Effects of font- and letter-specific experience on the perceptual processing of letters

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Subjects made speeded decisions as to whether strings contained all letters or a nonletter. Strings were 2 to 6 items long, and were initially drawn from one subset of letters and nonletters from one font. During the session, the stimuli were changed without warning to either new letters of the same font or new letters of a new font (Experiments 1 and 2), or to new instances of the same letters in a new font (Experiment 3). Changes to new instances of letters caused considerable cost, in the form of an increase in the reaction time slopes due to string length. The results are consistent with the idea that perceptual processing relies upon the retrieval of prior instances.

In general, the perception of familiar patterns and objects has been studied within an *abstractionist* perspective, in which recognition is assumed to result from the activity of abstract detectors that are insensitive to the exact details of instances of a pattern. Abstractionist models are exemplified by the logogen model of word perception, in which all visible instances of a given word are recognized by an abstract detector called a *logogen* (Morton, 1969, 1979). This approach has been challenged recently by the idea that recognition relies upon the retrieval of memories of specific past instances (e.g., Jacoby & Brooks, 1984; Logan, 1988, 1990). In such *exemplar* or *instance* models, each experience with an item is stored as a unique memory, and new instances of a familiar pattern or object are recognized by retrieving similar prior experiences (see also Medin & Schaffer, 1978).

Instance models have been supported by effects of specific, recent experience on perception. One general type of evidence (consistent with both instance models and abstractionist models) is that the perceptual identification of an item is facilitated by recent prior experience with that item (*repetition effects*). Such effects occur for a variety of types of stimuli (novel patterns: Musen & Treisman, 1990; familiar patterns: Sanocki, 1990; words and nonwords: e.g., Rueckl, 1989; pictures of novel objects: Schacter, Cooper, & Delaney, 1990; pictures

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of familiar objects: e.g., Jacoby, Baker, & Brooks, 1989). Instance models attribute such effects to the facilitative effects of retrieving the recent prior experiences (e.g., Jacoby & Brooks, 1984). Abstractionist models explain such effects in terms of priming of abstract representations (e.g., Biederman & Cooper, 1991; Morton, 1979).

Support for instance models is provided by the finding that repetition effects are larger when target instances share superficial details with the corresponding prior instances. Thus, facilitation is greater when words are in the same case (Jacoby & Hayman, 1987), when letters are of the same font (Sanocki, 1990, Experiment 2), and when pictures of an object are similar (Jacoby et al., 1989). These results are consistent with the idea that the facilitative effects of a prior memory depend on its probability of being retrieved during identification, and that this probability is related to the overall similarity between the current episode and the prior episode. Similarity is determined both by task-relevant properties of the episodes and by ostensibly irrelevant properties such as the item's font (Jacoby & Brooks, 1984). These results are difficult for abstractionist models to explain because abstract detectors such as logogens should not be sensitive to details of instances.

However, the effects of superficial similarity are typically rather small. In fact, there is now considerable controversy over the relation between superficial similarity and repetition effects. For words, some researchers have found that repetition effects vary with similarity between prior and current instances (e.g., Jacoby & Hayman, 1987; Kirsner, Dunn, & Standen, 1987), but other researchers have not found such effects (e.g., Morton, 1979; Rayner, McConkie, & Zola, 1980; Scarborough, Cortese, & Scarborough, 1977; for reviews see Carr, Brown, & Charalambous, 1989; Kirsner et al., 1987; Monsell, 1985).

One possible explanation of these conflicting results is that in experiments showing effects of superficial similarity, the task has changed between the first and second exposures to the words (Carr et al., 1989). Such changes may reduce repetition effects in general while increasing their dependence on exact surface form (Carr et al., 1989). Another variable that may be important in these conflicting results is level of attention. Words can be processed as either forms (i.e., strings of letters) or in terms of meaning (e.g., M. C. Smith, 1979), and it is possible that effects of superficial details depend on attention to form. That repetition effects require attention is implied by the finding (reported in Jacoby & Brooks, 1984) that repetition effects occurred for target words that had to be attended but not for non-target words that were fixated but only minimally processed.

In the present experiments, the importance of superficial similarity was investigated in a task that involved processing letters in unrelated strings. Because the strings were meaningless, it is more likely that subjects would attend only to form. Superficial similarity was manipulated by using different-font versions of lowercase letters. The first experiment was motivated by a model of letter recognition that includes both abstractionist and instance-based assumptions (Sanocki, 1987, 1988). The model includes general structures that are invariant from instance to instance (font to font), and "parameters" that become set for the details of a font. The parameters concern details common to letters in a font, such as size, shape, and slant, and are set during experience with letters. Once set, the parameters allow efficient processing of letters of a single font (see Sanocki, 1987). In contrast, if the letters are from more than one font, there is no single, optimal set of parameter settings, so processing cannot be as efficient. Therefore, perceptual processing is predicted to be more efficient for letters of a single font than for letters from a mixture of fonts.

This prediction has been confirmed in experiments measuring the processing of short strings of unrelated letters in two main conditions. In *regular* conditions, the target set consists of *n* letters from a single font, whereas in *mixed* conditions, there are *n* target letters from two or more fonts (Sanocki, 1987, 1988). In Sanocki (1987), processing efficiency was measured with a letter-nonletter task (see below); responses were markedly faster in regular conditions than in mixed conditions. An advantage for regular over mixed conditions has also been obtained for accuracy in a backward masking task (Sanocki, 1988). Advantages for consistent conditions over mixed conditions (mixtures of letter style, size, or case) have also been obtained in word recognition (e.g., Corcoran & Rouse, 1970; McClelland, 1976) and reading (e.g., Rudnicky & Kolers, 1984; F. Smith, Lott, and Cronnell, 1969).

These findings of a "regularity effect" present problems for both strict abstractionist and strict instance models. The finding that the regularity of (font-specific) details of instances affects processing is problematic for abstractionist models because the same abstract detectors would be used in regular and mixed conditions; therefore, there is no reason for a difference in perceptual processing. Instance models have problems with the fact that regularity effects occurred even though there was an equal number of target instances in regular and mixed conditions. If perception is affected by recent experience with instances, then performance should be equal in regular and mixed conditions because the frequency of instances was equal between those conditions.

The present experiments further examined the role of information about font-specific instances of letters in perceptual processing. In Experiments 1 and 2, subjects were given experience with one subset of target letters from one font, and then the target set was changed to new letters of the same or different font. Of particular interest are predictions by instance models and the Sanocki (1987) model about the effects of these types of changes. The general idea that information about instances is important was examined in Experiment 3.

Present task

The present experiments always used the letter-nonletter task, in which subjects discriminate between strings with all letters and strings with one nonletter. Reaction time (RT) was the main measure. Because nonletters were similar in general form to letters (they were created by deleting one segment from a letter), it seems that this task would require comparing items against representations of letters in memory. Indeed, when the length of the target strings was varied in an experiment, RTs increased approximately linearly with string length and the slope for "all-letter" responses (138 ms/item) was approximately twice that for "nonletter" responses (51 ms/item; Sanocki, 1987, Experiment 2). The increase in RT with string length would follow from a capacity-limited process (which may be serial *or* parallel; see Townsend & Ashby, 1983). The slope differences imply that the process was self-terminating (and can terminate sooner, on the average, on trials in which a nonletter is found). This relatively slow, late-occurring process will be referred to as a *checking process* because it is assumed that each stimulus item is checked against representations in memory.

However, given substantial previous evidence that letter recognition is a highly efficient, parallel process (e.g., Pashler & Badgio, 1985; Shiffrin & Schneider, 1977), it is likely that the *initial* encoding of the letters occurs in parallel. In fact, regularity effects have been additive with string length effects, implying that they affect a separate and presumably earlier process (such as the initial encoding of letters), but not the later process of checking the structure of each item (see Sanocki, 1987).

Several other considerations support the distinction between the checking process and the initial encoding process. First, a checking process probably is necessary in the present task because the presence of multiple targets can cause visual noise (e.g., Pashler, 1987) or illusory conjunctions (e.g., Treisman & Schmidt, 1982). These sources of error may be minimized only through more prolonged, capacity-limited processing (e.g., Treisman & Gelade, 1980). Second, the checking process can be assumed to be late-occurring (the last perceptual process) because it is difficult to imagine other perceptual or decision processes that might follow a self-terminating process. Third, relations between effects of string length and regularity, and between RT results and backward masking results, seem to rule out most other types of interpretations.

As mentioned, regularity effects were found to be additive with string length effects (Sanocki, 1987). This finding implies that the two factors affect separate stages of processing within additive-factors models (Sternberg, 1969), most cascade models (Ashby, 1982; McClelland, 1979), and in other types of models (see Townsend & Ashby, 1983). If we assume a late-occurring, self-terminating checking process, then the regularity effect can be attributed to an earlier process.

Independent support for the conclusion that regularity affects an early perceptual process was provided by a backward masking experiment (Sanocki, 1988, Experiment 1) in which accuracy was higher and increased at a faster rate in regular than in mixed conditions. The fact that effects were found when perceptual processing is limited is inconsistent with interpretations of RT results in which regularity affects processes after the checking process. Further support for the present interpretations comes from the fact that similar models have been proposed by investigators for similar tasks (e.g., Hoffman, 1978, 1979; Pashler, 1987). These models also distinguish between early parallel processes and later, capacity-limited checking processes.

In sum, in the present task, effects of changing letters might occur during the initial encoding of letters, which should produce effects that are additive with string length, or during the later checking process, which should produce an interaction with string length.

Predictions

As will be seen, the data from all three experiments reported here indicated that changes caused substantial effects on the later checking process. Therefore, predictions from the models will be described here for change effects on the checking process. Complementary results from a task sensitive to effects on initial encoding (Sanocki, 1990) will be discussed below.

In instance models, perception relies upon retrieval of prior episodes, so it seems likely that during the checking process prior episodes with instances similar to the target letter would be retrieved and checked against the target. When target letters are used repeatedly, the checking process should become rather efficient because there would be recent, highly accessible episodes with instances similar to the target. Changing the target set should slow this process, however, because episodes with instances similar to the new letters would be less accessible. Crucially, the degree of slowing should be equal for changes to new letters of the same or a new font, because memories of letters are separate and unique in instance models. In contrast, in the Sanocki (1987) model, the application of font parameters to a letter's deep-level representation instantiates a sensory representation that could be checked against the stimulus (see Sanocki, 1987). Experience with a target set should cause accurate parameters for those letters to become established, increasing the efficiency of perceptual processing. Changing the target set could slow the checking process, but there should be less cost with new letters of the same font than with new letters of a new font because font parameters would have already been established for the old font.

EXPERIMENT 1

METHOD

Subjects

Thirty-six introductory psychology students from the University of Wisconsin participated for extra course credit (9 subjects in each font-sequence group).

Stimuli and design.

Two fonts of 16 letters each (the "gothic" and "serif" fonts) from Sanocki (1988) were used. The fonts had the same total heights (top to bottom points) of approximately 1.6° of visual angle at the viewing distance used, but were designed to differ maximally in style (see Figure 1). The fonts differed on the shapes of their components, the relative sizes of components (ratio of body size [middle] to ascender and descender size), and the presence (vs. absence) of serifs. In the present experiments, each font was divided into two subsets of 8 letters. The letters were assigned so that the subsets would contain similar letters and similar features (e.g., one subset had *b* and one had *d*). For each instance of a letter, a nonletter foil was created by deleting a portion of the letter.

For a given subject, one stimulus subset was used for 2 practice blocks and the first 8 test blocks. Each block consisted of 12 trials. At the start of the 9th test block, the stimuli were switched in either of two ways: either to the other subset of the same font (change of letters-only), or to the other subset of the other font (change of letters and font). The stimuli remained the same during the next 8 blocks, and then beginning with test Block 17, the subset was switched again. This time, the change that did not occur on Block 9 occurred. Thus, each subject received each of two types of changes, either on Block 9 or Block 17. The initial fonts and change orders were counterbalanced across subjects, producing the four font sequences shown in Table 1.

Within the 12-trial blocks, string type (all-letter vs. nonletter) and string length (two, four, or six items) were crossed, resulting in 2 trials for each type and length of string. For all-letter strings, items were chosen randomly with the constraint that each letter appear equally often (three times) within a block. Nonletter strings were created as if for all-letter trials; then one letter within each string was selected and changed to a nonletter.

Apparatus and procedure

Subjects were tested individually in sessions lasting approximately 40 min. The stimuli appeared on a 22.9-cm video monitor driven by an Apple II+

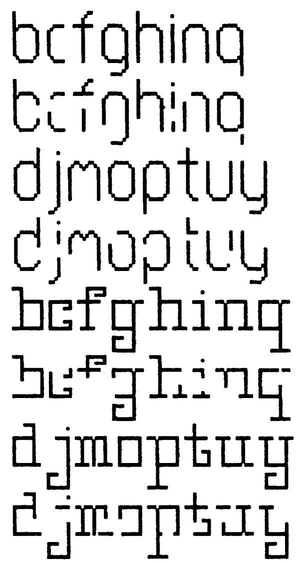

Figure 1. Stimuli in Experiment 1 (the gothic font appears first, then the serif font; there are two sets for each font, and each set includes letters in the top row and nonletters in the next row)

Table 1. Font sequences in Experiment 1

	Group			
Blocks	1	2	3	4
1– 8	S1	S1	G1	G1
9–16	G2	S2	S2	G2
17–24	G1	G1	S1	S1

Note. S refers to the serif font and G to the gothic font; 1 and 2 refer to the different subsets of letters within the fonts.

microcomputer, in white-on-black dot matrix letters. Subjects were seated approximately 56 cm from the screen. A trial began with the presentation of the stimulus string, centered on the screen (thus, shorter strings began to the right of longer strings). Subjects were instructed to press a key indicating *yes* (they are all letters) or *no* (there is a nonletter) as quickly and accurately as possible. The stimuli remained on the screen until a response was made. If the response was correct, the screen was erased immediately; otherwise, the stimuli were redisplayed along with feedback informing the subject of the correct response, until the subject made an additional response. The next trial began 1 s later. The subjects were instructed beforehand that the letters may change during the experiment, but no further information about the changes was provided. A session consisted of 2 practice blocks and then 24 test blocks, with short breaks given after each block.

RESULTS

Of primary concern were the effects of changes on RTs for correct all-letter responses. To examine these effects, the data were collapsed relative to the change blocks, and performance after a change was compared with performance during the 2 blocks immediately before the change. This "before-change baseline" controls for general level of practice with the task. The resultant means are plotted as the top pair of lines in Figure 2. Each subject contributed one mean to each data point in the figure; half of the time the change occurred on Block 9, and half of the time the change occurred on Block 17.

As can be seen in Figure 2, during the baseline blocks, performance

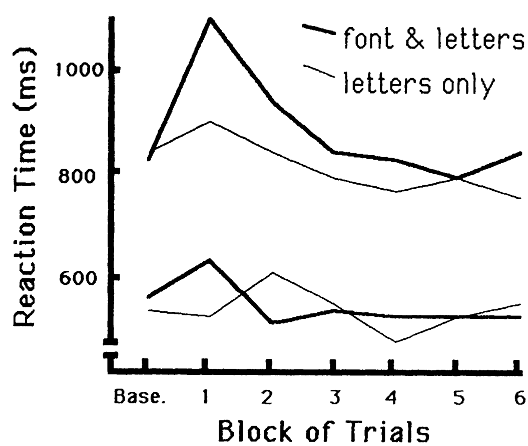

Figure 2. Reaction times for all-letter trials, relative to the change blocks in Experiment 1; the top pair of lines is for total reaction times, and the bottom pair of lines is for the estimates of the intercepts (see text)

in the two change conditions was about equal. However, after the changes, RTs increased, with the greatest increase occurring after a change of letters and font. To examine the change effects statistically, the block after the change was compared with the before-change baseline blocks. The factors were block (before change vs. after), change type, and font sequence. There was a main effect of block, $F(1, 32) = 25.20, p < .001$. More important, the 279-ms cost following the letter and font change was reliably greater than the 69-ms cost following the letter change, as indicated by the crucial interaction of block and change type, $F(1, 32) = 9.89, p < .01$.

However, in the above analysis there also was an interaction of block, change type, and font sequence, $F(3, 32) = 4.52, p < .01$. Examination of the means for each change and each font sequence indicated that change effects were quite large for the gothic to serif change (497 ms), but not for the other three change sequences (averaging between 59 and 80 ms each; the means are shown in Table 2). The large cost for the gothic to serif change was not an artifact of one stimulus set, because large effects occurred with each of the two stimulus sets (see Table 1) involved in the gothic to serif change. Also, note that there were two changes to the serif font from the other subset of the serif font, but these change effects were small (see Table 2). The reason for the large gothic to serif effect is not obvious, but possible relevant factors include the greater complexity of the serif font, and perhaps the fact that it may be less typical of common fonts than the gothic font.

The idiosyncratic font-sequence effect indicates that there is no general advantage for letter-only changes over changes of letters and font; there was a disadvantage only for the gothic to serif change sequence. Changing from the serif to the gothic font did not cause more cost than the two changes of letters-only.

Although font sequence was an important factor, other counterbalance factors were not important. In particular, costs were about the same for the first change (Block 9, 165 ms) as for the second change (Block 17, 183 ms) of the session.

Table 2. Change effects for each of the four sequences of fonts in Experiment 1

Font sequence	Change effect (ms)
Serif-serif	80
Gothic-gothic	59
Serif-gothic	62
Gothic-serif	497

Responses to foils, and error rates

Data for nonletter trials were similar to those for all-letter trials. Change effects on responses to foils were faster than responses to all-letter strings, $F(1, 32) = 12.60$, $p < .01$, but none of the above-mentioned effects varied as a function of response including, in particular, the crucial block by change type interaction ($F < 1$). The RTs for foils in each block relative to the changes are shown in Table 3.

Error rates relative to the change blocks are reported in Table 4. These data were also generally consistent with all-letter RTs: In the analysis of the first block effect, there was a main effect of block, $F(1, 32) = 20.21$, $p < .001$, and of response, $F(1, 32) = 10.73$, $p < .01$. The interaction of block and change type was marginal, $F(1, 32) = 3.62$, $.10 > p > .05$; errors tended to increase more after a change of letters and font than after a change of letters-only.

String length effects

Analyses of string length effects support the assertion that the checking process may have been the major locus of the change effect. String length effects after changes were compared with string length effects during the baseline blocks. The string length effects on both responses

Table 3. Reaction times (ms) for foils in Experiment 1

		Block after change					
Condition	Baseline	1	2	3	4	5	6
Font and letters change	755	947	822	775	726	784	760
Letters change	738	764	734	757	739	720	716

Table 4. Error rates (%) in Experiment 1

		Block after change					
Condition and response	Baseline	1	2	3	4	5	6
Font and letters change							
All letters	1.2	5.0	1.0	2.3	1.4	1.4	2.3
Nonletters	4.2	12.0	6.4	8.3	8.3	4.6	7.4
Letters change							
All letters	1.4	4.6	4.0	0.4	0.9	1.4	0.9
Nonletters	4.4	6.9	6.4	6.0	5.1	5.1	6.0

for the baseline blocks are shown in Figure 3 (dark lines). Reaction time increased approximately linearly with string length, and the slope for all-letter trials (73 ms per letter) was about twice that for foils (34 ms). These data are consistent with the two-stage model introduced earlier, in which string length effects arise from a capacity-limited, self-terminating checking process that is subsequent to the initial encoding process.

The string length effects for the first block after the change are shown as the light lines in Figure 3. For one subject there were no correct nonletter responses for a string length within a condition (0.1% of the data); this missing observation was replaced with the subject's mean for the other string lengths within that nonletter condition. As can be seen, the slopes are inflated relative to the baseline blocks, indicating that the checking process was slowed by the changes. The effect of string length varied with block, $F(2, 64) = 4.28$, $p < .05$.

Slopes were estimated for each subject as in regression, and the duration of a two-item check was subtracted from the mean for the two-item strings, leaving intercept values, which should reflect the duration of initial encoding processes. The means of the intercept values are shown in Figure 2 as the bottom pair of lines. As can be seen, the changes had little or no effect on the intercepts in the six blocks after the change. For the first block after the change, there was no effect of block ($F < 1$) and no block by change type interaction, $F(1, 32) = 1.15$, $p > .20$. This implies that the major effect of changes is on the late-occurring checking process, rather than the initial encoding of letters.

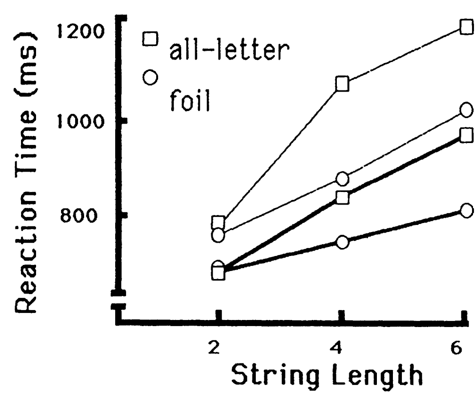

Figure 3. Reaction times as a function of string length in Experiment 1, before (dark lines) and after (light lines) the changes

DISCUSSION

Although mean RTs provided some support for the Sanocki (1987) model's prediction of an advantage for changes of letters-only over changes of letters and font, the advantage stemmed entirely from the difficulty of the gothic to serif change sequence. Cost following the serif to gothic change was no greater than following changes of letters-only. These results are more consistent with instance models, in that costs resulted from changes to new letters, but there was no general advantage for font-specific information extracted during experience with a subset of letters.

The difficulty of the gothic to serif font change may be controlled by idiosyncratic properties of the fonts, or perhaps by factors such as the greater complexity or novelty of the serif font, which had serifs and complex (squarish) forms that the gothic font lacked. However, the serif font may also be less typical of common fonts than the gothic font. (This was confirmed by data reported in the Method of Experiments 2 and 3.) Changing to a more novel font may cause difficulty for a process that checks items against representations in memory, because letters of novel fonts would be similar to fewer prior episodes (in instance models) or would require unusual ranges of font parameters (in the Sanocki model). In response to such difficulties, subjects may prolong the checking process. The importance of these factors was examined further with a new pair of fonts in Experiment 2.

The conclusion that the major effect of changes was on the checking process was supported by the analyses of string length slopes and intercept estimates. According to the intercept estimates, change effects on the initial encoding of letters were either nonexistent or too small to be measured in the present case (e.g., there may be small effects early in the first block after changes). Change effects on the initial encoding of letters can be investigated with a task that is sensitive to early processing and that prevents or discourages prolonged perceptual processing. In fact, a series of experiments with the backward masking task was conducted subsequent to the present experiments (Sanocki, 1990). In that task, stimuli were presented briefly (<120 ms), followed by a mask that interfered with further stimulus processing. Change effects were obtained, but they were relatively small and occurred only for the first three trials of the first block after changes. This provides converging support for the conclusion that the major effect in the present experiment was on the checking process because most of the present effects (i.e., the effects after the first few trials) were eliminated when perceptual processing was limited by masking. In the backward masking experiments, change effects were of equal size after changes to a new or different font, consistent with instance models.

EXPERIMENT 2

In Experiment 1, the only advantage for a change of letters-only occurred for the serif font; changes from one subset of the serif font to the other subset of the serif font produced much less cost than changes from the gothic font to the serif font. The advantage for changes of letters-only may be stronger for more novel or more complex fonts, perhaps because prior experience has a larger effect with such a font. In Experiment 2, both fonts were more novel than the gothic font in Experiment 1. If advantages for changes of letters-only occur for novel fonts, then there should be such advantages for both fonts in Experiment 2. The fonts were generally similar to those in Experiment 1 in their respective degrees of complexity; therefore, if for changes of letters-only, advantages occur only with complex fonts, then the advantage should again be stronger for the serif font.

METHOD

The method was the same as in Experiment 1 except for the stimuli (see Figure 4). Thirty-six new subjects participated. Compared with Experiment 1, the only changes in the letters were certain details and their size (total letter heights were smaller, approximately 1°, in Experiment 2). Properties that make the present serif font more novel include the treatment of serifs (serifs are always connected directly to letter bodies and some of the serifs on ascenders point to the right, in contrast to most serif fonts). The main novel property of the present gothic font is the asymmetrical body shape. To assess the relative typicality of these fonts and those used in Experiment 1, the fonts were presented to a group of 13 graduate students naive to the purpose of the present studies, to rate on a scale from 1 (*most common*) to 7 (*most novel*). The mean ratings were 4.5 and 4.9 for the present gothic and serif font, respectively. The means were not reliably different from each other, $F < 1$. The mean for the gothic font from Experiment 1 was 3.1, and this was reliably less than either the present gothic font, $F(1, 12) = 9.04, p < .05$, or the present serif font, $F(1, 12) = 12.75, p < .01$. The mean for the serif font in the previous experiment was 5.3.

RESULTS

Means of correct all-letter decisions are shown as the top pair of lines in Figure 5. One subject had no correct "all-letter" responses during the first block after a change of letters-only; this missing ob-

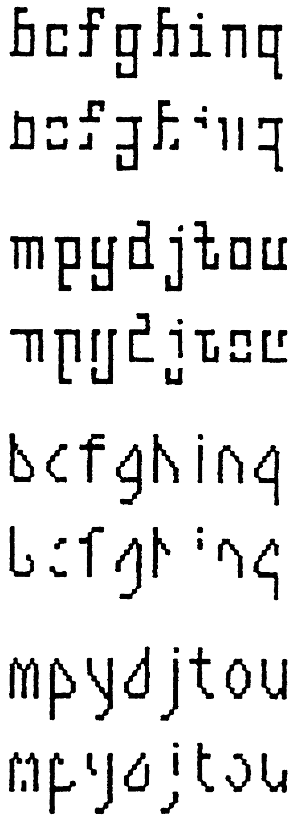

Figure 4. Stimuli in Experiment 2

servation was replaced with the mean from the next block. There were large increases in RT after the changes, but in contrast to the previous experiment, there is no clear separation between the two change conditions. For the first block after the change, the effect of block was reliable, $F(1, 32) = 15.34$, $p < .001$, but the cost was not different for a change of letters-only (184 ms) than for a change of letters and font (258 ms), $F(1, 32) = 1.58$, $p > .20$. For the second block after the change, there tended to be greater cost following the change in letters-only (although this difference was also not reliable). Thus, it appears that when both fonts are more novel, there are substantial costs due to changes, but there is no advantage of holding the font constant. Again, the results are consistent with instance models.

There was also an interaction involving block, change type, and font sequence. However, in the present experiment the largest change effect was for the serif to gothic change (see Table 5). (The gothic

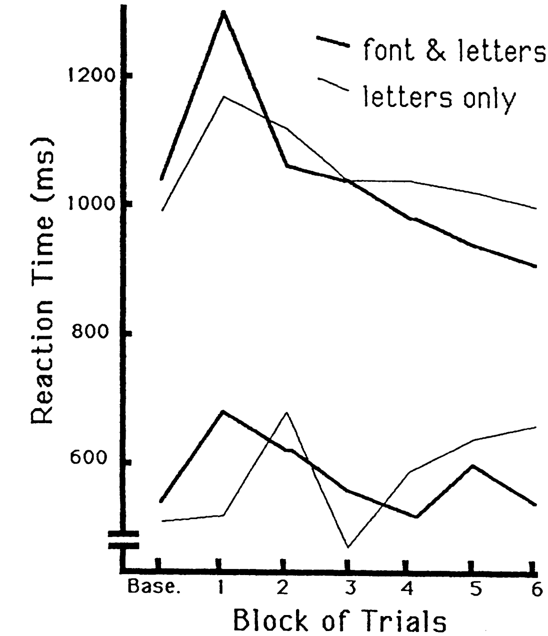

Figure 5. Reaction times for all-letter trials, relative to the change blocks in Experiment 2; the top pair of lines is for total reaction times, and the bottom pair of lines is for the estimates of the intercepts (see text)

Table 5. Change effects for each of the four sequences of fonts in Experiment 2

Font sequence	Change effect (ms)
Serif-serif	164
Gothic-gothic	190
Serif-gothic	386
Gothic-serif	129

to serif change had been most difficult in Experiment 1.) This implies that neither typicality nor complexity produces an advantage for changes of letters-only. The RTs for correct nonletter trials and for errors of both types are shown in Tables 6 and 7. Responses were again faster on nonletter trials, but response did not interact with block or change type (Fs < 1). For error rates, there were main effects of response, $F(1, 32) = 23.12$, $p < .01$, and block, $F(1, 32) = 48.17$, $p < .01$, but no interactions involving these factors or the change type factor, ps $> .20$.

Table 6. Reactions times (ms) for foils in Experiment 2

Condition	Baseline	Block after change 1	2	3	4	5	6
Font and letters change	875	1153	1021	935	844	853	890
Letters change	830	971	1030	960	896	874	883

Table 7. Error rates (%) in Experiment 2

Condition and response	Baseline	Block after change 1	2	3	4	5	6
Font and letters change							
All letters	2.3	12.5	3.2	3.7	1.8	0.9	2.3
Nonletters	10.8	17.6	11.1	9.3	9.3	13.8	10.2
Letters change							
All letters	4.0	9.7	5.6	3.2	4.2	2.3	3.7
Nonletters	8.8	14.4	11.1	6.9	11.1	10.6	9.7

During the baseline blocks, the string length slopes were 44 and 122 ms/letter for nonletter and all-letter strings, respectively. Missing data for string length conditions were replaced as in Experiment 1. The number of replacements ranged from 15 (1.7% of the data) in the first block after the change to 1 (0.1%) in the sixth block after the change. The slopes increased after changes, $F(2, 64) = 3.21$, $p < .05$. This indicates that, as in Experiment 1, changes affected the checking process. Intercepts were estimated as before, and are shown as the bottom pair of lines in Figure 5. As can be seen, there was little or no effect of changes on the intercepts and no clear differences between change conditions. Therefore, the present interference effects occurred mainly on the checking or decision process.

DISCUSSION

In Experiment 2, there was no advantage for a change of letters-only over a change of letters and font, which is consistent with the conclusion for Experiment 1. This result supports instance models, but is not consistent with the Sanocki (1987) model. Because both fonts were relatively novel in Experiment 2, novelty does not appear to cause an advantage for changing letters-only. The serif font was still more complex in Experiment 2, but there was no advantage for holding the serif font constant (as in Experiment 1). Therefore, complexity does not appear to cause an advantage for changing letters-only. The determinant of the magnitude of change effects is not clear at this time.

EXPERIMENT 3

Experiment 3 was conducted for two reasons. First, it provided a direct test of the idea from instance models (and the Sanocki, 1987, model) that information about font-specific instances of letters is important in perception. After subjects received experience with one subset of letters from one font, the stimuli were changed either to new exemplars of those same letters (i.e., a new font) or a control change. If information about font-specific instances is important, then changing to new exemplars should increase processing time. In contrast, abstractionist models would not predict such costs because abstract detectors would not be sensitive to details of instances.

The control change was a change of only the nonletters (the letters were the same as before). This condition was intended to evaluate an alternative explanation of change effects in Experiments 1 and 2. In the previous experiments, the nonletters changed along with the letters. It is therefore possible that the costs were caused at least partly by changes in the nonletters. If new nonletters cause cost, then there should be cost in the control condition of Experiment 3. In contrast, if change effects are restricted to letters, there should be no cost in this condition.

METHOD

The method was the same as in Experiment 2 except for the change types and the sample of subjects. The change types shown in Table 1 were replaced with changes of font-only and control changes in which only the nonletters changed. The first subset of letters in each font was used (Figure 4), and it appeared with two different sets of nonletters. Sixteen new subjects participated.

RESULTS

Means for correct all-letter responses are shown as the top pair of lines in Figure 6. The major comparison in this experiment is between a change of only the font and a control change (of nonletters only). There was considerable cost (453 ms) following the change of font

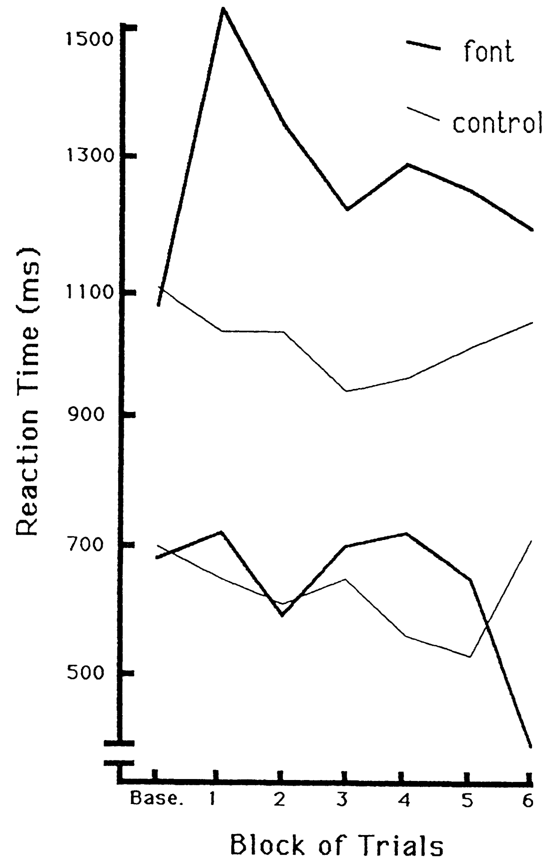

Figure 6. Reaction times for all-letter trials, relative to the change blocks in Experiment 3; the top pair of lines is for total reaction times, and the bottom pair of lines is for the estimates of the intercepts (see text)

but not following the control change (−74 ms effect), $F(1, 12) = 14.08$, $p < .01$ for the interaction of block and change type. As can be seen, the difference between conditions continues throughout all postchange blocks. This indicated that changing the font (changing exemplars of letters) while holding abstract letter identities constant produces cost. In addition, because there was no cost following the control change, it is clear that changing nonletters does not contribute to change effects.

There were no reliable interactions involving font sequence in this experiment. Reaction times for correct nonletter responses and error rates are shown in Tables 8 and 9, respectively. For RTs, nonletter responses were again faster than all-letter responses, $F(1, 12) = 10.69$,

Table 8. Reaction times (ms) for foils in Experiment 3

Condition	Baseline	Block after change 1	2	3	4	5	6
Font change	858	1323	1034	1033	1076	977	1049
Control	896	857	847	862	825	879	786

Table 9. Error rates (%) in Experiment 3

Condition and response	Baseline	Block after change 1	2	3	4	5	6
Font change							
All letters	3.6	15.6	8.3	2.1	6.2	1.0	2.1
Nonletters	3.6	15.6	17.7	13.5	14.5	5.2	11.4
Control							
All letters	1.0	3.1	2.1	1.0	0.0	1.0	0.0
Nonletters	6.8	6.2	4.2	3.1	5.2	6.2	0.0

$p < .01$, but response did not interact with block or change type (Fs < 1). Error rates increased more after the font change than after the control change, $F(1, 12) = 12.41$, $p < .01$.

String length slopes increased following changes, although the interaction of string length and block was not reliable ($p > .20$). Missing data for string length conditions were replaced as before. The number of replacements ranged from four (2% of the data) in the first block after the change, to zero in the fifth and sixth blocks after the change. The lack of reliability can be attributed to the reduced power of the present experiment resulting from the smaller sample. When intercepts are estimated as before, the costs following a change of font-only are no longer present. These data are plotted as the bottom pair of lines in Figure 6. Thus, as in the previous experiments, the present change effects are restricted mainly to the checking process.

DISCUSSION

The results of Experiment 3 are clear. First, changing only the font (while keeping abstract letter identities constant) causes considerable cost. Such an effect is consistent with instance models and the Sanocki (1987) model, in which details of instances are important. The effect is clearly inconsistent with abstractionist models because all instances of the same letter should be handled by the same detector; therefore, changing instances should not have effects. The second major result of Experiment 3 was that changing only the nonletters had no effect on performance. This indicates that changing the nonletters in the previous experiment had no effect. In view of instance models, the lack of an effect of changing nonletters could be surprising because new instances of any pattern might be expected to cause difficulty. However, recent evidence suggests that not all instances are strongly encoded. In an object perception task, it appears that nonobjects are not encoded (Schacter et al., 1990). And, as mentioned above, nontarget words are not well encoded (Jacoby & Brooks, 1984). These results seem analogous to the apparent lack of encoding for nonletters in the present task. More generally, it appears that how (or whether) an instance is encoded may vary with task demands.

GENERAL DISCUSSION

In all three of the present experiments, considerable costs were produced by changes from old to new instances of letters. Costs occurred with changes to new letter identities (Experiments 1 and 2), and with changes to new (font-specific) instances of old letter identities (Experiment 3). There was no indication that keeping the font constant across changes from old to new identities reduced costs. These results are consistent with an important implication of instance models, namely, that different font-specific instances of a letter are perceived as separate, unique items (e.g., Jacoby & Brooks, 1984; Logan, 1988). Instance models make the further claim that each *encounter* with an item is encoded separately, but the present data are not relevant to that claim.

The robustness of the present effects is important for instance models because in previous experiments with words, effects of specific instances have generally been small and often unreliable. Carr et al. (1989) suggested that effects of specific instances may be restricted to when the task changes between study and test. However, the present results argue against that explanation because the task remained constant throughout the session. An alternative explanation is that effects of specific instances depend on the level(s) of attention demanded by the task (Sanocki, 1990). In tasks with words, attention may often be focused on the level of meaning, reducing the effect of an item's visual structure. In the present task, attention is directed more at the visual structure of items; accordingly, effects of specific visual structure should be stronger. Carr and Brown (1990) have recently argued for a level-of-attention explanation of differences in effects between studies.

The present results are clearly inconsistent with predictions from the Sanocki (1987) model. In no case was there evidence that parameters established for some letters of a font transferred to other letters of the font. Also, the finding of cost for changes of font-only (while abstract letter identities are constant; Experiment 3) is inconsistent with models in which perceptual processing depends on abstract entities, because the processing mechanisms should not be sensitive to details of instances (e.g., Morton, 1969).

In both Experiments 1 and 2, idiosyncratic font-sequence effects occurred. However, the effects in the two experiments were not consistent with simple explanations in terms of the novelty or the complexity of the fonts. At this time, it appears that the difficulty of changes is controlled by unspecified, idiosyncratic effects of the font. Such a result may be more consistent with instance models, in which performance would be controlled by properties of the specific memories retrieved during processing.

Examination of string length slopes in all three experiments indicated that most of the change effects were restricted to relatively late-occurring checking and decision processes; there were no significant effects on intercepts. The agreement between the three experiments provides strong support for this conclusion, because it is unlikely that such agreement between experiments would result if the lack of change effects on intercepts occurred by accident. This implies that although the present data are relevant to prolonged, somewhat detailed perceptual processes, they do not reflect initial encoding processes.

As noted, change effects on early processing can be examined with a task that prevents the prolonged stimulus processing that occurred here. The backward masking experiments mentioned earlier appear to meet that requirement (Sanocki, 1990). Those experiments support two important conclusions suggested here. First, the conclusion that the present effects occurred for late-occurring checking processes was supported by the fact that the present effects were eliminated in those experiments: Change effects were much briefer than in the present experiments, being limited to the first three trials after changes. Second, if information about specific instances is important, then costs should be as great for changes of letters-only as for letters and font. Indeed, the brief effects of these two types of change were equal in those experiments. Thus, although the present experiments are relevant mainly to more prolonged perceptual processing, the masking experiments are relevant to the initial encoding of letters. The convergence of these studies provides strong support for the idea within instance models that different instances of an item are encoded separately.

However, regularity effects (Sanocki, 1987, 1988) remain problematic for instance models because the amount of experience with instances was equal between regular and mixed conditions. Regularity effects may result from underlying similarities of same-font letters; for example, sets of font-specific features may become primed (Sanocki, 1990), along with representations of letter instances (present experiments; Sanocki, 1990).

In summary, the present results provide further evidence that information about instances (in the present case, font-specific instances of letters) is important in perceptual processing. Information about instances is important both for prolonged, somewhat detailed perceptual processing (present experiments) and for initial identification processes (Sanocki, 1990). Taken together, these effects argue against purely abstractionist models. Further work should be directed at integrating the present evidence, which supports the importance of instances, with other work indicating that underlying similarities of same-font letters are important (e.g., Sanocki, 1987, 1988).

Notes

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