Perceptual equivalence, pattern perception, and multidimensional methods[1]

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Two samples of 10 random polygons were scaled tactually and visually using multidimensional scaling techniques. Unidimensional solutions were very similar for both modalities and were linearly dependent upon the number of independent sides of the forms. Solutions of higher dimensionality did not produce clearly interpretable unique orderings of the forms beyond the first dimension with these samples. Within the limits imposed by these samples of forms, the data strongly support equivalence for visual and tactual form perception.

This study is one in a series designed to contribute to the development of a psychophysics of form perception (Brown & Andrews, 1968; Brown & Owen, 1967; Behrman & Brown, 1968; Fenker & Brown, 1968; Forsyth & Brown, 1967; Forsyth & Brown, 1968; Owen & Brown, 1968). In particular, it was concerned with the problem of intermodal perceptual equivalence. Perceptual equivalence for modalities can be said to exist when comparable stimulus variation presented to different modalities leads to comparable responses. When this occurs, the implication is either that similar input processing systems exist or that input is referred to a common perceptual apparatus regardless of the input channel involved. The theoretical basis for such an analysis is inherent in Gibson's position (e.g., 1959) which states that stimulation conveys all information necessary for correspondence between input variation and response variation. If comparable stimulus variation is presented to two modalities and if comparable responses occur, the resulting percepts are functionally equivalent.

It has been previously demonstrated that cross-modal matching and transfer can occur between the visual and tactual modalities (Caviness & Gibson, 1962, 1964; Bjorkman, Garville, & Molander, 1965). For those with a psychophysical bent, this leaves an obvious and important extension of such demonstrations unanswered. Perceptual equivalence implies stimulus equivalence and the question of what input attributes account for the equivalence arises. While psychophysicists have been timid in attempting to develop a meaningful physics of stimulation for complex perceptual situations, recent developments in visual pattern perception have been encouraging (e.g., Attneave & Arnoult, 1956; Brown & Owen, 1967; Evans, 1967; Michels & Zusne, 1965). Moreover, pattern perception represents a reasonable context within which to examine stimulus equivalence between visual and tactual perception. Pattern perception is undoubtedly common to auditory, visual, and tactual perception. In audition, patterns are events and are organized in time. While tactual and visual perception undoubtedly involve temporal aspects, both also refer to organization of stimulation in space, or objects. It seems reasonable that a perceptually relevant spatial physics may be common to both modalities.

In earlier studies (e.g., Owen & Brown, 1966, 1968) a very high degree of correspondence was demonstrated between unidimensional complexity judgments when random polygons were scaled tactually and visually. Moreover, both perceptual scales were predictable from a common set of physical shape measures. The present study was designed to extend those results by applying multidimensional scaling (MDS) techniques to ratings of patterns presented for both visual and tactual judgments.

METHOD

Subjects

Thirty-two male and 32 female undergraduates served as Ss. Of these, 19 served to satisfy partial requirements for an introductory psychology course, while each of the remaining 45 was paid for participation.

Patterns

Two samples of 10 random polygons were selected from previous scaling results to be approximately equidistant on a unidimensional, visual complexity continuum (Owen & Brown, 1968). Each form series, designed Set A and Set B, contained two representatives each of 4, 8, 12, 16, and 20-sided forms. It should be noted that even though patterns were specifically selected to be perceptually equidistant, this does not assure unidimensionality when MDS procedures are used. Indeed, one of the purposes of the present study was to validate previous unidimensional findings and to extend these results to MDS for the two modalities.

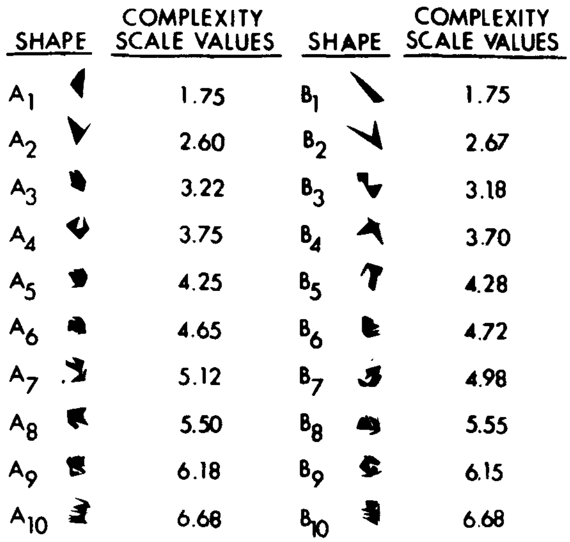
Patterns were generated in a 100 by 100 unit matrix according to a modified Method I of Attneave and Arnoult (1956) with a single modification of these rules to avoid the problem of dependent form sides. All forms were equated for area at 1250 sq units and centered by equating the distance of the form vertically and horizontally on the 100 x 100 mm white posterboard squares on which they were presented. Forms were cut from black, finely-graded sandpaper (Behr-Manning 360A) and glued to the posterboard squares.

A detailed discussion of the nature of the stimulus domain from which these forms are a sample has been presented (Brown & Owen, 1967). The forms used in this study are shown in Fig. 1 with their unidimensional complexity scale values.

Apparatus and Procedure

The apparatus, which has been described in detail elsewhere (Owen & Brown, 1968), consisted essentially of a Plexiglas display surface for presenting forms tactually and visually and circuitry for measuring scaling latency.

The Ss were randomly assigned to one of four experimental conditions with the restriction that an equal number of male and female Ss participate in each condition. These conditions were



SHAPE	COMPLEXITY SCALE VALUES	SHAPE	COMPLEXITY SCALE VALUES
A_1	1.75	B_1	1.75
A_2	2.60	B_2	2.67
A_3	3.22	B_3	3.18
A_4	3.75	B_4	3.70
A_5	4.25	B_5	4.28
A_6	4.65	B_6	4.72
A_7	5.12	B_7	4.98
A_8	5.50	B_8	5.55
A_9	6.18	B_9	6.15
A_{10}	6.68	B_{10}	6.68

Fig. 1. The two samples of shapes and their unidimensional, visual complexity scale values.

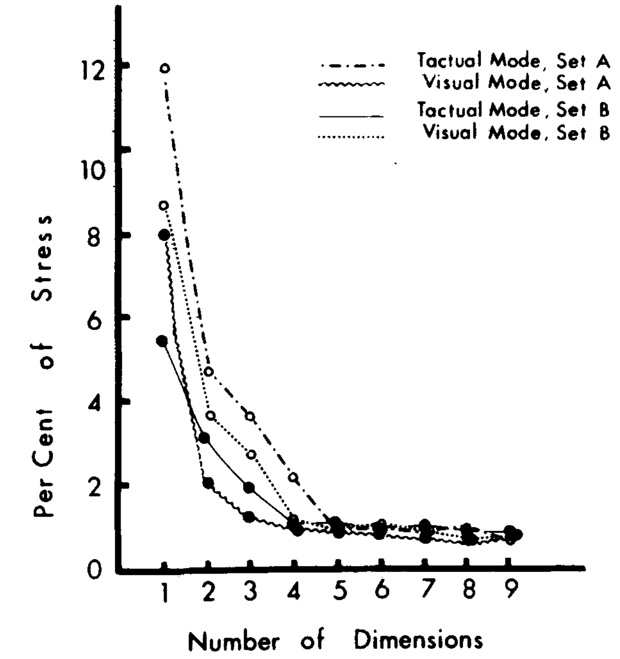


Fig. 2. The stress curves for the four experimental conditions.

defined by factorially combining two modes of stimulus presentation (visual and tactual) with the two form series. Ss were individually presented with the 45 pairs of forms defined by the paired comparisons of the 10 forms of each set. Order of the 45 pair presentations was according to the procedure developed by Ross (1934) which insures that a maximum and equal number of trials intervene between successive presentations of any one form.

The order of pair presentations was reversed for half of the Ss under each condition and the left-right position was randomly determined for each trial and was also reversed for half the Ss under each condition.

Ss were tested individually under all conditions. They were instructed to rate pairs of forms on a 7-point scale in terms of similarity of complexity with forms most similar in complexity rated "7," and forms least similar in complexity rated "1." Prior to data collection, 10 practice problems, selected to familiarize Ss with the complexity range of experimental forms, were presented. Ss were instructed to make their ratings as rapidly as possible, but to be sure of the rating before responding.

Under visual conditions, forms were hidden from view by a curtain between trials. On each presentation, a timer was activated when the curtain was drawn and was stopped when S spoke his rating into the microphone of a voice key. Under tactual conditions, Ss wore goggles throughout testing. On each trial, a timer was activated when S removed his preferred hand from a depressed panel and was stopped when the rating was spoken. Exploration of the form on the left was followed by exploration of the form on the right and Ss were free to explore shapes repeatedly on each trial and to use any pattern of exploration of each shape. Total testing time was approximately 45 min for visual ratings, and 1 h for tactual ratings.

RESULTS

Median similarity-of-complexity ratings were computed for each of the 45 form pairs across the 16 Ss in each experimental group. The median ratings were then entered into an upper triangular similarities matrix and a binomial test was used to assure that the median ratings satisfied properties of an ordinal scale for each group. The assumption of random ordering was rejected in each case ($p < .001$).

Subsequent analyses were directed primarily toward evaluating the dimensionality of the MDS solutions for each matrix, comparing the results for the two modalities, comparing these results to previously-obtained unidimensional complexity scales,

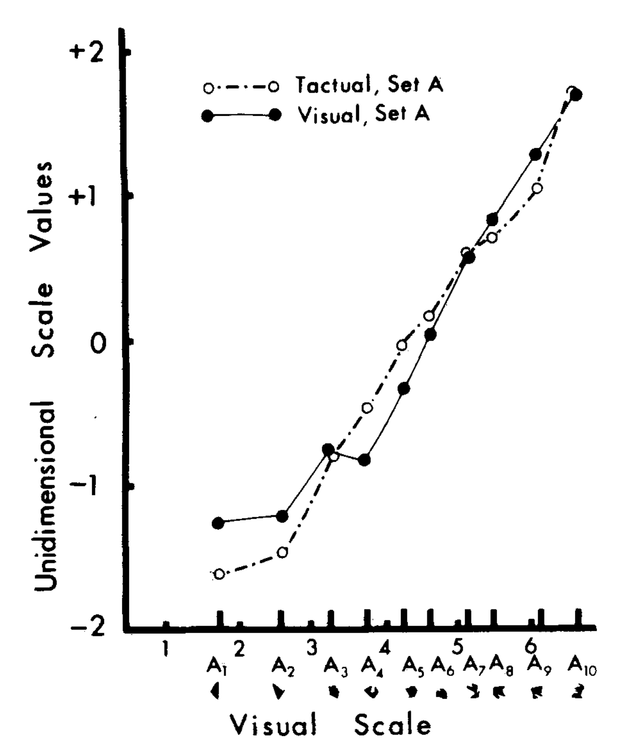


Fig. 3a. The unidimensional tactual and visual scales, Set A forms, plotted against the unidimensional visual scale used to select shapes.

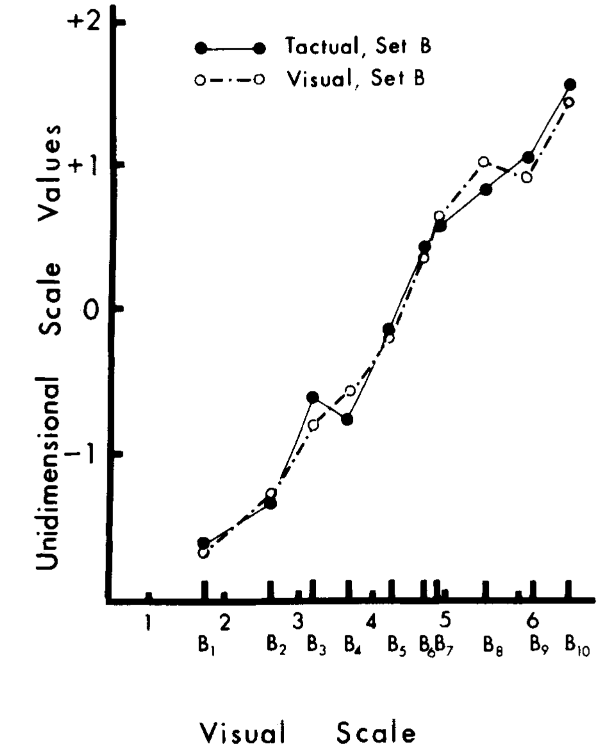


Fig. 3b. The unidimensional tactual and visual scales, Set B forms, plotted against the unidimensional visual scale used to select shapes.

Table 1
Intercorrelations Among Projections for Set A Scaling Results (Decimels and Signs Omitted)

Dimensions	V_1	V_2	V_3	T_1	T_2	T_3	T_4	T_5	$V_{1(1)}$	$T_{1(1)}$	C	S
V_1		-80	24	91	-83	16	26	18	96	95	93	95
V_2			01	72	92	09	53	24	93	91	92	93
V_3				19	08	70	50	26	16	14	14	17
T_1					65	03	96	14	86	86	84	83
T_2						17	46	21	90	93	95	93
T_3							08	32	13	11	16	10
T_4								18	38	48	36	49
T_5									26	19	28	24
$V_{1(1)}$										98	98	98
$T_{1(1)}$											99	98
C												98
S												

V_1 - V_3 = Visual Dimensions, 3-dimensional solution.
T_1 - T_5 = Tactual Dimensions, 5-dimensional solution.
$V_{1(1)}$ = Visual Dimension, 1-dimensional solution.
$T_{1(1)}$ = Tactual Dimension, 1-dimensional solution.
C = Scale values from visual, unidimensional scale.
S = Number of sides.

and relating the MDS results to physical shape measures.

The Kruskal (1964a, b) nonmetric analyses were applied to each of the four matrices and were limited to Euclidean solutions since in previous studys (Behrman & Brown, 1968; Brown & Andrews, 1968) the Euclidean metric has provided satisfactory solutions with this stimulus domain. The stress curves for the four solutions are shown in Fig. 2. One may apply at least three criteria to determine the dimensionality of the solutions; the absolute magnitude of stress, the presence of a clear break in the function relating stress to dimensionality, and interpretability of results obtained at a given dimensionality. Using the shape of the stress curves, one would conclude that three dimensions are required to fit the visual data and that five dimensions fit the tactual data for Set A forms. Four dimensions fit both tactual and visual data with Set B forms. However, it is worth noting that the stress values are low for all solutions. Kruskal (1964a) considers that 10, 5, and 2.5% stress provide "fair," "good," and "excellent" fits respectively. Using those criteria, unidimensional solutions provide "fair" fits and two-dimensional solutions are either excellent or good in each case. The point at which the stress curves break is always with stress less than 1%. Based upon the fact that the patterns were originally selected to be equally spaced unidimensionally, one might argue in favor of a solution in few dimensions.

Since one purpose of the study was to compare the dimensionality and the nature of dimensions extracted for tactual and visual data, it was decided that the break in the stress curve would be used as an upper bound for the number of dimensions (3, 5, 4, and 4 dimensions for visual, Set A, tactual, Set A, visual, Set B, and tactual, Set B, respectively) and that interpretability would be used to determine the nature and number of dimensions in the final configurations. It was expected that either one- or two-dimensional solutions would, however, be most meaningful.

As a first interpretation step, linear correlations (Pearson, product moment) were computed among projections on all visual and tactual dimensions and between dimensions of these solutions and unidimensional solutions, the previously-obtained unidemensional visual complexity scale, and the number of independent sides of the forms. These correlations are shown in Table 1 and Table 2 for Sets A and B, respectively.

It is very clear from both tables that unidimensional solutions are very similar across modalities, are closely related to the previous visual scales, and are linearly dependent upon sidedness. The smallest correlation among these variables is .97. It should be recalled that the unidimensional solutions provided "fair" fits to all four sets of data (stress ≤ 10%). The unidimensional results are shown graphically in Fig. 3.

It is more difficult to decide whether or not other dimensions are meaningful and whether they are the same for both modes of presentation. In the case of Set A forms (Table 1), it is clear that the first two dimensions are closely related to the unidimensional

Table 2
Intercorrelations Among Projections for Set B Scaling Results (Decimels and Signs Omitted)

Dimensions	V_1	V_2	V_3	V_4	T_1	T_2	T_3	T_4	$V_{1(1)}$	$T_{1(1)}$	C	S
V_1		76	58	48	77	82	53	50	87	87	85	79
V_2			70	59	88	89	45	71	96	96	96	95
V_3				54	73	73	69	30	76	79	74	82
V_4					66	47	52	62	63	65	71	72
T_1						71	39	60	92	91	92	93
T_2							48	49	91	92	87	87
T_3								38	55	53	57	57
T_4									65	69	72	62
$V_{1(1)}$										99	99	97
$T_{1(1)}$											99	97
C												97
S												

V_1 - V_4 = Visual dimensions, 4-dimensional solution.
T_1 - T_4 = Tactual dimensions, 4-dimensional solution.
$V_{1(1)}$ = Visual dimension, 1-dimensional solution.
$T_{1(1)}$ = Tactual dimension, 1-dimensional solution.
C = Visual, unidimensional scale values (Owen & Brown, 1968).
S = Number of sides

solutions, to each other, and to sidedness and that they are quite similar across modalities. It appears, however, that the third visual and tactual dimensions represent a unique ordering which is stable across modalities. That is, they are uncorrelated with all other variables, but have a reasonably high correlation (.70) with each other. An attempt was made to interpret these dimensions by relating them to 80 physical measures (Brown & Owen, 1967), but the largest correlations between physical measures and these dimensions ranged between .60 and .80 and since the measures are also partially correlated with sidedness, these relationships were not psychophysically useful. With Set B forms (Table 2), the results were similar. In both four-dimensional solutions, two dimensions are closely related to the unidimensional solutions, and other dimensions bear an intermediate relationship to each other and all other variables. There do not seem to be any unique dimensions above the first which are clearly stable across the two modalities.

DISCUSSION

These data confirm earlier results with regard to the similarity of perceived complexity between the visual and tactual modalities (Owen & Brown, 1968) and demonstrate that a high degree of perceptual equivalence obtains when MDS techniques are applied. With the forms used in this study, it seems unlikely that more than the first dimension is interpretable. However, in the case of Set A forms where a clearly different dimension occurred it was similar for the two modalities. In other studies, meaningful 3-dimensional solutions have been obtained with judged similarity data (Behrman & Brown, 1968) and with discrimination latency (Brown & Andrews, 1968) for visual presentation. Modality comparisons need to be made with samples of shapes which can be expected to result in meaningful solutions in several dimensions and work is in progress to provide this stronger comparison between visual and tactual pattern perception.

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NOTES

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