Parallel processing in visual same-different decisions¹

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Two to 13 geometrical shapes were exposed simultaneously to S who decided whether all shapes were the same or whether one was different from the rest. Correct different decisions were usually faster than correct same decisions, but latency was independent of the number of shapes presented. We conclude that input from all the shapes was simultaneously processed into either one or two shape categories, and that a decision-theory choice was made between "same" (one shape category) and "different" (two shape categories) independent of the total number of shapes. This parallel processing is thought to be a characteristic of codable stimuli. Some observed same-different latency reversals were probably caused by a shift in the same-different criterion on the continuum for one- vs two-category decisions.

The "same-different" task requires S to respond "same" or "different" to simultaneous or successive presentations of a set (usually two) of stimuli. He responds "same" if all the stimuli are identical, and "different" if one or more is different from the rest. A variety of results has been obtained with this task. When multi-attribute stimuli are being compared, decision time for two different stimuli increases as the number of different attributes (d) decreases (Egeth, 1966). But "same" decision time is faster than predicted by extrapolation to $d = 0$ from the "different" data—so much faster that the mean decision latencies of same and different stimuli are virtually identical. This is true whether the stimuli are presented simultaneously or successively (Nickerson, 1967). Letters, colors, and simple geometric shapes are often responded to faster when they are the same (Nickerson, 1965; Bindra, Donderi, & Nishisato, 1968). However, the response to different tones is faster than to identical tones (Bindra, Williams, & Wise, 1965; Bindra, Donderi, & Nishisato, 1968). The response to line pairs of same or different length depends on the difficulty of the length discrimination; same judgments are faster when the discrimination is hard, while different is faster when discrimination is easier (Bindra et al, 1968).

Bindra et al (1965) represent same and different stimulus presentations as points normally and randomly distributed around two means on a decision axis. The average reaction latency for right and wrong "same" and "different" responses depends on the relative locations of the distribution means and the decision criterion point, and on the variance of the two distributions. This approach explains the previously described data for responses to different tones (Bindra et al, 1965); and to line lengths (Bindra et al, 1968).

But if a decision-criterion model explains data for easily discriminable line lengths (different faster than same), it cannot equally well explain the opposite results for easily discriminable letters (same faster than different). Bindra et al (1968) suggest that an additional attribute of letters and geometrical shapes—their codability (Brown & Lenneberg, 1954)—is involved. Codability means the degree to which the stimulus in question is associated with a particular verbal response. A highly codable stimulus has a consistent association with a single verbal response.

Same-different decisions can be studied in experiments where more than two stimuli are simultaneously present. S is instructed to respond "same" if all stimuli are the same, and "different" if at least one stimulus is different from the rest. The experiments reported here used simultaneous presentation of 2 to 13 geometric shapes to study the decision process with

multiple codable stimuli. The results indicate that same and different decision latencies are independent of the number of codable stimuli within the range of from 2 to 13 shapes. Our conclusion is that categorization precedes the decision process and that the categorization is "parallel" for all of the shapes in our experiment.

METHOD

Several shapes were exposed simultaneously, and S depressed a key labeled "same" if he thought the shapes were all alike, or a key labeled "different" if he thought that one was different from all the rest. S knew in advance that these were the only alternatives. He was not informed of his results. Each S received 12 or 16 practice trials, and 60 test trials. Each trial was immediately preceded by a 2-sec 280-Hz ready signal. The interval between successive ready signals was about 15 sec. The S was told that while we were interested in the accuracy of his responses, he should make his choice as quickly as possible. His right arm rested on a table beside a tachistoscope, and his finger rested at a point equidistant from the large "same" and "different" keys. Decision latency was recorded from the stimulus onset. Position of the keys was reversed between each S. Each S rested for 5 min halfway through the session which lasted about 30 min.

The number of shapes exposed varied from trial to trial. The angular distance between the farthest shapes was the same regardless of the total number seen, so the more numerous shapes were spaced more closely together. Half of the trials were "same" and half were "different." In the preliminary experiments, same trials were circles, and different trials were circles with a triangle. In Experiments 1 and 2, same trials were either all squares or all circles, and different trials were either squares with a semicircle, or circles with a triangle.

One stimulus card was made for each condition [number of shapes, judgment (same or different), and shape set (square and semicircle or circle and triangle)]. The location of the shapes varied from card to card. Fig. 1 illustrates some cards used in the experiments. Dimensions of the individual shapes

Fig. 1. Typical stimulus cards. The five-shape (same) and nine-shape (different) cards were used in the preliminary experiments. The seven-shape cards were used in Experiments 1 and 2.

Fig. 2. Mean correct same and different response latency for the 2-, 7-, and 11-shape presentations of Experiment 1. Seven of the 25 Ss had latency reversals of the same pattern as the group mean result.

were: side of square, 0.9 cm (0.5 deg visual angle), side of triangle, 1.4 cm (0.7 deg), diameter of circle and semicircle, 1.1 cm (0.6 deg). The square, circles, and triangles had equal areas. The separation of the farthest shapes varied from 5.5 deg to 6.5 deg among the cards. The cards were presented five times each in a randomized order which was the same for all Ss within an experiment.

The practice trial stimuli were pairs of circles or squares (same) or one of each (different). Their maximum angular separation was 3 deg. Their dimensions were identical to those of the squares and circles of the test trials. Half the trials were "same" and half were "different."

Subjects observed the stimuli while seated at the binocular eyepiece of a three-channel tachistoscope. Tachistoscopic viewing distance was 52 cm. Preexposure, exposure, and postexposure field backgrounds reflected 1.28 ft-L at eye position. Room illumination was normal during the experiment.

Subjects were 53 high school and university students (22 male). The high school students were paid an hourly wage, the university students were volunteers.

Preliminary Experiments

Seventeen Ss were tested at 50 msec (3), 200 msec (9), or ad lib (5), exposure conditions. From 2 to 13 shapes were presented on each trial. The results were similar to those reported in detail for Experiments 1 and 2. There was little variation in average decision latency over the different numbers of shapes exposed, and "different" responses were made on the average slightly faster than "same" responses. Data from the three Ss tested in preliminary experiments at 50-msec exposures is incorporated into Fig. 2 and into the

calculations which determined the significance of the difference between same and different decision latency.

Experiment 1

Each S ($N = 25$, seven male) saw 50-msec exposures of 2, 7, and 11 circles or squares (same); and circles and triangle or squares and semicircle (different). There were 12 practice and 60 test trials.

Experiment 2

Each S ($N = 11$, four male) saw 50-msec exposures of 7, 11, and 13 shapes. There were 16 practice trials. This experiment was like Experiment 1 in all other respects.

RESULTS

Experiment 1

When two and seven shapes were presented, average different decision latencies were shorter than same latencies; when 11 shapes were presented, different latencies were longer than same (Fig. 2). This interaction [$F(2,48) = 6.63$, $p < .01$] was the only significant source of variance among the experimental conditions (number of shapes, judgment, and shape set). Accuracy was virtually 100% in all conditions, as in the preliminary experiments. Latency data from correct responses only is reported for each experiment.

Seven of the 25 Ss gave individual results consistent with the significant interaction: different latencies shorter with 2 and 7 shapes, and longer for 11. Two Ss were faster on same for both 7 and 11. For seven Ss, the difference between same and different was smallest at 11 shapes, but different latencies were always shorter than same. There were nine people whose results did not at all match the pattern of the interaction. In summary, 16 out of 25 people showed a reversal or reduction of the difference between same and different decision latencies at 7 or 11 shapes.

Experiment 2

Accuracies were lower in this experiment with 7, 11, and 13 shapes (Table 1). Responses to circles or circles and triangle were significantly faster than responses to squares or squares and semicircle [$F(1,10) = 9.34$, $p < .05$]. Different decisions were generally faster [$F(1,20) = 3.8$, $p < .10$] than same decisions.

Number of Shapes

Data from the three 50-msec Ss in the preliminary experiments and from all groups in Experiments 1 and 2 were combined to obtain a better understanding of the relationship between number of shapes and decision latency. The data for each S were averaged over all correct same and different presentations at each number of shapes presented. The grand

Table 1
Mean Decision Latency (msec) for Correct Responses in Experiment 2. Exposure Time 50 msec.
Percent Correct Responses in Parentheses to the Right of Each Mean Decision Latency.

	Number of Shapes Presented						Mean Latencies
	7		11		13		
Presentation: Same (S) or Different (D)	S	D	S	D	S	D	
Circles (S) or circles and triangle (D)	1286 (96)	1181 (98)	1402 (96)	1249 (87)	1253 (96)	1231 (93)	1267
Squares (S) or squares and semicircle (D)	1342 (96)	1239 (95)	1356 (98)	1275 (95)	1403 (95)	1339 (73)	1326
							Grand Mean
Mean Latencies	1314	1210	1379	1262	1328	1285	1296

Fig. 3. Mean correct response latency as a function of number of shapes and same or different presentation: 50-msec exposure data from all experiments. One SD of the group mean above and below the grand mean is plotted for each number of shapes.

mean of mean decision latencies for every S tested at 50 msec is almost constant over the range from 2 to 13 shapes (Fig. 2). What little variation there is suggests that intermediate numbers of shapes are responded to faster than either few or many shapes. Each S is represented in three (Experiments 1 and 2) or five (preliminary experiments) of the grand means and their standard deviations. This data is consistent with the results of the Ss tested at ad lib or 200-msec exposures during the preliminary experiments. Their shortest decision latencies were also recorded to the seven- and nine-shape exposures.

Same and Different Presentations

The same and different points on Fig. 2 were calculated by averaging each Ss' latencies separately for same and different conditions at each number of shapes, and then finding the grand mean for same and different presentations over all Ss. Fig. 2 shows that average different decisions are faster than average same decisions for every number of shapes presented, despite the significant reversal at 11 shapes found in Experiment 2 alone. Although different was on the average faster than same within each experiment, the difference between them was significant in none. Statistical comparison of mean latency for same and different presentations over all 50-msec conditions can easily be made because the basis for comparison is an intra-S difference. The mean (same-different) latencies for each of the 39 Ss tested at 50 msec was averaged over all other conditions. The distribution of mean differences was almost rectangular, with a mean of 71 msec and a standard deviation of 192 msec. There were significantly more positive differences (30) than negative differences (9) ($p < .001$, sign test). One of the negative differences occurred in the preliminary experiments ($N = 3$), six occurred in Experiment 1 ($N = 25$), and two occurred in Experiment 2 ($N = 11$). The mean same latency was 1360 msec, the mean different latency, 1289 msec.

The difference between same and different decision latencies decreases as the number of shapes increases, although the grand mean remains about the same (Fig. 2). In Experiment 1 the significant interaction means that there is at least a reduction of the difference between same and different latencies as the number of shapes increases. Ferguson's (1965) nonparametric monotonic trend test applied to the (same-different) latency difference for each number of shapes presented demonstrated a significant trend (confirming the

significant interaction in the analysis of variance) for Experiment 1 ($p < .05$). Figure 2 suggests that this happens over the whole range for all the 50-msec data, but the same nonparametric test did not demonstrate a significant trend in the data from either the preliminary experiments or Experiment 2.

DISCUSSION

Simultaneous same-different decisions are not slowed by the addition of up to 12 identical codable geometrical shapes. The constancy of average latencies suggests that a decision results from the serial operation of two processes, both of which are independent of the number of shapes presented from 2 to 13. The first process is categorization. The O puts each shape into a category, which proceeds as rapidly with 13 shapes as it does with 2. The second process is the decision whether one category (same) or two categories (different) are represented. This is theoretically described by Bindra et al (1965). Since different decisions were usually faster than same decisions, the criterion on the same-different decision continuum was usually closer to the same than to the different mean. The few exceptions occurred among the Os of Experiment 1, where the latency reversal between same and different shape presentation of 11 shapes indicated a change in the location of the criterion point relative to the means of the one- and two-category distributions. Because same and different latencies may become more similar as the number of shapes increases, perhaps the means of the one- and two-category distributions approach as the number of shapes increases. In other words, as the number of shapes increases the difference between one and two categories may become harder to discriminate.

It is clear that scanning each shape in the stimulus, or in the afterimage, or the fast-decaying trace cannot account for the obtained consistency of decision latencies. Scanning would produce longer decision latencies for more shapes; and this does not happen. Fig. 2 even suggests that intermediate numbers of shapes are responded to a little faster than either few or many shapes. The relative constancy of decision time is our justification for concluding that part of the decision process which occurred during this experimental task involved "parallel processing."

The parallel processing occurred with codable stimuli. Most other results with codable stimuli give same decision latency as equal to or faster than different decisions. Why was this not so in our experiments? In the previous work, both the number of stimuli per presentation and the location of the stimuli to be presented were known in advance by S. Under those conditions it is possible that categorizing the first shape activates a central process corresponding to its category. If the second shape were a member of the same category, it would reactivate the already primed central process, with a savings in total activation time. The "same" decision would thus depend on the activation of one central process twice in succession. If the second shape belonged to a different category, it would activate another process, and the two processes would have to be compared. This would require the physical transmission of information from one part of the CNS to another at the expense of some small amount of time. But in our experiments, where the S cannot attend to a specific place or cannot even anticipate a predetermined number of inputs, a less efficient two-stage categorization and decision process like the one previously described takes place. The stimulus uncertainty may also explain the relatively long decision times compared with other same-different experiments.

Our main finding is that since decision time was independent of the number of shapes, parallel categorization of the shapes preceded a same-different decision between one or two shape categories. The same and different categories may have become less discriminable as the number of shapes

increased. This produced a nonsignificant general decrease in the latency difference between "same" and "different" responses, and in some cases latency reversals between same and different decisions.

The existence of parallel processing of multiple codable inputs raises interesting questions concerning the capacity of the attentive person to process information from an array of many shapes. Does parallel processing occur when the number of shapes in either category may vary? Ss in our experiment knew that only one different shape would be present. What happens to processing time as the number of categories increases beyond two? Our Ss made what Neisser (1967, Chap. 4) calls preattentive or "motor" decisions. Will more categories demand a sequential, "sensory" synthesis?

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NOTES

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