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INDIVIDUAL LOUDNESS FUNCTIONS OBTAINED BY ABSOLUTE MAGNITUDE ESTIMATION

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Six subjects estimated, in individual listening sessions loudness of 1/3–octave noise band centered at 1 kHz. The results confirm that numerical estimates of loudness are unique characteristics of individual observers. In the present study no evidence for the existence of an absolute loudness scale could be observed.

W eksperymencie opisanym w niniejszej pracy przeprowadzono badania przebiegu wartościowania głośności szumu pasmowego o szerokości tercji i częstości środkowej 1 kHz. W pomiarach uczestniczyło 6 słuchaczy. Stwierdzono znaczne zróżnicowanie osobniczych funkcji wartościowania głośności. Uzyskane wyniki nie potwierdzają hipotezy o absolutnej zależności między wielkością wrażenia głośności i wartościami liczbowymi przypisywanymi głośności w skalowaniu.

1. Introduction

Numerous experiments have been conducted to examine the relationship between sound pressure and the subjective magnitude of loudness. Since STEVENS [11] demonstrated that loudness could be measured by assigning numbers directly to the magnitude of sensation perceived, the method called magnitude estimation has been employed in a large number of experiments.

The magnitude estimation method may be applied in two ways. In one, the listener is presented with a standard stimulus and told that the sensation of loudness it produces has a certain numerical value (modulus). The subject is asked to assign numbers to the loudness of subsequent stimuli in such a way that his judgments reflect the ratios between their loudness and the loudness of the reference tone [4; 11]. In the other version of the method the modulus is entirely omitted. In this procedure, usually called absolute magnitude estimation, the listener is instructed to assign to each of the stimuli presented a number which matches the subjective magnitude of loudness [5; 15]. There is no limitation as to the range of numbers: the subject is allowed to use any positive number that appears appropriate.

It has been demonstrated in numerous investigations that loudness scales derived from magnitude estimation data obey the formula known as "Stevens' Power Law", that is, $L = kp^n$, where L represents the magnitude of loudness, p the sound pressure, k is an arbitrary constant which depends on the scale unit, and n, the power exponent.

STEVENS [11] observed that the form of loudness functions obtained by magnitude estimation was dependent on the intensity of the reference tone. HELLMAN and ZWISLOCKI [4] confirmed in a more elaborated study that the chosen sensation level of the reference stimulus had a substantial effect on the shape of the loudness function (Fig. 1). The form of the loudness function was also affected when the loudness of the reference tone was associated with different numbers.

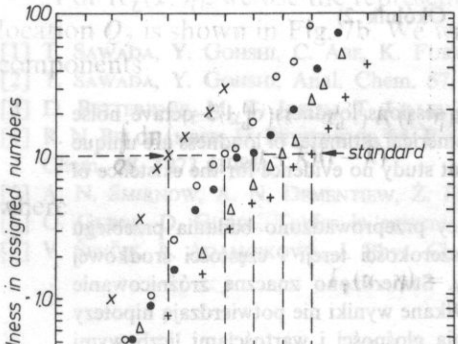

FIG. 1. Median loudness estimates of a 1–kHz tone obtained with the reference number 10 associated with five different sensation levels. (Data from [5], quoted in [15])

HELLMAN and ZWISLOCKI [4] argued that the observed influence of the modulus value on the shape of the loudness function is evidence that subjects make numerical judgments of loudness on an absolute rather than a ratio scale. If numbers assigned to loudness represented a ratio scale, the intensity of the reference tone or the number associated with the modulus, should have only influenced listeners' judgments in changing them by a multiplicative constant. The observed nonlinearity between responses obtained with different modulus results from the existence of a natural, absolute coupling between loudness and its numerical estimates. Subjects assign numbers to loudness in such a way that their subjective impression of how large a number is matches the subjective magnitude of loudness. If loudness of the reference stimulus and the reference number are not in agreement with the natural, absolute scale, listeners tend subconsciously to correct their responses to converge with the absolute loudness function that is obtained without a designated modulus and data normalization.

The concept of an "absolute" scale has been derived from Stevens' classification of scales based on permissible mathematical transformations that leave the scale form invariant. The highest level scale in Stevens' classification is the ratio scale which allows the scale values to be multiplied by a constant. The absolute scale, as stated by Zwislocki and Goodman [15] "implies a fixed unit and, therefore, an absolute coupling between numerals and psychological magnitudes."

Zwislocki and Goodman [15] pointed out that the absolute scaling hypothesis may also be supported by the convergence of magnitude estimation and magnitude production data obtained in experiments which were conducted in different laboratories on separate groups of subjects. The results compared in Fig. 2 show that on the average, two different groups of listeners associated approximately the same numbers with the same sensation levels. On the basis of the data shown in Fig. 2, Zwislocki and Goodman presented a loudness function which reflects the absolute (constant) relationship between the sensation level of a 1 kHz tone and the numbers assigned to its loudness (Fig. 3).

The absolute scaling hypothesis was suggested from the convergence of average data obtained on groups of subjects, however, it has been demonstrated in a number of investigations that among listeners with normal hearing the exponents of

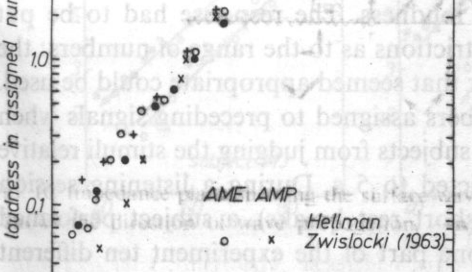

Fig. 2. Loudness of a 1–kHz tone in monaural presentation. Absolute magnitude-estimation (AME) and absolute magnitude-production (AMP) results obtained in two independent studies (Data from [5] and [8], quoted in [15])

Fig. 3. Loudness function of a 1–kHz tone in binaural presentation. Absolute relationship between the sensation level of the tone and numbers assigned to its loudness. (After [15])

individual loudness functions vary within a large range [2; 3; 6; 7; 9]. The variability of individual loudness functions leads to the conclusion that not all listeners perform absolute magnitude estimates of loudness in accordance with the function presented in Fig. 3. If subjects made numerical estimates of loudness on an absolute scale, it could therefore be assumed that the loudness function shown in Fig. 3 represents the mean of different, individual absolute loudness scales.

The aim of the present study was to examine whether the tendency to couple numbers with loudness on a constant, absolute scale may also be observed in judgments by individual observers.

2. Procedure

Six students aged 20 to 24 years estimated, in individual listening sessions, the loudness of 1/3–octave noise bursts centered at 1 kHz. The stimuli, recorded on tape were played back through a loudspeaker placed in a listening room, 2 m from the subject. The noise signals were presented in series comprising 21 stimuli of different sound pressure levels. The duration of each noise burst was 1 s with an interstimulus interval of 5 s. Ten tapes with stimuli recorded in different, randomly chosen sequences were used.

The experiment was conducted in two parts. In the first, sound pressure levels of the signals, measured in the place occupied by a listener's head ranged from 40 to 80 dB SPL. In the second part, which was carried out after a six-week interval, the same tapes were played, but sound pressure levels of all signals were increased by 10 dB.

The method employed for scaling loudness was that of absolute magnitude estimation. The subjects were requested to assign to each of the stimuli presented a number which reflected its magnitude of loudness. The response had to be put down on an answer sheet. There were no restrictions as to the range of numbers: the observers were told that any positive number that seemed appropriate could be used. The listeners were instructed to ignore numbers assigned to preceding signals when judging a particular stimulus. To prevent the subjects from judging the stimuli relative to one another, the answer time was restricted to 5 s. During a listening session which lasted about 45 minutes (including short rest breaks), a subject performed judgments of 8–10 experimental series. In one part of the experiment ten different sequences of stimuli were presented to a listener 4 times each, so each subject performed 40 answers per data point (i.e. 4 responses × 10 sequences).

3. Results

Figure 4 shows individual results of loudness estimation obtained in the first and second part of the experiment. Each point indicates the geometric mean of 40 judgments. The data are approximated by a power function determined by a least

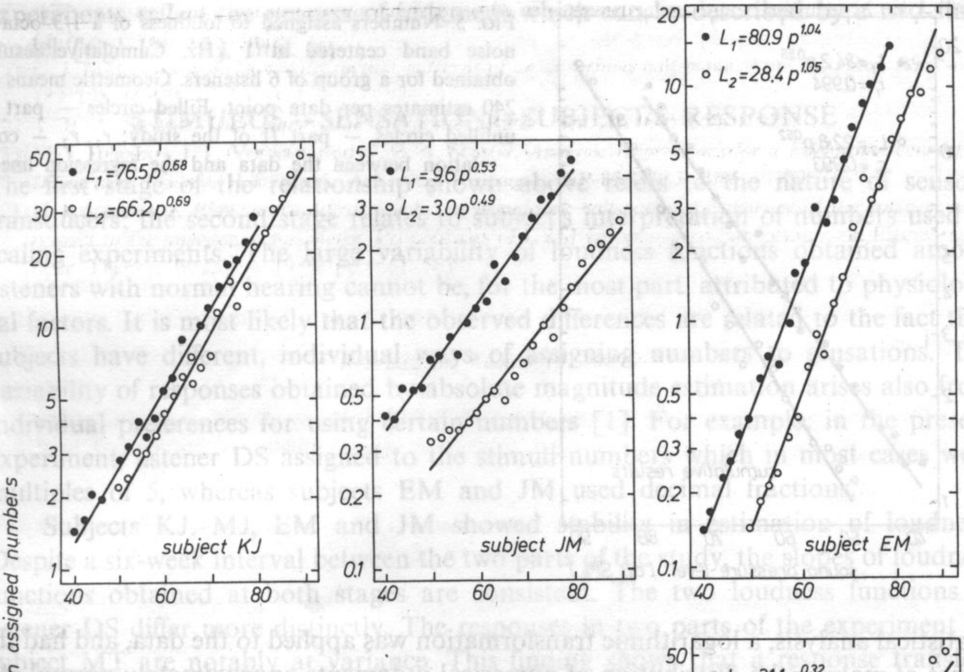

FIG. 4. Numbers assigned to loudness of a 1/3–octave noise band centered at 1 kHz. Individual results – geometric means of 40 estimates per data point. Filled circles – part I, unfilled circles – part II of the study

squares fit. Cumulative results are presented in Fig. 5 which shows the geometric means of 240 estimates (6 listeners × 40 judgments).

In order to examine the statistical significance of the differences between numbers assigned to stimuli having the same sound pressure levels in both parts of the experiment, a *t*-test analysis of the data was carried out. For the purpose of

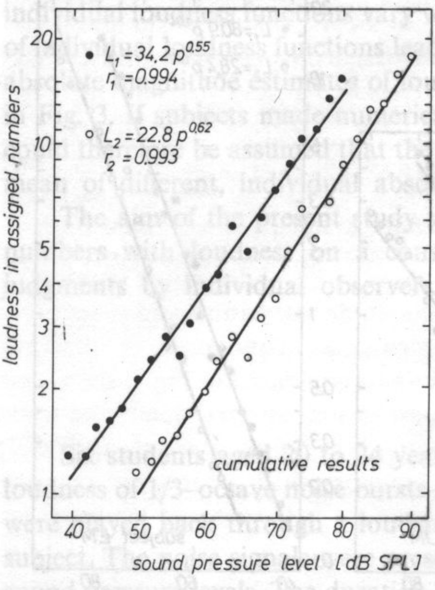

FIG. 5. Numbers assigned to loudness of a 1/3–octave noise band centered at 1 kHz. Cumulative results obtained for a group of 6 listeners. Geometric means of 240 estimates per data point. Filled circles – part I, unfilled circles – part II of the study; r_1, r_2 – correlation between the data and the regression line

statistical analysis, a logarithmic transformation was applied to the data, and had the effect of making the distribution of numerical judgments approximately normal. All subsequent computations were carried out on the transformed variable. Table 1 specifies the calculated "t" values and the significance level in which the "t" value falls.

Table 1. Statistical significance of differences between numbers associated with loudness of stimuli having the same sound pressure levels in parts I and II of the experiment. Calculated t-test values and significance levels

Subject	KJ	MJ	EM	JM	DS	MT	Cumulative results
t-value	4.28	8.86	4.10	5.71	8.44	3.49	6.36
Significance level	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001

4. Discussion and conclusions

The exponents of individual loudness functions range from 0.32 to 1.04 (in I part of the experiment) and from 0.35 to 1.06 (in II part). Variability of individual exponents observed in the present investigation is similar in range to that reported in previous studies [2; 3; 6; 9].

It has been stated in the literature that responses performed in sensory scaling experiments reflect the process of judgment which can be described by a two-stage model [e.g. 12; 13], that is:

STIMULUS → SENSATION → SUBJECT'S RESPONSE

The first stage of the relationship shown above refers to the nature of sensory transducers; the second stage relates to subject's interpretation of numbers used in scaling experiments. The large variability of loudness functions obtained among listeners with normal hearing cannot be, for the most part, attributed to physiological factors. It is most likely that the observed differences are related to the fact that subjects have different, individual ways of assigning numbers to sensations. The variability of responses obtained by absolute magnitude estimation arises also from individual preferences for using certain numbers [1]. For example: in the present experiment, listener DS assigned to the stimuli numbers which in most cases were multiples of 5, whereas subjects EM and JM used decimal fractions.

Subjects KJ, MJ, EM and JM showed stability in estimation of loudness. Despite a six-week interval between the two parts of the study, the slopes of loudness functions obtained at both stages are consistent. The two loudness functions of listener DS differ more distinctly. The responses in two parts of the experiment by subject MT are notably at variance. This finding shows that a response transformation function describing the way in which a subject assigns numbers to the magnitude of sensation may not be stable over time.

The observed differences between values associated with loudness of stimuli having the same sound pressure levels in the first and second parts of the study suggest that none of the subjects performed estimates of loudness on an absolute scale. The results obtained from listeners DS and EM demonstrate that a 10 dB increase of sound pressure level did not even result in a statistically significant increase of the numbers which were assigned to loudness. In the case of subject EM, both slopes of loudness functions and numerical values representing loudness were almost identical in both parts of the experiment.

Cumulative results (Fig. 5) are approximated by power functions with exponents of 0.56 (in I part of the study) and 0.62 (in II part). According to the obtained values of exponents the increase of sound pressure level required to double loudness is 10.8 and 9.7 dB. These values, obtained for 1/3-octave noise centered at 1 kHz, agree fairly well with the standard loudness function of a 1 kHz tone, based on the experimental data which have been compiled by Stevens [10] from numerous sources. Just as it has been found in individual data, the comparison of cumulative results obtained in both parts of the experiment does not demonstrate evidence of estimating loudness on an absolute scale.

What then are the reasons for the failure to obtain estimates of loudness on an absolute scale in the present work? Zwislocki [14] pointed at the difference between a formally defined scale and its experimental realization. A scale formally defined as absolute should not be considered as being less susceptible to experimental biases than any other scale. Therefore the experimental conditions should be arranged so that the subjects would be able to respond according to the scale definition.

The present investigation was conducted according to the procedure specified by Zwislocki and Goodman [15]. This procedure is very convenient for use in loudness scaling experiments. However, the failure to obtain results that would support the absolute scaling hypothesis leads to a conclusion that conditions under which an absolute scale can be proved to exist need to be determined in more detail. The variability of individual data obtained in experimental conditions arranged in the present investigation argues that further attempts to examine the absolute scaling hypothesis should also include results of loudness scaling obtained from individual observers.

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References

[1] J. C. Baird, *Numbers and exponents*, Proc. 2nd Annual Meeting of the International Society for Psychophysics – "Fechner Day". Cassis (1986)

[2] C. M. de Barbenza, M. E. Bryan, W. Tempest, *Individual loudness functions*, J. Sound. Vib., **11**, 399–410 (1970).

[3] R. P. Hellman, *Stability of individual loudness functions obtained by magnitude estimation and production*, Percept. Psychophys, **29**, 63–70 (1981).

[4] R. P. Hellman, J. J. Zwislocki, *Some factors affecting the estimation of loudness*, J. Acoust. Soc. Am., **33**, 687–694 (1961).

[5] R. P. Hellman, J. J. Zwislocki, *Monaural loudness function at* 1000 cps and interaural summation, J. Acoust. Soc. Am., **35**, 856–865 (1963).

[6] A. W. Logue, *Individual differences in magnitude estimation of loudness*, Percept. Psychophys., **19**, 279–280 (1976).

[7] W. J. McGill, *The slope of the loudness function. A puzzle*, In: Psychological scaling, [eds] H. Gulliksen, S. Messick. Wiley, New York 1960.

[8] R. Rowley, G. Studebaker, *Monaural loudness-intensity relationships for a* 1000-Hz *tone*, J. Acoust. Soc. Am., **45**, 1186–1192 (1969).

[9] J. C. Stevens, M. Guirao, *Individual loudness functions*, J. Acoust. Soc. Am., **36**, 2210–2213 (1964).

[10] S. S. Stevens, *The measurement of loudness*, J. Acoust. Soc. Am., **27**, 815–827 (1955).

[11] S. S. Stevens, *The direct estimation of sensory magnitudes – loudness*, Am. J. Psychol., **69**, 1–25 (1956).

[12] M. Treisman, *Sensory scaling and the psychological law*, Quart. J. Exper. Psychol. **16**, 11–12 (1964).

[13] J. J. Zwislocki, *Group and individual relations between sensation magnitudes and their numerical estimates*, Percept. Psychophys., **33**, 460–468 (1983).

[14] J. J. Zwislocki, *Absolute and other scales: Question of validity*, Percept. Psychophys., **33**, 593–594 (1983).

[15] J. J. Zwislocki, D. A. Goodman, *Absolute scaling of sensory magnitudes: A validation*, Percept. Psychophys., **28**, 28–38 (1980).

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