The relation between category and magnitude estimates of tactile intensity*

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Magnitude estimates of a wide intensive range of electrotactile stimuli were plotted against two category scales of the same stimuli. One scale was obtained with the usual narrow range of categories, the other with an expanded range derived from the numerical magnitude estimates. With the narrow range of categories, the function relating category ratings to magnitude estimates was curved concave downward as is usual. With the wide range of categories, the function was linear. Thus, the curvature previously ascribed to prothetic continua in general was found rather to result from a specific property of the response dimensions, i.e., from the restricted set of numbers made available as categories to the Ss.

Magnitude estimates of the apparent intensity of stimuli grow roughly as a power function of physical intensity or many prothetic sensory continua (e.g., vibration (Gibson, 1960), electrotactile intensity (Gibson, Dillmann, & Tomko, 1967), brightness and loudness (Stevens, J. C., & Hall, 1966), and electric shock intensity (Stevens, S. S., Carton, & Shickman, 1958)). On such continua, category ratings are related to magnitude estimates of the same stimuli by a function which is ordinarily concave downward (Stevens, S. S., & Galanter, 1957). Because this curved relation holds primarily for prothetic, and not usually for metathetic, continua such as the pitch of high frequencies, it has been suggested as a criterion for identifying prothetic continua (Stevens, S. S., & Galanter, 1957).

However, the curved nature of this function is perplexing, as it implies that there is not a simple correspondence between magnitude estimates and category ratings on the same intensive dimension. If category ratings and magnitude estimates both measure the same dimension of apparent intensity, the function relating them might be expected to be linear.

These two scaling procedures differ in one respect which may be relevant to this problem. In magnitude estimation, O selects and uses a range of numbers which represents his range

of apparent intensities. By contrast, in category rating, E chooses an arbitrary range of categories for use by O. This range, frequently eight or so categories, is ordinarily smaller, though sometimes larger, than the range which is chosen naturally by O in magnitude estimation. If the natural expression of numerical relationships between the apparent intensities of a number of stimuli depends on the set (range and/or number) of categories available, the typical category rating procedure may constrain O's judgments. Thus, the category ratings may not represent the growth of apparent intensity in the same way as do magnitude estimates, with the result displayed as a nonlinear relationship between the two.

The purpose of the present experiment was to determine the effect of the range of categories available to O on the function relating category and magnitude estimates of the stimuli. The apparent intensity of a wide range of tactile electric stimuli (cf. Gibson, 1968) was scaled, using

two sets of categories. One set of seven categories comprised the cardinal numbers 2-8, the use of which was expected to provide the usual curved function. The second set of 49 categories comprised the cardinal numbers 2-50 and was derived from the mean range of numbers reported as magnitude estimates of the same stimuli. The essential point of the experiment was to determine the shape of the function relating these category ratings with the magnitude estimates.

METHOD

Observers

Thirteen male and 20 female University of Pittsburgh undergraduates served as Os.

Stimuli

Eighty-millisecond-long trains of 0.5-msec anodal rectangular pulses were presented at a repetition rate of 100 pps. Thus, each 80-msec stimulus consisted of nine brief pulses, identical in duration, with 10-msec interpulse onset intervals. Only pulse amplitude was manipulated to vary stimulus intensity. At moderate intensities, such a train of pulses feels like a single brief tap (Gibson, 1968).

Apparatus

Stimuli were delivered to the palmar base of the right thumb (thenar eminence) through a flat 16-mm-diam stainless steel disk electrode embedded flush in a 38-mm-diam Plexiglas surround disk. The function of the surround was to separate the mechanical and electrical edges of the stimulator, thereby ensuring no pain arousal. The large indifferent aluminum electrode covered the sole of the right foot.

The Tektronix 160 series pulse and waveform generators in Fig. 1 initiated and shaped the pulse trains. Train

*The research was supported in part by Grants NB 06304 from the National Institutes of Neurological Diseases and Stroke and HRSKI-II from the Health Research and Services Foundation to the first author. The research was carried out while the second author was a predoctoral NIH trainee and was supported by Psychobiology Training Grant MH 114-02 to the Departments of Psychology and Pharmacology, University of Pittsburgh.

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Fig. 1. Stimulus generation and monitoring equipment.

Fig. 2. Geometric mean magnitude estimates plotted as a function of stimulus intensity in peak milliamperes.

duration was monitored by using a Tektronix 360 oscilloscope with input shown in the block diagram. The pulse trains were fed into a constant-current pulse amplifier which supplied a pulse with amplitude continuously variable from 0.1 to 10.0 mA.

During stimulation, O's interelectrode tissue resistance (between the active and indifferent electrodes) was placed across the amplifier output, in electrical series with a 100-ohm precision measuring resistor (shown in Fig. 1 as a 100-ohm or a 1.0 K ohm resistor). For calibration, a 6.8 K ohm resistor (shown in Fig. 1 as a 6.0 K ohm-10.0 K ohm resistor) replaced O.

Stimulus intensity was varied as peak current through O, measured by a peak reading voltmeter monitoring the voltage across the precision resistor. Peak current was displayed as milliamperes on the digital voltmeter shown in the block diagram. The pulse shape was monitored by a Tektronix 561A oscilloscope (Fig. 1) in electrical parallel with the measuring resistor.

Procedure

Each O served in a single 50-min session of two parts. The first part of the session was identical for each O and consisted of nine ascending method of limits series threshold measurements. In the second part of each session, O scaled the apparent

intensity of suprathreshold stimuli using one of three scaling procedures: (1) magnitude estimation, (2) category rating using the whole numbers 2-8 as categories, or (3) category rating with the range of categories derived from the mean range of magnitude estimates.

The stimuli covered the range from 1 to 14 dB above each O's threshold, in 1-dB steps. The most intense stimulus, about five times threshold, was reported to feel like a very strong touch. Thus, the perceptual range was quite wide, from barely suprathreshold to nearly intolerably strong.

Magnitude Estimation

Fourteen stimuli were presented in a different random order to each of 11 Os. They covered the range from 1 to 14 dB above threshold in 1-dB steps. A modulus-free method of magnitude estimation was used by O to rate the apparent intensity of the stimuli. He was instructed to assign a number to each stimulus which was proportional to its strength. The 4-dB stimulus was always presented for judgment first. It was then repeated for judgment as the middle (seventh) stimulus in the otherwise random array of 14 stimuli.

Category Rating

The same 14 stimuli were presented to 11 other Os with the same random orders as above. The category rating procedure used was as follows: O was instructed to assign each stimulus to a category representing its strength, using as categories the whole numbers 2-8. The first standard stimulus presented to each O, an example of Category 2, was 1 dB above threshold. The second standard stimulus, presented as Category 8, was 14 dB above threshold. In an effort to have categories based on equal intensive intervals, O was further instructed to assign the stimulus halfway between the highest and lowest intensities to the category midway between the standards. In order to eliminate end effects, O was told to use Categories 1 and 9 to represent intensities exceeding the standards. Each of the 12 remaining stimuli (2 to 13 dB above threshold in 1-dB steps) was then presented once each for rating.

Categories Derived from Magnitude Estimates

The procedure for category rating stimuli (by 11 different Os) was the same, with these exceptions: The categories were the whole numbers 2-50, whose range approximated the range assigned by the Os during magnitude estimation. The first stimulus (Category 2) was 1 dB above threshold; the second was 14 dB (Category 50). O was told to use Categories 1 and 51 to represent

Fig. 3. Arithmetic mean category ratings plotted as a function of geometric mean magnitude estimates of electrotactile stimuli between 2 and 13 dB above threshold. Categories were the whole numbers 2-8.

intensities exceeding the two standards in order to eliminate end effects.

RESULTS

Figure 2 shows magnitude estimates of electric tactile stimuli plotted as a function of peak current. The data points are geometric means across 11 Os. As a first approximation, apparent magnitude grows as a power function of stimulus intensity. The slight downward curvature at low stimulus intensities would be eliminated by correcting for threshold (Gibson, Dillman, & Tomko, 1968). The value of the exponent, 2.1, is somewhat less than the usual 3.5 reported for electric stimuli (Gibson, Dillman & Tomko, 1968; Hawkes, 1960; Stevens, S. S., Carton, & Shickman, 1958). The gentle slope is not unusual in light of the wide range of intensities which was presented for judgment (cf. Poulton, 1968).

Figure 3 shows category ratings obtained with the restricted range of categories (whole numbers 2-8), plotted as a function of magnitude estimates of the same stimuli. The data points are arithmetic means of the category ratings. The function is concave downward. The Peters (1946) index of curvature¹ for this function is -0.178 , well above the -0.10 minimum criterion value which Peters established as indicating a substantial amount of downward curvature.

In Fig. 4, category ratings obtained with an expanded range of categories obtained from the numerical range of magnitude estimates (whole numbers 2-50) are plotted as a function of the same magnitude estimates. These category ratings are linearly related to the magnitude estimates, in marked contrast with the curved function in Fig. 3 above. The Peters index of curvature for this function is -0.007 , well below his criterion for curvature and close to the value zero, which would indicate a straight line.

The relationship shown in Fig. 4 has been corroborated by the results of an additional similar experiment performed with an additional group of 11 Os. The function appears essentially identical when using the data from either group. Moreover, of the total group of 22, there were 12 Os whose magnitude estimates actually fell between the limits 2 and 50. When the means of their category ratings (Categories 2 and 50) are plotted against their magnitude estimates, a straight line with a slope of 1.0 results, having no measurable curvature and having scatter that is considerably reduced over that in Fig. 4.

DISCUSSION

Stimulus properties, such as spacing

Fig. 4. Arithmetic mean category ratings plotted as a function of geometric mean magnitude estimates of electrotactile stimuli between 2 and 13 dB above threshold. Categories were the whole numbers 2-50.

(cf. Poulton, 1968; Stevens, J. C., 1958), have been found to influence the nature of the magnitude estimation function. However, the parallel effects of response dimension properties are not yet fully understood. Yet, the curvature of category scales plotted against magnitude estimates of the same stimuli has been held to distinguish prothetic from metathetic continua. It is obvious that response constraints implicit in direct estimation procedures are not the same as those operating in category scaling methods. The effects of such constraints on the form of the category scale, and thus on the nature of the relation between magnitude and category scales, are not obvious.

Direct estimation procedures permit relatively free numerical expression of sensory magnitudes from a theoretically infinite and continuous range of numbers.² By contrast, in the typical category scaling experiment, the range and number of categories available to O is set by E, and thus is limited and arbitrary. The integers 2-7 are frequently used as categories; both the range and the spacing between successive numbers are fixed. Given two methods of estimating sensory magnitudes and assuming a common underlying intensive continuum, it is reasonable to expect a linear function to relate them if the response constraints are effectively similar.

In the present experiment, when the limited arbitrary set of response categories was replaced by an expanded set of O-determined categories, the curved relation between category and magnitude functions became linear. This finding increases the generality of some form of the power function as being an appropriate description of the growth of apparent intensity. The result holds only within the limits of the response range used, of course; this means that no information is available about the absolute maximum range within which the linear relation holds (although there should be nothing magic about the range 2-50). The generality to other sensory scales, and answers to questions such as the relative extent to which the linearity results from an expansion of the number of categories

(rather than, say, simply an increase in the numerical response range) remains to be experimentally determined.

The major point of this paper is the suggestion that the previous curved relation found between magnitude and category scales is an artifact of the restricted range of response categories supplied to the O. While it might be argued that setting the category ranges to be the same for both methods fixed the slope at 1.0, the relevant point is not the value of the slope but the fact that every intermediate response was approximately the same under both scaling methods, thus removing the curvature normally expected. The suggestion has previously been made that "the nonlinearity of category scales when plotted on the same coordinates as the power functions is related to the report system [Gibson, 1960, p. 12]." Marks suggested, "When adjusted by means of an additive constant, category scales can be described as power functions of stimulus intensity [Marks, 1968, p. 479]." From the present results, we might expect that such a corrective additive constant, as a measure of disparity between response constraints in the two scaling operations, reduces to zero when the set of categories assigned matches the set of numbers O reports as magnitude estimates. The curvilinear relation between category and magnitude scales should be seen, not as a criterion for prothetic continua, but as reflecting the noncorrespondence of the range and/or grain of the respective response dimensions.

However, we are still left with the problem of the mathematical meaning of the scale units. In the present case, where one set of categories was arranged to be set equal to another set of responses, the resulting linear function implies exact correspondence between the numbers given to magnitudes on both scales. Yet, one set of responses was obtained by instructing O to give equal ratios, the other by instructions aimed at obtaining equal differences between adjacent scale steps. We are reminded of Torgerson's (1958) understated caution, after he had scaled lightness and darkness both by magnitude and by category methods, that the E's

instructions to form ratios may not be sufficient to conclude that the reports bear ratio relations among themselves.

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NOTES

1. We are indebted to W. S. Ray for advice on this procedure. The Peters index of parabolic curvature was chosen to indicate empirically (and independently of scale values) the amount of downward curvature. The index is not influenced by the physical expansion of the ordinate scale in Fig. 2.
2. However, in practice, the presumably infinite series of positive fractions available to O turns out to be quite finite. We have observed both in the present experiment and in others that Os tend to use whole numbers.

(Accepted for publication April 8, 1972.)