The effect of goodness on encoding time in visual pattern discrimination*

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Previous results have implied that pattern goodness, as defined by rotation/reflection equivalence set size, is a determinant of encoding time. A direct test of this implication was made via a discrete RT task using good and poor dot patterns in a two-stimulus discrimination. The following discrimination conditions were used: (1) good vs good; (2) poor vs poor; and (3) good vs poor. Overall RTs for Conditions 1 and 3 were equal, but each was significantly faster than Condition 2. In the first two conditions, there was no difference in RT within pairs and no consistent transitive ordering of the patterns. In Condition 3, however, the good pattern consistently produced the smaller RT. These results indicate that patterns of equal goodness are equally encodable, and the better the pattern, the faster it is encoded. In addition, there was evidence that pattern similarity affects RT.

Consider the perceptual task in which one of two alternative stimuli is presented to S on each of many trials, and S is required to make one response to one of the stimuli and a different response to the other stimulus, as rapidly and as accurately as possible. Such a task is designed in general to measure discrimination between stimuli, but in a particular experimental context the task might well be called identification, classification, or choice reaction.

Ordinarily the experimental outcome with this task, whether speed or accuracy, is assumed to reflect the similarity (or conversely, the discriminability) of the pair of stimuli. That is to say, the outcome is assumed to reflect a property of the *pair* of stimuli rather than properties of the individual stimuli per se. However, it is entirely possible that processing of information in such a task involves properties of each individual stimulus in addition to a property of the pair of stimuli. In this paper, such pertinent properties of the individual stimulus will be called its encodability, and the processing of such properties will, in the appropriate experimental situation, result in a measurable encoding time. The property of the pair of stimuli, on the other hand, presumably affects a comparison process, probably between the specific stimulus and the memorial representation of each of the stimuli.

Clement and Varnadoe (1967) first suggested that visual pattern goodness might affect encoding time in a two-choice classification task. Their stimuli were patterns of five dots located in the imaginary cells of a 3 by 3 matrix. These patterns had first been used by

Garner and Clement (1963), who showed that pattern goodness is greatest when the pattern is unique when rotated and/or reflected; is next greatest when the pattern is one of a subset of four patterns which produce each other when rotated and/or reflected; and is least when the pattern is one of a subset of eight patterns produced by rotation and/or reflection. Thus the patterns can be described in terms of subset sizes of 1, 4, or 8 (the only ones possible with these stimuli), and these sizes are inversely related to pattern goodness.

The experimental task used by Clement and Varnadoe was speeded classification of a deck of cards containing two alternative patterns, different pairs of patterns being used in different conditions. This task does not allow a separate measure of reaction time for each pattern in a comparison. However, their results showed that discrimination of two unique patterns was faster than discrimination of a pattern with Subset Size 1 from one with Subset Size 4, and that discrimination was in turn faster than when a pattern with Subset Size 1 was discriminated from a pattern with Subset Size 8. Such a result (and other equivalent results) is not reasonable if only similarity is affecting the speed of classification, since the greater the difference in subset size, the less similar are the patterns (a result which had previously been found by Garner and Clement, 1963). So Clement and Varnadoe concluded that the speed of classification was affected by encoding time of the specific stimuli, and that encoding time was faster for patterns with greater goodness (i.e., those from smaller subset sizes). Thus the classification time for a good and a poor pattern is an average for a fast and a slow encoding time, while a good-good comparison is faster because it is an average for two fast encoding times.

Further evidence that good patterns are encoded

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Fig. 1. The six stimulus patterns used in the experiment.

faster than poor patterns comes from an experiment by Checkosky and Whitlock (1973), with argument for an encoding effect provided by Garner (1974). This experiment used a recognition paradigm in which S held either two or three of the same kinds of five-dot patterns in memory, and then were required to respond YES or NO that a test stimulus was or was not in the memory set. The result of interest in the present context was that recognition time increased by a constant when a negative test stimulus was changed from a subset of Size 4 to a subset of Size 8. Following Sternberg's (1967) argument, such a change reflects an encoding process rather than a memory process. Furthermore, the result was in line with the argument of Clement and Varnadoe that good patterns are encoded faster than poor patterns.

Purpose of Present Experiment

These results, which suggest faster encoding for good than for poor patterns, clearly imply, but do not actually demonstrate, that if a good pattern is to be discriminated from a poor pattern with a choice reaction procedure, then the reaction time (RT) to the good pattern will be shorter than that to the poor pattern. The present experiment was designed to provide a direct test of this implication.

METHOD

Stimuli

The six stimulus patterns used in the present experiment are shown in Fig. 1. These patterns were generated by placing nine dots in the imaginary cells of a 5 by 5 matrix. Three of these patterns, (A, B, C), are "good," coming from subsets of Size 1 defined by rotations and/or reflections (i.e., any reflection or 90-deg rotation reproduces the same pattern); and three of the patterns (D, E, F)

are "poor," coming from subsets of Size 8 by the same criterion. These larger patterns were used rather than the previously used five-dot patterns to make more good patterns available and to decrease the similarity between the good and the poor patterns. Of the many poor patterns available, those used were chosen to avoid any obvious nonpattern cues such as compactness.

The patterns were printed on slides and were back-projected onto a screen, with the patterns showing as black dots against a white background. As projected, the dots were 5 mm in diam, with the centers of dot locations being 13 mm apart horizontally and vertically. The patterns were viewed by S from within a sound-deadened room (2.13 m square), at an average distance of 1.0 m. The total pattern thus subtended a visual angle of approximately 3 deg.

Task and Subjects

In a given condition, one stimulus was presented at a time, preceded by a brief flash of light (0.25 sec) which served as a warning light and was followed immediately by the stimulus, which remained on until S made his response, as rapidly as possible. The next warning signal followed the response by 5.2 sec, and the process continued for an entire sequence. The time required for the response was measured by an electronic clock to the nearest millisecond. RT as well as the response were recorded by E, who also changed the stimulus slide between stimulus presentations. All timing and measurement were controlled by BRS logic circuitry.

The response was made by S's pressing one of two keys with one finger of one hand. The assignment of response key to stimulus pattern was indicated by placement of a prototype pattern above each key. A "home base" key was located between the two response keys, and S was required to keep his finger on this key until the stimulus came on. If he raised his finger prematurely, the stimulus did not come on. This arrangement prevented S from attempting to anticipate the response. The two responses can be described as inward and outward movements, and counterbalancing for assignment of movement to each particular stimulus was carried out across Ss as evenly as possible. Such counterbalancing is hardly necessary, however, since the overall RT was 565 msec for inward movements and 567 msec for outward movements. Moreover, there were no consistent effects of response direction either within particular Ss or within particular conditions. Thus this response system provided a pair of unbiased alternative responses.

For each pair of patterns (condition) discriminated by a

particular S, there was a sequence of 176 stimuli and responses, the first 20 of which were identical to the last 20 and the data for which were discarded. These were the warm-up trials, unknown to S. Three different sequences were generated from a table of random numbers subject to the restrictions that both stimuli occur equally often and that a run length could not exceed 5. The proportion of repeated stimuli was .47. The error rate was under 5% for all conditions, and RTs to errors were excluded from the analysis. Thus, for each stimulus in each condition, there were approximately 78 responses contributing to a mean reaction time per stimulus per condition per S.

A total of nine right-handed undergraduate and graduate students served as Ss, seven of them being male.

Conditions and Experimental Design

There were 15 different pairs of patterns (conditions), and these divide themselves into three types, as indicated in Table 1. Three pairs represent *good-good* discriminations, and these involve Patterns, A, B, and C. Three pairs represent *poor-poor* discriminations, and these involve Patterns, D, E, and F. Nine pairs represent *good-poor* discriminations, and these involve all six patterns.

Every S was assigned each of the good-good and the poor-poor conditions. For assignment to the good-poor conditions, the Ss were divided into three groups of three, and assigned to the good-poor conditions as indicated in Table 1. This assignment was arranged by making a Latin square of the three good patterns, the three poor patterns, and the three groups. Thus, each group had each good pattern and each poor pattern, but in different combinations. The net result of this assignment of conditions was that each S had an equal number of each of the three types of discriminations.

Each S was run in three different sessions, occurring on 3 separate days, each session lasting about 1 h. A 5-min break was given between each condition. In each session, he was assigned one of each of the three types of conditions, in an order which was maintained over sessions. However, different Ss were assigned different orders so that across Ss there was counterbalancing for type of condition at each order within each session. The three different stimulus sequences were assigned so that across sessions each sequence was used once with each type of condition for each S.

RESULTS

RTs for each stimulus of each pair of stimuli, averaged across Ss, are given in Table 1, along with various means. For each pair of stimuli, the stimulus giving the smaller RT is listed first. Several different analyses of variance were carried out on the data, appropriate to different questions. All statements of statistical significance are based on these analyses (p level of .05 as criterion), unless otherwise noted.

Good-Good Discriminations

Three pairs of stimulus patterns involved discriminations between two good patterns. Within each pair, the difference in RT between the two patterns ranged from 2 to 11 msec (mean difference of 7 msec), and in no case did the difference approach significance. In fact, for the largest difference (between Patterns B and C), only 5 of the 9 Ss gave a result in the same direction.

While these three intrapair differences indicated a transitive ordering of RT ($C < A < B$), a transitive ordering from three pairs will occur by chance three

Table 1
Discrete Reaction Times (Milliseconds) to Each Stimulus Pattern in Different Pairs

Stimulus Pair	Reaction Time		
	Smaller	Larger	Mean
A-B*	551	559	555
C-A	545	547	546
C-B	540	551	546
Mean (Good-Good)	545	552	549
D-E	581	589	585
F-D	671	676	673
E-F	555	563	559
Mean (Poor-Poor)	602	609	606
A-D†	527	529	528
B-E	543	589	566
C-F	539	587	563
A-E	522	542	532
B-F	546	561	553
C-D	477	512	494
A-F	539	597	568
B-D	533	561	547
C-E	537	542	540
Mean (Good-Poor)	529	558	543

*In each pair, the first pattern is the one with the smaller RT.

†The first three pairs for good-poor comparisons were used by Group I, the second three by Group II, and the third three by Group III, each group consisting of three Ss. Other comparisons were used by all nine Ss.

out of four times. Furthermore, inspection of the results of individual Ss showed that only four of the nine Ss gave a transitive ordering, and only one of these was the ordering produced by the average data. Thus the lack of overall differences between stimuli in the pairs was not due to the averaging of reliable effects within individual Ss which were inconsistent across Ss. There is no evidence at any level of analysis of differences in RT within pairs which could be produced by encoding differences between the individual patterns: all three good patterns are equally encodable.

The mean RT for these three pair discriminations ranged over only 9 msec, and these differences were not statistically significant. Thus there were no differences in the similarities of the three pairs which would be evidenced by differences in average RT to the pairs.

Poor-Poor Discriminations

Three pairs of stimulus patterns involved discriminations between two poor patterns. Within each pair, the difference in RT between the two patterns ranged from 5 to 8 msec (mean difference of 7), and in no case did the difference approach significance. Furthermore, for these patterns, the mean data indicate an intransitive ordering of RT, and only four of the individual Ss gave a transitive ordering. Thus the evidence is that all three of these patterns are equally encodable.

The mean RT for the F-D pair of patterns was approximately 100 msec greater than the average RT for the other two pairs, and this difference is statistically significant. (The difference of 26 msec between the other two pairs is not statistically significant.) Thus the F and D patterns are more similar than either is to Pattern E, and examination of the patterns does suggest a similarity of the overall configurations of these two patterns. This difference had not been intended in selection of the patterns, yet its appearance lends assurance that similarity of a pair of stimuli is still an important determiner of average RT.

Good-Poor Discriminations

Nine pairs of stimulus patterns involved discriminations between one good and one poor pattern. The differences in RT between the members of a pair ranged from 2 to 58 msec. With this type of condition, it was anticipated that the good pattern of a pair of stimuli would give a smaller RT than the poor pattern, so the critical question is not whether differences were statistically significant, but rather whether they were in this expected direction. The data give an unequivocal answer, since in all of the nine good-poor pairs, the good pattern produced a smaller RT than the poor pattern. This result ($p = .002$, binomial) is especially impressive when it is considered that data for each pair were obtained from just three Ss. Data for individual Ss show that eight out of nine ($p = .02$, binomial) gave a lower mean RT to the good pattern.

An analysis of the Latin square (good patterns, poor patterns, groups) of the difference scores between the good and the poor patterns showed no significant effects due to the particular good pattern, the particular poor pattern, or unique combinations of them. This result strengthens that obtained with the other two types of conditions, namely that there are no encoding differences within the three good or the three poor patterns. The differences in encoding are due entirely to differences in pattern goodness, and not to particular patterns within a given level of goodness.

The mean RTs for each pair of patterns ranged from 494 to 568 msec, but these differences were not statistically significant. Thus there is no evidence of differences in similarity between different pairs of good and poor patterns.

One question remains: Are the differences in similarity between the three types of conditions meaningful? There is no significant difference in mean RT between good-good pairs and good-poor pairs, but each of these types is significantly different from the average results for poor-poor pairs. Since the different pairs within the poor-poor type were significantly different from each other, it is clear that

differences in similarity can be manipulated, both within and between levels of pattern goodness.

DISCUSSION

The data are unequivocal in demonstrating that RTs in a simple discrimination task are affected by properties of the single stimulus, i.e., by properties that are probably pertinent to encoding of the stimulus. The average discrimination time for any pair of stimuli, however, is a function not only of the stimulus encoding, but also of the interstimulus similarity, a property of the pair of stimuli and probably pertinent to some sort of comparison process. We cannot, from the present data, determine how much time is actually required for encoding of the single stimulus, or how much time is required for the comparison process, since the data only allow determinations of relative encoding times, or relative effects of similarity. From the meager evidence, however, similarity of the pair of stimuli appears to be the more potent factor, with differences in similarity in the present experiment producing differences in RT of 100 msec compared to the 29-msec effect found due to encoding differences.

In the Clement-Varnadoe (1967) experiment, discrimination of good-good patterns was faster than discrimination of good-poor patterns, while these two types of discrimination were equally fast in the present experiment. The use of more complex patterns in the present case can easily account for this discrepancy, however, since almost certainly the good patterns are less similar to the poor patterns in this experiment than they had been in the Clement-Varnadoe experiment.

Other explanations of the discrepancy are possible, however, and are of some interest. There are many procedural differences between the two experiments, since a completely self-paced classification task, with no time between successive stimuli, was used by Clement and Varnadoe, while S had no control over the timing in the present experiment, and the time between successive stimuli was rather large. The point of interest, however, pertains to the possible differential effects of procedural factors on the two aspects of the discrimination task. It is quite possible that encoding time remains constant with different procedures, while the comparison process affected by interstimulus similarity is greatly influenced by procedural changes. Such differential effects could, of course, lead to different rank orders of different stimulus comparisons, depending on the relative importance of the two factors in the discrimination task.

Of some interest also is whether differences in encoding time change with practice on the part of S. The experimental design provided complete

counterbalancing across Ss of the nine different good-poor discriminations within each session, so that average encoding differences between the good and the poor stimulus can be determined for each session. These differences were 39, 18, and 29 msec from the first to the third session. Thus there was no systematic change over sessions, and thus no evidence that encoding processes become more or less important with practice.

We have used the term "encodability" to refer to those properties of the stimulus pattern which are unique to the single stimulus rather than to the pair. The present data do not help to answer the question of exactly what the encoding processes are. They can be simple registration, placement in a short-term memory or buffer store, or even a response readiness. The present data do not differentiate. Further research will be required to clarify the exact nature of what we have called encoding.

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