Interactions among levels of processing

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This article examines associations among representations of physical, name, and category information by determining effects of category repetition on and following physical, name, and category match trials. Subjects decided whether two letters were from the same half of the alphabet. Category repetition effects were evidenced by faster and more accurate responses when letters from the same half of the alphabet were used on successive trials. Although physical matches showed no effect of category repetition, name and category matches did. Trials following physical matches were less affected by category repetition than were trials following name or category matches. The results suggested that these category repetition effects were mediated by interletter associations: Reaction time increased with the alphabetic distance between preceding and current letters. However, these distance effects held only for forward ($A \rightarrow B$) and not backward ($B \rightarrow A$) alphabetic sequences, suggesting that the alphabetic representation is ordinal and unidirectional.

The concept that qualitatively different types of codes may be used in information processing, and the related idea of different levels of processing, reflect the fact that people can deal with a stimulus in a variety of ways: according to its physical properties, its name or various aspects of its meaning. The emphasis in past research has been on isolating these codes in order to verify and describe their differences. Demonstrations that responses based on physical, name, and category information have different latencies (Posner & Mitchell, 1967), are differentially affected by certain independent variables (see Posner, 1978, for a review), and lead to memory traces of varying durability (Craik & Lockhart, 1972; Posner & Warren, 1972) have laid a firm empirical foundation for theoretical descriptions of the nature of physical, name, and semantic codes.

Although the consideration of codes as isolable subsystems of information processing has proved fruitful, a growing body of literature suggests that we should also consider the interactions in the use of different codes or levels of processing. This literature raises the need for investigating not only the associations operating within a given level of processing, but also the associations among the physical, name, and semantic codes of a given item. Specifically, this research indicates that responses based on one level of processing are affected by associations existing at a higher level.¹

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The decision that two words, pictures, or colors are physically identical can be based on the physical properties of the stimuli. Yet Rosch (1975a, 1975b) has shown that these decisions are affected by a preceding prime that is semantically related to the stimuli. Hearing the word "fruit," for example, facilitates decisions of physical identity for good members of the category, such as "apple/apple," and inhibits such decisions for poor members, such as "lemon/lemon."

Similarly, saying the name of a word, letter, or digit can be based on its name or phonetic code and does not require retrieval of information about its meaning or category membership. Naming latencies are nevertheless affected by semantic context. Meyer, Schvaneveldt, and Ruddy (1975) conducted an experiment in which subjects were shown pairs of letter strings. Subjects had to decide whether or not the first string was a word, but they only had to name the second string. When the second string was a word, subjects could name it faster when it was a semantic associate of the preceding word. Becker and Killion (1977) and Warren (1977) presented pairs of words sequentially. Subjects named the second word in each pair, but no overt response was made to the first word. Once again, naming latencies were shorter when the two words were semantic associates. When Marcel and Forrin (1974) asked subjects to name single letters and digits that were presented sequentially, they found that category repetition significantly reduced naming latency: Subjects could name a digit faster when they had just named another digit than when they had just named a letter.

These data indicate that tasks involving physical and name codes can be affected by semantic associations or higher level category relations. A variety of theoretical accounts of such results is possible. There may exist strong associative links among the physical, name, and semantic codes of a given item (Anderson & Bower,

1973; Meyer & Schvaneveldt, 1976). Collins and Loftus (1975), for example, have proposed such links between nodes in a semantic network, consisting of semantically associated concept nodes, and those in a lexical network, consisting of phonemically related name nodes. When a stimulus is processed semantically or phonemically, the corresponding node is activated. Furthermore, this activation can spread across links within or between networks and increase the accessibility of other nodes. This "spreading activation" could mediate the effects just described. The processing of a category name, the first of a pair of words, or a letter or digit could activate the corresponding semantic code; such activation could spread to semantic associates and to the name (and perhaps physical) codes of these associates, thus facilitating their later use.

A related explanation of the results is provided by an attentional "location-shifting" model (Meyer & Schvaneveldt, 1971). If physical, name, and semantic codes of a given item, as well as the semantic codes of related items, are strongly associated and are in some sense stored near each other in memory, then shifting attention among them may be relatively fast. According to this notion, if attention were directed to the semantic code of a word, for example, a subsequent response based on the name code of that word or of a semantically related word would be faster than a response based on the name code of an unrelated word; it would take longer to shift attention in the latter situation than in the former.

An alternative theoretical account is that semantic context affects lower levels of processing, not via circuitous code-to-code activations or shifts of attention, but more directly. Meyer et al. (1975) proposed that associated items may share a common processing pathway even before the level of graphemic encoding. "Spreading excitation could therefore increase the speed and sensitivity of visual-feature analyzers that form graphemic representations of associated words" (Meyer et al., 1975, p. 114).

Finally, it is possible that subjects do not limit their processing to the lowest level required for the task. Although the physical code is adequate for a decision about physical identity, for example, subjects might access information about its meaning before responding, especially if the physically identical pairs are embedded among pairs that require retrieval of semantic or category information. Rosch (1975a) showed that the category priming effects she found for physically identical word pairs when category-identity instructions were used disappeared when physical-identity instructions were used. However, in her similar experiments on color matching (Rosch, 1975b), the priming effects were evident in both instruction conditions.

This sample of theories indicates the variety of processing interactions that might exist in the use of physical, name, and category information. A closer

empirical examination of such interactions seems warranted. The experiments described above were designed to assess the effect of semantic or category relations on the use of physical and name information. They did not directly address the opposite question: To what extent does the use of physical or name information *produce* effects based on higher level relations? The Marcel and Forrin (1974) experiment provides evidence that these latter effects must exist. The category repetition effect they reported for the naming of letters and digits indicates that the use of name codes can be affected by category repetition and can also produce effects of category repetition on succeeding trials.

The present experiment investigated interactions among levels of processing by determining: (1) the extent to which tasks based on physical, name, and category information are affected by category repetition and (2) the extent to which these tasks produce effects of category repetition. On each trial of this reaction time experiment, subjects were shown a pair of letters and were asked to decide whether the letters were in the same or different halves of the alphabet. On some trials requiring a "same" response, two different letters were presented, for example, BH. Such trials require the retrieval of alphabetic information. However, on other trials the letters were either physically identical (BB) or had the same name (Bb). Responses to these pairs can be based on physical or name information, respectively, and do not require retrieval of alphabetic information. Evidence for a category repetition effect consisted of differences in response latency and accuracy when letters from the same half of the alphabet were used on successive trials vs. when letters from different halves of the alphabet were used on successive trials. The magnitude of the category repetition effect on physical, name, and category identity trials indicates the degree to which these tasks are affected by context based on relations at the category level. Likewise, the magnitude of the category repetition effect on trials following physical, name, and category matches shows how effective these tasks are in producing such context effects. An additional independent variable was the response-to-stimulus interval (RSI). The time between a response and the onset of the next stimulus varied from 0 to 600 msec. Within the framework of a spreading activation theory, it has been proposed (Collins & Loftus, 1975) that the strength of activation decreases with time. If the category repetition effect is mediated by such a process, the magnitude of the effect may decrease as RSI increases.

In addition to Marcel and Forrin (1974), Loftus (1973; Loftus & Loftus, 1974) and Rabbitt and Vyas (1973) have reported category repetition effects: Subjects produced an instance of a category more quickly when the category was repeated across trials. All of these studies used well-learned and fairly distinct categories, for example, animals, fruits, and colors. The

first and second halves of the alphabet, however, are not learned as distinct categories. Finer analyses of the category repetition effect to be reported here suggest that the effect is mediated, not by the repetition of a distinct category, but rather by trial-to-trial transitions between letters that are more strongly associated to each other.

METHOD

Procedure

On each trial two letters were presented simultaneously and adjacently in the center of an oscilloscope. Subjects had before them four response keys; they were instructed to press the two inside keys with their thumbs if the letters were in the same half of the alphabet and to press the two outside keys with their index fingers if one letter was in the first half and the other in the second half of the alphabet. Subjects were instructed to respond as quickly as possible without making too many errors. Reaction time was measured from stimulus onset to the first keypress. Later analyses showed that subjects generally pressed the two keys at the same time. This double keypress response technique was used to avoid interactions due to stimulus-response compatibility that might have resulted if a single keypress had been required on each trial. If the response choice had been left vs. right key, there might have been a tendency to press the left key in response to letters early in the alphabet and the right key in response to letters late in the alphabet.

No warning signal was used and no feedback was provided. The RSI, measured from the second keypress to the onset of the next letter pair, was 0, 150, 300, or 600 msec. RSI varied randomly within a block of trials.

Stimuli

The letters A, B, E, F, H, J, N, P, Q, R, T, and Y were used. Equal numbers of letters were taken from the first and second halves of the alphabet.

On one-sixth of the trials in a block the two presented letters were physically identical (AA); on one-sixth the two letters had the same name but were in different cases (Aa); and on one-sixth they were different letters within the same half of the alphabet (AB). These three trial types are referred to as physical match, name match, and category match trials, respectively. The remaining half of the trials within a block consisted of pairs of letters from different halves of the alphabet (AP). On category match and different trials, the two letters were in the same case and different cases equally often.

Category repetition trials included physical, name, and category match trials on which the letters presented were from the same half of the alphabet as those used on the preceding physical, name, or category match trial. Category repetition involved only the repetition of the alphabet half and not the repetition of a specific letter. On category shift trials, the letters were from the opposite half of the alphabet as those used on the preceding trial.

Subjects

Nine subjects, ranging in age from 19 to 40 years, were obtained from the subject pool of the Cognitive Laboratory at the University of Oregon. The subjects were tested for three sessions on 3 consecutive days. They were paid \$2 for each session, which lasted approximately 1 h. During a session they performed eight blocks, each consisting of 217 trials.

RESULTS AND DISCUSSION

The data to be reported here are from the last four blocks of Day 1 and the last six blocks of Days 2 and 3.

The first trial of each block and trials following incorrect responses were excluded from analysis.

Mean correct reaction time (RT) and percent correct were computed for physical match, name match, and category match trials as a function of the preceding trial type (physical, name, or category match), the preceding RSI (0, 150, 300, or 600 msec), and category repetition (category repetition or category shift). A four-way (3 by 3 by 4 by 2) repeated-measures analysis of variance (ANOVA) was performed on the RT and accuracy data.

Responses were slowest (734 msec) and most accurate (94.4%) at the 0-msec RSI. RT and accuracy both decreased with longer RSIs: Mean RT was 695 msec (92.6% accuracy) following the 150-msec RSI, 689 msec (93.8%) following the 300-msec RSI, and 695 msec (92.8%) following the 600-msec RSI. These results produced significant effects of RSI on RT [$F(3,24) = 5.05, p < .01$] and accuracy [$F(3,24) = 3.72, p < .025$] and are consistent with the speed-accuracy tradeoff that is normally produced by increasing preparation time (Posner, Klein, Summers, & Buggie, 1973).

Because RSI did not interact significantly with any other variable, most of the discussion will involve results collapsed across RSI. These values are presented in Table 1, which includes mean correct RT and percent correct on physical, name, and category match trials separated by preceding trial type and category repetition. Also shown in Table 1 is the category repetition effect for each condition, consisting of the difference between category repetition and category shift trials, and the results of *t* tests for the significance of these category repetition effects.

Category Repetition Effect

The results of primary interest involved the significant effect of category repetition on RT [$F(1,8) = 83.91, p < .001$] and accuracy [$F(1,8) = 78.46, p < .001$]. Category repetition trials were responded to more quickly and more accurately than category shift trials. The main effect amounted to a difference of 47 msec in RT and 6.8% in accuracy. However, the size of the category repetition effect varied with both the current trial type and the preceding trial type, as shown by significant interactions of category repetition and current trial type on RT [$F(2,16) = 8.73, p < .005$] and accuracy [$F(2,16) = 32.78, p < .001$], as well as interactions of category repetition and preceding trial type on RT [$F(2,16) = 8.57, p < .005$] and accuracy [$F(2,16) = 23.79, p < .001$]. There was also a significant three-way interaction between category repetition, current trial type, and preceding trial type on RT [$F(4,32) = 4.54, p < .01$] and accuracy [$F(4,32) = 11.70, p < .001$].

The sources of these interactions are the main concern of this paper, for they indicate that the effect of repeating a higher level category depends both on the task currently performed and the task just completed.

Table 1
Mean Reaction Time, Percent Correct, and the Category Repetition Effect

Preceding Trial	Category Repetition		Category Shift		Category Repetition Effect	
	RT	Percent Correct	RT	Percent Correct	RT	Percent Correct
Physical Match Trials						
Physical Match	507	99.5	514	98.8	7	.7
Name Match	514	99.8	522	99.6	8	.2
Category Match	543	99.3	568	98.7	25	.6
Name Match Trials						
Physical Match	637	99.6	635	97.5	-2	2.1**
Name Match	610	99.2	667	97.6	57††	1.6**
Category Match	640	99.7	706	92.9	66**	6.8†
Category Match Trials						
Physical Match	930	87.5	938	81.6	8	5.9
Name Match	909	89.7	965	77.0	56*	12.7**
Category Match	828	96.9	1024	66.2	196†	30.7††

* $p < .05$. ** $p < .02$. † $p < .01$. †† $p < .001$.

The performance of a physical match is unaffected by category repetition. The simple main effect of category repetition on physical matches was not significant [$F(1,16) = 1.28$ for RT and $F(1,16) = .217$ for accuracy], nor was the simple interaction between category repetition and preceding trial type for physical matches [$F(1,32) = .379$ for RT and $F(1,32) = .059$ for accuracy].²

The performance of a name match, however, is affected by category repetition, despite the fact that the retrieval of alphabetic information is unnecessary for this task. The simple main effect of category repetition on name matches was significant for both RT [$F(1,16) = 12.35$, $p < .005$] and accuracy [$F(1,16) = 5.87$, $p < .05$]. However, the magnitude of the effect depended on the task just performed, as indicated by significant simple interactions between category repetition and preceding trial type for name matches [$F(1,32) = 4.47$, $p < .05$, for RT and $F(1,32) = 4.46$, $p < .05$, for accuracy]. As Table 1 shows, the category repetition effect on name matches was significant following both category and name match trials. A preceding physical match produced a category repetition effect on the accuracy but not the latency of name matches.

The results for category match trials showed a pattern similar to that for name matches. The simple main effect of category repetition was significant [$F(1,16) = 56.85$, $p < .001$, and $F(1,16) = 132.27$, $p < .001$, for RT and accuracy, respectively], and there was a significant interaction between category repetition and preceding trial type for both RT [$F(1,32) = 32.42$, $p < .001$] and accuracy [$F(1,32) = 87.80$, $p < .001$]. The category repetition effect on category matches was greatest following category matches, intermediate following name matches, and least (in fact, not significant) following physical matches.

These analyses, together with the results of t tests

shown in Table 1, can be summarized in the following way:

(1) Physical matches are unaffected by category repetition, and are relatively ineffective in producing effects of category repetition on succeeding trials. Only the accuracy of name matches showed a significant category repetition effect following physical matches.

(2) Name matches show a category repetition effect when preceded by name or category matches. (The accuracy, but not the latency, of name matches is affected by category repetition when the preceding trial was a physical match.) Name matches also produce category repetition effects on succeeding name and category matches.

(3) Category matches are affected by category repetition when preceded by name or category match trials and produce such effects on subsequent name and category matches.

This pattern of results does not support the idea that this category repetition effect is produced at a level of processing preceding graphemic encoding. If it were, the presence of the effect would not depend on the preceding or current trial type.

It is possible that category repetition affected only the use of alphabetic information. If responses to physical matches were always based on the physical code, one would expect the lack of category repetition effects on and following such responses. Although retrieval of the name code is adequate for name match trials, it may be that subjects occasionally accessed alphabetic information before responding. Name matches would thus be expected to show and produce category repetition effects that were significant but smaller than those for category match trials, which always involve retrieval of alphabetic information. Although the possibility that subjects did not limit processing to the name code on name match trials cannot be ruled out, the large difference in RT (283 msec) and accuracy (14.6%) on name

match and category match trials suggests the consistent use of different levels of processing for the two tasks.

A third explanation of the results is that the category repetition effects involving name match trials are mediated by associations between the alphabetic and name codes of a letter. The "alphabetic code" of a letter is considered here as a memory representation which includes information about the relative alphabetic position of a letter; it may involve simply an associative chain of the alphabetic sequence. Within the framework of a spreading activation theory (Collins & Loftus, 1975), the activation of the alphabetic code of a given letter may spread to those of associated letters—primarily to those close to it in the alphabet—and increase their accessibility. Because letters close to each other in the alphabet tend to be in the same half of the alphabet, later responses to letters in the same half of the alphabet would be facilitated. Furthermore, strong associations between the name code and alphabetic code of a given letter may allow activation to spread from the name code processed on a name match trial to the corresponding alphabetic code, to associated alphabetic codes, and then to the name codes of these associates. The result would be a category repetition effect on trials involving a current or preceding name match. The lack of category repetition effects for trials involving physical matches may indicate weak associations between physical and alphabetic letter codes. People generally learn the alphabet by reciting letter names in order, rather than by memorizing the orthographic form of the alphabet. Thus, one might expect that associations to alphabetic codes would be stronger for the name codes than the physical codes of these materials.

The data are also consistent with an attentional model which assumes that the speed with which attention can be shifted between two memory representations varies directly with the associative strength between them. According to this idea, the category repetition effect reflects the longer time required, on the average, to switch attention between letters in different halves of the alphabet than between letters in the same half. Furthermore, the category repetition effect should occur not only for trials requiring the use of alphabetic codes (category match trials), but also for trials involving a code that is strongly associated to the alphabetic code. Thus, if there exist strong associations between name and alphabetic codes, attention will be shifted faster between the name codes of associated letters, and a category repetition effect will occur for trials involving preceding and current name matches. If the associations between physical and alphabetic codes are weak, there will be no difference in the time required to shift attention on category shift and category repetition trials for physical matches, and thus no category repetition effect.

The data do not allow a definitive comparison of the adequacy of the spreading activation and attentional theories. There are, however, two aspects of the results

that are relevant to such a comparison. First, the spreading activation theory predicts that the size of the category repetition effect should decrease as RSI increases. The results were suggestive of such a trend: The category repetition effect was 64 msec in RT and 7.2% in accuracy at the 0-msec RSI, 58 msec (7.6%) at the 150-msec RSI, 41 msec (6.6%) at the 300-msec RSI, and 24 msec (5.8%) at the 600-msec RSI. However, the interaction between category repetition and RSI was not significant [$F(3,24) = 1.71$, $p < .20$, for RT and $F(3,24) = .70$, n.s., for accuracy].

The second point involves whether the category repetition effect is entirely due to the facilitation of responses on category repetition trials (as the spreading activation theory predicts) or whether it includes an interference effect on category shift trials as well (as the attentional theory predicts). Without a neutral condition involving no task-relevant prior activation or attentional focusing, it is difficult to determine which processes operate (Posner & Snyder, 1975). In the present experiment, trials preceded by a physical match could be considered to approximate such a neutral condition. Table 1 shows that, relative to the RT when the preceding trial was a physical match, name match and category match trials show both faster responses on category repetition trials and slower responses on category shift trials. The latter difference could be interpreted as an attentional "cost" effect. However, this increase in RT as the preceding trial type changes from physical to name to category match may simply be an example of the fact that RT on a given trial increases with the RT on the preceding trial (Broadbent & Gregory, 1967).

In short, the results obtained here could be mediated either by a facilitatory spread of activation or by an attentional process yielding both costs and benefits. With regard to the present data, it seems useful to stress the following points of agreement between these two approaches: The category repetition effect reflects the stronger association between letters in the same half of the alphabet than between letters in different halves; the presence of the effect on and following name matches reflects the effectiveness of associations between name and alphabetic codes; the absence of the effect on and following physical matches reflects the relative ineffectiveness of associations between physical and alphabetic codes.

Alphabetic Associations

When subjects are asked to decide whether two words are instances of the same category, positive decisions are faster if the two words are semantically similar or strongly associated; semantic similarity slows down negative decisions (Collins & Quillian, 1969; Schaeffer & Wallace, 1969, 1970; Wilkins, 1971). A similar effect might be expected for the present categorization task. If it is assumed that the strength of association between two letters is a decreasing function of the alphabetic

distance between them, then deciding whether the two are in the same half of the alphabet may vary with alphabetic distance. Specifically, the speed and accuracy of responses on category match trials should be negatively correlated with alphabetic distance; the speed and accuracy of responses on different trials (letters in different halves of the alphabet) should be positively correlated with alphabetic distance.

These hypotheses were tested by determining mean correct RTs and accuracy on category match and different trials as a function of alphabetic distance. The results are shown in Figures 1 and 2.

RT on different trials tends to decrease as the distance between letters increases. An analysis of variance performed on these data indicated a significant effect of alphabetic distance [$F(17,136) = 12.25$, $p < .001$]. Accuracy on different trials showed no significant effect of alphabetic distance, perhaps because accuracy was always quite high. On category match trials RT increased and accuracy decreased with alphabetic distance. Both effects were statistically significant [$F(9,72) = 6.82$, $p < .001$, for RT and $F(9,72) = 11.09$, $p < .001$ for accuracy]. The correlation between RT and alphabetic distance for category match trials was $.245$ [$t(58) = 1.92$, $p < .05$]; for different trials, the correlation was $-.75$ [$t(70) = 9.50$, $p < .001$].

Although these results are in the predicted direction, another factor is confounded with alphabetic distance. Assuming that there is no clear boundary between the cognitive representation of the first and second halves

of the alphabet, it might be expected that responses to stimuli including letters near the center of the alphabet would be slow and inaccurate. On trials requiring a "different" response, the use of letters near the center of the alphabet involves short alphabetic distances, whereas, on category match trials, the use of these letters generally involves greater alphabetic distances.

When the results were analyzed according to the specific letter pairs that were used, it became clear that RT on category match and different trials increased when the stimulus pair included a letter near the center of the alphabet. A more precise description of this relation between RT and alphabetic position was provided by first computing for each letter pair the minimum alphabetic distance from the center of the alphabet. For example, this value for Pair NR is .5; for AY it is 11.5. Mean RT on category match and different trials was then computed as a function of the minimum distance from the alphabetic center. These results are shown in Figures 3 (category match trials) and 4 (different trials). For both trial types, RT decreased as the minimum distance from the alphabetic center increased.

To determine whether the effects of the alphabetic distance between letters on RT were spurious, the partial correlation between alphabetic distance and RT was computed, with the effect of alphabetic position (distance from alphabetic center) controlled. This partial correlation for category match trials was $.06$ [$t(58) = .44$]. Thus, RT on category match trials is not determined by the alphabetic distance between the letters, but rather by the minimum distance between the letters used and the category boundary. The partial correlation between RT and the minimum distance from the alphabetic center, with distance between letters controlled, was $-.81$ [$t(58) = 10.53$, $p < .001$].

RT on different trials, however, is affected by both the alphabetic distance between letters and alphabetic position. The partial correlation between RT and distance between letters was $-.74$ [$t(70) = 9.20$, $p < .001$]; the partial correlation between RT and the minimum distance from the alphabetic center was $-.44$ [$t(70) = 4.12$, $p < .001$].

Although RT on different trials is affected by the alphabetic distance between letters, these analyses show that the major determinant of RT on category match trials is not the distance between letters, but rather the distance of the letters from the category boundary, which corresponds, in a sense, to how typical of the category the items are. A similar conclusion was reached by Rips, Shoben, and Smith (1973), who found that the best predictor of the time required to decide whether two words were instances of the same category was item typicality rather than the semantic distance between the two items.

Sequential Effects

The possibility of sequential effects of alphabetic distance remains. The degree to which responses to a

Figure 1. Reaction time on category match (triangles) and different (circles) trials as a function of alphabetic distance between letters.

Figure 2. Accuracy on category match (triangles) and different (circles) trials as a function of alphabetic distance between letters.

Figure 3. Reaction time on category match trials as a function of the minimum alphabetic distance between the letter pair and the center of the alphabet.

Figure 4. Reaction time on different trials as a function of the minimum alphabetic distance between the letter pair and the center of the alphabet.

given letter are facilitated by the prior processing of another letter may depend on the alphabetic distance between them. Marcel and Forrin (1974) reported an effect of this sort in their study of sequential effects in the naming of digits: Naming latency was an increasing function of the numerical difference between the current and preceding digit. For example, RT to the digit "6" was faster when preceded by 5 or 7 than when preceded by 3 or 9. Marcel and Forrin attributed this effect to a spread of activation through an associative, ordinal representation of digits.

To determine whether a similar effect might be involved in the processing of letters, responses to physical and name matches when preceded by physical and name matches were analyzed according to the alphabetic distance between letters used on successive trials. Results were also separated by whether the preceding letter was earlier or later in the alphabet than the current letter. Mean correct RTs are shown in Figure 5 as a function of the alphabetic direction and distance of letters used on successive trials. A value of +1 on the abscissa, for example, would correspond to physical and name matches of a given letter when preceded by the letter which immediately precedes it in the alphabet (e.g., BB preceded by AA). A value of -1 would correspond to letters preceded by the letter which immediately follows it in the alphabet (e.g., AA preceded by BB).

The data appear fairly noisy, probably because there were rather few observations (an average of eight) per cell per subject. However, an analysis of variance emphasized several interesting aspects of the data. Although there was no main effect of alphabetic distance [$F(22,176) = 1.37, p < .20$], there was an effect of the alphabetic direction of the transition [$F(1,8) = 13.52, p < .01$], as well as an interaction of direction and distance [$F(22,173) = 2.18, p < .005$]. The interaction resulted from the fact that, when positive alphabetic transitions were used, RT tended to increase with alphabetic distance. When negative transitions were used, there seemed to be no effect of distance. This difference between positive and negative transitions was confirmed by trend analyses: There was a significant linear trend of distance for positive transitions [$F(1,8) = 13.54, p < .01$], but none for negative transitions [$F(1,8) = 3.59, p < .10$]. In neither case were residual trends significant [$F(21,166) = 1.04$ and $F(21,167) = 1.34$].

The main effect of direction in the ANOVA was somewhat puzzling, since negative transitions tended to be faster than positive transitions. This difference might have resulted from the fact that positive transitions tended to involve more responses to letters late in the alphabet, whereas negative transitions involved more responses to letters early in the alphabet. When RT to each letter when preceded by itself was analyzed, it was found that responses to letters in the first half of the alphabet were 41 msec faster than those to letters in the second half.

To determine whether the effect of direction could be attributed to differences in overall RT to each letter, the data were reanalyzed in the following way: For each subject, the mean RT to each letter when preceded by itself was subtracted from the RT to that letter when preceded by each other letter. The data were then sorted according to the direction and distance of the alphabetic transition. These difference values are shown in Figure 6.

An ANOVA performed on these difference scores showed no significant effect of direction [$F(1,8) = .08$].

Figure 5. Reaction time on physical and name match trials as a function of the alphabetic distance and direction between the current letter and preceding letter.

Figure 6. Reaction time on physical and name match trials when preceded by a different letter, minus reaction time on those trials when preceded by the same letter, as a function of the alphabetic distance and direction between current and preceding letters.

However, the linear trend of distance on positive transitions was still present [$F(1,8) = 11.03$, $p < .025$]. The linear trend of distance on negative transitions [$F(1,8) = .76$], residual trends on positive transitions [$F(21,166) = .86$], and residual trends on negative transitions [$F(21,167) = 1.06$] remained nonsignificant. The presence of a distance effect on positive transitions using these difference scores indicates that the effect did not result from differences in overall RT to particular letters. Further evidence that the distance effect is not simply due to the fact that different alphabetic distances involve different sets of letters comes from an analysis of sequential distance effects on RT to a given letter. Name and physical matches for the letter "Y" always involve positive transitions, with alphabetic distance varying from 0 to 24. The correlation between alphabetic distance and RT to name and physical matches for Y was .85 [$t(10) = 5.10$, $p < .001$]. Responses to the letter "A," on the other hand, always involve negative transitions, with distance again varying from 0 to 24. The correlation between distance and RT to name and physical matches for A was .47, which was not statistically significant [$t(10) = 1.69$, $p < .10$].

These data indicate that the processing of a given letter can facilitate later responses to associated letters. The fact that the amount of facilitation depends on alphabetic distance and that only positive transitions are facilitated illustrates two aspects of the alphabetic representation. First, it is an ordinal representation: Associations are strongest between letters that are close to each other in the alphabet. And second, alphabetic associations are unidirectional. The absence of distance effects on negative transitions indicates that associations from a given letter to letters earlier in the alphabet are generally weak. In contrast, Marcel and Forrin (1974) found significant effects of numerical distance on negative (e.g., $9 \rightarrow 8$) transitions, although the slope was shallower than that for positive transitions. Both results are intuitively plausible. People are nearly as adept at

counting backward as forward, but few people can recite the alphabet in reverse. Studies of word processing (Warren, 1974, 1977) have also shown that the magnitude of sequential effects depends on both the strength and the direction of association between words.

In summary, studies of sequential effects on the speed of response seem capable of revealing associative strength in memory. This study has shown that such effects are not limited to tasks based on a single level of processing, but also operate when sequential tasks involve different levels of processing. They therefore can provide information about associations among representations of physical, name, and category information. Although these codes have isolable properties, there are also functional associations among them that produce interactive effects on information processing.

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NOTES

1. My use of the terms "higher" and "lower" levels of processing is in reference to a logical hierarchy of abstractness rather than a serial processing hierarchy.

2. The Satterthwaite approximation, described by Winer (1971), was used to determine the denominators and degrees of freedom for denominators of the F ratios for simple main effects and simple interactions.

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