Visual and tactual form complexity: A psychophysical approach to perceptual equivalence¹

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Equivalence of two modalities for processing form-complexity information was investigated by obtaining category judgments of the complexity of 100 random forms from 40 Ss who explored the forms visually and 40 Ss who explored them tactually. Intercorrelations of judgments and multiple regression analyses with form measures indicate that information was used in the same fashion independent of input modality. Latencies were interpreted as reflecting information gaining and processing capabilities.

Perceptual systems overlap in the capability of processing information about objects and events. A case that has received particular attention is that of form perception where contour information can be picked up either visually or tactually. Researchers comparing the two modalities have found comparable association values (Ellis & Bessemer, 1962), an ability to match objects cross-modally without previous experience (Caviness & Gibson, 1962), and cross-model transfer of training (Bjorkman, Garvill, & Molander, 1965; Caviness & Gibson, 1964; Gaydos, 1956; Gibson, 1963; Lobb, 1965; Pick, 1965; Rudel & Teuber, 1963). While perceptual equivalence implies equivalence in stimulation, only Pick (1965) has made an attempt to vary stimulus characteristics to assess the dimensions that underlie common specificity of form.

One area where knowledge of relevant form characteristics has been particularly elucidating is in accounting for judged complexity. Stimulus complexity has been quantified by such measures as number of turns in a figure and angular variability, and successfully related to visual complexity judgments using category scaling techniques (Attneave, 1957; Arnoult, 1960; and Stenson, 1966). Identical distribution of form contour can be achieved by making the spatial representation of an abrupt visual brightness gradient, e.g., black to white, identical to that of an abrupt tactual texture gradient, e.g., rough to smooth, allowing a comparison of complexity scaling. By employing identical stimulus variation in visual and tactual presentation and using category judgment as a common response indicant, equivalence of perceived

complexity can be demonstrated. Specifically, tactual and visual judgments of form complexity should approach a correlation of 1.00 and should be related to the same form dimensions.

METHOD

Subjects

Eighty male undergraduates served as Ss in fulfillment of an introductory psychology course requirement. Forty participated in the visual experiment and 40 served in the tactual experiment.

Stimuli and Experimental Design

One hundred forms were sampled from the 1,000 forms generated by Brown and Owen (1967), providing 20 stimuli at each of the following levels: 4, 8, 12, 16, and 20 sides. The forms were generated in a 100 by 100 matrix by Method I rules for angular shapes of closed contours as described by Attneave and Arnoult (1956). All forms were equated to an area of 1,250 units and plotted in a 100 x 100 mm coordinate system. The tactual stimuli were constructed from Behr-Manning 360A abrasive paper, analogous to very fine sandpaper, and glued onto 100 x 100 mm squares of smooth poster board. The visual stimuli were transparencies, black on a white background, presented with the same area as the tactual forms on a rear-projection screen. The 100 forms were assigned randomly to four groups, and within the groups forms were assigned randomly to five blocks of five forms so that each block contained one form from each of the sidedness levels. The Ss were assigned randomly to the four columns of a Latin square, with rows made up of the four groups of stimuli to control for sequence effects.

Apparatus and Procedure

The S was given a 7-point adjective scale that ranged from "extremely simple" through "medium" to "extremely complex," as used by Attneave (1957). When the S had memorized the scale, he explored 10 practice forms to acquaint himself with the range of complexity. The forms were presented by means of apparatus that also provided for measurement of the time from which the S exposed the stimulus to himself to the

point at which he made a judgment of the complexity of the stimulus. His verbal response stopped a 1/100-sec timer by operation of a voice key. For exploratory purposes, latencies to ratings were recorded in addition to the ratings themselves.

RESULTS

Ratings

In order to make the adjectival ratings amenable to numerical analysis, the ratings were converted to a scale from 1 to 7, corresponding to the category labels from "extremely simple" to "extremely complex." Since the representation of a verbal scale by numbers makes necessary some assumptions about the interval properties of the numbers, the complexity ratings were scaled using the method of "graded dichotomies" proposed by Attneave (1949). This procedure allows computations of category boundaries from which category widths, as well as scale values, can be determined. The category widths were approximately equal for both the visual and the tactual scales, and plots of mean ratings vs scale values showed none of the curvilinearity found when category widths are constricted at the ends of the scale. In view of these comparisons, it appeared that numerical representation of the categories was warranted for these data and, accordingly, all further analyses were performed using the observed ratings.

Means computed across the 40 Ss provided a complexity value for each form and means of the 20 forms were taken to represent each sidedness level. The sidedness means are presented in Fig. 1, with 1 SD of the 20 form means above the sidedness mean for the visual ratings and below the sidedness mean for the tactual ratings. An analysis of variance revealed that the sides main effect and all other effects are significant at the .01 level, except the modalities main effect (significant, $p < .05$), the Modality by Sides interaction (nonsignificant, $p > .10$), and the Modalities by Forms-Within-4-Sides interaction (nonsignificant, $p > .25$). Analyses of the trend of the sides main effect for the visual and tactual data reveal that the significant linear component ($p < .01$) accounts for 96% and 95% of the total sides variation, while the significant quadratic component ($p < .01$) accounts for 3% and 5%, respectively.

Fig. 1. Mean rating at each sidedness level with 1 SD of the 20 form means shown above the visual means and below the tactual means.

Further support for the inference that Ss are using information picked up by the two different modalities in essentially the same fashion is evidenced by a correlation of .98 between the two sets of ratings. Intercorrelations among the visual Ss' ratings ranged from the high .80s to the low .90s, while those for the tactual Ss ranged from the .70s to the middle .80s, indicating that Ss' ratings are generally homogeneous.

Latencies

Latency means for forms and sidedness levels were computed in the same way as for the ratings (see Fig. 2 for the visual means and Fig. 3 for the tactual means). As suggested by the difference in the shape of the two curves, a significant Modality by Sides interaction ($p < .05$) was found. The interaction is well illustrated by trend analyses on the sides main effect where the linear and quadratic components were significant ($p < .01$). The curve for the visual latencies has a linear component that accounts for 40% of the sides variation and a quadratic component that accounts for 58%. In contrast, the tactual latency curve is 94% linear and 6% quadratic, the similarity to the visual and tactual ratings being emphasized by correlations of .94 and .95, respectively.

The possibility that the shape of the visual curve might be related to the extremeness of the rating category used led to the plotting of both visual and tactual mean latencies across the adjectival scale. The mean for each category was found by summing the latencies corresponding to each time the rating was used and dividing

by the number of times the category was used. The visual curve was almost identical to the curve plotted across sides, and the tactual curve also revealed a decidedly nonmonotonic function, with a peak at the "complex" category and dropping by 2 sec to the "extremely complex" category.

Multiple Regression Analyses

The previous analyses make it quite clear that both tactual- and visual-complexity ratings are closely associated with the number of independent sides of the shapes studied. However, it should be noted that considerable variation existed between ratings for individual shapes within each sidedness level. Subsequent analyses were directed toward attempting to account for such variation through linear regression techniques in which physical shape measures were related to ratings.

Seventy-nine of the 80 shape measures described by Brown and Owen (1967) were used, with the replacement of the most redundant measure by number of sides in the form since these analyses were carried out across sidedness levels. The 80 measures, computed for each of the 100 forms, were intercorrelated and factored into their principal components. Twelve factors were rotated and factor scores were computed for each form, characterizing the forms in terms of 12 orthogonal factors in place of the original correlated 80 measures. This form analysis was identical to that reported in detail by Brown and Owen (1967) except that this analysis was computed across sidedness levels and was limited to the sample of forms used in this study.

In order to assess the relative contributions of factor dimensions in accounting for performance variance, a multiple linear-regression analysis was used to relate the 12 form measures to ratings and to latencies. The results of these analyses are summarized in Table 1 for the best four predictors in each equation. Since predictors were orthogonal and the coefficients summarized in Table 1 are simply the zero-order correlations between dependent variables and the factor measures, interpretation is straightforward. The order in which a predictor entered an equation is indicated by its magnitude, the square of each coefficient represents the per cent of variance that is predictable using only that factor measure, and the sum of squared coefficients represents the per cent of variance predictable by combining predictors (the square of the multiple correlation coefficient). Using only F_2 , for instance, it is possible to account for 88% of the visual complexity ratings of individual shapes; adding the other three predictors contributes 6% so

Fig. 2. Mean visual latency at each sidedness level with 1 SD of the 20 form means shown above and below the sidedness mean.

that a total of 94% of the variation in visual ratings is predictable with four factor measures. It is obvious that the ratings and the tactual latencies are readily predictable using a small set of predictors, most of the prediction is accounted for by F_2 , and a great deal of similarity exists in the prediction equations. This latter outcome is assured by the high degree of linear correlation among those three dependent variables. Prediction of visual latencies, while statistically significant, was not impressive but is best accomplished by combining F_2 and F_9 .

Factor 2 is perhaps best described as a "jaggedness" factor; it was highly

Fig. 3. Mean tactual latency at each sidedness level with 1 SD of the 20 form means shown above and below the sidedness mean.

Table 1
Standardized Regression Weights and the Square of the Multiple Correlation (R^2)
Using the Best Four Predictors

Dependent Variable	Factor Score Predictor						R^2
	F1	F2	F3	F8	F9	F10	
Visual Complexity	-.10	.94	—	—	-.12	-.18	.94
Tactual Complexity	-.13	.92	—	—	—	-.13	.90
Visual Latency	—	.44	.13	.21	-.44	-.27	.50
Tactual Latency	—	.88	—	.17	-.10	-.18	.85

correlated with number of sides (.87), perimeter length (.98), and the second central moment of interior angles (.87). With fixed area, shapes that have a longer perimeter tend to have variable angle sizes and these variables covary with the number of sides of the shape. It should be noted that number of sides alone was correlated .95, .93, and .89 with visual complexity, tactual complexity, and tactual latency, respectively, and is, therefore, the best single performance predictor.

DISCUSSION

The comparison of form complexity judgments presents a convincing case for equivalence of the visual and tactual modalities in processing information required for performance of the task employed. One of the most important findings was the lack of a significant Modality by Sides interaction for the ratings where one might well have been expected. The results of the multiple-regression analyses compare favorably with similar visual studies by Attneave (1957), Arnoult (1960), and Stenson (1966), where 91%, 87%, and 92% of the variance in the respective complexity judgments of random forms were accounted for by several physical predictors. Stenson applied a set of factor predictors reduced from 24 form measures, and comparison reveals that Factors 2 and 10 correspond, in fact, very closely to Stenson's Factors D and H, respectively, in terms of their defining measures. The stimulus information weighted in making complexity judgments seems to be gained and processed very nearly as well from tactual input as from visual.

Since no previous studies have recorded latency to make a complexity judgment, interpretation of this variable must be considered exploratory. The linear relationship between the tactual latencies and log number of sides suggests that information gaining is primarily reflected, while the visual latencies appear to reflect primarily information processing. A quadratic function was also observed by Behar (1963) when response time in a 10-category visual size-judgment task was plotted across the physical values of the stimulus, i.e., area. The drop in tactual latencies at the high end of the scale

further supports the explanation that stimuli perceived as extreme are judged more quickly, perhaps because the information needs to be compared with fewer category "ideals" near the end of the scale.

The results lend psychophysical support to Gibson's (1962) contention that when the visual and tactual modalities are considered as channels for information gaining with active and exploratory sense organs, they are capable of registering the same information. Stated in terms of partial equivalence of perceptual systems (Gibson, 1966), a form in the present experiment is the source of at least two kinds of information. One kind is provided by the distribution of the brightness gradient and another by the distribution of the texture gradient. Each alone can specify the complexity of the form. The slightly lower tactual complexity ratings at higher sidedness levels can be attributed to the poorer acuity of the tactual system in picking up invaginated details. In other words, if the forms were larger, no difference in judgment would be expected.

Assuming that equivalent information is picked up, it can be further hypothesized that the features extracted are weighted in some consistent fashion similar to that proposed by Brunswik (1955). The multiple regression equation is an attempt to recover the weighting scheme. The common functional validity of the two different specifications of form-contour information is verified when perception of form complexity can be functionally equivalent even though that information is carried by different forms of stimulus energy and processed by different perceptual systems.

The argument parallels an earlier conceptualization of a visual world where perception of an object remains constant with a varying visual field (Gibson, 1950, 1952). Analogously, there is a constancy of the tactual world with variation in the tactual field. By extension of the notion, there can be an object or event constancy that is modality independent, a *perceptual world* that exhibits invariances regardless of input modality. There will be equivalence of visual and tactual information transmitted when both radiant and mechanical energy have specified the

same object as indicated by response similarity. Verification of such a statement is, as proposed by Brown and Owen (1967), ultimately a function of the predictive utility of a psychophysical method. Efficacy of the psychophysical approach employed is clearly evidenced by the proportion of variance accounted for in the ratings and the similarity of the regression equations as a case for equivalence of the two modalities.

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NOTES

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