Vibration		Noise	
	RME n_{vr}	AME n_{va}	RME n_{sr}	AME n_{sa}
1	0.638	0.468	0.359	0.600
2	0.675	0.464	0.386	0.591
3	0.802	0.382	0.590	0.575

Figure 1 Subject on the test rig.

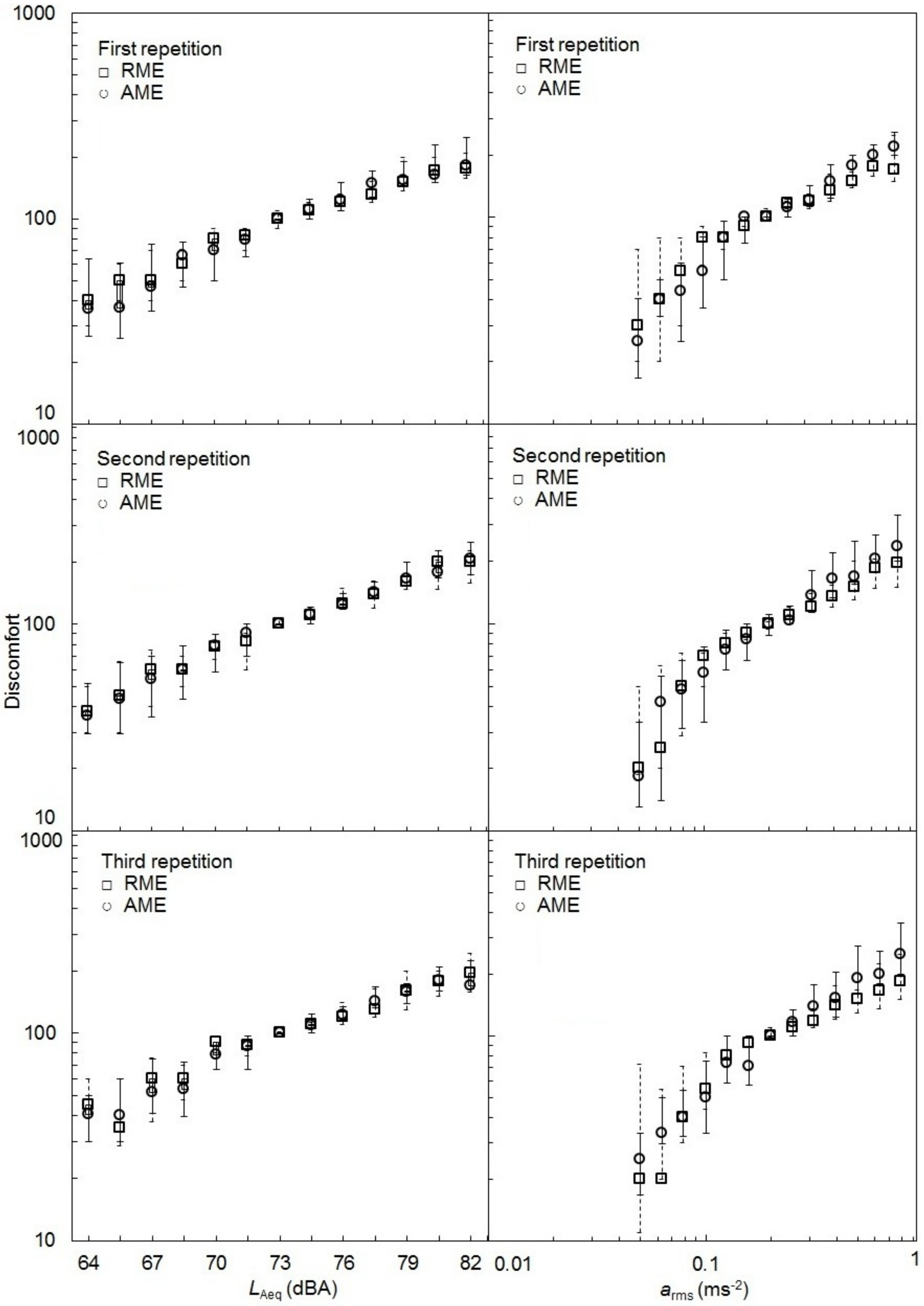

Figure 2 Subjective magnitudes of discomfort produced by noise (as a function of L_{Aeq}) or vibration (as a function of a_{rms}) when using the RME and AME magnitude estimation methods. Medians and inter-quartiles ranges of 20 subjects (--○--RME; —□--AME).

Comparison of absolute magnitude estimation and relative magnitude estimation for judging the subjective intensity of noise and vibration
Huang, Y. & Griffin, M. J. Mar 2014 In : Applied Acoustics. 77, p. 82-88

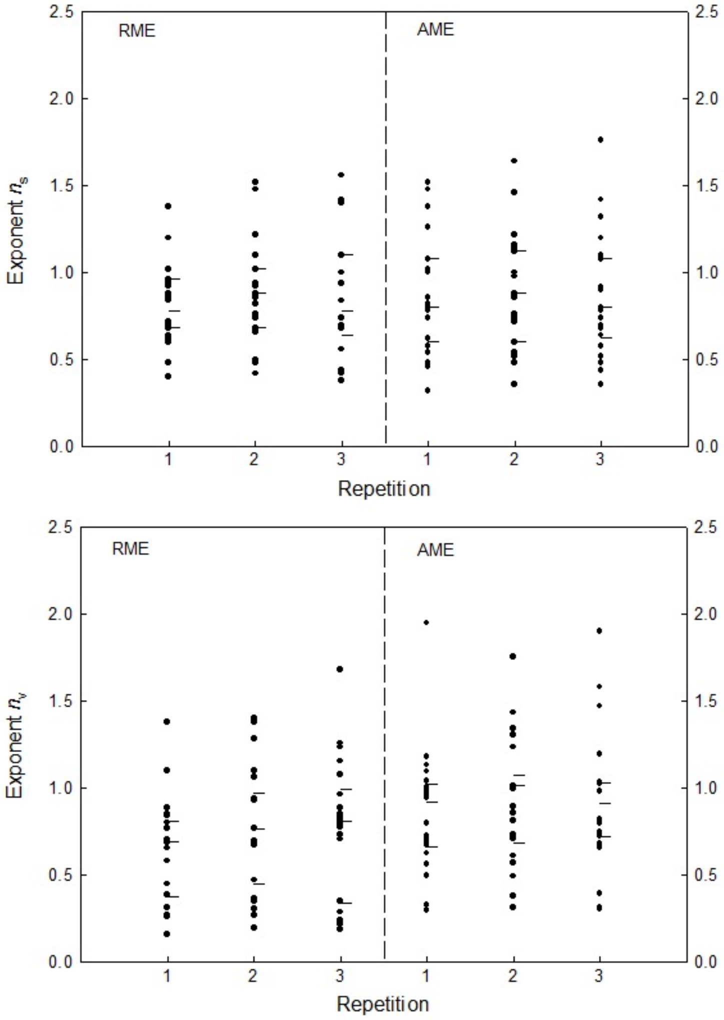

Figure 3 Individual exponents, *n*, of vibration and noise when using the RME and AME magnitude estimation methods. — Medians and inter-quartiles ranges of 20 subjects.