Specificity of perceptual processing in rereading spatially transformed materials

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While most studies using the task of reading spatially transformed text do not reveal evidence of specific perceptual transfer, a study by Masson (1986, Experiment 3) provides clear evidence of such effects. Several experiments were designed to identify the basis for this empirical discrepancy. The only substantive evidence of specific perceptual transfer occurred when the words were presented in an unfamiliar typography, although each study suggested a trend toward perceptual specificity effects. The results are discussed in terms of Graf and Ryan's (1990) ideas about the role of distinctive memory representations.

The dominant theoretical view of human memory during the 1970s was that information that was processed semantically was remembered better than information that was processed nonsemantically (e.g., Craik & Lockhart, 1972; Hyde & Jenkins, 1969). This view was also evident in the semantic memory models of linguistic representation (e.g., Bransford & Franks, 1972; Kintsch, 1974). While there were several demonstrations of memory for nonsemantic features of stimuli in the literature (e.g., Frost, 1972; Geiselman & Bellezza, 1976; Graesser & Mandler, 1975; for a review, see Hunt & Elliott, 1980), perhaps one of the most often cited sources of evidence of this comes from the task of reading spatially transformed text, introduced by Kolers and his colleagues (for reviews, see Kolers, 1979; Kolers & Roediger, 1984; Levy, 1993). In addition to demonstrating memory for nonsemantic features, Kolers's work also led him to the notable conclusion that nonsemantic features played the most important role in the reading of spatially transformed text (Kolers, 1975b; Kolers & Ostry, 1974), a conclusion that formed the basis of the subsequent procedural view of memory and information processing (Kolers & Roediger, 1984).

Kolers (1979) based his conclusions on the results from two primary research techniques. Both entailed the reading of spatially transformed text on the study trial. One technique involved a detailed signal detection analysis of recognition performance for the studied materials (the "read-and-sort" task), and the other was the more fa-

miliar task of rereading the spatially transformed text. In contemporary parlance, the former is an explicit, or direct, memory test whereas the latter is an implicit, or indirect, memory test (Graf & Schacter, 1985).

Several read-and-sort studies were reported by Kolers (1973, 1974, 1975a; Kolers & Ostry, 1974), in which the signal detection analysis of recognition performance was used to assess memory for the various components of the initial processing of sentences, including the perceptual components. The results of these studies were offered as evidence that perceptual details of previously read materials were retained in memory. Although there are a number of interpretive concerns with the measures used by Kolers (see Horton, 1989), other research on the recognition of the orientation of sentences (Horton, 1989; Masson, 1984) and the recognition of several other perceptual details of previously studied materials (e.g., Frost, 1972; Glisky & Rabinowitz, 1985; Graesser & Mandler, 1975) clearly shows that subjects are able to remember perceptual details at the explicit level in several experimental situations.

The logic of the second research technique, the task of rereading spatially transformed text, was that any differential increase in rereading speed for sentences originally read in a transformed orientation and later reread in the same transformed orientation, as opposed to those reread in a different transformed orientation, could be attributed to the memorial benefits of repeating the processing of the unique perceptual details of the sentence on the test (Kolers, 1979). Subjects initially read sentences in either normal orientation or a transformed orientation (typically, by inverting the materials or reversing them from right to left). This was factorially combined with the test orientation, which again was either normal or transformed. Some new sentences were also included in the test trial. The results showed a small benefit in rereading speed when sentences were originally read in the normal orientation and tested in the transformed orientation, relative to new sentences presented in the transformed orientation at test. However, there was a

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much larger benefit when sentences were presented in the transformed orientation on both the study and test trials, relative to sentences presented in normal orientation at study and transformed at test.

Subsequent work with the rereading task has challenged Kolers's conclusion that the benefit of initially reading in a transformed orientation and then testing in the same transformation was due to memory for perceptual features. Masson and Sala (1978) provided the first critical evidence against the hypothesis that memory for perceptual details underlies this effect. They demonstrated that rereading identical sentences at test resulted in no additional benefit in rereading speed compared with rereading a paraphrase of the studied sentences (see also Graf & Levy, 1984). Because the perceptual details of the paraphrases clearly were not identical to those processed during the study trial, these data suggested that the conceptual information processed at study was the basis for the increase in rereading speed. Graf (1981, 1982) later demonstrated that generating a sentence on the basis of the individual words resulted in the same memorial benefits as did reading it in a transformed orientation. Assuming that the sentence generation task is a strong semantic encoding task, these data suggest that memory for the perceptual details is not the basis for the enhanced memory of transformed materials. Subsequently, Horton (1985) and Tardif and Craik (1989) showed that reading sentences in one transformation and rereading them in a different transformation resulted in the same amount of transfer as did reading and rereading in the same transformation. Because the perceptual details of the sentences are different in the two transformations, it is evident that memory for perceptual details from the initial reading of the sentence cannot be mediating the transfer under these conditions. An additional finding in the Tardif and Craik study was that practice at reading the transformation used at test had a large effect on rereading speed, but nonetheless there was no evidence of specific perceptual transfer from the study trial on the rereading time measure. Overall, then, these data show that subjects are able to recognize the transformation in which previously studied materials have appeared, but that specific perceptual pattern-analyzing operations associated with initially reading a particular passage in a particular transformation have no effect on rereading speeds beyond that conferred by general practice at reading the transformation.

In contrast to these findings, Masson (1986, Experiment 3) reported unequivocal evidence of specific perceptual transfer on rereading times.¹ On the study trial, subjects read unrelated triplets presented both transformed and in alternating case format. At test, subjects read old and new triplets. Two other variables were also manipulated. Each old word was presented in exactly the same alternating case pattern as at study, or in the complementary pattern. This variable was included to assess the role of perceptual processing for units larger than the individual letters: Because subjects had experience with

all letters in both uppercase and lowercase in the transformation, presentation of the complementary alternating case pattern should not affect performance if perceptual effects operate only at the level of individual letters. As a final manipulation at test, words appeared in the same triplet as at study, or they were rearranged across triplets. This variable was included to determine the effects of conceptual processing: If subjects were using memory of the conceptual processing of the members of the triplet to facilitate rereading of the triplets at test, then changing the membership of the triplets between study and test should negate this benefit, and thereby reduce the amount of transfer.

The results indicated that presenting words in the same alternating case pattern at study and test facilitated rereading relative to presenting them in the complementary alternating case pattern, thus demonstrating a transfer effect that is attributable to the specific perceptual processing carried out during the study trial. However, neither a change in the membership of the triplets nor the interaction of the two variables reliably affected rereading speed for old words, suggesting that the transfer effects were operating at the level of individual words. The finding of specific perceptual processing effects on the rereading time measure with transformed materials is important, because it contrasts with other findings obtained by using this measure (Graf & Levy, 1984; Horton, 1985; Masson & Sala, 1978; Tardif & Craik, 1989). The present research was designed to resolve the conflicting findings.

There are a number of differences in the procedures used by Masson (1986) and those used by other researchers who have failed to find evidence of specific perceptual transfer effects on the rereading of spatially transformed text. Tardif and Craik (1989) suggested that the short delay between the study and test trials may be a factor contributing to the specific perceptual transfer effects reported by Masson. However, other studies in which relatively short delays were created by mixing the study and test sentences failed to yield evidence of specific perceptual transfer effects (Horton, 1985). Thus, test delay does not seem to be a likely candidate for explaining the empirical inconsistencies.

Perhaps the most obvious difference in procedures was that Masson (1986) presented triplets composed of unrelated words, whereas all studies that have failed to find evidence of specific perceptual transfer have used textual materials (either sentences or paragraphs; Horton, 1989). If subjects in the latter studies attempted to make maximum use of the conceptual structure inherent in the sentences and paragraphs when they first read these materials in the transformed typography (Graf, 1981; Horton, 1985; Levy, Newell, Snyder, & Timmins, 1986; Masson & Sala, 1978), they might be expected to have had a rich conceptual memory trace available for use on the subsequent reading of the sentences. By contrast, rather less conceptual processing would be expected with strings of unrelated words, and thus percep-

tual processing effects might be more evident with such materials (cf. Horton & Nash, 1990; Roediger, Weldon, & Challis, 1989).

We initiated the present series of experiments to test this idea. Subjects read triplets composed of three unrelated words or three conceptually related words. The related triplets were included to allow subjects the opportunity to engage in conceptual processing such as they appear to do with textual material. We predicted that related triplets would show conceptual processing effects on rereading times but not specific perceptual processing effects. By contrast, we predicted that unrelated triplets would show specific perceptual processing effects but not conceptual processing effects.

EXPERIMENT 1

Method

Subjects. Fifteen undergraduate volunteers were tested individually. None of the subjects in this or the subsequent experiments had previously participated in an implicit memory experiment, including reading of transformed materials.

Design and Materials. A 3×2 repeated measures factorial design was used, with word type (related or unrelated) and alternating case format (same, different, or new) as the two variables. A total of 198 words were selected for the experiment. Six unrelated words were shown as examples. An additional 6 related and 6 unrelated words were presented as practice items at the beginning of the study list. Both the examples and the practice items appeared in triplets, consistent with the critical experimental items.

The remaining 180 words were the critical items. Nine words were selected from each of 10 conceptual categories by using the Battig and Montague (1969) and Horton (1983) norms. Ninety unrelated words were then selected to match the related words on word length (4 to 8 letters, $M = 5.8$) and word frequency (1 to 216 per million, $M = 30$; Kučera & Francis, 1967). The related words within each category were randomly arranged as three triplets. The matched unrelated words were arranged in corresponding triplets. Two of the three triplets from each category, along with the corresponding unrelated triplets, were presented on the study trial for each subject.

The words were presented by an Apple IIe microcomputer, using the default 40-character screen and the default text characters. The three words within a triplet were randomly ordered for each subject. The order of presentation of the triplets on the study trial was also randomly determined for each subject. Following the presentation format reported by Masson (1986, Experiment 3), the words within a triplet were presented in alternating case format. For each subject, the first letter of the first word in each triplet was randomly assigned to uppercase or lowercase. The individual letters were also rotated 180° around the vertical axis. Thus, words were read from left to right, but the orientation of each letter was reversed. Each word was separated by two blank spaces on the screen. All triplets appeared equally often in the same format, different format, and new conditions across the experiment.

For the test trial, one word from each of the studied triplets and one word from each of the nonstudied triplets was randomly selected. Of the previously studied words, half appeared in the same alternating-case format as that in which they had appeared at study and half appeared in the complementary alternating case format. Letters were rotated exactly as at study.

Procedure. The subjects were informed that they were participating in an experiment to determine how people process familiar

words presented in an unusual visual format. The subjects were instructed to read the words aloud from left to right, as quickly and as accurately as possible. If they noticed that they had made a reading error, they were to correct it and continue reading. The experimenter did not identify reading errors to the subjects. Examples were presented to illustrate the visual format of the words.

The study trial began with four practice triplets, followed by the 40 experimental triplets. The study trial was initiated by a key-press by the experimenter. Triplets appeared centered on the screen until the experimenter pressed a key to indicate that the subject had read the triplet. The next triplet appeared 2 sec later. The experimenter recorded reading errors on a separate sheet. Instructions for the test trial indicated that the task and the visual format of the words were identical to those of the study trial, except that only individual words would be presented.

Reading times were excluded if the subject read an item incorrectly on either the study or the test phase, regardless of whether the misread word on the study trial was the word presented on the test trial. To ensure stable reading time data, a criterion of 6 out of 10 triplets read correctly within each cell of the design was established. This resulted in the exclusion of the data from 8 additional subjects.

Results

A significance level of .05 was established for all statistical tests reported in this paper, unless otherwise indicated.

Study trial. The mean reading times for correctly read triplets appear in Table 1. Analysis of variance revealed a reliable difference in reading times for the related and unrelated triplets [$F(1,14) = 118.46$, $MS_e = 2.46$], with the related triplets read faster (related = 7.72 sec, unrelated = 13.95 sec). Neither the effect of format nor the interaction was reliable (both $F_s < 1$).

Test trial. Analysis of the mean test trial reading times also indicated faster reading for items from related than from unrelated triplets [$F(1,14) = 11.53$, $MS_e = .33$]. In addition, there was a reliable effect of format [$F(2,28) = 15.26$, $MS_e = 1.78$], but no interaction of type of item and format ($F < 1$). It is evident from Table 1 that new items were read more slowly than previously studied items. A separate analysis of test trial reading times for only the previously studied items revealed faster reading of related than of unrelated items [$F(1,14) = 6.43$, $MS_e = .36$], no difference between same and different format [$F(1,14) = 1.24$, $MS_e = .30$], and no interaction of type of item and format ($F < 1$). The latter two results are particularly important because they indicate, first, that changing the visual features of an item between study and test had no reliable effect on rereading times and, second, that related and unrelated items showed exactly the same pattern.

Discussion

The data replicate those of Horton (1985), Masson and Sala (1978), and Tardif and Craik (1989) in showing no effect of changing the visual features of items between study and test on rereading times. The finding that reading times for unrelated items were unaffected by this manipulation appears to be in contrast to the finding reported by Masson (1986, Experiment 3) that

Table 1
Mean Reading Times for Study and Test Trials for Experiments 1–5

Experiment	Type of Triplet	Grouping	Reading Time				
			Study		Test		
			Same	Different	Same	Different	New
1*	Related		(7.72)		1.97	2.09	3.32
	Unrelated		(13.95)		2.32	2.53	3.58
2	Related		7.36	6.58	3.45	3.64	5.26
	Unrelated		14.10	13.81	6.62	6.81	9.69
3	Unrelated		11.92	11.11	6.58	6.87	10.00
4	Unrelated		15.26	15.51	6.29	6.82	9.98
5	Unrelated	same	9.60	8.14	4.44	4.73	6.46
		different	9.31	9.01	5.17	5.24	7.14

*The raw data for the study trial reading times in Experiment 1 were lost. The values in parentheses are combined over same and different formats.

unrelated items are affected by changing the visual features. However, one potentially important difference between our study and Masson's study was that our test trial included only a single word from the studied triplets, whereas Masson presented the entire triplet at test. Although it seemed reasonable to expect that presenting single items at test might promote specific perceptual processing effects (Horton & Nash, 1990; Roediger et al., 1989), Levy and her colleagues (Levy & Kirsner, 1989; Levy, Masson, & Zoubek, 1991) have suggested an alternative explanation. They indicate that perceptual specificity effects from prior reading of meaningful passages do not appear when isolated words are the test units. Thus, in the present context, if subjects developed associations (either perceptual or conceptual) among the members of the triplets during the study trial, presenting individual members of the triplets at test might not recruit the episodic representations and therefore perceptual specificity effects might not be expected. Although the conclusions of Levy and her colleagues were based on reading of normal text, we decided to resolve this concern directly in Experiment 2. A critical difference in Experiments 1 and 2 was that the entire study triplet was presented at test in Experiment 2.

EXPERIMENT 2

Method

Subjects. Thirty-six undergraduate volunteers were tested. All subjects satisfied the scoring criterion of at least 6 out of 10 triplets read correctly on both the study and the test trials.

Design and Materials. A 3×2 repeated measures factorial design was used. The example and practice items were identical to those from Experiment 1. A new set of critical experimental materials was selected, because the frequency of the words used in the previous study was much lower than the frequency of the words used by Masson (1986). Because of the restriction in Experiment 1 that we select nine words from each category, the final pool of experimental words had a relatively low frequency count. This likely contributed to the high rate of reading errors. For Experiment 2, three words were selected from each of 36 conceptual categories (Battig & Montague, 1969; Horton, 1983). These words were 4 to 8 letters in length and had an average frequency of 76 occurrences per million (Kučera & Francis, 1967). A matched set of unrelated words was also selected. These words, 4 to 8 letters in length, had

an average frequency of 77 occurrences per million, and each began with the same first letter as did the corresponding related word. All triplets appeared equally often in the same format, in the different format, and in new conditions. The words within the test triplet always appeared in the same order as in the study triplet.

Procedure. The subjects were given instructions similar to those of Experiment 1, with appropriate modifications to take into account the fact that the triplets were typed in standard IBM Courier font (10 point) and presented on slides. A keypress by the experimenter resulted in offset of the slide and initiated a 3-sec blank interval prior to presentation of the next slide.

Results

Study trial. The data appear in Table 1. Analysis of mean reading times on the study trial revealed faster reading of the related than of the unrelated triplets [$F(1,105) = 90.81$, $MS_e = 19.34$]. Neither the effect of format nor the interaction was reliable (both F s < 1).

Test trial. Analysis of mean reading times on the test trial revealed reliable effects for type of triplet [$F(1,175) = 96.15$, $MS_e = 7.24$] and format [$F(2,175) = 18.28$]. The interaction of type of triplet and format was not reliable [$F(2,175) = 1.31$]. The effect of format was attributable to the new triplets at test, as indicated by a separate analysis including only studied triplets. This analysis revealed faster reading of related than of unrelated triplets [$F(1,105) = 130.81$, $MS_e = 2.77$], but no effect of either format or the interaction (both F s < 1).

Discussion

The critical prediction in Experiment 2 was that unrelated triplets would be read faster on the test trial when presented in the same format as at study than when they were presented in the different format. By contrast, it was expected that related triplets would show no effect of the format manipulation. Test trial reading times revealed no effect of format on either unrelated or related triplets, thereby replicating the results of Experiment 1. It appears that testing single words in Experiment 1 rather than triplets was not the critical factor in the failure to find evidence of specific perceptual transfer.

Another potentially important difference between Masson's (1986) study and our second experiment was that we presented related and unrelated triplets through-

out the study and test trials, whereas Masson presented only unrelated triplets. Presenting related triplets may invite subjects to focus on conceptual information during the study and test trials (Horton, 1989). This conceptual information may facilitate reading of all triplets, and thereby minimize specific perceptual transfer effects. The use of conceptual information could also account for the much faster reading times for related than for unrelated triplets during the study trial. Although it is not obvious that subjects can avoid careful analysis of the perceptual information for unrelated triplets when they are spatially transformed, we decided to repeat the experiment, using only unrelated triplets. Also, to increase the similarity with Masson's work, we used his materials.

EXPERIMENT 3

Method

Seventeen subjects participated in the experiment for bonus credit in an introductory psychology course. All subjects satisfied the scoring criterion noted previously. The only variable in the study was the format of the triplet at test—same format, different format, or new triplets.

With the exception of 3 words that we replaced, the words were those used by Masson (1986, Experiment 3). The 180 critical and 6 practice words were 5 to 7 letters in length and had a mean frequency of 225 occurrences per million (Kučera & Francis, 1967). The words were randomly arranged into triplets, with the restriction that obviously related words were assigned to different triplets. The test triplets were identical to the study triplets, in terms of both membership and order of words. Forty triplets were presented during the study trial, and all 60 triplets were presented during the test trial. The study and test trials were presented by an IBM-compatible personal computer driving a TTX video monitor. The default font was used, with the exception that certain letters were modified minimally in order to increase their discriminability and to decrease reading errors. For example, the uppercase *I* and the lowercase *l* were modified by changing the lengths of the lines at the top and bottom of the letters. In all other regards, the experiment was identical to Experiment 2.

Results

Study trial. The data appear in Table 1. The analysis indicated no reliable effect of format on mean study trial reading times [$F(1,16) = 1.18$, $MS_e = 4.80$].

Test trial. Analysis of the mean test trial reading times revealed a reliable effect of format [$F(2,32) = 24.23$, $MS_e = 2.52$], reflecting the slower reading times for new triplets. This interpretation was supported by a separate analysis of the reading times for triplets in the same- and different-format conditions. There was no reliable difference in mean reading times for the same- and different-format conditions [$F(1,16) = 1.60$, $MS_e = 0.47$].

Discussion

The results of Experiment 3 failed to replicate those of Masson (1986, Experiment 3). It appears that including related triplets in the testing sequence was not a critical factor in the failure to find evidence of specific perceptual transfer in Experiment 2. Experiments 4 and 5 were designed to replicate other features of Masson's (1986)

work, in order to determine whether they might be critical to the finding of specific perceptual transfer.

One notable difference between our research and that of Masson was the format of the display. In all three of our studies, the materials were presented in a very familiar and easy-to-read font either on a computer screen or on slides, whereas Masson presented his materials on an Apple II+, using an 80-column video card. The 80-column display is somewhat more difficult to read in terms of the legibility of the individual characters, as is evidenced by the reading time required by Masson's subjects ($M = 13.20$ sec) during the study phase in comparison with that required by our subjects in Experiment 3 using identical materials ($M = 11.52$ sec). In Experiment 4, we increased the difficulty of the reading task by presenting the triplets in a font that was more difficult to read. Increasing the uniqueness of the perceptual details might be critical to finding perceptual specificity effects (Graf & Ryan, 1990; Jacoby & Hayman, 1987).

EXPERIMENT 4

Method

Thirty-six undergraduate volunteers were tested individually. All subjects satisfied the scoring criterion. The materials were identical to those used in Experiment 3. The triplets were presented on slides, as in Experiment 2. The items were printed in WordPerfect Version 5.0 "Shadow" font on a Hewlett-Packard LaserJet III. In addition, each letter was mirror imaged on the y-axis.

Results

Study trial. The data appear in Table 1. The shadow font had the desired effect of slowing reading times. Overall, the mean reading time was 15.38 sec. There was no difference in mean reading times for triplets in the same- and different-format conditions [$F(1,35) < 1$, $MS_e = 24.65$].

Test trial. Analysis of mean test trial reading times revealed a reliable effect of format [$F(2,70) = 42.27$, $MS_e = 3.38$]. Excluding the new triplets on the test trial from the analysis still resulted in an effect of format that approached significance [$F(1,35) = 3.68$, $MS_e = 1.34$, $p < .07$], indicating somewhat faster reading of triplets presented in the same format at study and test.

Discussion

These results provide the first evidence in support of the data reported by Masson (1986, Experiment 3), although the effects were still somewhat modest, even with the relatively large number of subjects tested. It appeared that the distinctive visual format of the letters might be critical to the finding of perceptual specificity effects. We will take up this issue in more detail later.

EXPERIMENT 5

In Experiment 5, we considered one further aspect of Masson's (1986) procedure. In other research cited previ-

ously, faster rereading of spatially transformed textual materials has been attributed to memory for conceptual processing carried out during the study trial. A notable feature of most of these experiments was that the sentences were identical on the study and test trials. Similarly, subjects in Experiments 2–4 reported here saw all previously studied words in the same groupings on the test. By presenting all studied words in the same groupings at test, we might have induced our subjects to exploit their memory for conceptual associations among members of the triplets while trying to reread the triplets on the test, even though the words were nominally unrelated. Such a strategy would likely have reduced the reliance on perceptual information and thereby minimized the potential for finding evidence of specific perceptual transfer effects. Masson's subjects would have been less likely to engage in this strategy because, as noted previously, half of the previously studied words were presented in the same groupings at test and half were rearranged into new groupings.

In Experiment 5, we assessed the role of this factor by presenting one group of subjects with all studied words in their original groupings on the test trial and a second group with all studied words in new groupings. If the use of conceptual associations among members of a triplet restricts perceptual transfer in this task, then it would be expected that subjects presented with the same groupings at study and test would be less likely to show evidence of specific perceptual processing effects than subjects presented with different groupings at study and test. The critical prediction, then, was that there would be an interaction between the grouping and format manipulations.

Method

Twenty-four undergraduate volunteers were randomly assigned to each of two groups, defined by the type of test groupings. All subjects satisfied the scoring criterion. The subjects in the same-grouping condition were treated exactly as the subjects in Experiment 3, in that previously studied words were presented in the same triplets, and in the same order, on the test trial. The subjects in the different-grouping condition were always presented the previously studied words in new triplets at test. The new triplets were formed by taking one word from each of three different study triplets. Three restrictions were imposed on the selection and ordering of members of the new triplets, in order to minimize the utility of any strategies related to the organization of the new triplets. First, pairing of any two words from different study triplets restricted against pairing of any other members of the same two study triplets in other test triplets. Second, one word from each of the three positions in the study triplets was included in each new triplet. Finally, depending on the position of each word in its study triplet, there were six possible orders of members of the test triplet. Each of these orders was used approximately equally often. The uppercase/lowercase format for each word was determined by the format of the word on the study trial. In all other regards, the experiment was identical to Experiment 3, except that only 10 rather than 20 new triplets appeared on the test trial, and all materials were presented on slides.

Results

Study trial. The data appear in Table 1. Analysis of the mean study trial reading times revealed no main ef-

fect of grouping [$F(1,46) < 1$, $MS_e = 34.27$] or format [$F(1,46) = 2.40$, $MS_e = 7.68$] or interaction of these two variables [$F(1,46) = 1.04$].

Test trial. Analysis of the mean test trial reading times revealed no effect of grouping [$F(1,46) = 1.86$, $MS_e = 7.96$]. There was a reliable effect of format [$F(2,92) = 38.77$, $MS_e = 1.51$], but no interaction ($F < 1$). New triplets on the test trial contributed substantially to the effect of format, as indicated by a second analysis excluding these items. This analysis revealed no effect of format [$F(1,46) = 1.52$, $MS_e = 0.51$]. This second analysis also revealed a marginally reliable effect of grouping [$F(1,46) = 3.02$, $MS_e = 3.06$, $p < .09$], but no interaction of grouping and format [$F(1,46) < 1$]. This second analysis shows that subjects in the same-grouping condition showed a tendency to read the triplets faster than subjects in the different-grouping condition.

Discussion

The tendency of subjects in the same-grouping condition to show faster reading times on the test trial than did subjects in the different-grouping condition is consistent with the hypothesis that the former group of subjects benefited from conceptual associations among members gained during the processing of the triplets on the study trial. An alternative interpretation of this result is that it is due to perceptual processing effects associated with repeating the same words in the same order on the test trial (i.e., perceptual effects operating on the triplet as a whole). Such a conclusion would also seem to require that subjects in the same-grouping condition would read triplets faster in the same than in the different format, but there was no evidence of this. Therefore, the evidence does not support this alternative interpretation. We cannot, however, rule out the possibility that subjects in the different-grouping condition were suffering perceptual-level interference, rather than subjects in the same-grouping condition experiencing conceptual-level facilitation.

The critical prediction in Experiment 5 was an interaction between grouping condition and format. If subjects in the same-grouping condition were more likely to use their memory for the conceptual associations among members of a triplet than to use their memory for perceptual processing, in comparison with subjects in the different-grouping condition, then the format manipulation should have relatively less of an effect in the same-grouping condition than in the different-grouping condition. This interaction failed to materialize, indicating that the lack of a main effect of format applied equally to the same- and different-grouping conditions. We interpret this result as evidence that our manipulation of perceptual information does not affect rereading times for the word triplets beyond that conferred by practice (Tardif & Craik, 1989).

GENERAL DISCUSSION

Previous research has yielded conflicting evidence of specific perceptual transfer in the task of reading spa-

tially transformed materials. The present research was designed initially to assess the hypothesis that the conflicting findings were attributable to the different types of materials used by various researchers. Studies that have revealed no reliable evidence of specific perceptual transfer in this task have typically used sentences or textual material, whereas Masson's (1986, Experiment 3) work showing evidence of specific perceptual transfer used individual words or groups of unrelated words. We attempted to bridge the gap by including related and unrelated groups of words in our first two studies, but we found no evidence of specific perceptual transfer in either study. When we included only unrelated groups of words, we also failed to find evidence of specific perceptual transfer, except under conditions in which the quality of the perceptual display was reduced markedly (Experiment 4). The latter result is consistent with results of previous studies showing evidence of specific perceptual transfer in this task under similar conditions (Graf & Ryan, 1990; Jacoby & Hayman, 1987; Masson, 1986).

Our failure to replicate Masson's (1986) findings under a variety of experimental conditions attests to the fragile status of the perceptual specificity effect in reading spatially transformed materials, at least as it relates to changes in font. Richardson-Klavehn and Bjork (1988) noted a consistent trend toward greater transfer on this task when font was identical across the study and test trials than when they were different, although this trend has never been reliable in studies in which other influences have been eliminated (e.g., Horton, 1985; Levy & Kirsner, 1989; Tardif & Craik, 1989). The data we have presented here show the same pattern, but again the differences between the same- and different-format conditions were not reliable, despite the relatively large numbers of subjects in some of the experiments.

The fragile status of the perceptual specificity effect in the reading of spatially transformed materials is further evidenced by an evaluation of the statistical effect size for the alternating-case format variable. A summary of the relevant statistics for Experiments 2–5 appears in Table 2. The delta statistic (Cohen, 1977; May, Masson, & Hunter, 1990) shows for each study a small effect of the format variable (Cohen, 1977). The same conclusion holds in a combined analysis of all studies in which unrelated triplets were presented at test (Experiments 2–5), even though this analysis revealed a reliable effect of the format manipulation [$F(1,136) = 5.31$, $MS_e = 1.04$, $p = .023$]. The statistical reliability of this effect would appear to be attributable to the large number of subjects included in the analysis, despite the small effect size. It is also notable that these effect sizes are consistently smaller than the effect size of 0.385 found by Masson (1986, Experiment 3; personal communication, 1994).

Studies with other implicit memory tasks have also failed to provide consistently reliable evidence of perceptual specificity effects due to manipulations of font and case. Roediger and McDermott (1993) have noted

Table 2
Statistical Effect Size (Delta) and Power for the Alternating-Case Format Manipulation for Unrelated Triplets in Experiments 2–5 (Based on May, Masson, & Hunter, 1990)

Experiment	Effect Size	Power*
2	.059	
3	.234	.25
4	.232	.57
5	.312	.95
2–5 (combined)	.134	.72

*Power estimates are presented by May et al. (1990) for statistical effect sizes of 1.00 and greater. The power associated with an effect size of .059 is less than .17.

that changes in font have relatively little effect on most implicit priming measures, although other manipulations of perceptual information (e.g., modality changes) often have reliable effects (e.g., Blaxton, 1989; Jacoby & Dallas, 1981).² While Roediger and McDermott suggest that the "findings with regard to alterations in typography are quite messy," we would submit that there is at least some suggestion of a pattern to the data. This pattern follows their distinction between perceptual and conceptual implicit tests.

Overall, conceptual implicit tests appear to show little or no evidence of effects of typography changes. This describes the results of studies using the task of rereading spatially transformed text (e.g., Horton, 1985; Levy & Kirsner, 1989; Tardif & Craik, 1989), along with the data reported by Blaxton (1989) in which subjects answered general knowledge questions. In a variation on the standard word fragment completion task, we have also reported no effect of a case manipulation on priming when the test fragment was presented in the context of a meaningful sentence (Horton & Nash, 1990). On the same task, depth of processing had a strong effect, parallel to that seen on most explicit tests. The common feature of all these tasks is that they are primarily conceptual implicit tasks.

Perceptual implicit tasks, however, reveal some mercurial evidence of effects of font (and case) manipulations. For example, Blaxton (1989), Madigan, McDowd, and Murphy (1991), and Roediger and Blaxton (1987) all reported some evidence of perceptual specificity associated with typography changes on traditional word fragment completion tasks, but Rajaram and Roediger (1993) found no evidence of a priming advantage for the same typography condition over the different typography condition.³ On the perceptual identification test, some evidence has also been reported that changes in typefont (and case) reduce priming (Feustel, Shiffrin, & Salasoo, 1983; Graf & Ryan, 1990; Jacoby & Hayman, 1987), although there are contradictory findings here also (Clarke & Morton, 1983; Levy & Kirsner, 1989; Rajaram & Roediger, 1993). In addition, some of the findings of these effects on the perceptual identification task have only occurred through higher order inter-

actions or analyses not reported in other papers. Overall, then, perceptual specificity effects associated with font and case are very rare on conceptual implicit tests but do appear, albeit inconsistently, on perceptual implicit tests.

A notable feature of our data is that typography effects appear to be enhanced when an unfamiliar or unusual font is used. Graf and Ryan (1990) and Jacoby and Hayman (1987) reported similar effects on a perceptual identification task. Graf and Ryan offered an interpretation that may account for this somewhat stronger evidence of perceptual specificity when an unfamiliar font is used. Their account is a variation on the proceduralist model described by Kolers (e.g., Kolers & Roediger, 1984), in which the procedures used to encode information are the basis for the memorial representation of an event. While Kolers emphasized the perceptual components of these procedures (though not to the exclusion of other components; cf. Kolers, 1979), Graf and Ryan incorporated other components in the representation, including "sensory/perceptual, phonemic, semantic, [and] other word attributes" (p. 988). Thus, the subject's response to an unusual or difficult-to-read stimulus may include extensive processing of information other than, or in addition to, the perceptual details of the event (see also Graf & Levy, 1984; Horton, 1985; Levy, 1993; Tardif & Craik, 1989). To the extent that this additional processing results in a distinctive representation of the event (Hunt & Elliott, 1980; Jacoby & Craik, 1979), memory for the event will be enhanced if the same information is reactivated at test. As Graf and Ryan have suggested, reading of even spatially transformed materials presented in a familiar font may not result in a sufficiently distinctive perceptual representation of the material, since university subjects have had extensive experience with the font. Thus, the processing strategies that they use, even when the material is presented in a spatial transformation, may emphasize other components of the encoding procedures. By contrast, reading the same material in an unfamiliar font (e.g., our Shadow font, Graf & Ryan's pudgy font, or Masson's 80-character Apple font) may yield a sufficiently distinctive perceptual representation for perceptual specificity effects to appear. While Kolers (1979) argued that spatial transformation of textual material was sufficient to produce "a deeper and richer [perceptual] representation" (p. 384), this may not be adequate to yield reliably faster rereading times unless the perceptual representation is also distinctive.

Other factors may also be critical in evidencing perceptual specificity effects on memory measures. Ether-ton and Logan (cited in Logan, 1991) and Jacoby, Toth, and Yonelinas (1993, Experiment 2) found no evidence of perceptual specificity when they manipulated the color of target items between study and test on a lexical decision task and a word stem completion task, respectively; however, Ether-ton and Logan did report a small but reliable effect of this manipulation after subjects had

been exposed to the target items 16 times. Using reading speed as the critical measure, Levy, Di Persio, and Hollingshead (1992, Experiment 2) reported no effect of changing font in the middle of a paragraph when subjects read a paragraph the first time, but they did find a numerically small but statistically reliable effect of this manipulation after subjects had been exposed to the paragraph three times without font changes. Thus, multiple identical exposures to stimuli within the experimental context may be another sufficient condition for perceptual specificity effects to obtain.

Jacoby, Levy, and Steinbach (1992) suggested another factor. In their study, subjects either read questions aloud or generated answers to the questions at a semantic level. When the task was to read aloud, Jacoby et al. (1992) found no effect on reading speed of changing the font when the question was presented a second time. However, when the task was to answer the question, they found a small but reliable effect of changing the font on the second presentation of the question. They concluded that focusing subjects' attention on the task of simply reading material printed in normal orientation might orient subjects to a "word-by-word focus" (p. 17), and that this type of orientation was insensitive to changes in perceptual details. By contrast, perceptual specificity effects appeared when subjects focused on the task of generating a meaningful response to the question because, as they suggested, the perceptual details were relied on more when the task of reading itself was automatic, or "when reading [was] backgrounded in service of gaining meaning" (p. 21).

Overall, the data appear to suggest that perceptual specificity effects due to changes in font may occur, on the one hand, when the task is the reading aloud of transformed materials presented in a very distinctive font (Graf & Ryan, 1990; the present research) or, on the other hand, when the material is very familiar (Ether-ton & Logan, cited in Logan, 1991; Levy et al., 1992) or the task of reading is automatic (Jacoby et al., 1992). It appears that these two situations may represent the extremes of perceptual proficiency and thus that the source of the effects may reflect different processing mechanisms or strategies.

Since our work focused only on the condition of visually unfamiliar stimuli, we cannot be more explicit about the nature of the critical mechanisms that determine these effects. Indeed, although we have interpreted our findings in the context of Graf and Ryan's (1990) ideas about the role of distinctiveness in perceptual specificity effects, the present research was not designed to address their hypothesis directly. Therefore, our research does not provide definitive evidence for this hypothesis. Nonetheless, our data are clearly consistent with some aspects of their ideas. More direct tests of their hypothesis are in order—particularly given the range of presentation styles that are now possible with pixel-by-pixel character definition for computerized display. Since different researchers use different equipment and software

to generate materials, it is important to know whether features of the stimulus display, including the familiarity of the font, are critical to finding perceptual specificity effects.

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NOTES

1. Tardif and Craik (1989) noted that the results of each of the other studies reported by Masson (1986) could be interpreted as evidence of either specific perceptual transfer or general practice effects associated with exposure to the particular transformation. Thus, only the results of the third experiment in Masson's paper will be considered here.

2. It is notable, however, that modality effects do not seem to be symmetrical. Whereas priming on visual tests is almost invariably less following an auditory study trial than following a visual study trial, priming on auditory tests shows little evidence of modality specificity (May, 1992; McClelland & Pring, 1991).

3. It should be pointed out that Madigan et al. (1991) do not report statistical comparisons of the relevant conditions. Completion rates in the same-case and different-case conditions averaged 41.4% and 38.5%, respectively. The baseline rate was 29.6%.

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