Pattern uncertainty and the discrimination of visual patterns[1]

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Sixty Ss individually sorted eight decks of 50 cards each. A deck contained 25 cards each of two stimulus patterns. The patterns were drawn from different sets of five-dot patterns judged to be equivalent. The eight decks represented pairs of patterns drawn (a) from the same equivalence set, (b) from different equivalence sets of the same size, and (c) from different equivalence sets of different sizes. Sorting times were shown to increase with increasing size of equivalence set, and were shown to be greater for patterns drawn from within the same equivalence set than for patterns drawn from different equivalence sets. Ratings of pattern goodness were found to be useful predictors of sorting time only in their capacity to discriminate between equivalence sets of different sizes. The results were interpreted as supporting the importance of equivalence set membership in a discrimination task where the S logically does not have to consider stimuli other than the given criterion stimuli.

Following the suggestion of Garner (1962) that size of equivalence set or pattern uncertainty is the independent or determining variable in pattern perception, ratings of pattern goodness were shown to be a correlate of both objective and subjective measures of equivalence-set size (Garner & Clement, 1963). The ease of encoding of a visual pattern, as determined by the latency and uncertainty of a verbal naming response (Clement, 1964), and as determined by the rate of learning in a paired-associate task (Clement, 1967), also correlates highly with pattern goodness, and thus with pattern uncertainty. Making the reasonable assumption that visual information is encoded on some basis prior to the actual discrimination response, then ease of encoding should be related to ease of discrimination as well.

In one type of discrimination task—sorting of visual stimuli—the S must somehow encode the stimulus to be classified and then compare it to some number of criterion stimuli, placing it in the category which it matches or most closely matches. The criterion stimuli may be given prior to the experiment, or they may be inferred by the S under the sorting instructions given. They may be physically present during the entire task, or the S may have to remember them. The encoding strategy used by the S is certainly a function of the specific task conditions and stimuli, but in each of the experiments cited above, it did seem to involve the processing of the whole pattern. With the dot patterns of Fig. 1, encoding difficulty is a correlate of the size of equivalence set, or pattern uncertainty (e.g., Clement, 1964). The difficulty of the second part of a sorting task—assignment of patterns to categories—is influenced by the similarity among categories, or more appropriately, among the encoded categories. Similarity among the categories for the patterns of Fig. 1 would seem related logically both to pattern uncertainty and to the identity of the specific equivalence set for each pattern (Handel & Garner, 1966). Thus, difficulty of a sorting task using these dot patterns should be a function of the pattern uncertainty for each pattern and the identity of the equivalence set to which it belongs. This discriminability is a correlate of ratings of pattern goodness only insofar as pattern goodness reflects such pattern uncertainty and equivalence set membership.

Royer (1966) investigated discrimination, as mea-

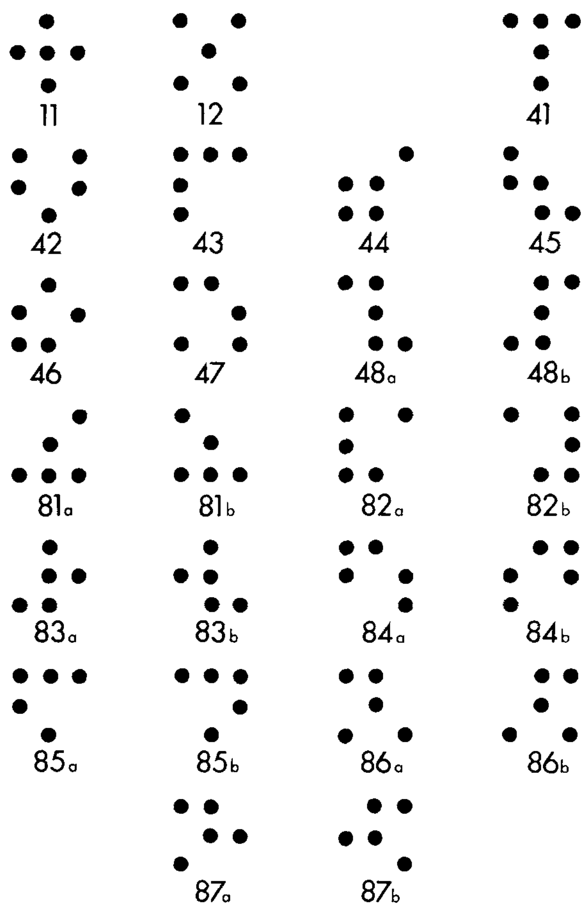

Fig. 1. Dot patterns used as stimuli.

from Garner and Clement (1963). (These patterns are included among those in Fig. 1.) He found sorting time to be significantly correlated with mean rating of pattern goodness for the sets of patterns (the lower the rating, the "better" the pattern). He found the goodness ratings correctly predicted differences in sorting times between sets of "equal" uncertainty, where two sets of patterns were considered equal if they had the same column configurations of dots within corresponding patterns, but with the three columns in each pattern interchanged between sets. This is a perfectly legitimate way of determining pattern uncertainty. However, the relations found previously (e.g., Garner & Clement, 1963) depended upon pattern uncertainty being defined by the number of patterns considered equivalent to the pattern under consideration. For the dot patterns used by Royer (1966) and in the present study, this is the same as the number of different patterns which can be formed by 90° rotations, reflection from left to right, or combinations of these operations. The size of such equivalence sets, for these patterns, can have the values of one (e.g., Pattern 11 in Fig. 1), four (e.g., Pattern 41 in Fig. 1), or eight (e.g., Pattern 81 in Fig. 1). Royer's study confounded discriminability differences among patterns belonging to the same equivalence set, among patterns belonging to different equivalence sets of the same size, and among patterns belonging to different equivalence sets of different sizes.

This study investigated differences in discriminability, as measured by sorting times and errors, for pairs of patterns chosen to represent all combinations of equivalence set membership and equivalence set size possible with the patterns in Fig. 1. The general hypotheses were: (a) When both patterns are drawn from within the same equivalence set, sorting time is longer than when they are drawn from different sets; (b) When the two patterns are drawn from different equivalence sets, each of the same size, sorting time is a positive monotonic function of the equivalence set size; and (c) When the two patterns are drawn from different equivalence sets of different sizes, sorting time is a positive monotonic function of the size of the smaller equivalence set, and a negative monotonic function of the difference between the sizes of the equivalence sets. Errors were expected to increase with increasing sorting time.

METHOD

Subjects

Sixty students (39 male, 21 female) from the introductory course in psychology were used as Ss.

Stimuli

The patterns used as stimuli were taken from Garner and Clement (1963), and are shown in Fig. 1. The patterns were printed in black, centered on 3 in. centered in a 5/16 in. sq. cell (cells were arranged in a three-by-three square matrix, with no boundary lines actually present on the stimulus cards).

The identification of the patterns was derived as follows: A two digit number was assigned to each pattern, the first digit describing the size of the equivalence set to which the pattern belonged (either 1, 4, or 8), and the second digit identifying the particular equivalence set. In addition, if reflection from left to right produced a pattern which could not be superimposed upon the original pattern by some combination of 90° rotations, the letters "a" and "b" were assigned to the two "different" reflections. For example, patterns 84a and 84b come from the fourth equivalence set of size eight, and represent reflections which cannot be made to correspond exactly by 90° rotations. Pattern 44 is from the fourth equivalence set of size four, and has no "different" reflection. The purpose of the distinction between reflected forms will be made clear in the description of Experiment 2.

The cards were made into decks of 50 cards, 25 each of two different stimulus patterns. Each S was given eight decks, which contained the following discriminations ("x" and "y" are used to indicate a given equivalence set, using the identification system described above): 1x vs 8y; 1x vs 4y; 4x vs 8y; 11 vs 12; 4x vs 4y; 8x vs 8y; 48a vs 48b; 8xa vs 8xb. For example, "1x vs 8y" might be a deck with 25 cards bearing Pattern 12, and 25 cards bearing Pattern 83; "8xa vs 8xb" might be a deck with Patterns 87a and 87b. The only discrimination task possible between patterns from sets of size one is 11 vs 12; the only one possible between *different* reflections of patterns from a set of size four is 48a vs 48b.

General experimental task

The Ss were run individually. Each S was told, by tape-recorded instructions, that he would be required to sort the cards in each of eight shuffled decks of cards into two bins, one deck at a time. Mounted on a vertical surface at the rear of each bin was a card bearing one of the two stimulus patterns which were included in each deck, and the S was instructed to place each card into the bin in front of the pattern which it matched (the criterion stimulus). The S was told to proceed as fast as possible while avoiding errors. Two warmup trials were run with a deck of black cards and white cards prior to the eight experimental trials. In each trial, one E placed a covered deck of cards in front of the S, then uncovered the criterion stimuli. A second E, who sat facing the S, gave the order to begin, and timed the duration of the trial. The first E recorded sorting errors at the end of the task.

Experiment 1

Thirty Ss were run in this experiment. The patterns in each deck of cards were in a fixed orientation, identical to that of the criterion stimuli. Thus no manipulation of the patterns in the deck, either physically or conceptually, was required in order to determine which criterion stimulus was the same as the pattern being sorted.

Experiment 2

Thirty different Ss were run in this experiment. The patterns in each deck of cards were randomly mixed among all possible orientations, and thus could be turned 0°, 90°, 180°, or 270° from the criterion stimuli. The Ss in this experiment were told that the patterns in the deck might be turned from the criterion patterns, and that it might be necessary to turn the cards (or imagine them as turned) in order to determine which criterion each matched. For two patterns drawn from the same equivalence set (of size four or eight) the only meaningful discriminations under these random orientation conditions were those of the forms 4xa vs 4xb and 8xa vs 8xb. No discrimination would be possible unless the patterns could *not* be superimposed by 90° rotations.

Within each experiment, the following variables were counterbalanced, with specific values randomly assigned to each S (with the restriction of using no pattern twice for the same S, except Patterns 11 and 12): equivalence set within each discrimination task; specific pattern from each equivalence set; location of each criterion pattern (left or right, to the S); orientation of each criterion pattern; and order of presentation of the eight tasks (with the restriction of no two consecutive sortings which included either Pattern 11 or 12). The Ss for the two experiments were randomly paired, with each S for Experiment 2 having exactly the same conditions on the above variables as one S from Experiment 1.

RESULTS

Sorting times were positively skewed for each S, so the median sorting time was selected as the appropriate measure of central tendency. The mean of median sorting times for Experiment 1 was 37.9 sec; for Experiment 2, 38.5 sec. These were not significantly different. Since individual differences in median times were great (values ranged from 24.9 sec to 63.8 sec), and since the purpose of the experiments was to obtain ordinal relations among the different discriminations which might hold across Ss, the sorting time data were transformed into deviations from the median sorting time for each S. These transformed data (henceforth referred to as "deviation times") were independent of individual differences in central tendency, while retaining individual differences in dispersion. Mean deviation times for the eight discriminations are shown in Table 1. "Fixed orientation" refers to Experiment 1, while "random orientation" refers to Experiment 2.

Table 1. Mean Deviations from Median Sorting Times (in sec)

Discrimination Task	Orientation Fixed (Exp. 1)	Orientation Random (Exp. 2)
11 – 12	– 3.1	– 5.3
4x – 4y	– 1.1	– 1.8
8x – 8y	3.4	8.5
48a – 48b	9.3	35.5
8xa – 8xb	14.7	58.7
1x – 8y	– 2.0	– 2.8
1x – 4y	– 2.9	– 4.6
4x – 8y	1.2	2.4

The first hypothesis predicted discriminations 4xa vs 4xb and 8xa vs 8xb would be more difficult than any others, while the second hypothesis predicted the order of difficulty among equivalence sets of the same size would be 8xa vs 8xb, then 4xa vs 4xb; and 8x vs 8y, then 4x vs 4y, then 11 vs 12 (in decreasing order). These hypotheses were verified, as may be seen in Table 1. The first five discrimination tasks in each column are in perfect increasing order. A Spearman rank-order correlation (rho) for the rank order of the mean deviation times for these tasks was 1.0, which was significant at the .01 level. A better indicator of the consistency of this ordinal relation was found by obtaining values for each S, then averaging these. The averaged rho for all 60 Ss was .80, also significant at the .01 level. Thus the first two hypotheses hold for the performance of individuals, as well as for average performance.

The third hypothesis assumed difficulty of the task to be a positive function of the size of equivalence set for the pattern from the smaller set, and a negative function of the difference between patterns in equivalence set size. The predicted order for the discriminations among patterns from sets of different sizes was (in decreasing difficulty) 4x vs 8y, then 1x vs 4y, then 1x vs 8y. This was not verified, as the 1x vs 4y task proved easier than the other two. The order of the mean deviations times reflected fair consistency among Ss, since the averaged Spearman rho (for all 60 Ss) between the order of these three mean values and the order of difficulty of the three discrimination tasks within each S was .58.

Since part of the third experimental hypothesis was based on an assumed ease of discriminating patterns from sets of different size, and since ratings of pattern goodness (taken from Clement, 1964) correlate with size of equivalence set, product-moment correlations were obtained for each discrimination task (except those with no difference in ratings between patterns) between difference in ratings of pattern goodness for the two patterns and deviation sorting time. Negative correlations, indicating faster sorting with greater differences, were expected. All correlations were in the range from –.31 to +.19, indicating no consistent relations and no practically significant effect.

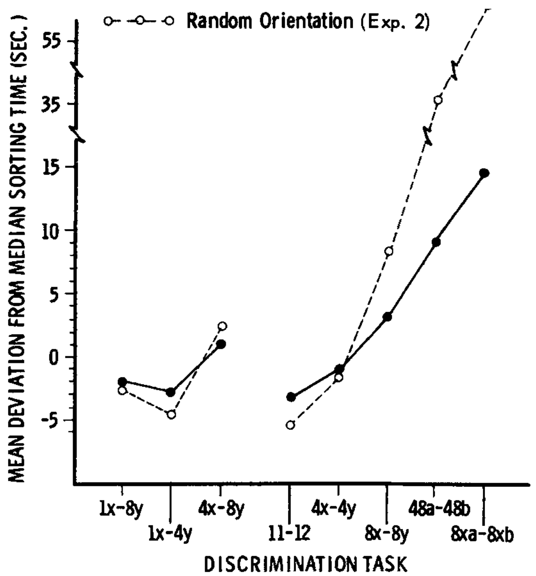

Fig. 2. Sorting times for the different discrimination tasks.

Royer (1966) had found a positive correlation between mean rating of pattern goodness and sorting time for his task. Positive correlations would have been expected here, were his hypotheses correct, both within discrimination tasks and across all tasks. The product-moment correlation between mean rating and deviation time across all tasks was .35. However, the average correlation between mean rating and deviation time within discrimination tasks was much lower, $r_{avg} = .14$. Correlations within the tasks ranged from −.13 to +.37 for all discriminations except 8xa vs 8xb. For that one task, the correlation (average of Experiments 1 and 2) was .54.

A Type III analysis of variance (Lindquist, 1953) was run on the data from the discriminations involving equivalence sets of the same size to verify some of the apparent relations shown in Fig. 2. For the five discrimination tasks represented on the right side of the graph, significant terms ($p < .01$) were obtained for the main effect of discrimination tasks ($F = 55.45$, df = 4/116) and for the interaction between tasks and experiment—or between task and orientation of cards in the deck ($F = 18.6$, df = 4/116). A trend analysis for the linear trend was run on the data from both Experiment 1 ($F = 56.6$, df = 1/116) and Experiment 2 ($F = 156$, df = 1/116). This trend was significant ($p < .01$) for both orientations of cards in the deck. It should be noted carefully that since the abscissa on Fig. 2 is intended to display only an ordered relation among tasks, not an interval scale, the obtained trends are appropriately described as "monotonic" rather than "linear." The analysis of variance of data from both experiments showed no significant effect of the order of presentation of the task, indicating the effectiveness of the warmup tasks in attaining a stable basal performance level for the other tasks.

Table 2. No analyses were run on these data due to the extremely low frequency of errors in five of the eight discrimination tasks. The error distribution seems to reflect, to an extreme degree, the information obtained from the deviation times. The hardest task involving patterns from different equivalence sets is 8x vs 8y, while the two tasks (4xa vs 4xb and 8xa vs 8xb) involving patterns from the same equivalence set are immensely more difficult than any others.

DISCUSSION

The results clearly support the hypothesis of correlation between size of equivalence set and difficulty in a discrimination task such as card sorting. The larger the size of equivalence set, the more information must be processed by the S, and the longer it takes for a single pattern from that set to be encoded. In addition, after the pattern is encoded, it must be matched with the appropriate criterion pattern. When the two criterion stimuli are from the same set (as in 4xa vs 4xb and 8xa vs 8xb), this step is more difficult than when the patterns come from different sets. Unfortunately, from the standpoint of the usefulness of ratings of pattern goodness, the correlation of goodness ratings with sorting times (Royer, 1966) appears to be an artifact of the great differences in ratings between sets of *different* sizes. For discriminations between patterns from sets of the *same* size, the correlations were trivial ($r_{avg} = .14$), with the possible exception of the 8xa vs 8xb discrimination ($r = .54$). The results obtained by Royer (1966) are explained most parsimoniously as an increase in sorting times for a group of patterns when the proportion of patterns from larger equivalence sets is increased, and a large increase in sorting times when more than one pattern from the same equivalence set are included in a group of patterns.

The failure of the third experimental hypothesis concerned the relation between discrimination difficulty and difference in size of equivalence sets for the two patterns. It was supposed that the more differences there were between patterns, including the number of processing steps necessary for encoding (which correlates with set size), the easier any discrimination task would be. A reasonable post hoc

Table 2. Mean Number of Errors
(and Number of Ss with at least One Error)

Discrimination Task	Orientation Fixed (Exp. 1)	Orientation Random (Exp. 2)
11 – 12	2 (1 S)	6 (4 Ss)
4x – 4y	4 (2 Ss)	6 (4 Ss)
8x – 8y	25 (10 Ss)	19 (9 Ss)
48a – 48b	168 (17 Ss)	318 (20 Ss)
8xa – 8xb	133 (18 Ss)	263 (20 Ss)
1x – 8y	1	0
1x – 4y	1	1
4x – 8y	10 (4 Ss)	5 (5 Ss)

explanation is that both patterns must be encoded (in this experiment, 25 times each) so that patterns from larger sets make for longer encoding times, and thus longer sorting times. Also, difference in number of encoding steps between patterns in a given task is not useful (or, rather, used) in discrimination. This implication that both patterns are completely processed each time they are presented may support a template matching hypothesis for this kind of discrimination task, rather than other procedures such as element sampling (for a discussion of pertinent ideas, see Uhr, 1966, especially pp. 372-375). Of course, this would support the emphasis placed here upon the primacy of processes which specify the equivalence set over processes which involve the single presented stimulus alone.

The two different experimental conditions, fixed and random orientation of cards in each deck, were used to determine whether the relations discussed above would hold when the S was not forced to process the whole pattern (fixed orientation) as well as when he was (random orientation). The significant interaction between orientation and discrimination tasks is seen in Fig. 2 as an increase in the differences between tasks in Experiment 2 (random orientation) relative to Experiment 1 (fixed orientation). The monotonic relation holds for both, but the slope is different. For the more difficult tasks, this can be considered a natural consequence of the added processing steps for the random orientation (an S given task 8xa vs 8xb, for instance, either would have to reorient about three-fourths of the cards to match them, or he would have to be matching against two subsets of four patterns each rather than against just the two criterion patterns given). This explanation, however, leads to the prediction that the random orientation group would take longer to sort the 4x vs 4y discrimination, and the data contradict this. Also, the 11 vs 12 discrimination should give the same sorting time for both groups, since the task is identical for both. Again, the random orientation group sorts faster. (It should be recalled that even though the data in question are deviations from median times, the average median time was the same for both groups). Thus, though logic leads to two trends which diverge from a common source (the 11 vs 12 discrimination), the data show trends which cross at a higher point. One possible explanation for the results lies in the strategies used by the Ss. With random orientation, the S was forced to process the entire pattern. With fixed orientation, however, a S could make the same discrimination by focusing his attention on any of the nine possible dot locations which differed (dot or no dot) between the two patterns. Exclusive use of this strategy would lead to elimination of all but random variability about a central value for sorting time among the discrimination tasks. Occasional use by all Ss, or use by some Ss, of this strategy would attenuate differences from the median value between the tasks, leading to the slope obtained for Experiment 1. The ordinal consistency of the predicted relations within Ss argues against extensive use of a strategy other than whole-pattern processing, but not against occasional or inefficient use of an alternative strategy.

In human performance, the number of encoding steps necessary for classification of a stimulus (in this case, indicated by the size of equivalence set for a pattern) is important even for simple discrimination tasks in which such classification is not logically necessary. The pattern uncertainty, or number of encoding steps, must be defined always in reference to the subjective or perceived set of alternatives for a given S, and this may not agree with the view of the E (as may have occurred in Experiment 1). Humans organize information. Even in simple discrimination tasks, the systems which they use to organize that information have as great a role in performance as the task stimuli themselves.

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