Form-Specific Visual Priming in the Left and Right Hemispheres

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Word fragment completion performance was examined for items that were presented in the same or different letter case at study and test. During the study phase words and nonwords were presented at central fixation, then during the test phase a divided visual field technique was used in which word fragments were presented briefly to the right hemisphere (left visual field) or the left hemisphere (right visual field). Previous research using the word stem completion task indicated that only the right hemisphere was sensitive to case changes in words from study to test. In contrast, the current results indicate that in the fragment completion task the priming effects for the test items presented to either hemisphere were greater when the fragments were in the same compared to different letter case at study and test. These results indicate that both hemispheres are capable of supporting form-specific visual implicit memory. © 2001 Academic Press

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In explicit memory tests, such as recognition and free recall, subjects are instructed to actively remember previous events, whereas in implicit memory tests, subjects are not instructed to explicitly use memory. For example, in a word stem completion test, subjects are first exposed to a series of words (e.g. SALMON) and are then shown word stems, such as SAL__, and are instructed to complete the stem with the first word that comes to mind. Subjects are more likely to complete a stem with a word if it was previously studied (i.e., exhibit priming effects), even if they do not consciously recollect having studied that word. Moreover, amnesic patients who perform more poorly than normal subjects on tests of explicit memory, perform normally on tests of implicit memory (e.g., Schacter, Chiu, & Ochsner, 1993), indicating that implicit and explicit forms of memory rely on partially distinct neuroanatomical substrates. These two forms of memory also exhibit distinct functional properties. For example, changes in the perceptual format of words between study and test, such as from uppercase letters to lowercase letters or from auditory to visual presentation, greatly reduces the priming effects observed in implicit tests such as stem completion

(for reviews see Roediger & McDermott, 1993; Schacter et al., 1993). In contrast, similar changes in perceptual format often do not affect performance on explicit tests like recognition and recall.

The sensitivity of implicit memory performance to changes in perceptual format has been taken as evidence that these tests rely on form-specific sensory memory processes or systems (Jacoby, 1983; Roediger & Blaxton, 1987; Schacter, 1992). However, significant priming effects are observed even when the study and test format changes, indicating that implicit memory tasks also rely in part on abstract form-independent memory processes, such as phonological, lexical, or semantic processes (e.g., Curran, Schacter, & Galluccio, 1999; Rueckl & Mathew, 1999).

Several studies suggest that the form-specific component of visual implicit memory may be supported primarily by the right hemisphere, whereas the abstract component can be supported equally by both hemispheres (e.g., Marsolek, Kosslyn, & Squire, 1992; Marsolek & Hudson, 1999). For example, Marsolek et al. (1992) used a divided visual field technique to examine hemispheric contributions to stem completion priming. Words were studied centrally either in upper- or lowercase letters, then upper- and lowercase word stems were presented briefly to either the left visual field or right visual field. Both hemispheres exhibited priming effects (i.e., critical words were more likely to be used to complete the stems if they had appeared in the study list than if they had not). However, only the right hemisphere was sensitive to case changes in stimuli. That is, the two hemispheres showed significant and equal effects of priming when the stem was in a different case from the study word, but the right hemisphere showed additional priming if the stem was in the same case. The authors concluded that an abstract visual form system functions equally well in both hemispheres, but that, in addition, a form-specific visual form system operates in the right hemisphere.

The laterality effects appear to be quite robust with the stem completion task (e.g., Marsolek et al., 1992; Marsolek & Hudson, 1999). However, these effects are not generally observed with another commonly used implicit memory test; the perceptual identification task (e.g., Burgund & Marsolek, 1997; Koivisto, 1995). For example, Koivisto (1995) used a task in which test words were briefly presented to one or the other hemisphere and subjects were required to name the words out loud. Results indicated that *both* hemispheres showed significantly greater identification of words that were studied and subsequently presented in the same case. One potential reason for the discrepancy between the hemispheric effects seen in these two tasks is that the perceptual identification task may rely less on purely visual memory processes than the stem completion test. Indirect support for this comes from the finding that although case changes generally influence stem completion performance, perceptual identification performance is sometimes not sensitive to such visual form changes (e.g., Rajaram & Roediger, 1993). However, in the divided visual field studies of perceptual identification described above, robust effects of changing letter case were observed in both hemispheres, indicating that the task was sensitive to visual form changes. Thus, is it not clear why the hemispheric effects are observed in some tasks and not others.

To further examine the hemispheric effects, we examined form-specific priming in another common implicit memory test; word fragment completion. Words and nonwords were studied centrally, then subjects were presented with word fragments (e.g., _ALA_ or L_C_L for SALAD and LOCAL, respectively) to either their left or right visual fields and instructed to complete them with the first word that came to mind. The letter case was varied in order to examine the effects of changing the visual form between study and test. The fragment completion test has been extensively studied and is known to be sensitive to visual format manipulations (e.g., see Roediger & McDermott, 1993). The results of the current study will be informative

in assessing the generalizability of the hemispheric effects observed in stem completion. If the effects are observed across a variety of implicit tests then this has implications for the current theoretical accounts of implicit memory in the sense that it would indicate that different hemispheres play different roles in this form of memory. On the other hand, if the hemispheric effects are only consistently observed with one type of test, this would indicate that these effects are not a general property of implicit memory, but rather a property of a process that is specific to that one memory task.

METHOD

Subjects

Twenty-four undergraduates at the University of California participated as subjects for course extra credit. All subjects were right-handed, native speakers of English and had normal or corrected-to-normal vision. Hand preference was determined using a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971). Each of the 12 items in the inventory was scored from 1 to 5, where an item score of 5 indicates a strong right-hand preference and an item score of 1 indicates a strong left-hand preference. A total score was computed, which could range from 5 to 60. Only subjects who reported being right handed and who had a total score greater that 46 on the inventory were included in the experiment. The average handedness score across the 24 subjects was 55.2.

Materials

One hundred eighty common five-letter English nouns, ranging in word frequency from 787 to 100,000, were selected from the Oxford Database Dictionary. Each word formed a symmetrical fragment of the form X_X_X (e.g., O_B_T for ORBIT) or _XXX_ (e.g., _PAS_ for SPASM). Symmetric fragments were used to partially equate the information obtainable from the fragment when it was presented to the left and right visual fields. Each fragment was unique within the stimulus list. A pilot study was conducted with 30 subjects in order to exclude fragments that were never completed by any subject or that were completed by all the subjects. Although the target items were the most common completion for each fragment, alternative completions were also possible for some of the fragments. For example, the target solution for P_P_R was PAPER, but PIPER is an alternative potential solution item. A list of 140 five-letter nonwords was created by randomly selecting five letters at a time such that no five-letter combination formed a word in the English language and no letter appeared in a given five-letter combination more than once.

Procedure

Stimuli were presented in black letters on a white background. Words were written in a bold sans serif font, and each word appeared 22 mm wide × 7 mm high on the screen. Subjects viewed the computer screen from a distance of 57 cm, thus each word subtended 2.2° of visual arc.

In the study phase, a randomized mixture of 140 words and 140 nonwords was presented one at a time, and subjects were required to indicate whether each item was a word or nonword. Half of the words and half of the nonwords were presented in uppercase, the other half in lowercase. This list was presented twice, in a different order each time. Subjects were instructed to focus on the fixation cross that appeared at the center of the screen. Each of the 560 trials began with a central fixation cross appearing for 350 ms, which was replaced by either a word or nonword for 500 ms before the screen went blank (white). Subjects pressed the ''?'' key if the string formed a word and the ''z'' key if the string formed a nonword. If the subject responded incorrectly, they heard an error tone. After each response, there was a 2000-ms interval before the next trial was initiated. The brief item presentation duration, combined with the relatively shallow level of encoding, was expected to support visual priming while minimizing explicit memory for the study items.

In the test phase, word fragments were presented one at a time and subjects were instructed to complete each fragment with the first word that came to mind. As in the study phase, subjects were asked to focus their attention on a fixation cross. Each of the 280 test trials began with a central fixation cross appearing for 750 ms. A word fragment was then presented on the screen for 165 ms. Half of the fragments were presented to the left of fixation (such that the last letter ended 12 mm—or 1.2° of visual arc—from the fixation point) and half were presented to the right of fixation (such that the first letter began 12 mm

from the fixation point). In order to reduce eye movements toward the presented fragment, a row of ampersands was always displayed to the opposite side in the same position. Over the course of the test trials, there were 90 word fragments presented to the left and 90 to the right, 30 of each of these 90 could only be completed by new words (i.e., not presented during the study phase), 15 in uppercase and 15 in lowercase. The remaining 60 fragments on each side could be completed by words that had been presented in the study phase—15 in each of the four possible study-test letter-case conditions. Assignment of fragments to the resulting 12 conditions was counterbalanced so that, across subjects, each word appeared in each condition twice. Subjects had 6 s to verbally report the word that would fit the fragment to the experimenter, who then recorded the response. The test fragments were presented in a pseudorandom order, with restrictions on the number of runs (i.e., fragments could not appear on the same side for more than three trials in a row) and number of sequential alternations was restricted to two (e.g., left right left right). In addition, the quarter of the study list in which a word appeared was the same as the quarter of the test list in which its corresponding fragment appeared. This resulted in each primed fragment having approximately the same retention interval.

RESULTS

The average proportion of correct fragment completions in each experimental condition are presented in Table 1. Priming effects were measured by subtracting the proportion of unprimed items completed from the proportion of primed items completed in each condition, and the results were analyzed using a three-way analysis of variance. The letter case of the word fragments (upper- vs lowercase letters), hemisphere of test presentation (left vs right hemisphere), and case matching at study and test (same vs different case) were all within-subjects variables. The priming effects were significantly greater for items presented in the same case at study and test (23.5%) compared to items that were in a different case at study and test [19.7%, $F(1, 23) = 5.190, p < .05$], indicating that form-specific memory was observed in the fragment completion test. Lowercase fragments were associated with greater priming effects (24.4%) than were upper case fragments [18.5%, $F(1, 23) = 30.459, p < .05$], and fragments presented to the left hemisphere (26.9%) led to greater priming effects than those presented to the right hemisphere [16.3%, $F(1, 23) = 14.544, p < .05$]. Most importantly, there was no evidence for a significant interaction between case matching (same vs different case) and presentation hemisphere, indicating that the form-specific priming effects were equivalent in both hemispheres ($p = .217$). No other interactions were significant.

The critical results are illustrated in Fig. 1. Given that none of the interactions were significant and the specific letter case of the items was not of direct interest, the data was averaged over the letter case conditions. The figure shows that performance on the primed same-case items was greater than the primed different-case

TABLE 1
Mean Proportions of Correct Completions for Fragments Presented to the Left and Right Hemispheres as a Function of Study and Test Letter Case

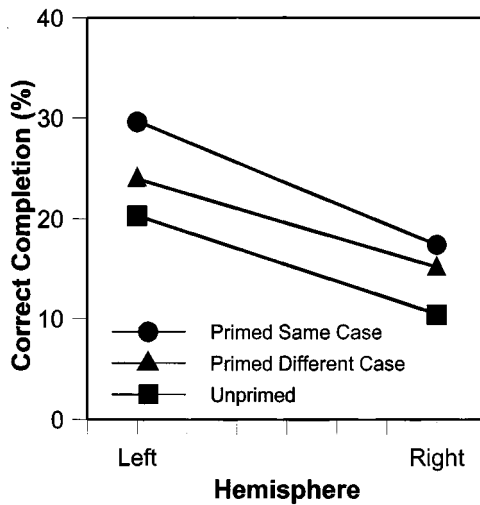|	Test case					
	Upper			Lower		
	Study case			Study case		
	Upper	Lower	New	Upper	Lower	New
Hemisphere						
Left	.269	.208	.178	.272	.314	.208
Right	.144	.119	.081	.186	.203	.117

FIG. 1. Mean correct fragment completion rates as a function of the hemisphere of fragment presentation and of whether the completions had been shown during the study phase (Primed) on not (Unprimed), and, if primed, whether the prime had been in the same or different case as the fragment.

items in both the right and left hemispheres. There was no evidence that this difference was greater for the right hemisphere than the left, as would have been expected on the basis of previous stem completion studies. In fact, numerically, the same-case advantage was slightly larger in the left hemisphere than in the right.

The new item completion rate was greater for items presented to the left hemisphere than items presented to the right hemisphere. In order to determine if the difference in new item completion rates differentially influenced the priming effects in the two hemispheres, performance was reanalyzed using proportional priming scores (the absolute priming effects divided by the proportion of new items completed). As with the original analysis, the critical interaction (same vs different study-test case) by hemisphere was not significant [$F(1, 23) = 2.29; p < .1441$], suggesting that the differences in new item completion rates did not influence the pattern of priming effects. An additional analysis indicated that the absolute priming effects were not correlated with baseline performance [$R^2(22) = .021$], providing further evidence that the observed pattern of priming effects was not produced by differences in new item performance in the two hemispheres.

DISCUSSION

In the current experiment, fragment completion priming was greater when the letter case was the same at study and test than when letter case changed, indicating that the fragment completion test exhibited form-specific priming effects. Most importantly, a similar same-case advantage was observed in both hemispheres, indicating that both the right and left hemispheres support form-specific priming in the fragment completion task. Thus, there was no evidence that the form-specific priming observed in the fragment completion test was greater in the right than left hemisphere.

These results are consistent with those reported under standard perceptual identification test conditions (e.g., Koivisto, 1995; Burgund & Marsolek, 1997). However, our results contrast with those found with the stem completion task (e.g., Marsolek et al., 1992; Marsolek & Hudson, 1999), where the same-case advantage is found in the right hemisphere but not the left. Thus, the lateralization effects seen in the stem

completion test do not generalize to perceptual identification or to fragment completion tests. The results indicate that both hemispheres can support form-specific priming, and the lack of form-specific priming observed in the left hemisphere in the stem completion task is not a general property of implicit memory performance, but rather must reflect the operation of a process that is specific to the stem completion task.

Could the difference in hemispheric effects in the stem completion vs the perceptual identification and fragment completion tests be due to differences in statistical power in those studies? A comparison of those studies suggests not. First, the design and procedures in these different experiments were comparable. Moreover, robust same-case vs different-case effects were observed in the current fragment completion test and in the previous perceptual identification tests. Furthermore, the magnitudes of the case-effects in the fragment completion and perceptual identification studies were comparable to those seen in the stem completion studies.

In conclusion, word fragment priming effects were greater when the letter case was the same at study and test compared to when letter case changed, and these effects were found when words were presented either to the left or the right hemispheres. These results indicate that form-specific priming processes are present in both hemispheres.

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