Subject differences in cross-modality matching*

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Forty-eight Ss performed four tasks each: (1) magnitude estimation of area, (2) magnitude estimation of numerousness, (3) cross-modality matching of force of handgrip to area, and (4) cross-modality matching of force of handgrip to numerousness. An additional 48 Ss performed Tasks 2 and 4. Psychophysical power functions were fitted to the data of each S for each condition. Higher correlations between individual exponents were found for conditions employing a common response (i.e., estimating or squeezing) than were found for conditions with the same set of stimuli. Individual differences among exponents stem more from the idiosyncratic use of the dependent variable than from different sensory characteristics.

Individual S's exponents from psychophysical power functions vary reliably between Ss and are correlated across continua (Bruvold & Gaffey, 1965; Jones & Marcus, 1961; Rule, 1966, 1968, 1969). The present study examines whether such variability is due to factors associated with Ss' sensitivity to the stimuli presented or to those associated with selecting a stimulus from the response continuum to match the sense impressions.

Stevens (1961) has suggested that for Ss with normal sensory functioning, differences in sensitivity probably account for a minor part of the variability of Ss' responses, and Markley (1965) and Rule (1966) have argued that variability of exponents reflect differences in response factors. But Ekman, Hosman, Lindman, Ljungberg, and Åkesson (1968) noted that correlations between continua were much smaller than estimates of reliability and concluded that the major portion of the reliable interindividual variance was due to differences in Ss' sensitivity.

In the present study Ss judged numerousness and area using two response procedures, magnitude estimation and cross-modality matching with force of handgrip. By employing two response procedures to obtain exponents for the same stimuli, it was possible to determine if differences in sensitivity to input stimuli were a major source of interindividual variability. Stevens (1961) has suggested a similar procedure for distinguishing Ss with sensory defects from those with deviant conceptions of sensory ratios.

METHOD

Subjects

The Ss were 96 right-handed males enrolled in an introductory course in psychology. Participation in psychological experiments was a required part of the course work.

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Apparatus

Seven circles and seven numerousness displays were prepared on 35-mm slides. The areas of the projected circles were 12.5, 20.5, 33.5, 54.5, 89.4, 146.1, and 239.2 cm^2. The numerousness displays were patterns of dots located randomly in the same circular area. The displays contained 25, 31, 39, 49, 61, 76, or 95 dots. Projected images appeared white on a black background. Exposure time was set at 1 sec and controlled by a shutter (Alphax) mounted in front of a slide projector.

A hand dynamometer was constructed such that movement of the grip was imperceptible when force was applied, so that perceived movement was not confounded with perceived force. The frame and grip were from a hand dynamometer (Lafayette). The grip was attached rigidly to the center of a steel bar, 12.7 cm long and .64 cm thick. When force was applied to the grip, the bar would bend a small amount. The amount of displacement of the center of the steel bar was converted to voltage change by a displacement transducer (Sanborn). The transducer was connected to a recorder (Esterline Angus). The amount of displacement was less than .1 cm for a force of 100 kg.

Procedure

Estimates of subjective magnitude were obtained from four conditions: (1) magnitude estimation of circle area, (2) magnitude estimation of numerousness, (3) cross-modality matching of force of handgrip to circle area, and (4) cross-modality matching of force of handgrip to numerousness. Forty-eight Ss took part in all four conditions.

For the magnitude estimation tasks a standard stimulus (54.5 cm^2 or 49 dots) was presented first and assigned the value 10. Ss were instructed to assign numbers to subsequent stimuli that were proportional to the Ss' subjective impression of their magnitude. For the tasks employing force of handgrip Ss were first allowed to become familiar with the apparatus by squeezing the hand dynamometer a number of times. They were then instructed to apply a force on the handgrip that matched the apparent magnitude of each stimulus. Instructions for the area conditions employed the term "subjective size" rather than subjective area.

For each condition the series of seven stimuli was presented four times. The stimuli were presented in a random order with the restriction that the stimulus presented first in the two cross-modality matching tasks was the standard for magnitude estimation. Within a condition all Ss received the same order of stimuli. The order of presentation of conditions was varied in all 24 possible permutations. Two Ss were assigned to each order. Each S completed all four tasks in a single session.

An additional 48 Ss participated in a replication of the magnitude estimation of numerousness and matching of force of handgrip to numerousness conditions.

RESULTS

For each S psychophysical power functions were obtained from magnitude estimation of area and numerousness and from matching of force of handgrip to area and numerousness. The functions were fitted by the method of least squares applied to the logarithmically transformed stimulus and response measures. Geometric

Table 1
Mean and Standard Deviation of Individual Exponents

	Condition					
	Initial Experiment				Replication	
	Magnitude Estimation Circles	Handgrip Circles	Magnitude Estimation Numerousness	Handgrip Numerousness	Magnitude Estimation Numerousness	Handgrip Numerousness
M	.72	.55	1.15	.97	1.25	.91
SD	.14	.25	.28	.51	.34	.48

Table 2
Correlation Coefficient of Individual Exponents

Condition	1	2	3	4
Magnitude Estimation Circles	.82** (.90)[a]	.46** (.50)[b] (.61)[d]	−.11 (−.06)[c]	−.03 (−.01)[c]
Magnitude Estimation Numerousness		.66** (.80)[a]	.20	.33* .28 (.16)[e]
Handgrip Circles			.80** (.89)[a]	.70** (.84)[c]
Handgrip Numerousness				.75** (.86)[a]

[a] Corrected by the Spearman-Brown formula; [b] Data from Rule (1966); [c] Data from Markley (1965); [d] Data from Rule (1969); [e] Unpublished data.
$^{*} p < .05$; $^{**} p < .01$

means were used to average each S's responses to each stimulus. The arithmetic mean and standard deviations of Ss' exponents for each condition are presented in Table 1.

The geometric mean of individual S's ratio of exponents from magnitude estimation and force of handgrip for each stimulus set provided predicted exponents for apparent force of 1.43 from area conditions, 1.37 from numerousness conditions, and 1.49 from the replication of numerousness conditions. The predicted exponents are smaller than that of 1.7 reported previously (Stevens & Mack, 1959; Stevens, Mack, & Stevens, 1960).

Pearson product-moment correlation coefficients were computed between individual exponents obtained from the first two presentations of each series of stimuli with those obtained from the last two presentations to provide split-half estimates of reliability. These estimates were corrected for the lower number of presentations by the Spearman-Brown formula. The corrected and uncorrected coefficients are presented as diagonal entries in Table 2. Presented as off-diagonal entries in Table 2 are correlations between conditions computed on individual exponents obtained from all four presentations. The correlation for the replicated numerousness conditions appears immediately below that of the initial experiment. The correlations were tested for significance of the difference from zero with a t test.

Correlations between exponents for these conditions obtained in several other studies are presented as off-diagonal entries enclosed in parentheses in Table 2. One of the correlations for magnitude estimation of area and magnitude estimation of numerousness was based on four responses to seven stimuli from each of 36 Ss (Rule, 1966), and one was based on four responses to nine stimuli from each of 48 Ss (Rule, 1969). Markley's (1965) study employed 24 Ss who gave eight responses to each of seven stimuli. The correlation of .16 for numerousness conditions was obtained from 48 Ss who made magnitude estimations of numerousness and matched force of handgrip to numerousness as part of another experiment. Three responses to eight stimuli were obtained from each S. The stimuli ranged from 25 dots to 119 dots in equal logarithmic steps.

DISCUSSION

Cross-modality matching entails two stages: In the input stage a S evaluates the subjective magnitude of a stimulus, and in the output stage he selects a stimulus from another continuum which matches its subjective magnitude. Each stage is characterized by a power transformation. The exponent, q, from cross-modality matching is a ratio of exponents from the input and output transformations such that for the present study: $q_{cm} = C/M$, $q_{ch} = C/H$, $q_{nm} = N/M$, and $q_{nh} = N/H$, where C and N denote input exponents for circle area and numerousness, respectively, and M and H denote output exponents for numbers (from magnitude estimation) and force of handgrip. The corresponding lower-case symbols appearing as subscripts denote the cross-modality matching condition (e.g., q_{cm} represents magnitude estimation of circle area).

Correlations of condition exponents reflect the relationships among input and output exponents. The two highest correlations were for conditions with a common output exponent (i.e., .5 for magnitude estimation and .7 for force of handgrip). This finding suggests that individual differences among exponents were due primarily to differences in output exponents. However, it could be argued that the correlations were due to relationships other than that between output exponents. In particular, a correlation might be expected for input exponents from the two visual continua, area and numerousness. Such a possibility can be eliminated by correlating the difference in logarithms of q_{cm} and q_{ch} with a similar difference for q_{nm} and q_{nh}. These are the logarithms of the predicted exponents for apparent force.

The differences may be expressed as:

$$\log q_{cm} - \log q_{ch} = (\log C - \log M) - (\log C - \log H) = \log H - \log M, \quad (1)$$

$$\log q_{nm} - \log q_{nh} = (\log N - \log M) - (\log N - \log H) = \log H - \log M. \quad (2)$$

The correlation (.53) for the differences expressed in Eqs. 1 and 2 is a function only of output exponents.

Lower correlations were found for conditions with common input exponents (i.e., −.1 for area and .3 for numerousness). It could be argued that the true correlations for input exponents were higher but were masked by other relationships among components (e.g., a negative correlation for C and 1/H or for C and 1/N). Evidence that output exponents for magnitude estimation do not correlate with input exponents is provided by Curtis, Attneave, and Harrington (1968). They obtained input and output exponents from judgments of differences in weight magnitude. The correlation for their exponents was .01. In a similar study on brightness (Curtis, 1970), the correlation was .11. (The output exponent in each study was comparable to 1/M.) Expressions similar to Eqs. 1 and 2 containing only input exponents are as follows:

$$\log q_{nm} - \log q_{cm} = (\log N - \log M) - (\log C - \log M) = \log N - \log C, \quad (3)$$

$$\log q_{nh} - \log q_{ch} = (\log N - \log H) - (\log C - \log H) = \log N - \log C. \quad (4)$$

The correlation for the differences expressed in Eqs. 3 and 4 was −.14. A positive relationship between C and N, which could have influenced the correlation, has already been shown not to have been responsible for the correlations for conditions with a common output continuum and was not a component of the correlations for conditions with a common input continuum.

Although the correlation for

numerousness conditions was not high, it appears to be a reliable finding. It suggests that for some continua a part of the interindividual variability may stem from an input component. However, the proportion of the variance due to such a component appears to be small. It is possible that the correlation was due to a greater degree of complexity in the stimuli, since they varied in configuration of dots as well as in number. It seems reasonable that individual differences in the input stage would be more pronounced with more complex stimuli (e.g., reversible figures). With complex stimuli, perceptual dimensionality may vary between Ss, and Ss may differ in the weight given to each dimension (Shepard, 1964).

The evidence indicates that for Ss with normal sensory functioning, the interindividual variability of exponents arises primarily from differences in the use of the dependent variable. Although the correlation for handgrip conditions could reflect differences in the sensation of force, no such sensory process was present when numerical estimates were made. It seems reasonable that variability of exponents stems more from idiosyncratic response biases than from differences in sensory operating characteristics.

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