A partial repetition effect in choice reaction time for multidimensional stimuli

DAVID L. HIGGINS and CHARLES F. GETTYS
University of Oklahoma, Norman, Oklahoma 73019

Bertelson (1963), and others more recently, have observed that when the same stimulus is presented consecutively the reaction time (RT) to the second presentation is faster than the RT to the first presentation. In Experiments 1 and 2, two-dimensional stimuli are used in a discrete four-choice RT task where the stimuli can either be completely repeated, partially repeated, or completely different. In Experiment 3, three-dimensional stimuli were used in a discrete eight-choice RT task where the stimuli can either be completely repeated, partially repeated with respect to two dimensions, partially repeated with respect to one dimension, or completely different. The partial repetition of multidimensional stimuli showed a significant facilitation effect on RT with all sets of stimuli used in the present experiments. This result is discussed in respect to the various possible loci of the repetition effect.

Bertelson, in a series of studies (1961, 1963, 1965), and Bertelson and Renkin (1966) observed that choice reaction times (CRTs) to a stimulus preceded by the same stimulus are faster than CRTs to a stimulus preceded by a different stimulus. This observation, christened the repetition effect by Bertelson, has been replicated in a number of other experiments (Hale, 1969; Keele, 1969; Peeke & Stone, 1972; Smith, Chase, & Smith, 1973; M. Smith, 1968; Umiltá, Snyder, & Snyder, 1972), and represents a basic phenomenon in the CRT literature. A recent review of the repetition effect and other sequential effects may be found in Kornblum (1973).

Several hypotheses have been proposed to account for the effects of repetition. An expectancy hypothesis, first investigated by Hyman (1953), maintains that the CRTs will decrease if the expected event is presented. This facilitation is assumed to be the result of cognitive prereponse processes or preparatory motor responses. Bertelson (1963) hypothesized that subjects make an initial check for repetition of the stimulus. If this identity check is positive, then the same response given to the previous trial can be made without further analysis. If, however, the identity check is negative, then a complete, more time-consuming analysis must be made. Another related idea was studied by Theios and Smith (1972) and Smith et al. (1973), who hypothesized that the subject makes a sequential

self-terminating search of short-term memory. These authors suggested that the memory list searched tends to begin with the stimuli which have been most recently processed. Other approaches involve the idea of a fading memory trace (Peeke & Stone, 1972; M. Smith, 1968). The memory trace approach receives support from the result that the repetition effect sometimes diminishes as the intertrial interval (ITI) between the repeated stimuli increases, but Kornblum's (1973) review of a number of experiments suggested no clear-cut relationship between the ITI and the repetition effect.

There are several stages in a CRT that repetition may facilitate. The main stages that are found in most theories of pattern recognition are: the stimulus processing stage, where the stimulus information is received and extracted; the central cognitive stage, where the stimulus is identified and the appropriate response is selected; and the overt motor response stage, where the response is executed. In the usual CRT task, a repetition of a stimulus must mean that all the stages are repeated, the subject receives the same stimulus, makes the same identification, the same response selection, and the same overt response.

Bertelson (1965) mapped several stimuli onto each response, thus enabling responses to be repeated while the stimuli differed on successive trials. Bertelson used the following stimulus-response transitions: (1) a stimulus-repeated, response-repeated transition (identical), (2) a stimulus-not-repeated, response-repeated transition (equivalent), and (3) a stimulus-not-repeated, response-not-repeated transition (different). However, M. Smith (1968) argued that there was an artifact which could possibly affect Bertelson's experiment. The subjects may have been classifying the numerical stimuli as odd or even, and

The first two studies of this paper were reported as the senior author's Masters thesis, submitted to the University of Oklahoma. The authors are indebted to the members of the thesis committee, Roger Mellgren and Larry Toothaker, for their advice, encouragement, and helpful suggestions. Studies 1 and 2 were presented at the May 1974 meeting of the Midwestern Psychological Association.

responding on that basis. This reduces the equivalent transition to an identity transition. In M. Smith's experiment, the equivalent transition did not have this possible artifact. A repetition of the same response did not have any facilitation effect when different stimuli were shown. The data relevant to response repetition suggest that there is no definite response facilitation and that repetition must facilitate some earlier stage of the CRT process.

Rabbitt (1968) supports M. Smith's findings involving identical vs. equivalent stimuli. In all cases Rabbitt's identical stimuli were faster than the equivalent stimuli. Even though this difference declines with practice, Rabbitt states "the repetition of a response seems to facilitate RT much less than the repetition of a signal" (p. 237).

Recently, the repetition paradigm has been broadened to include other interesting manipulations such as: frequency effects (Bertelson & Tisseraye, 1966; Hawkins, MacKay, Holley, Frieden, & Cohen, 1973), analysis of stimulus and response selection (Rabbitt, 1971), and multidimensional stimuli (Felfody, 1974).

The present studies involve multidimensional stimuli which allow repetition of some features of the stimuli while other features are changed, thereby creating a new partial repetition condition. Partial repetition can be achieved by using four two-dimensional stimuli with each dimension having two values. Using these four stimuli in a sequential presentation creates four repetition transitions: a complete repeat (CR), a novel (N), and two transitions of partial repetition (PR), where one of the two dimensions is repeated while the other is not repeated. By using stimuli which share some common features, but which have a different response, we can further define the locus of the repetition effect by comparing partially repeated stimuli with stimuli that have no stimulus or response repetition (novel transitions).

A comparison between CR and PR reveals two differences; (1) the PR transition has one less repeated stimulus dimension, (2) the PR transition does not repeat the response, while the CR does repeat the response. When comparing PR and N, there is nonrepetition of the response in both transitions, the only difference is in the number of stimulus features repeated. With this comparison, we are attempting to isolate any possible effects due to stimulus factors.

Partial repetitions can be treated at two levels. At a concrete level, the experimenter can manipulate the characteristics of the stimuli, observe the latencies of the overt responses, and describe the relationships between his experimental manipulations and the latencies. At a theoretical level, the inferences that the experimenter makes depend largely on his theoretical assumptions about the nature of response

and stimulus processes. However, irrespective of the theoretical assumptions made, neither the final response selection nor the final overt response is repeated in the partial repetition condition. We shall discuss a number of theories and their predictions concerning any effects due to partial repetition at a later point in the paper. If a partial repetition effect occurs, this facilitation might occur during a partial stimulus identification or partial response selection. If, however, it is assumed that stimulus identification is a response selection process, as Keele (1973) assumes, then the question would become; which part of the response selection process is facilitated? In any case, attempts to explain any partial repetition effect must account for the fact that any facilitation effect found in the partial repetition condition when compared to the N condition cannot be due the final response selection or the overt response.

Part of our interest in partial repetition is because of the fact that events are rarely exactly repeated outside the laboratory. Either the same physical object undergoes trial-to-trial transformations, such as perspective or rotational transformations between one identification and the next, or another similar, but not identical, stimulus follows the first stimulus. If a facilitation of the identification process can be shown for stimuli that are similar but not identical, then the generality of the repetition effect will thereby be increased. Studying a partial repetition paradigm will also expand the understanding of effects of repetition and will let us look at other repetition conditions normally encountered.

EXPERIMENT 1

Method

Stimuli. The stimuli of Experiment 1, shown in the upper left part of Figure 1, were four two-dimensional geometric stimuli which varied in shape and the slant of an enclosed line. The shape dimension was varied by changing the height of a rectangle from 14.9 to 38.1 cm, in terms of the projected image, while holding the width constant at 25.4 cm. The corresponding visual angles are 5.4° and 13.8° for the height and 9.2° for the width. Slant was varied by changing the inclination of a line within the rectangle. The enclosed line was centered, slanted at an angle of 45° to the left or right of vertical, and was 4.2 cm in length. The width of all lines was 1.4 cm. These stimuli were reproduced photographically, mounted on 2 × 2 in. slides, and projected from a slide projector. The projected stimuli were white lines on a dark field. The dimensions of the stimuli were unidimensionally scaled in a pilot study by adjusting the values of the shape dimension until the reaction times to identify the shape difference were approximately equal to the reaction times to identify the slant differences.

Design. On trial n , if the stimulus is identical to the preceding stimulus on trial $n - 1$, then a "complete repeat" (CR) is said to have occurred. The four possible CR sequences are AA, BB, CC, and DD, where A through D are the stimuli, as shown in the upper-left part of Figure 1. The stimuli which have the same value of the shape dimension on trial n as the stimuli on trial $n - 1$, while having different values of slant, i.e., AB, BA, CD, and

Figure 1. The geometric stimuli of Experiment 1 are found in the upper left part of the figure, the face stimuli of Experiment 2 are found in the upper right part of the figure, and the face stimuli of Experiment 3 are found in the lower half of the figure.

DC, are termed partial repeats on shape (PRSH). In the other partial repeat condition, the slant value on stimulus n is the same as the slant value on stimulus $n - 1$, while the shape values differ. These stimuli, termed partial repeat slants (PRSL), are AC, CA, BD, and DB. With neither dimension repeated, AD, DA, BC, and CB, the stimulus on trial n is said to be novel (N).

Blocks of stimuli were arranged randomly, with the restriction that every possible ordered pair be present in each block of 16 trials. An order was used such that there were four CRs, four PRSHs, four PRSLs, and four N events in each block of 16 trials. An example is found in the 16 trials after the first trial of the following sample stimulus order: D CACBDDDBABCCDAAD.

An extra trial was required at the beginning of the first block to preserve the completely counterbalanced properties of the first block; that is, the initial D of the previous example provided the missing DC pair of the first block. After the initial stimulus was added to the first block of trials, the last trial of each succeeding block served the same purpose for the next block. Additional properties of this order of presentation are that the four stimuli occur equally often and each of the 16 ordered pairs occurs in each block of 16 trials after the starting trial. Ten such blocks of 16 were generated and eight blocks were picked at random for each subject.

The stimuli had the property that each served as both the first and second stimulus of a stimulus pair. Taking the previous example, the initial A is the second stimulus of the CA pair and is the first stimulus of the AC pair. Thus, each stimulus after the first was responded to with respect to the preceding stimulus and simultaneously determined the repetition transition for the next stimulus.

During the experiment, the first 65 trials (one starting stimulus plus four 16-stimulus blocks) were considered practice and after a short break to reduce fatigue, 97 trials (one starting stimulus plus six 16-stimulus blocks) were given. The CRTs to all trials, a total of 162, were recorded with the last 96 used in the data analysis. The four stimuli were completely counterbalanced over the response locations for the 24-subject design to control for response compatibility effects.

Error rates. The data of those subjects showing an error rate of greater than 5% were not retained in the analysis for several reasons. First, since each stimulus establishes the repetition condi-

tion for the next stimulus, the latency of a response following an error must be discarded, thus the percentage of data lost is double the error percentage. Secondly, Rabbitt (1966) and Morton (1964) have shown that the disruptive effects of an error persist for at least three or four trials after an error. Because of this, data collected immediately after an error would tend to add to the variability of the experiment.

If, for example, a subject had an error rate of 15% then the majority of his data might be suspect. To minimize these problems, we imposed a low error rate, although a low error rate makes the presence of a speed-accuracy tradeoff more difficult to assess. The strategy employed in the present experiment was to keep the error rate low. In subsequent analysis, we found no evidence for a speed-accuracy tradeoff and based the data analysis on the latencies of correct responses.

Instructions and Procedures. Each stimulus was projected on the screen, and the subjects were asked to identify each stimulus by pressing the appropriate response key. When the experiment began, the subjects were told to press the center button when ready and to respond by pressing the appropriate key using only the preferred forefinger as fast and as accurately as possible. After the practice trials, the subjects were shown the number of errors on their scoresheets. The subjects had an opportunity to compare their errors with those of four previous subjects who had less than 5% errors. At the end of the experiment, the subjects were thanked and any questions they had were answered.

Subjects. The subjects were 28 male Introduction to Psychology students at the University of Oklahoma, who could partially fulfill a course requirement by participating in the experiment. The data from four subjects were discarded due to an error rate exceeding 5%.

Apparatus. Each stimulus slide was presented for 120 msec. The duration of the exposure was controlled by the action of a shutter mounted on a Ledex rotary solenoid in front of the lens of a Kodak Carousel slide projector. The slides consisted of white lined figures on a dark background with a white square in the upper right-hand corner. The slides were projected on a white screen with a photocell mounted in the upper right-hand corner where it could be activated by the white square of the slide. The screen was 2.75 m from the projector. The onset of the stimulus slide activated the photocell and started a Hunter Model 131c

digital timer with a Hunter Model 142 digital display. The response of depressing any of four Standard precision lever-action micro-switch keys stopped the timer. The response board was 1.62 m from the screen and consisted of six response keys arranged in a semicircle around a center home button. The middle four keys were used in this experiment. Each key had a fiberboard circle attached to the microswitch lever arm. The key circles were 2.8 cm in diameter and mounted 2.0 cm apart from edge to edge in an arc of 10.5 cm radius measured to the center of each key. A detachable mount was placed to the side of each key where a picture of the stimulus was placed depending on the particular assignment of stimuli to keys for each subject.

Before each stimulus exposure, the experimenter would ask, "Ready?" When the subject was ready to receive the stimulus he would press the center home button with his preferred forefinger. The center home button had a dual purpose. Before each stimulus exposure, the subject's responding forefinger was placed in the same position an equal distance from each response key. Also, pressing the button served as an indication that the subject was ready to respond. A center home button was adopted because it was felt desirable to confine the physical response to one finger of one hand, particularly when many responses were required, as was the case in Experiment 3. The use of a center home button does, however, increase the mean latency of the RTs. When this ready button was pressed, it activated a light on the experimenter's monitoring panel, and on this cue the stimulus was presented. The monitoring panel also contained lights for each of the response keys. Using this apparatus, the latency from the onset of the stimulus to the reaction of pressing a response key could be recorded and any identification errors could be detected. The average ITI was approximately 8 sec. Since the present experiments are self-paced and the repeated measures are all within subjects, we can treat the small ITI variability as a random source of error variance. Variability in ITI is primarily due to variance in the subjects' latencies.

Results and Discussion

A median RT was computed for each repetition condition for each subject. The four repetition-condition scores were examined by a repeated measures ANOVA and planned comparisons.

The mean RTs for the four conditions were: CR, 753 msec; PRSH, 777 msec; PRSL, 882 msec; and N, 887 msec. The repeated measures ANOVA comparing the means was significant ($F = 21.45$, $df = 3,69$, $p < .001$). The traditional repetition effect was shown; CR RTs are 135 msec faster than N RTs ($F = 8.232$, $df = 1,69$, $p = .005$), but the results of primary interest are the partial repetition RTs. Surprisingly, the PRSH condition showed almost as much facilitation as the CR condition; PRSH RTs are 110 msec faster than N RTs ($F = 5.55$, $df = 1,69$, $p = .02$). The PRSL condition, however, showed no facilitation effect; the PRSL vs. N difference between RTs is only 5 msec, a small and insignificant difference.

These results may be due to the saliency of the dimensions chosen. Alternatively, dimensional processing order may have an effect: there may be a tendency for these dimensions to be processed from the outside in.

Even though the PRSH RTs clearly support the existence of a partial repetition effect, the wide discrepancy between the two PR conditions may be due

to these particular stimuli. In order to determine whether these results were unique to the stimuli of Experiment 1, a second experiment was performed using stimuli which could not be processed from the outside in.

EXPERIMENT 2

Method

Stimuli. The four stimuli in Experiment 2 were faces, with the head outline and eyes held constant. The features that varied were the nose and mouth, shown in the upper right part of Figure 1. The two nose conditions were a 10° and 40° angle between the two lines forming the nose, and the two mouth conditions were a 50° arc and an 80° arc. When projected on the screen, the head outline was 40.6 cm tall and 26 cm wide. The small smile was 7.6 cm wide and the big smile was 13.3 cm wide. The two lines for the nose condition were 3.8 cm long. The line of the head outline was 1.5 cm wide and all lines for the features were 1 cm wide.

Design, Apparatus, Instructions, and Procedure. These were the same as in Experiment 1, with nose and mouth repetition conditions substituted for shape and slant repetition conditions. For Experiment 2, the average ITI was approximately 8.5 sec.

Subjects. An additional 40 male Introductory Psychology students at the University of Oklahoma, who could partially fulfill a course requirement by participating in the experiment, were used. The 5% error criterion was maintained to preserve the same conditions as in the previous experiment. Evidently, the discriminations required by the face stimuli were much more difficult, as evidenced by the longer RT latencies and because the data of 16 subjects were excluded due to an error rate in excess of 5%. This high rejection rate was due to only a slight increase in errors. Eleven of the 16 rejected had less than 10% errors. This increase in the error rate probably was due to increased stimulus difficulty, but may also have been influenced by the fact that the two experiments were performed at different times in the semester.

Results and Discussion

The subjects' RT scores in Experiment 2 were analyzed in the same manner as in Experiment 1, and the four repetition conditions were examined by a repeated measures ANOVA and planned comparisons. The mean RTs across conditions are: CR, 1,283 msec; partial repeats with respect to nose (PRN), 1,404 msec; partial repeats with respect to mouth (PRM), 1,426 msec; and N, 1,479 msec. Using the second set of stimuli, the repeated measures ANOVA shows a significant effect due to repetition ($F = 14.947$, $df = 3,69$, $p < .001$). CR RTs are 196 msec faster than the N RTs ($F = 41.50$, $df = 1,69$, $p < .001$). In the PR conditions, PRN RTs were 75 msec faster than N RTs ($F = 5.425$, $df = 1,69$, $p = .023$) and the PRM RTs are 53 msec faster than the N RTs ($F = 2.750$, $df = 1,69$, $p = .102$). The PRN RTs were not significantly different from the PRM RTs ($F < 1.0$).

Again, a significant partial repetition effect was obtained replicating the first experiment. Evidently, the experimental manipulation tended to equalize the saliency of the stimulus dimensions or prevented inner-outer processing as the PR means are nearly equal.

As we compare the CR, PR, and N transitions, it

would be tempting to conclude that the amount of facilitation varies according to the number of stimulus dimensions repeated. However, as previously mentioned, the complete repeat differs from a partial repeat in two ways; first, the CR has one more dimension repeated, and second, the CR repeats the overt response.

It may be possible to further investigate these factors by using a three-dimensional task with a complete repeat, a partial repetition of two dimensions (PR2), a partial repetition of one dimension (PR1), and a novel condition.

The response is never repeated in N, PR1, or PR2 transitions, while the number of repeated dimensions varies between 0, 1, or 2, respectively. If RT decreases as the number of repeated dimensions increase, this result would be due to the increase in stimulus dimensions repeated and would support the generalization that as the number of stimulus dimensions repeated increases, the reaction time decreases.¹ Experiment 3 was designed to investigate this generalization.

EXPERIMENT 3

Method

Stimuli. We can create three-dimensional stimuli by varying the eyes of the stimuli used in Experiment 2, thus increasing the number of stimuli in Experiment 3 to eight. The eye dimension was varied by the horizontal or vertical placement of two lines which measured 1.0×5.0 cm when projected (see lower half of Figure 1).

Design. The design, similar to those of the previous experiments, was expanded to accommodate eight stimuli. This led to 64 distinguishable ordered pairs, creating eight CRs, 24 partial repeats on two dimensions (PR2) (eight PR2s with respect to eyes and nose, eight PR2s with respect to eyes and mouth, and eight PR2s with respect to nose and mouth), 24 partial repeats on one dimension (PR1) (eight PR1s with respect to eyes, eight PR1s with respect to nose, eight PR1s with respect to mouth), and eight Ns. Each stimulus and possible stimulus pair occurred equally often. One hundred and ninety-three trials (one starting stimulus plus three 64-stimulus blocks) were used for 2 successive days. The CRTs to all trials were recorded with the last 128 trials of the 2nd day used in the data analysis. The eight stimuli were assigned response locations by randomly constructed Latin squares to counterbalance possible response compatibility effects.

Apparatus. An eight-choice response board was built to perform the same timing and recording functions, as required in the previous experiments. An improved response display employed recessed illuminated switches. The stimuli were displayed under transparent caps placed over the switches. These caps were circular and detachable. The switches were arranged in a semi-circle around a center home switch. The caps were 3.8 cm in diameter and mounted 5.2 cm apart from center to center in an arc of 11.6 cm radius measured to the center of each switch. This response board was inclined at an angle of 5° .

Instructions and Procedures. Experiment 3 was conducted in two sessions due to the increased number of stimuli. To reduce errors, the stimuli remained on the screen until the subject made the correct response. The average ITI was 9.6 sec. Again, as in Experiment 1 and 2, the response was made using the subject's preferred forefinger. Other instructions and procedures were similar to those of the previous experiments.

Subjects. Twenty-seven subjects were drawn from the same pool. The data of three subjects were discarded due to an error rate exceeding 5%.

Results and Discussion

The subjects' RT scores in Experiment 3 were analyzed in the same manner as the previous experiments. For an initial analysis, the means of the three PR2 and three PR1 medians were combined and examined for overall repetition effects. The mean RTs were: CR, 1,832 msec; PR2, 2,255 msec; PR1, 2,330 msec; N 2,371 msec. A repeated measures ANOVA showed a significant effect due to the repetition conditions ($F = 18.121$, $df = 3,69$, $p < .001$). Planned comparisons showed that CR RTs were 548 msec faster than N RTs ($F = 42.463$, $df = 1,69$, $p < .001$). Although the combined PR2 RTs are 116 msec faster than N RTs, this difference is not statistically significant ($F = 1.986$, $df = 1,69$, $p = .163$). The combined PR1 RTs are 41 msec faster than the N RTs, and this difference also is not statistically significant ($F = .249$, $df = 1,69$, $p = .6239$).

The traditional repetition effect was shown. The effects of the partial repetition conditions were of considerable magnitude and in the predicted direction, but the differences between the combined PR2 and PR1 latencies and the N latency were not statistically significant.

However, previous unpublished research by the authors suggests that there may be an effect on RT due to dimensional processing order. Repeated dimensions that are processed first seem to show a more facilitative effect. During the postexperimental questioning, the subjects were asked which dimensions they saw first, second, and third. The subjects' answers suggested that they processed dimensions in a definite sequential order. A typical answer was similar too: "First I saw the eyes, then the nose, then the mouth." Because we suspected an effect due to processing order, the PR conditions were analyzed in relation to the subjects' stated order of processing.

If subjects process the dimensions in a sequential order, the partial repetitions could occur either early, midway, or late in the order of processing. Suppose that the processing order of dimensions does affect the amount of facilitation of repeated dimensions. Perhaps repeated dimensions are more facilitating if processed early. If the subjects reported seeing the eyes first, followed by the nose second and the mouth third, then among the PR2s, the PR2 eyes-nose condition would have the repeated dimensions processed first and second and should be the most facilitated. A PR2 eyes-mouth condition for this example would have the repeated dimensions processed first and third and should show less facilitation. The PR2 conditions where the dimensions are processed

second and third (PR2 nose-mouth) should have the least amount of facilitation. The PR1 eyes condition would have the repeated dimension (eyes) processed first and should be fastest among the PR1s followed by the PR1 nose condition where the reported dimension is processed second and the PR1 mouth condition where the repeated dimension is processed last.

The mean latencies of the different processing orders of the repeated dimensions shown in the left half of Figure 2 were examined by a repeated measures ANOVA and show a significant overall effect ($F = 10.818$, $df = 7,161$, $p = .0012$). Several comparisons of interest can be made. When the repeated dimensions of the PR2 condition are processed first and second (early), this RT is 230 msec faster than the N RT ($F = 7.707$, $df = 1,161$, $p = .0063$). This processing order for the repeated dimensions is designated on Figure 2 as (1,2). The PR2 condition where the repeated dimensions are processed first and third (intermediate) seem to show considerable facilitation (128 msec), but it is not statistically significant ($F = 2.387$, $df = 1,161$, $p = .124$). The PR2 condition where the repeated dimensions are processed second and third (late) clearly shows no facilitation. When the repeated dimensions of the PR1 condition is processed first (early), the RT is 163 msec faster than the N RT ($F = 2.939$, $df = 1,161$, $p = .088$). There is no effect if the repeated dimension of the PR1 condition is processed second (intermediate) or third (late). In both PR conditions, as the repeated dimension is processed earlier in the processing order there is a tendency for the RT to become faster.

The finding that the size of the PR effect is influenced by order of processing may explain why the earlier partial repetition analysis which ignores processing order did not reach significance, although the sizes of the PR effects were large. Evidently there is considerable facilitation (up to 230 msec for PR2 and 163 msec for PR1), if the repeated dimension(s) is processed early in the sequence, and no PR facilitation if processed last. When the data are analyzed with processing order taken into account, the partial repetition effect becomes highly reliable in PR2. This processing order result may also explain the anomalous result of Experiment 1. The subjects may have been processing the shape dimension first, followed by slant. If this was the case, then the result that a partial repetition of shape facilitated RT by 115 msec while partial repetitions of slant had little facilitation can be readily explained.

A question may arise concerning the different orders of processing.² The interaction between stated orders of processing and transition conditions was not significant, indicating the same general effect for all processing orders. If the repeated dimension occurs

early in the processing order, the latency is greatly facilitated, but if the repeated dimension occurs late in the processing order little or no facilitation occurs. It is not important whether eyes, nose, or mouth is processed first; the lack of an interaction indicates that this effect occurs irrespective of which particular dimension is processed first, second, or third.

In all experiments, the classical repetition effect was shown by the significantly faster CR RTs. In Experiment 1, there was a large partial repetition effect for one stimulus dimension and no effect for the other. This difference may have been due to using stimuli where the dimensions were processed in the same order by most subjects. Using different stimuli in Experiment 2, we find that both partial repetition conditions show about an equal amount of facilitation when conditions were changed in an attempt to make both dimensions equally salient. In Experiment 3, we find a strong partial repetition effect when stated order of processing is taken into account. By using multidimensional stimuli in a CRT task, a partial repetition condition can be created which facilitates RT. Significant partial repetition effects were found with all three sets of stimuli demonstrating a facilitation of RT when common features of multidimensional stimuli are repeated.

Theoretical interpretations. The partial repetition effect is not anticipated by any of the theories reviewed earlier.³ While it is entirely possible that repetition may speed several stages of CRT, theories that assume that only one stage is facilitated by repetition are at best incomplete and should be re-evaluated in light of these results. For example, the identity check notion entertained by Bertelson (1963) and others cannot account for the partial repetition effect. Partially repeated stimuli should not result in a positive identity check but yet show facilitation. The expectancy explanation (Hyman, 1953) has no mechanism which would predict facilitation of partial repetition of a stimulus. Ideas that the repetition effect is due to a fading memory or stimulus-response trace (Peeke & Stone, 1972; M. Smith, 1968) are challenged by the partial repetition result. In a partial repetition, the response is different from that for the preceding stimulus.

Using an associative notion, if the whole S-R process were facilitated, then a partial repetition might elicit two responses, the correct response for the current trial and an inappropriate conflicting response from the preceding trial. Such response interference might be expected to increase reaction time rather than facilitate it. The notion of a "response strength carry-over" implicit in the logogen model (Keele, 1969) is a similar, modern version of these ideas. While the "carry-over" notion does predict facilitation of partial repetitions, no support for this notion was found in our data.⁴ The serial,

self-terminating memory search hypothesis (Smith et al., 1973; Theios & Smith, 1972), assumes that facilitation occurs when the stimulus presented on the preceding trial is found at the beginning of the memory search list for the next trial. To account for the partial repetition effect, this hypothesis can be modified to assume that the list searched is extensively reordered before each trial so that the preceding stimulus has the first location, and that stimuli which share common features are found next on the list. Such an ordering would account for the partial repetition effect. Unfortunately, such an extensive reorganization of memory after each trial appears to be too laborious. A more parsimonious explanation would be to assume that the process of identifying stimuli is facilitated by repetition and that no serial self-terminating memory search need take place. If it is assumed that complete repetition gives more facilitation to the stimulus encoding and/or the pattern identification process than does partial repetition, then the present results can be accounted for nicely, although admittedly in a post hoc fashion. The present results suggest that repetition may facilitate earlier stages of the CRT process than many authors have believed, although our results do not rule out facilitation of later response stages. Likely candidates for the locus of the partial repetition effect might be either the feature extraction process or the identification process itself, or both processes if they are assumed to occur concurrently.

When stimuli are completely repeated, there may be facilitation due to repetition of several stages of the CRT process. The partial repetition results suggest a facilitation of stimulus processing factors, as have Eichelman (1970), Rabbitt (1968), and others. On the other hand, Keele (1969), Schvaneveldt and Chase (1969), and many others suggest facilitation of response processes. There is no reason to believe that repetition necessarily facilitates only one aspect of the CRT process. Felfoldy (1974), for example, interprets his results to support facilitation of both the stimulus and response processes. A reasonable assumption is that various stages may be facilitated by repetition and that the extent of the facilitation of each stage depends on the task. Tasks requiring extensive stimulus processing, as does the present task, may show more stimulus facilitation than tasks with little stimulus processing, such as that of Schvaneveldt and Chase (1969). Similarly, if little stimulus processing is required, and if the response processing demands are high, as they were in Schvaneveldt and Chase's low S-R compatibility condition (matching numbers to scrambled-order buttons), repetition may facilitate response aspects considerably. While these ideas are speculative at this time, many of the discrepant results concerning the repetition effect may be due

to task characteristics that affect the relative amounts of stimulus and response processing. Perhaps the question should be "What is the relative contribution of repetition to the various stages of CRT?" rather than "What stage of CRT does repetition facilitate?"

Relative contributions of repetition to various stages. A tentative model can be developed which will assess the relative contributions of repetition to the various stages of CRT in the partial repetition paradigm. First, assume that the facilitation due to repetition of the stimulus is additively combined, with facilitation due to repetition of the response (Donders, 1969; Sternberg, 1967). Second, assume that stimulus facilitation is linearly related to the number of repeated dimensions. A PR repeats some of the stimulus information and does not repeat either the final response selection or the overt response. A CR repeats all aspects of the CRT. If the facilitation reflected by latency is linearly related to the number of dimensions repeated, then by linear extrapolation the effect due to stimulus factors of the dimensional repetition for the CR can be estimated. This effect can be subtracted from the total facilitation present in the CR to estimate the effect due to repetition of the final response selection process and the overt response.

Processing order influences the amount of facilitation obtained; a CR which repeats all dimensions will be maximally facilitated by any processing order. However, the various PRs within each PR condition will be facilitated more by an earlier processing order than by a later processing order. Since the optimal conditions for facilitation occur in the CR, it follows that the PR latencies employed in the regression analysis should also be those which are maximally facilitated. These latencies are designated in Figure 2 as "early."

A regression line was calculated using the "early processing" data of Experiment 3 to estimate the facilitation due to repeating various numbers of dimensions. The result of this analysis was $RT = 2,362 - 115D$, where D is the number of dimensions repeated ($D = 0, 1$, or 2) and latencies are in milliseconds. Assuming linearity, each additional dimension repeated facilitates RT by 115 msec, and the data are well fitted by the regression line ($r = .991$).⁵ If the regression line is solved for $D = 3$, the effect of repeating three dimensions in the CR without taking the facilitation due to response repetition into consideration is estimated to be 2,017 msec by linear extrapolation, and the facilitation due to stimulus factors for repeating three dimensions is estimated to be 345 msec (3×115 msec). The total facilitation of a CR as compared to a N is 545 msec (2,377 computed from the regression line for $D = 0$ minus the 1,832 latency for CR). If the total facilitation is estimated to be 545 msec and the dimensional

Figure 2. The effects of the order of processing on repeated dimensions is shown on the left. The right panel replots the "early processing" data to show the relative facilitation of stimulus and response processes due to repetition.

facilitation is estimated to be 345 msec, the facilitation due to repetition of the final response selection and the overt response can be estimated to be 185 msec. The result of this analysis is shown in the right half of Figure 2. This function is the same as the function of repeated dimensions labeled "early" shown in the left-hand side of Figure 2. It should also be noted that the right-hand figure also contains a predicted point. In percentage terms, 65% of the facilitation can be attributed to the "stimulus" repetition and 35% of the "response" repetition.⁶

The relative contributions of the "stimulus" and "response" components may differ from task to task. The task used in Experiment 3 required the subject to discriminate among easily confusable multidimensional stimuli. Other tasks, where the stimuli are less confusable, should show a lesser "stimulus" component and a greater "response" component. Felfoldy (1974) used a simpler one-dimensional discrimination and found 40% stimulus facilitation and 60% response facilitation in a 4 → 2 S-R mapping task. The partial repetition paradigm may prove to be useful in determining the relative contributions of repetition to the various stages of CRT.

REFERENCES

- BERTELSON, P. Sequential redundancy and speed in a serial two-choice responding task. *Quarterly Journal of Experimental Psychology*, 1961, 12, 90-102.
- BERTELSON, P. S-R relationships and reaction times to new versus repeated signals in a serial task. *Journal of Experimental Psychology*, 1963, 65, 478-484.
- BERTELSON, P. Serial choice reaction-time as a function of response versus signal-and-response repetition. *Nature*, 1965, 206, 217-218.
- BERTELSON, P., & RENKIN, A. Reaction times to new versus repeated signals in a serial task as a function of response-signal time interval. *Acta Psychologica*, 1966, 25, 132-136.
- BERTELSON, P., & TISSEYRE, F. Choice reaction time as a function of stimulus versus response relative frequency of occurrence. *Nature*, 1966, 212, 1069-1070.
- DONDERS, F. C. On the speed of mental processes (Trans. W. G. Koster). In W. G. Koster (Ed.), *Attention and performance II*. Amsterdam: North-Holland, 1969.
- EGETH, H. E. Parallel versus serial processes in multidimensional stimulus discrimination. *Perception & Psychophysics*, 1966, 1, 245-252.
- EICHELMAN, W. H. Stimulus and response repetition effects for naming letters at two response stimulus intervals. *Perception & Psychophysics*, 1970, 7, 94-96.
- FELFOLDY, G. L. Repetition effects in choice reaction time to multidimensional stimuli. *Perception & Psychophysics*, 1974, 15, 453-459.
- HALE, D. Repetition and probability effects in a serial choice reaction task. *Acta Psychologica*, 1969, 29, 163-171.

- HAWKINS, H. L. Parallel processing in complex visual discrimination. *Perception & Psychophysics*, 1969, 5, 56-64.
- HAWKINS, H. L., MACKEY, S. L., HOLLEY, S. L., FRIEDIN, B. D., & COHEN, S. L. Locus of the relative frequency effect in choice reaction time. *Journal of Experimental Psychology*, 1973, 101, 90-99.
- HYMAN, R. Stimulus information as a determinant of reaction time. *Journal of Experimental Psychology*, 1953, 45, 188-196.
- KEELE, S. Repetition effect: A memory-dependent process. *Journal of Experimental Psychology*, 1969, 80, 243-248.
- KEELE, S. *Attention and human performance*. Pacific Palisades, Calif: Goodyear, 1973.
- KORNBLUM, S. Sequential effects in choice reaction time: A tutorial review. In S. Kornblum (Ed.), *Attention and performance IV*. New York: Academic Press, 1973. Pp. 259-288.
- MORTON, J. The effects of context on the visual duration threshold for words. *British Journal of Psychology*, 1964, 55, 165-180.
- MORTON, J. Interaction of information in word recognition. *Psychological Review*, 1969, 76, 165-178.
- NICKERSON, R. S. "Same"- "different" response times with multi-attribute stimulus differences. *Perceptual and Motor Skills*, 1967, 24, 543-554.
- PEEKE, S., & STONE, G. Sequential effects in two- and four-choice tasks. *Journal of Experimental Psychology*, 1972, 92, 111-116.
- RABBITT, P. M. A. Errors and error correction in choice-response tasks. *Journal of Experimental Psychology*, 1966, 71, 264-272.
- RABBITT, P. M. A. Repetition effects and signal classification strategies in serial choice-response tasks. *Quarterly Journal of Experimental Psychology*, 1968, 20, 232-240.
- RABBITT, P. M. A. Times for the analysis of stimuli and for the selection of responses. *British Medical Bulletin*, 1971, 27, 259-265.
- SCHVANEVELDT, R. W., & CHASE, W. G. Sequential effects in choice reaction time. *Journal of Experimental Psychology*, 1969, 80, 1-8.
- SMITH, E. E., CHASE, W. G., & SMITH, P. G. Stimulus and response repetition effects in retrieval from short-term memory: Trace decay and memory search. *Journal of Experimental Psychology*, 1973, 98, 413-422.
- SMITH, M. Repetition effect and short-term memory. *Journal of Experimental Psychology*, 1968, 77, 435-439.
- STERNBERG, S. Two operations in character recognition: Some evidence from reaction time measurements. *Perception & Psychophysics*, 1967, 2, 43-53.
- THEIOS, J., & SMITH, P. G. Can a two-state model account for two choice reaction-time data? *Psychological Review*, 1972, 79, 172-177.
- UMILTÁ, C., SNYDER, C., & SNYDER, M. Repetition effect as a function of event uncertainty, response-stimulus interval, and rank order of the event. *Journal of Experimental Psychology*, 1972, 93, 320-326.

NOTES

1. In a "same-different" binary classification task, the typical results are that the latency of different responses decreases as the number of dimensions in common between the two stimuli increases (Egeth, 1966; Hawkins, 1969; Nickerson, 1967). This may appear to be in conflict with the present results, but there is a basic difference between a same-different task and a CRT task. For a same-different design, just finding one dissimilar feature will give a correct "different" response. If subjects engage in a self-terminating search for dissimilar features as the above authors suggested, then the more dissimilar features there are, the quicker the search will terminate and the quicker the "different" response will be made. In the present study, each stimulus has a discreet response and an exhaustive analysis of each stimulus is necessary to give the correct response. These "same-different" results appear to be attributable to a self-terminating process, and are not in conflict with the results of the present experiment, which must involve exhaustive processing.

2. There were 13 subjects who reported an eyes-nose-mouth (ENM) order of processing, 5 subjects reported an EMN order, 3 subjects reported a NME order, 2 subjects reported a MNE order, and 1 subject reported NEM order of processing.

3. An extensive series of analysis were performed on these data to check for possible alternative explanation, none of which received support. Specifically, in all three experiments, we found no evidence for a response-compatibility/repetition-effect interaction.

4. The logogen model (Keele, 1973; Morton, 1969) receives no support as an explanation of the partial repetition effect. When similarity to the n^{th} trial correct response is held constant, errors do not increase as similarity to the $n - 1$ correct response increases.

5. Only three points are used because the CR transition includes a confounding response repetition. Expanding the design to more than three dimensions proves impractical, because increasing the stimulus dimensions exponentially increases the possible responses.

6. The words "stimulus" and "response" are put in quotes to indicate the tentative nature of this usage, and to suggest that this usage is a short-hand expression for the more cumbersome phraseology used earlier. The theoretical interpretations of these two components will differ with the theory emphasized. The authors are not inclined to definitively endorse any theoretical positions at this time.

(Received for publication October 1, 1976;
revision accepted January 7, 1977.)