Matching patterns vs matching digits: The effect of memory dependence and complexity on "same"- "different" reaction times*

JOAN GAY SNODGRASS†

New York University, University Heights, Bronx, N.Y. 10453

Two experiments are reported in which "same"- "different" reaction times (RTs) were collected to pairs of stimuli. In Experiment 1 stimuli were matrix patterns, and in Experiment 2 stimuli were digits. In both experiments, the pairs were presented simultaneously (discrimination task) and successively (memory task) for a set of nine simple and a set of nine complex stimuli. The following results were obtained: discrimination RTs were longer than memory RTs; RTs to complex stimuli were longer than RTs to simple stimuli; "same" RTs were faster than "different" RTs across all conditions except simple pattern discrimination, for which "different" RTs were faster than "same" RTs; and discrimination RTs for complex patterns were longer than would be predicted from the other conditions. Some evidence was obtained that the form of encoding for both patterns and digits in the memory task was visual. These results are discussed in terms of encoding and comparison strategies.

Measuring the time required for a S to decide whether two stimuli are the same or different has become a popular research strategy in the last few years, and the resulting RTs have been used to infer strategies of search through either the memory or perceptual store (Sternberg, 1966, 1967, 1969; Neisser, 1963), encoding strategies (Posner, 1969; Tversky, 1969), and fundamental processes of comparisons (Egeth, 1966; Bamber, 1969; Nickerson, 1965, 1966, 1967). The present research is concerned with the latter two problems.

The simplest matching paradigm is one in which only two stimuli are presented and the S must decide whether they are the same or different. The two stimuli may be presented successively, in which case the match is said to be memory-dependent, or simultaneously, in which case the match depends on visual factors. Situations in which stimuli are presented successively are here called memory tasks, and those in which stimuli are presented simultaneously are called discrimination tasks.

Major interest in the simple two-stimulus paradigm centers around

the difference between "same" and "different" response times, which is taken as an indication of the underlying comparison process that S engages in to reach a decision. Although "same" RTs are often found to be slower than "different" RTs for unidimensional stimuli which are not highly discriminable (Kellogg, 1931; Bindra, Williams, & Wise, 1965), for multidimensional and easily discriminable stimuli "same" RTs are usually found to be faster than "different" RTs (Nickerson, 1967; Bamber, 1969). At the same time, "different" RTs decrease with increases in the difference between two unidimensional stimuli, or with increases in the number of dimensions along which two multidimensional stimuli differ. Restricting the discussion to multidimensional stimuli, with which the present paper is concerned, the results for "different" RTs suggest that Ss compare stimuli feature by feature; the more features that are different, the more likely Ss are to reach an early "different" decision. However, a feature-by-feature analysis would predict that "same" RTs should be slowest of all, since Ss must compare all features to verify that stimuli are, in fact, identical. Yet, as pointed out above, "same" RTs are typically faster than "different" RTs.

Because of these anomalous results, several investigators have proposed that different processes underlie judgments of identity and judgments of difference (Bamber, 1969; Tversky, 1969; Krueger, 1970). Most of these models propose that a fast identity reporter, perhaps based on template or

image matching, underlies "same" responses whereas a slower feature-by-feature comparator is responsible for "different" responses.

"Same" RTs have generally been found to be faster than "different" RTs for both memory and discrimination tasks (Posner, Boies, Eichelman, & Taylor, 1969), and, although Nickerson (1967) found insignificant overall differences between the two types of responses, he found that "same" RTs were faster than "different" RTs to stimuli differing in only one dimension for both memory and discrimination tasks.

Matches in the discrimination task are generally based on visual features of the stimuli rather than their names. For example, Hochberg (1968) has shown that familiarity had no effect on either RT or thresholds for "same"- "different" judgments for foveally presented strings of letters. Posner and his co-workers (Posner & Mitchell, 1967; Posner et al, 1969) have shown that "same" RTs for physical-identical stimuli were faster than for name-identical stimuli for discrimination tasks and for memory tasks in which the interstimulus interval was less than 1 sec. Although Posner's results suggest that, after that interval, a stimulus stored in memory is coded verbally, Tversky (1969) has shown that the form of the encoding may take a visual or verbal form, depending upon task requirements.

An important converging operation (Garner, Hake, & Eriksen, 1956) for determining the form in which stimuli are encoded is to analyze errors, as in tachistoscopic recognition experiments, or to analyze how "different" RTs vary with differences among various possible encoding dimensions for RT studies. Analyses of confusion matrices from tachistoscopic recognition experiments have revealed that most errors are acoustic rather than visual, indicating the visual trace is recoded into a verbal form before being reported (Baddeley, 1964; Conrad, 1964; Wickelgren, 1965), whereas Tversky (1969) used differences in "different" RTs as evidence that stimuli were encoded visually in some situations and verbally in others.

In the present set of experiments, the encoding variable is manipulated by using one set of stimuli—matrix patterns of black and white squares—for which verbal labels are not readily available and another set of stimuli—digits—for which verbal labels are readily available. Both sets of stimuli are run under the discrimination task, in which visual matching is likely to be used, and in the memory task, in which a recoded

*This study was supported by Research Grant MH 19165-01 from the National Institute of Mental Health. The author is indebted to Robin Zelkowitz for assistance in the collection and analysis of data and to Bruce Prussock, who wrote the computer program to generate the experimental sequences. A short report of this research was presented at the meetings of the Psychonomic Society, St. Louis, Missouri, November 1971.

†Address: 38 Philosophy Hall, New York University, University Heights, Bronx, New York 10453.

S I M P L E

C O M P L E X

Fig. 1. The two sets of matrix patterns used in Experiment 1.

form of the stimulus may or may not be used. Finally, each set of stimuli is run at two levels of complexity to determine what effect this variable has on "same"-different RTs.

METHOD

Subjects

Three undergraduate males (A.S., B.P., and B.Z.) and one female professor of psychology (J.S., the present investigator) served as Ss in Experiment 1, in which matrix patterns were stimuli. For Experiment 2, in which digits were stimuli, a female undergraduate, S.C., replaced B.Z. but the other Ss remained the same. The three undergraduates were recruited by promise of payment for participation. J.S., A.S., and S.C. were right-handed, and B.P. and B.Z. were left-handed.

Apparatus

For Experiment 1, two sets of nine matrix patterns were selected from a larger set of 42, which had been generated by computer by systematic

variation of three generation parameters. They were 9 by 9 matrix patterns consisting of approximately equal numbers of black and white squares and ranged from very simple to very complex. Objective and subjective complexity measures for the entire set of patterns are reported elsewhere (Snodgrass, 1971). The nine simple patterns were those rated simplest by various subjective judgments of complexity, and the nine complex patterns were selected from among those rated most complex. The two sets of patterns are shown in Fig. 1.

For Experiment 2, the set of nine simple digits consisted of the digits from 1 through 9. The set of nine complex digits were selected from a table of random numbers and consisted of the following two place digits: 14, 15, 36, 39, 46, 48, 72, 91, 93. Through random selection, some of the complex digits had one element in common and one pair (39 and 93) were inverses of one another, with two elements in common.

In Experiment 1, S was seated alone in darkness in one room and viewed the patterns, projected as slides on a screen, through a small $7\frac{1}{2} \times 4$ in. one-way mirror into an adjacent room in which E operated the projection and recording equipment. S was seated about 3 ft from the mirror and about 14 ft from the screen in the other room. The projected size of each stimulus was 7 in. square, with $2\frac{1}{2}$ in. separating adjacent stimuli when they were presented side by side for the simultaneous presentation. A single stimulus was foveal, subtending 2 deg 24 min in visual angle, and a pair was extrafoveal, subtending 5 deg 36 min.

The slides were presented by two Kodak Carousel slide projectors. The release of a slide in one projector actuated a microswitch which started a Hunter Klockcounter. S was provided with two standard telegraph keys with which to record his choice as "same" or "different." The press of one of the telegraph keys stopped the clock, and time was recorded to the nearest millisecond. A light on E's console and one on the desk at which S was seated signaled to both E and S which key had been pressed.

In Experiment 2, the digit stimuli were presented via a Gerbrands two-channel Harvard tachistoscope, Model T-1C-3. S was seated at a table and viewed the stimulus presentations through a viewing hood. E was seated on the other side of the table and actuated the stimulus presentation, recorded the time, and advanced the paper tape on which the stimuli were typed. The stimuli were typed on an IBM Standard Electric Typewriter equipped with Prestige Elite type. The digits were separated by a dash for the discrimination task. A single digit subtended a visual angle of 10 min horizontally and 20 min vertically, and a pair of stimuli were spaced so that they subtended a visual angle of 1 deg 24 min horizontally. The visual size was identical and foveal for both simple and complex pairs.

The same keys and timing apparatus were used in Experiment 2 as in Experiment 1.

Procedure

Experiment 1. Each S participated in five practice sessions and 10 experimental sessions. Each session consisted of a memory task with one set of stimulus patterns and a discrimination task with the other. In the memory task, Ss were shown stimuli successively, in the same spatial position, and responded to the second stimulus by pressing either the same or the different key. In the discrimination task, pairs of stimuli were presented simultaneously, side by side, and S signaled by his key choice

whether the patterns were the same or different. For a given experimental session, S received either simple stimuli for memory and complex stimuli for discrimination or complex stimuli for memory and simple stimuli for discrimination. The order of conditions was counterbalanced across the 10 experimental sessions and resulted in five sessions for each task/stimulus set combination. For Experiment 2, two practice sessions and eight experimental sessions were run, resulting in four sessions for each task/stimulus set combination. Half of the Ss used their dominant hands to respond "same," and half used their nondominant hands for "same" responses.

For both experiments, a given session consisted of 82 trials under each task/stimulus set combination. There were 10 practice trials, approximately divided between "same" and "different" trials, and 72 experimental trials, of which exactly half were "same" and half "different." The 36 "same" pairs consisted of four trials of each of the nine stimuli, and the 36 "different" trials consisted of one member of each of the 36 possible ordered pairs of nine stimuli. The 10 practice trials were of the same task type but of the different stimulus type than the experimental trials. Thus, if S was to receive complex discrimination, his practice set consisted of simple discrimination trials. Since each S received two task/stimulus set combinations per session, a complete session consisted of 144 experimental and 20 practice trials and lasted between 30 and 45 min.

A basic sequence of 72 experimental trials was constructed by computer by first ordering the "different" pairs by the procedure described by Ross (1934) such that each stimulus appeared equally often in each spatial or temporal position, and stimuli were maximally separated in time. "Same" pairs were then randomly introduced into this sequence of "different" pairs subject to the constraints that no more than eight "same" or "different" trials occur in sequence and no stimulus appear more than once within adjacent triples of trials. Position and order effects were counterbalanced by permuting this basic sequence in four ways to produce eight experimental sequences: (1) different pairs were switched in temporal or spatial positions so that stimuli that previously appeared first or left would appear second or right; (2) the basic sequence was run backwards; (3) a combination of (1) and (2); and (4) the four sequences thereby produced were transformed by subtracting the stimulus number from 10.

Table 1
"Same" and "Different" Correct RTs (in Milliseconds) for Memory and Discrimination Tasks With Simple and Complex Matrix Patterns*

S	Memory				Discrimination			
	Simple		Complex		Simple		Complex	
	Same	Diff	Same	Diff	Same	Diff	Same	Diff
(AS)	897	948	970	1007	1169	1118	1355	1360
(BP)	924	935	937	962	1040	1003	1256	1290
(BZ)	910	952	891	951	1030	999	1213	1250
(JS)	889	935	929	986	1082	1048	1387	1409
Mean	905	942	932	976	1080	1042	1303	1326
Percent Errors	2.8	2.8	2.4	2.4	2.8	2.2	1.5	3.6

*Means for each S are based on 180 responses.

In both experiments, stimuli were presented manually, and hence neither the intertrial interval nor the interstimulus interval of the memory presentations was constant. For Experiment 1, the first slide was displayed for approximately 2½ sec and the interval between the removal of the first slide and the presentation of the second was approximately 2½ sec for a stimulus onset to stimulus onset interval of approximately 5 sec. For Experiment 2, E had to advance a paper roll manually between the first and second stimulus for the memory task. The stimulus duration was fixed at 1.1 sec (which proved in virtually every case to exceed S's RT to it), and the interval between offset of the stimulus and onset of the second stimulus was approximately 4 sec, for a stimulus onset to stimulus onset interval of approximately 5 sec. The intertrial interval in Experiment 1 was approximately 5 sec, whereas it was approximately 6 sec for Experiment 2.

The three undergraduate Ss were paid \$1.50 for participating in each session and in addition were given payoffs for accuracy and speed designed to produce the lowest possible RTs consonant with nearly error-free performance. In Experiment 1, they were paid 1c for each response under 1 sec and penalized 10c for each error; in Experiment 2, they were paid 1c for each response under 500 msec and penalized 10c for each error. Although Ss were not given trial-by-trial feedback as to errors and times, they appeared to know when they had made an error. For the discrimination task, this was because the stimulus pair remained on after they had responded; for the memory task, only the second stimulus remained on, but sufficient information about the first stimulus was apparently still available. They were informed how much money they had won after each block of trials.

At the end of Experiment 1, all Ss were asked to indicate which nine simple and complex matrix patterns they had experienced by selecting

them from a photograph of the original 42 patterns.

RESULTS

Table 1 presents mean "same" and "different" RTs for each task, each level of complexity, and each S for the matrix patterns of Experiment 1. Only correct RTs were used in the analyses. The error rate appears at the bottom of the table and is based upon a total of 720 responses. The overall error rate is quite low (2.5%), and a two-way chi-square analysis on the frequency of error and correct responses indicates that the distribution of errors across the eight possible response categories is not significantly different from chance ($\chi^2 = 7.9$, $df = 7$, $p > .25$). Furthermore, individual Ss do not show large individual differences in error rates (the highest rate was 3.2% for J.S. and the smallest, 1.9% for B.P.). Since error rates were quite low and did not occur significantly more often for one category of response than another, only mean RTs were used in the analysis.

Table 2 presents the same data for the digits of Experiment 2. The total number of trials was 576 instead of 720. The overall error rate is somewhat higher (3.3%): a similar two-way chi-square analysis on the frequencies of error and correct responses indicated that the distribution of errors across the eight response categories was not significantly different from chance ($\chi^2 = 6.4$, $df = 7$, $p > .50$). Individual Ss showed somewhat greater variation in this experiment, however, with B.P. again showing the lowest rate (1.8%) and J.S. the highest (5.2%).

Figure 2 presents the major results of both experiments. RTs for pattern stimuli were considerably longer than for digit stimuli. This difference is due in part to differences in the two experimental procedures. In Experiment 1 the clock was started somewhat before the stimulus appeared on the screen. It may also reflect differences in difficulty

Table 2
"Same" and "Different" Correct RTs (in Milliseconds) for Memory and Discrimination
Tasks With Simple and Complex Digits*

S	Memory				Discrimination			
	Simple		Complex		Simple		Complex	
	Same	Diff	Same	Diff	Same	Diff	Same	Diff
(AS)	364	397	391	456	454	522	475	538
(BP)	344	379	357	401	449	500	497	546
(SC)	373	398	399	420	450	473	480	508
(JS)	328	377	361	386	452	469	504	519
Mean	352	388	377	416	451	491	489	528
Percent Errors	2.6	3.0	3.3	2.3	4.3	4.2	3.5	3.5

*Means for each S are based on 144 responses.

between the two sets of stimuli.

In both experiments, RTs for the discrimination task were consistently longer than those for the memory task. In addition, RTs to complex stimuli were longer than those to simple stimuli. However, complexity had a much greater effect in the discrimination than in the memory task for patterns, whereas it had equivalent effects for both tasks for digits. Finally, "same" RTs were consistently faster than "different" RTs except for discrimination of simple patterns, in which "different" RTs were faster than "same" RTs.

Figures 3 and 4 present session-by-session analyses of overall mean RTs, combined across Ss, for Experiments 1 and 2, respectively. It is clear that in Experiment 1 RTs were not at asymptote by the first experimental session, even though Ss had received five practice sessions. Although asymptote appears to have been reached by the fourth session for the two simple tasks, and perhaps by the fifth for complex memory, complex discrimination does not appear to have reached asymptote even by the fifth session. Furthermore, although the differences between "same" and "different" RTs are consistent throughout the five sessions for the two memory tasks, the differences are not as consistent for the two discrimination tasks.

In contrast, Fig. 4 suggests that there was minimal improvement in RTs across sessions in Experiment 2. Furthermore, differences between "same" and "different" RTs are consistent for both tasks and both complexity levels.

These conclusions are supported by the results of two four-way analyses of variance performed on the mean correct RTs for each experiment separately. The four-way repeated-measures ANOVA had as one factor task (memory vs discrimination), one factor complexity level (simple vs complex), one factor response type ("same" vs "different"), and one factor sessions. The results of

the two ANOVAs are presented in Table 3.

For Experiment 1, all four main effects are significant. There is a significant interaction between task and complexity level, indicating that complexity changes have different consequences for memory and discrimination. There is a significant interaction between task and response, indicating that "same" RTs are not always faster than "different" RTs across tasks. There is a significant interaction between task and sessions, indicating that all conditions did not reach asymptote at the same rate. There is a significant interaction between complexity level and response, because of the reversal in "same" and "different" RTs for simple discrimination. The two

significant triple-order interactions are due to the same reversal.

In contrast, the ANOVA for Experiment 2 reveals that only the four main effects are significant, whereas none of the interactions approach significance.

Several analyses were performed to determine the form of stimulus encoding in the memory task. As noted previously, there is a good deal of evidence that matches in the discrimination task are based on visual comparisons; long discrimination RTs are thus an indication of high visual similarity (but not necessarily high verbal similarity), whereas short discrimination RTs reflect low visual similarity (but not necessarily low verbal similarity). If the memory task were based on stored visual information, then memory RTs should show a relatively high correlation with discrimination RTs. If, on the other hand, information in the memory task were retained in a verbal (or some other) form, then correlations with discrimination RTs should be minimal.

Correlation coefficients (Pearson r) between memory and discrimination RTs for "same" and "different" pairs separately are shown in Table 4. All of the correlations are positive; however, only five of the eight are significantly different from zero. There is a small difference in average r for patterns and for digits (+.605 for patterns vs +.492 for digits), but the evidence is not

Fig. 2. Mean correct RTs across Ss and sessions for the conditions of Experiment 1 (patterns) and Experiment 2 (digits). Each data point for Experiment 1 is based on approximately 720 responses, and each point for Experiment 2 on approximately 576 responses.

EXPERIMENT 1

Fig. 3. Mean correct RTs across Ss plotted as a function of sessions for the patterns of Experiment 1. Each data point is based on approximately 144 responses.

overwhelming that encoding of patterns in the memory task is different from that for digits, and there is some evidence that encoding is visual for both types of stimuli in the memory task.

In addition, measures of visual confusability were developed for the simple and complex digit pairs. The simple digits 1 through 9 may be divided into three ordered classes, according to visual features. The first consists of the digits 1, 4, and 7, all composed of straight lines; the second consists of the digits 2 and 5, composed of straight lines and curves, and the third consists of the digits 3, 6, 8, and 9 composed of curves. Visual similarity for "different" pairs was defined as maximum for pairs selected wholly within a particular class (e.g., 14, 25), medium for pairs selected from adjacent classes (e.g., 72, 58), and minimum for pairs selected from the two extreme classes (e.g., 19, 48).

Mean "different" RTs for the three categories of similarity are presented in Table 5-A for memory and discrimination tasks separately. There is a small but consistent increase in RT with increased similarity for both memory and discrimination tasks, and this effect is significant by a one-way analysis of variance for both tasks.

Measures of similarity for complex digits were developed by joint consideration of the number of elements in common between any two pairs of digits, and whether those common elements were in identical

spatial positions. Four categories of similarity for pairs of "different" complex digits were defined: (1) maximum similarity, consisting of the single pair of complex digits having two elements in common in different spatial positions (39, 93); (2) those

pairs with one element in common in corresponding spatial positions (e.g., 46, 48); (3) those pairs with one element in common in different spatial positions (e.g., 14, 91); and (4) those pairs of minimum similarity with no elements in common (e.g., 72, 93). Mean "different" RTs for these four categories of similarity are presented in Table 4-B. One-way analyses of variance performed by comparing the combined categories, 1 and 2, with the separate categories, 3 and 4, proved to be highly significant for both memory and discrimination tasks.

To provide further support for the somewhat ad hoc definition of visual similarity for the simple digits, Johnson's methods of hierarchical cluster analysis (1967) were applied to the "different" RTs, which were considered as proximity measures for the nine simple digits. A computer program, employing two methods of cluster analysis, one based on the diameter method which identifies clusters which are optimally "compact" and the other based on the connectedness method which identifies clusters which are optimally "connected," was run on both memory and discrimination RTs in order to determine whether, in fact, clusters identified by this method would be identical to those stimuli considered most visually confusable in the previous analysis.

Table 6 presents the clusters for memory and discrimination RTs under

EXPERIMENT 2

Fig. 4. Mean correct RTs across Ss plotted as a function of sessions for the digits of Experiment 2. Each data point is based on approximately 144 responses.

Table 3
Summary of Analyses of Variance on Mean Correct RTs from Experiments 1 and 2*

Source of Variation	Experiment 1		Experiment 2	
	df	F	df	F
Task (T)	1,3	85.0†	1,3	90.0†
Complexity Level (C)	1,3	63.3†	1,3	391.9†
Response (R)	1,3	13.0*	1,3	24.2*
Sessions (S)	4,12	49.4†	3,9	5.1*
T by C	1,3	59.9†	1,3	< 1
T by R	1,3	21.9*	1,3	< 1
T by S	4,12	6.2†	3,9	< 1
C by R	1,3	46.8†	1,3	< 1
C by S	4,12	< 1	3,9	1.4
R by S	4,12	< 1	3,9	2.4
T by C by R	1,3	170.0†	1,3	< 1
T by C by S	4,12	2.8	3,9	2.3
T by R by S	4,12	< 1	3,9	< 1
C by R by S	4,12	4.2*	3,9	< 1
T by C by R by S	4,12	< 1	3,9	1.6

*In all cases the error term is the interaction of the factor with Ss.
†p < .01 *p < .05

Table 4
Correlation Coefficients (Pearson r) Between Memory and Discrimination RTs for "Same" and "Different" Pairs

	Experiment 1 Patterns		Experiment 2 Digits	
	Simple	Complex	Simple	Complex
"Same" Pairs (N = 9)	+852†	+182	+558	+477
"Different" Pairs (N = 36)	+723†	+664†	+297*	+635†

*p < .05 †p < .01

Table 5
Mean "Different" RTs for Simple and Complex Digits Pairs of Varying Degrees of Similarity

	N	Discrimination	Memory
A. Simple Digits			
Within Class	10	514	392
From Adjacent Classes	14	487	385
From Two Extreme Classes	12	478	373
F(df = 2/33)		4.73*	6.03†
B. Complex Digits			
Two Elements in Common	1	611	431
One Element, Same Position	5	593	463
One Element, Different Position	6	543	427
Zero Elements in Common	24	505	404
F(df = 2/33)		25.43†	18.00†

*p < .05 †p < .01

both methods, where the clusters become more compact or more connected as one proceeds to the bottom of the table. In all but the connectedness method for discrimination data, two major clusters emerge: 147 and 235689. The former is the class consisting of all straight lines and the latter, the classes consisting of all curves and of curves and straight lines. Clusters within the latter major class are less in agreement with the visual similarity analysis performed previously. The strongest clusters are 89 for memory and 69 for discrimination, both of which fall into the class consisting of all curves. However, both 23 and 235 emerge as

strong clusters in both tasks and under both methods, and their members are from different classes; 3 is the class consisting of all curves, and 2 and 5 in the class of curves plus straight lines.

Despite these differences between the cluster and visual similarity analyses, the most impressive result of the cluster analysis is the similarity in structure between the memory and discrimination tasks. The clusters in both tasks are almost identical and appear to be based on visual rather than some other type of similarity.

DISCUSSION

The following five results from the two experiments will be discussed:

(1) discrimination RTs are longer than memory RTs; (2) RTs to complex stimuli are longer than RTs to simple stimuli; (3) discrimination RTs for complex patterns are surprisingly long; (4) "same" RTs are longer than "different" RTs for simple pattern discrimination; and (5) the form of encoding in the memory task appears to be visual.

The discussion of the first two results is based upon deductions from a model for the comparison process in the discrimination and memory tasks. The model will first be presented in its qualitative form, and then under Result 2 a specific quantitative version of it will be applied to data from Experiment 2.

The Model

We assume that the basic steps underlying the matching or comparison process are the same for both discrimination and memory tasks. In order to compare the two stimuli, S encodes both of them. The first stimulus is encoded prior to the presentation of the second stimulus for the memory task, whereas both encodings take place after both stimuli are presented for discrimination. Stimulus elements from both displays are encoded element by element, and then a serial self-terminating comparison process between the elements from the two displays takes place. If a difference is detected, S terminates the comparison process and responds "different"; if no difference is detected, all comparisons are made and S responds "same." It is assumed that encoding time for similar elements (for example, elements in simple and complex digits) are identical, but the comparison time for a pair of identical elements may not be

Table 6
Clusters Obtained in the Hierarchical Clustering Procedure Based on "Different" RTs from the Memory and Discrimination Tasks*

Diameter Method	Connectedness Method
Memory Task	
417 236589	417 623589
417 236 589	417 23589
417 23 589	417 235 89
17 23 589	17 235 89
17 23 89	235 89
23 89	23 89
89	89
Discrimination Task	
147 235869	14235869
147 235 869	14 235869
14 235 869	14 235 869
14 235 69	14 23 869
14 23 69	14 869
14 69	14 69
69	69

*Compactness or connectedness of clusters increases from top to bottom.

identical to the comparison time for a pair of different elements. Furthermore, base times for "same" and "different" RTs may not be identical. According to the model, the difference between memory and discrimination is that in the memory task S has the opportunity to encode the first stimulus before the second one is presented. The difference between simple and complex stimuli is that there are more elements in the latter than in the former.

(1) *Discrimination RTs are longer than memory RTs.* This result has been reported for multidimensional nonalphanumeric stimuli by both Nickerson (1967) and Grill (1971), and for both verbally codable stimuli (letters) and stimuli not so easily verbally codable (color patches and random figures) by Taylor (1969). Taylor has argued that the advantage of memory over discrimination lies in the greater accessibility of the previously presented and stored item. A different interpretation is offered here. According to the model, some stimulus processing or encoding must take place for both stimuli before they can be compared. The encoding need not change the original form of the stimulus information; indeed, here it is tentatively assumed that for both discrimination and memory the encoded form of the stimulus retains its visual characteristics. In the memory task, the encoding of the first stimulus can proceed until the second stimulus is presented. For these experiments, the stimulus-onset to stimulus-onset time was about 5 sec, certainly enough time to complete encoding the first stimulus before the second was presented. Thus, memory RTs are shorter than discrimination RTs because in the former only one stimulus need be encoded, whereas in the latter they both must be encoded.

(2) *RTs to complex stimuli are longer than RTs to simple stimuli.* In these experiments, complexity was introduced by increasing the randomness of the matrix patterns of Experiment 1, and by adding an additional digit element in Experiment 2. However, there are other ways to increase complexity. One method is to add dimensions, such as shape, line orientation, extraneous figures, etc. The effects of adding dimensions in this way are both to make the stimuli more complex and to make the stimuli more discriminable. As noted previously, the more dimensions by which multidimensional stimuli differ, the faster difference judgments are made to them.

However, the effect of the present manipulation of complexity was to make stimuli *less* discriminable. Thus,

both memory and discrimination RTs were lengthened to complex stimuli.

This effect was particularly clear in the case of complex digits: because the two-place digits shared common elements, Ss were sometimes forced to compare both digits of a pair in order to decide whether or not they were identical. The data on similarity for complex digits indicated that RTs were longer to pairs of complex digits with one or two elements in common, particularly if the common elements shared the same spatial position. The similarity analysis thus suggests the operation of a sequential self-terminating comparison process, as assumed by the model, and one which operates position by position.

Because of the way complexity was introduced into the stimuli, complex stimuli are assumed to contain more elements than simple stimuli. It is assumed that each of these elements must be encoded before they are compared, and so complexity has the effect of increasing both encoding and comparison times.

These qualitative predictions of the model are made explicit and tested against the data from Experiment 2. The quantitative model is similar to that proposed by Bamber (1969), except that it includes the discrimination/memory and simple/complex distinctions.

Quantitative Model

Assumptions:

(a) Before making stimulus comparisons, S encodes all elements of the two sets, then compares the encoded elements serially, in a self-terminating fashion.

(b) Elements are single digits, and encoding and comparison times for elements are identical for both simple and complex digit sets. However, comparison times for different elements may differ from comparison times for identical elements.

(c) For simple digits, a single element from each display is always encoded and one comparison always made. For complex digits, two elements are always encoded from both displays, but the number of comparisons varies, depending upon the number of common elements. Exactly 2/3 of "different" pairs of complex digits have zero elements in common, so for these pairs only one different comparison is made; the remaining 1/3 of "different" pairs have one element in common; on half the trials when these pairs are presented a single "same" comparison will precede the single "different" comparison, for an average of 1.5 comparisons. Therefore, for complex digits the average number of "different" comparisons is 1.0, and

the average number of "same" comparisons for "different" pairs is $2/3 (0) + 1/3 (0.5) = 0.167$.

The basic equations for "different" RTs are:

SM (simple memory)

$$= t_D + 1ET + 1CT_D$$

SD (simple discrimination)

$$= t_D + 2ET + k + 1CT_D$$

CM (complex memory)

$$= t_D + 2ET + 1CT_D + 0.167CT_S$$

CD (complex discrimination)

$$= t_D + 4ET + k + 1CT_D + 0.167CT_S$$

where t_D = base time for "different" responses; ET = encoding time; CT_D = comparison time for different elements; CT_S = comparison time for identical elements; and k = time to shift attention from one stimulus to another in the visual display.

The corresponding equations for "same" times are:

$$SM = t_S + 1ET + 1CT_S$$

$$SD = t_S + 2ET + k + 1CT_S$$

$$CM = t_S + 2ET + 2CT_S$$

$$CD = t_S + 4ET + k + 2CT_S$$

where t_S = base time for "same" responses and the other components are as defined above.

From the equations for "different" RTs, it is possible to solve for ET, k , CT_S , and the sum ($t_D + CT_D$). From the equations for "same" RTs, it is possible to solve for all four unknowns. One would hope that CT_S , ET, and k , all estimated independently from both sets of times, would be close to one another. The four unknown component processing times were estimated from the overall mean RTs across Ss. Their estimates are shown below, separately for "same" and "different" RTs.

	"same" RTs	"different" RTs
ET	13	9
CT_S	12	114
k	86	94
t_S or $t_D + CT_D$	327	379

Although ET and k are satisfactorily close to one another, the two estimates of CT_S differ by an order of magnitude. It is not clear why this should be so, nor what changes could be made in the model to rectify the

estimates. Thus, although the model accounts for the qualitative differences among the RTs rather well, the quantitative predictions are relatively poor.

(3) *Discrimination RTs for complex patterns are surprisingly long.* Discrimination RTs were much longer for complex patterns than one would expect by extrapolating from the memory RTs. According to the model, complex discrimination includes both encoding and comparison times for several elements from both patterns. Complex discrimination should take more time than complex memory, which requires encoding several elements from only one pattern, or simple discrimination, which requires encoding fewer elements from each pattern and making fewer comparisons. Nonetheless, complex discrimination is still too long. The pattern discrimination situation is complicated by the fact that the pair of patterns was extrafoveal, and comparing them required eye movements. If several comparisons, and several eye movements, were required, this might account for the surprisingly long times.

(4) *"Same" RTs are longer than "different" RTs for simple pattern discrimination.* This is a difficult result to interpret only because in all the other seven conditions across the two experiments, "same" RTs were faster than "different" RTs. As noted previously, feature-by-feature analyses of comparison processes always predict longer "same" than "different" RTs. However, this reversal in the "same"-"different" difference does rule out an interpretation of the fast "same" times in the other conditions as a reflection of either response bias or differential error rates.

One might have expected the reversal in "same"-"different" RTs to have occurred for complex patterns, in light of the hypothesis presented by Bindra et al (1965) that "same" RTs are longer than "different" RTs when stimulus discriminability is low, thereby forcing S to adopt a stricter criterion for what he calls identical.

One extremely tentative hypothesis will be proposed here to account for the reversal of "same"-"different" times for simple pattern discrimination. The simple matrix patterns were sufficiently simple so that a pair of them projected simultaneously could be perceived and encoded as a single stimulus instead of as two separate stimuli. If this were the case, then S could simply make the decision as to whether the stimulus was symmetric (repeating) and hence "same" or nonsymmetric and hence "different." On the testable

Table 7
Correlation Coefficients (Pearson r) Between Memory and Discrimination RTs for "Same" and "Different" Pairs of Patterns for Each Session

Session	Simple Patterns		Complex Patterns	
	Differ-		Differ-	
	Same	ent	Same	ent
1	.712	.685	-.055	.425
2	.709	.401	.190	.203
3	.708	.239	-.248	.288
4	.934	.316	.096	.351
5	.825	.540	.376	.471

assumption, for which I know of no evidence, that deciding that something is not symmetric takes a shorter amount of time than deciding something is symmetric, one predicts that "same" RTs in this situation will be slower than "different" RTs.

(5) *The form of encoding in the memory task appears to be visual.* For the visual patterns of Experiment 1, the main evidence presented was the relatively high correlations between memory and discrimination RTs, indicating that factors affecting visual similarity in the discrimination task also seemed to be operating during the memory task. The alternative to visual encoding in the memory task would be some kind of idiosyncratic verbal labels developed by each of the Ss. However, in order to be able to use these labels reliably, Ss must be able to absolutely identify the visual patterns. At the end of Experiment 1, Ss were shown a photograph of the 42 matrix patterns from which the 18 matrix patterns for Experiment 1 were selected, and were asked to select the nine simple and nine complex patterns they had been seeing for the previous 15 sessions. All nine of the simple patterns were picked out correctly by all four of the Ss, but only two of the complex patterns were identified correctly by all four Ss, six were identified correctly by three of the four Ss, and the remaining pattern was identified correctly by only two of the four Ss.¹ The inability of all Ss to absolutely identify all complex patterns would appear to argue against verbal encoding.

However, it could be argued that Ss did develop verbal labels for the complex stimuli which were sufficient to distinguish among the nine patterns used in the experiment, but were not sufficient to distinguish them from among the complete set of 42 patterns in the recognition task. Furthermore, RT for patterns decreased considerably over sessions, suggesting a possible shift from visual to verbal encoding over the course of the experiment. If this occurred, one would expect that the correlations

between the "same" and "different" RTs for the memory vs the discrimination task should decrease over sessions.² Table 7 presents correlation coefficients (Pearson r) between the two tasks for each of the sessions. Although the correlations are somewhat variable, particularly for complex patterns, there is no evidence that their values are decreasing with session number; if anything, they appear to be increasing. This analysis does not provide any support for a shift from visual to verbal encoding for the memory task; in particular, it does not support the notion that the change from a visual to verbal encoding is responsible for the decrease in RTs with sessions.

For simple digits, evidence was presented that a visual measure of similarity predicted both memory and discrimination "different" RTs fairly well. Furthermore, the results of a cluster analysis supported in most important respects the visual measure of similarity used, and in addition produced very similar clusters based on data from the memory and discrimination tasks. Ideally, one would like to contrast the predictions derived from visual similarity from those derived from acoustic similarity; however, Conrad (1958) has shown that acoustic confusions do not occur more frequently among certain pairs of simple digits than among others. One would predict on the basis of Conrad's results that if acoustic encoding played an important role in the memory task, there would be insignificant differences among the three categories of visual similarities for memory RTs.

Unfortunately, the same argument does not hold for complex digits. Visual similarity for complex digits was defined in terms of shared elements, where an element is a simple digit. However, in this situation visual and acoustic similarity are almost identical. When a similar analysis is carried out for shared acoustic elements, only four items change classification category: these are the pairs 14-91 and 15-91, which have zero elements in common acoustically but one element in common visually, and the pairs 14-46 and 14-48, which have one element in common in identical temporal positions acoustically but one element in common in different spatial positions visually. When one-way analyses of variance are carried out on the three categories implied by an acoustic analysis, the F ratios remain highly significant, but F is slightly lower in numerical value for the discrimination times, and slightly higher in value for the memory times.

It is clear from the above analysis

that clear-cut differential predictions can only be made for stimuli whose acoustic and visual similarities are sharply different. Digits do not have this property, whereas a judicious selection of letters, or artificially constructed stimuli such as those used by Tversky (1969), can and do.

REFERENCES

- BADDELEY, A. D. Semantic and acoustic similarity in short-term memory. *Nature*, 1964, 204, 1116-1117.
- BAMBER, D. Reaction times and error rates for "same"-different judgments of multidimensional stimuli. *Perception & Psychophysics*, 1969, 6, 169-174.
- BINDRA, D., WILLIAMS, J. A., & WISE, J. S. Judgments of sameness and difference: Experiments on decision time. *Science*, 1965, 150, 1625-1627.
- CONRAD, R. Accuracy of recall using keyset and telephone dial and the effect of a prefix digit. *Journal of Applied Psychology*, 1958, 42, 285-288.
- CONRAD, R. Acoustic confusions in immediate memory. *British Journal of Psychology*, 1964, 55, 75-84.
- EGETH, H. Parallel versus serial processes in multidimensional stimulus discrimination. *Perception & Psychophysics*, 1966, 1, 245-252.
- GARNER, W., HAKE, H., & ERIKSEN, C. Operationism and the concept of perception. *Psychological Review*, 1956, 63, 317-329.
- GRILL, D. P. Variables influencing the mode of processing of complex stimuli. *Perception & Psychophysics*, 1971, 10, 51-57.
- HOCHBERG, J. In the mind's eye. In R. N. Haber (Ed.), *Contemporary theory and research in visual perception*. New York: Holt, 1968.
- JOHNSON, S. C. Hierarchical clustering schemes. *Psychometrika*, 1967, 32, 241-254.
- KELLOGG, W. N. The time of judgment in psychometric measures. *American Journal of Psychology*, 1931, 43, 65-86.
- KRUEGER, L. E. Effect of bracketing lines on speed of "same"-different judgments of two adjacent letters. *Journal of Experimental Psychology*, 1970, 84, 324-330.
- NEISSER, U. Decision time without reaction time: Experiments in visual scanning. *American Journal of Psychology*, 1963, 76, 376-385.
- NICKERSON, R. S. Response times for "same"-different judgments. *Perceptual & Motor Skills*, 1965, 20, 15-18.
- NICKERSON, R. S. Response times with a memory-dependent decision task. *Journal of Experimental Psychology*, 1966, 72, 761-769.
- NICKERSON, R. "Same-different" response times with multi-attribute stimulus differences. *Perceptual & Motor Skills*, 1967, 24, 543-554.
- POSNER, M. I. Abstraction and the process of recognition. In G. H. Bower and J. T. Spence (Eds.), *The psychology of learning and motivation*. Vol. 3. New York: Academic Press, 1969. Pp. 44-100.
- POSNER, M. I., BOIES, S. J., EICHELMAN, W. H., & TAYLOR, R. L. Retention of visual and name codes of single letters. *Journal of Experimental Psychology Monographs*, 1969, 79, No. 1, Part 2, 1-16.
- POSNER, M. I., & MITCHELL, R. F. Chronometric analysis of classification. *Psychological Review*, 1967, 74, 392-409.
- ROSS, R. T. Optimum orders for the presentation of pairs in the method of paired comparisons. *Journal of Educational Psychology*, 1934, 25, 375-382.
- SNODGRASS, J. G. Objective and subjective complexity measures for a new population of patterns. *Perception & Psychophysics*, 1971, 10, 217-224.
- STERNBERG, S. High-speed scanning in human memory. *Science*, 1966, 153, 652-654.
- STERNBERG, S. Two operations in character recognition: Some evidence from reaction-time measurements. *Perception & Psychophysics*, 1967, 2, 45-53.
- STERNBERG, S. Memory-scanning: Mental processes revealed by reaction-time experiments. *American Scientist*, 1969, 57, 421-457.
- TAYLOR, R. L. Comparison of short-term memory and visual sensory analysis as sources of information. *Journal of Experimental Psychology*, 1969, 81, 515-522.
- TVERSKY, B. Pictorial and verbal encoding in a short-term memory task. *Perception & Psychophysics*, 1969, 6, 225-233.
- WICKELGREN, W. Acoustic similarity and intrusion errors in short-term memory. *Journal of Experimental Psychology*, 1965, 70, 102-108.

NOTES

1. Due to an error, this pattern was projected during the experiment in an inverted position from the position portrayed on the photograph used by the Ss in making their decisions.
2. I am indebted to a reviewer for this suggestion.

(Received for publication November 22, 1971.)