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PRIMING EFFECTS IN A LETTER-BY-LETTER READER DEPEND UPON ACCESS TO THE WORD FORM SYSTEM*

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Abstract—Several types of cognitive and neuropsychological evidence suggest that priming effects on such implicit memory tests as word identification are mediated by a pre-semantic visual word form system that can operate independently of episodic memory. We investigate priming in a letter-by-letter reader, P.T., whose pattern of performance on neuropsychological tests indicates preservation of the word form system. Experiment 1 revealed robust priming on a word identification test following letter-by-letter study of target words, despite P.T.'s great difficulty in identifying non-studied words. Experiment 2 showed that the priming effect was modality specific whereas Experiment 3 indicated that recall of previously studied words was not modality specific, thus indicating that the observed priming could not be attributed to explicit memory strategies. Experiment 4 revealed no priming of illegal non-words on a letter identification test. The results support the notion that priming on the word identification test depends on access to the word form system.

INTRODUCTION

A GREAT DEAL of recent cognitive and neruropsychological research has been concerned with the phenomenon of direct *priming* [47]. Priming occurs when exposure to words, pictures, or other items facilitates subsequent processing of those items on tasks that do not make explicit reference to the prior study episode, such as word identification [18, 24], stem and fragment completion [10, 48], and lexical decision [35]. Priming is a type of implicit memory [13, 37] in the sense that it can occur independent of any intentional or conscious recollection of the target items or the episodes in which they were encountered [20, 40, 48]. Priming has been dissociated from explicit memory by experimental manipulations that affect the two types of memory differently, by findings of stochastic independence between priming and explicit memory, and by demonstrations that amnesic patients show intact priming despite impaired performance on explicit memory tests (for review and discussion, see [30, 37, 45, 47]).

In contrast to explicit memory, priming on such implicit tests as word identification, stem and fragment completion, and lexical decision occurs independently of any semantic or elaborative encoding at the time of study. Priming is generally as large following non-semantic encoding tasks (e.g. comparing the number of vowels and consonants in a word) as

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it is following semantic encoding tasks (e.g. rating the pleasantness of a word), whereas explicit remembering on recall and recognition tests is considerably higher following semantic than non-semantic study processing ([2, 5, 10, 11, 18] for similar findings with non-verbal materials, see [40]). In addition, priming is highly sensitive to study/test changes in various kinds of surface feature information, including sensory modality [14, 18, 24, 31, 35, 42], pictorial vs verbal format of presentation [22, 25], and under certain conditions, the precise physical appearance of a word ([12, 19, 31] but see [4]). Although not entirely immune to all conceptual or semantic influences [17, 41, 43, 46], the foregoing pattern of results suggests that priming is to a large extent a *pre-semantic* phenomenon: it need not entail semantic processing and is strongly dependent on structural processing of surface feature information.

In a recent conceptualization of priming, SCHACTER [38] see also [40, 47] attempted to link the notion of priming as a pre-semantic phenonmenon with neuropsychological observations of reading disorders that have revealed a sharp dissociation between access to semantic and structural information. Relevant observations were initially reported by SCHWARTZ *et al.* [44] (see also [9, 34], for similar cases). They described a demented patient (W.L.P.) who, despite impaired semantic processing of words was nevertheless able to read aloud both regular and irregular words. The fact that W.L.P. could read *irregular* words (e.g. cough, blood) in the absence of comprehension is particularly important, because it indicates that she was able to gain access to a representation of the visual form of a word without gaining access to semantics. These observations point to the existence of a *visual word form system* [49] that is dedicated to representation and retrieval of information about the form and structure of words, but not their meanings and associative properties. Recent neuroimaging evidence from position emission tomography studies of normal subjects [27] points to a similar conclusion. The visual word form system appears to be one of several subsystems that together form a pre-semantic *perceptual representation system* that handles information about the form and structure of words and objects [38, 40, 47].

In view of the pre-semantic nature of priming, it seems reasonable to hypothesize that the visual word form system plays a crucial role in priming effects on word identification and completion tests [38]. The general idea is that visual processing of a word may either activate a pre-existing representation of the visual form of a word or create a novel and highly specific representation of a word's visual and structural features. The word form representation is held to support priming on identification, completion, and similar tests, and to be distinct from the episodic memory representation that represents multiple features of a word and links its occurrence to a particular episode. This general account is similar in some respects to MORTON'S [24] logogen theory of priming. The major difference is that the present view holds that highly specific, novel word form representations are often involved in priming, whereas in the logogen theory, priming is based solely on the activation of abstract pre-existing representations.

Issues concerning the status of the visual word form system have also arisen in discussions of alexic patients who are characterized by the phenomenon of letter-by-letter reading. Such patients are generally unable to engage in "whole word" reading; but when allowed to read words in a serial, letter-by-letter manner, they are typically able to achieve word identification [25, 49]. Reading time in letter-by-letter readers is strongly affected by word length, and the deficit in whole word reading is observed for all words, regardless of grammatical class, word frequency, concreteness, and so forth [49].

By one account, the deficit in letter-by-letter readers is attributable to damage at the level of the visual word form system. WARRINGTON and SHALLICE [49] proposed that because patients' word form system (which normally supports whole word reading) is dysfunctional, reading is achieved by making use of a preserved *spelling* system, through a process referred to as "reverse spelling": The spelling system is somehow put into a "reverse" mode of operation in order to permit letter-by-letter word identification.

An alternative account was put forward by PATTERSON and KAY [25], who argued that the visual word form system is largely preserved in letter-by-letter readers, and that their deficit lies in a pathological limitation on the capacity to transmit information *in parallel* from letter detectors to the word form system. However, *serial* transmission of information from letter detectors to the word form system is held to be preserved; hence the ability of such patients to achieve word identification through letter-by-letter reading.

There have as yet been no reported investigations of priming in letter-by-letter readers. However, when considered in light of the proposal that the visual word form system mediates priming effects on word identification and similar tasks, the two foregoing hypotheses lead to rather different expectations concerning priming in letter-by-letter readers. On the one hand, if the word form system is inoperative or severely impaired in letter-by-letter readers, we would expect little or no priming following letter-by-letter study of a list of words on a task such as word identification. In view of evidence that the visual word form system has an extrastriate occipital locus [27], and the fact that such occipital areas are typically compromised in letter-by-letter readers [25, 29, 49], there is some basis for predicting weak or absent priming in this type of patient. On the other hand, if the word form system is preserved in such patients, and access to this system can be achieved through serial but not parallel transmission from letter detectors, then robust priming effects should be observed on a word identification or similar task following letter-by-letter study. By this account, occipital lesions of the kind typically found in letter-by-letters readers may produce impaired access to the word form system, rather than a deficit in the word form system itself.

In this article we describe a case of a letter-by-letter reader in which there are neuropsychological grounds on which to argue that the patient's visual word form system is preserved (see description below and case report by [28]). According to the view that priming effects on such tasks as word identification are mediated by the visual word form system, letter-by-letter study of a list of target words should produce robust priming on subsequent word identification performance in our patient. Consistent with these ideas, we report four experiments that document such priming, demonstrate that the observed priming effects are not based on explicit memory strategies, and also show that the locus of priming is at the level of the word form system.

CASE REPORT

A detailed description of patient P.T. is provided elsewhere [28], and we will only summarize the most relevant features of the case here. P.T. is a 63-year-old right-handed woman with 16 years of education who was presented to the Neurology Service in January 1989, complaining of "blurry vision" and an inability to read. Neurological examination revealed an incomplete right homonymous hemianopia, and CT scan showed left temporo-occipital infarction, a typical lesion site for letter-by-letter readers. P.T.'s spontaneous speech was generally fluent and gramatically correct and she achieved maximum scores on the Auditory Verbal Comprehension and Repetition sections of the Western Aphasia Battery [21]. When asked to read aloud, however, she attempted to name each component letter before producing the word and was unable to read unless she resorted to this letter-by-letter strategy. P.T. performed nearly perfectly on tasks that required matching upper and lower case letters to letters typed in the same case, or cross-matching across cases, and was also able to point correctly to visual representations of all letters of the alphabet in response to verbal instructions. However, P.T. had some difficulty in naming the letters of the alphabet (15/26 correct), although her repetition of the letters was flawless.

The crucial feature of P.T.'s neuropsychological profile concerns a dissociation between her reading and spelling performance (Table 1). The most relevant data are provided by a comparison of her abilities to read and spell regular and irregular words, respectively. On a task in which she was required to read 70 regular and 70 irregular content words that were matched for length and frequency, P.T.'s reading of regular words (0.49 correct) and irregular words (0.44) did not differ significantly. Most of her errors (0.87) were attributable to her aforementioned problem with letter naming; that is, she often failed to name all component letters of a word correctly. However, there were also a few errors (0.13) in which she correctly named all the letters but still failed to identify the word. On these occasions she usually responded with words that shared several letters with the target (*aisle* read as *assail*). Phonologically plausible "regularization" errors characteristic of surface dyslexia were never observed [7].

Table 1. Proportion of correct responses by P.T. in reading, written and oral spelling, and recognition of spelled words

	Task			
Word type	Written spelling	Oral spelling	Reading	Recognition of spelled words
Regular	0.93	0.86	0.49	0.99
Irregular	0.47	0.43	0.44	0.93

A markedly different pattern of results was observed in her written and oral spelling performance with the same regular and irregular words. When asked to write to dictation, P.T. spelled correctly 0.93 of regular words but only 0.47 of irregular words. In addition, most of her spelling errors were phonologically plausible (e.g. *circuit* spelled *surkit*). A similar pattern of results was observed on an oral spelling task: P.T. spelled correctly 0.86 of regular words and 0.43 of irregular words. Her errors in oral spelling were also phonologically plausible and highly consistent with her errors in written spelling.

The observed dissociation between reading and spelling performances has important implications for specifying the locus of P.T.'s deficit. If letter-by-letter readers use the process of "reverse spelling" to read [49], then P.T.'s reading and spelling performance ought to have been highly correlated (reading and spelling performance have generally been correlated in previous cases of letter-by-letter reading, which is why the case of P.T. is unique; see [28], for further discussion). Specifically, the "reverse spelling" hypothesis predicts that P.T.'s reading performance—just like her spelling performance—should have been considerably more accurate for regular than irregular words and should have been characterized by phonologically plausible errors, because the same spelling system allegedly underlies both reading and spelling performance. In view of the fact that word regularity had markedly different effects on reading and spelling performance and because the phonologically plausible errors that characterize P.T.'s spelling were not observed in her reading, we reject the hypothesis that P.T.'s reading performance is based on a "reverse spelling" operation. In line with the ideas of PATTERSON and KAY [25], we suggest instead that P.T.'s letter-by-letter reading is based on access to the visual word form system via serial inputs from letter detectors, and that her inability to engage in whole word reading reflects a deficit in parallel transmission from letter detectors to the word form system (it must be noted, however, that the data do not rule out the possibility of a post-word form system locus for P.T.'s impairment; see [8] for relevant data and ideas). Importantly, P.T. performed nearly perfectly on a task which required recognition of words from their oral spelling (Table 1); it has been argued previously that the visual word form or some similar system plays a role in recognition of orally spelled words [7, 28]. The argument that P.T.'s reading performance reflects access to the word form system is also consistent with evidence from other letter-by-letter readers that indicates preservation of the word form system [3, 29].

The foregoing observations are important because they provide an empirical basis for predicting that P.T. should show robust priming on a word identification task. The experiments that test this prediction were carried out between June 1989 and January 1990; P.T.'s condition remained stable during this time.

EXPERIMENT 1

The general strategy that we adopted was to show P.T. a list of common words, allow sufficient time for her to read each word letter-by-letter, and then give brief exposures to studied and non-studied items items on a word identification test in which P.T.'s task was to try to read each word. Priming in this paradigm is indicated by more accurate identification performance for studied than non-studied words. Because the case study format of the present research precludes use of such standard experimental strategies as replication across subjects and counterbalancing of materials across conditions, we attempted to gain information about the reliablity of our results by creating multiple study/test lists and assessing P.T.'s performance in a number of experimental sessions.

Method

Materials, design and procedure. We constructed two main sets of experimental materials, one consisting of five/six-letter words and the other consisting of four-letter words. For both the five/six- and four-letter words, we created three different study/test sets consisting of 32 words each. All words were concrete nouns of medium-to-high frequency in the KUCERA and FRANCIS [23] norms; four-letter words were selected from the PAIVO *et al.* [26] corpus. Individual sets of words were divided into two sublists each consisting of 16 words, that were equated for frequency, and in the case of five/six-letter words, for word length. One of the sublists was randomly designated as the study list; the other sublist appeared only on the word identification test, together with the studied list. Although P.T.'s reading deficit is unaffected by grammatical class, we used only concrete words in the present experiment in order to create a relatively homogeneous set of materials and thereby reduce the possibility of spurious item differences between studied and non-studied sublists.

In standard experiments on priming of word identification in normal subjects, identification performance is generally tested with brief (e.g. 30–60 msec) exposures of studied and non-studied items. In P.T.'s case, however, it is not possible to use such brief exposures. Pilot work indicated that with exposure durations comparable to those used in studies of normal subjects (e.g. 68 msec preceded and followed by a pattern mask), P.T. was unable to report a single letter of any word; moreover, she consistently denied that a word had been presented and typically stated that she saw only "jiggly lines" or "math symbols", referring to the pattern mask. To allow for a reasonable possibility of observing priming, we attempted to find an exposure duration at which P.T. could, without a prior study exposure, reliably identity at least some component letters of a word and occasionally identify the entire word. On the basis of pilot work, we determined that a 500 msec exposure fulfilled these conditions: for five letter words, P.T. identified correctly 0.05–0.10 of exposed words and identified three or more letters for over 0.50 of them. Because non-reading impaired individuals easily identify all words at this exposure duration, it is not possible to obtain meaningful data from control subjects under these conditions. An alternative possibility would be to run control subjects at an exposure duration that produces baseline performance levels that are comparable to the 0.05–0.10 baseline accuracy exhibited by P.T. In order to achieve such low levels of performance, however, extremely brief and heavily masked presentations would have to be used. Such a task would be radically different from the 500 msec unmasked exposure that we used with P.T., and it seems unlikely that anything at all could be concluded by comparing performance on two such disparate tasks. Accordingly, we did not run control subjects in the present set of experiments. We thus cannot address the question of whether P.T. shows entirely *normal* priming; the question that we can attempt to answer, however, concerns whether P.T. shows robust or significant priming.

Each study list consisted of 20 words: two primacy buffers, 16 critical targets, and two recency buffers. Words were presented for study one at a time by a Compaq 386 computer in the center of a Princeton Ultrasync 12 in. monitor; they appeared white against a dark grey background. The first letter of each word was in upper case, the remaining letters in lower case. P.T. was told that her task was to try to read each word. Words remained on the screen for up to 30 sec, until P.T. identified them correctly. As noted earlier, P.T. has some some difficulty with retrieving letter names. When she misidentified a letter name, she was informed of the mistake and attempted again to identify it correctly. If P.T. could not identify a word correctly after 30 sec of exposure, the experimenter stated the correct response and the next word then appeared.

After presentation of a study list, P.T. was instructed concerning the word identification test. She was told that a series of words would be flashed on the screen very quickly, and that she should do her best to try to identify each word, even though it might seem difficult to do so. She was instructed that she should provide a response for each item, and that guessing was allowed. Presentation of each word was preceded by a fixation point in the middle of the screen. Each time the fixation point appeared, P.T. was asked if she was ready for the next word, and when she responded affirmatively, a word was exposed for 500 msec. The first two words on each list were non-critical buffer items. Approximately 2 min intervened between presentation of the final critical study list word and the appearance of the first critical test item. The 16 studied and 16 non-studied critical words appeared in a randomly determined order on the identification task.

Two lists were studied and tested during each of three sessions. There was a break of approx 5–10 min between study/test of the first and second lists during each session.

Results

During the study phase, P.T. was able to identify 0.92 of target words accurately within the allotted 30 sec; the experimenter read aloud the remaining words. An analysis of time to read target words on each study list revealed that for four-letter words, P.T.'s median latencies were 6, 7 and 6 sec for lists 1–3, respectively. For the five/six-letter words, latencies were not recorded for lists 2 and 3 because of experimenter error. For list 1, median latency (13 sec) was considerably longer than was observed for the four-letter words, as would be expected in a letter-by-letter reader.

Table 2. Proportion of words identified correctly from a 500 msec exposure by patient P.T.

	Condition			
	Five/six-letter words		Four-letter words	
List	Studied	Non-studied	Studied	Non-studied
1	0.25	0.06	0.69	0.19
2	0.56	0.06	0.38	0.38
3	0.44	0.06	0.31	0.19
M	0.42	0.06	0.46	0.25

The critical data on word identification performance are presented in Table 2. Consider first the results for the five/six-letter words. Consistent with our pilot observations, P.T.'s baseline identification accuracy for unprimed words was extremely low; she identified only 0.06 of non-studied words correctly on each of the three lists. More importantly, the data also reveal clear and consistent priming: identification accuracy for studied items ranged from 0.25 to 0.56 correct, and there was strong evidence of priming on each of the three lists. Statistical analysis was achieved by collapsing across the three lists and comparing performance on studied and non-studied items with a non-parametric test for comparison between two proportions suggested by BENNETT and FRANKLIN [1]. The Bennett Franklin test revealed that word identification was significantly more accurate for studied than non-studied words ($P<0.01$).

Similar results were obtained with the four-letter words. Consistent with P.T.'s letter-by-letter reading strategy, overall baseline identification accuracy (0.25) was higher for four-letter words than for the five/six-letter words. Strong evidence of priming was observed for lists 1 and 3, whereas no priming was observed for list 2. Collapsed across the three lists, however, performance was significantly higher for studied than non-studied items ($P<0.01$).

Discussion

Experiment 1 has provided evidence of priming on a word identification test in a letter-by-letter reader. Despite P.T.'s almost complete inability to identify unprimed five/six-letter words from a 500 msec presentation, a single prior exposure to target words produced a marked priming effect on identification performance. Results with the four-letter words were similar, except that baseline performance was higher and priming was observed on only two of the three lists.

In view of the evidence that P.T.'s reading is achieved via access to the visual word form system, our results are consistent with, and provide evidence for, the proposal that priming on a word identification task depends on this system. An alternative interpretation, however, is also possible: P.T.'s enhanced ability to identify previously studied words may not reflect priming in the word form system, but instead may depend on the use of explicit memory strategies. Because a short retention interval was used and the study-test procedure was repeated several times, P.T. undoubtedly noticed that some items on the word identification test had appeared previously on the study list; indeed, she commented occasionally that she had seen a test item earlier. In view of the fact that P.T. is not amnesic, it is possible that she relied on explicit memory to retrieve target words: having identified the initial letters of a word, P.T. may have "thought back" to the study list and attempted to retrieve words that could fit the initial letters.

We have no evidence that P.T. performed the task in this manner. Nevertheless, in order to argue that the observed facilitation on the identification task reflects priming in the word form system, we must rule out the possibility that the observed results simply reflect the use of explicit retrieval strategies. One way to address the issue is to manipulate an experimental variable that is known to influence priming but not explicit memory [39]. If we are able to show that such a variable influences P.T.'s priming and explicit memory performance differently, then we can argue that her word identification performance does not depend on explicit retrieval strategies.

To achieve this objective, we examined the effect of a study/test modality shift on P.T.'s word identification performance. A number of studies have shown that priming effects on such implicit tests as word identification and completion are reduced or eliminated by a study/test modality shift, whereas explicit memory is little affected by the same manipulation [14, 18, 24, 42]. Accordingly, if the observed facilitations in P.T.'s word identification performance are attributable to priming, and not to explicit memory, then priming should be reduced substantially by a study/test modality shift.

In a preliminary attempt to test this hyothesis, P.T. was read a list of eight five/six-letter words; she spelled the words letter-by-letter in order to make the study task as similar as possible to the letter-by-letter reading study task that was used in Experiment 1. She was then given a word identification test under the same conditions as in Experiment 1; the test contained eight studied and eight non-studied words. The same procedure was then followed with four-letter words. Results indicated little or no priming in either condition: for five/six-letters words, 0.13 of studied words were identified and 0.00 of non-studied words were identified; for four-letter words, the corresponding numbers were 0.00 and 0.25. Although these results show a sharp reduction in priming across modalities and thus appear to provide evidence against the idea that P.T. was using explicit retrieval strategies, they are not entirely unambiguous. Analysis of response latencies that were recorded during the study task revealed that P.T.'s median time to spell five/six-letter words was 3.5 sec; the median time to spell four-letter words was 4 sec. These times are considerably faster than the corresponding latencies to read words during letter-by-letter study in Experiment 1. Accordingly, the observed reduction in priming could be attributable to reduced study time, and not to a modality shift. To separate these two explanations, it is necessary to equate study times in visual and auditory conditions.

In Experiment 2, we devised a procedure that yielded equivalent study times in these two conditions. As noted earlier, the major reason for P.T.'s lengthy reading times is that she sometimes fails to retrieve letter names. To circumvent this problem, we used a *modified visual exposure* condition in which the experimenter read aloud the name of the word as it appeared on the computer screen; P.T. then had to read aloud each letter of the word. Pilot work indicated that under these conditions, P.T. had no problem with individual letter names and read the words about as quickly as she could spell them in the auditory presentation condition described above. In this combined visual/auditory condition, however, we expected to observe robust priming, because P.T. was given visual exposure to words, and we assume that such exposure provides access to the visual word form system. By contrast, we expected to observe little or no evidence of priming in a purely auditory condition, even with equivalent study times in the two conditions.

EXPERIMENT 2

Method

Materials, design and procedure. We constructed a new set of critical study and test materials that consisted of 144 medium-to-high frequency, five-letter abstract words. We used abstract words in order to assess whether priming (in the visual condition) generalized to materials other than concrete words. Almost all of the words had regular spellings, in order to circumvent P.T.'s problems with spelling irregular words. The words were divided into six lists consisting of 24 words each. Each list was further subdivided into three sets of eight words that were equated for frequency. The three sets from each list were then randomly assigned to one of three conditions: modified visual study, auditory study, or non-studied.

Two lists were studied and tested in each of three sessions that were separated by three-four days; there was a break of about 10–15 min between the two lists that were used in a given session. For the modified visual condition, words appeared on the computer monitor in the same manner as described for Experiment 1, except that the experimenter read the word aloud as it appeared on the screen. The patient then had to read aloud each letter of the word. For the auditory condition, the experimenter read the word and the patient spelled it aloud, letter-by-letter. For half of the lists (1, 3 and 5), the modified visual condition occurred before the auditory condition, and for the other half of the lists (2, 4 and 6), the reverse order was used. One primacy and one recency buffer appeared at the beginning and end of each set of visual or auditory target items.

For the identification test, words from the modified visual and auditory conditions were randomly intermixed with each other and with non-studied words, thus yielding 24 test items. The identification task was administered in exactly the same manner as described in Experiment 1.

Results

Analysis of latencies to read and spell words at the time of study revealed comparable study times in the modified visual condition and the auditory condition: the mean of medians from the six study lists was 3.9 sec in the auditory condition and 3.6 sec in the visual condition. Thus, in contrast to the pilot study discussed earlier, P.T.'s study times in the visual condition were no slower than in the auditory condition; in fact, her study times were slightly faster in the visual condition.

Table 3. Proportion of words identified correctly by patient P.T. from a 500 msec exposure following visual and auditory study

	Condition		
List	Visual	Auditory	Non-studied
1	0.38	0.00	0.00
2	0.50	0.25	0.13
3	0.25	0.13	0.00
4	0.13	0.13	0.13
5	0.25	0.13	0.13
6	0.38	0.13	0.13
M	0.31	0.13	0.08

Data concerning word identification performance, presented in Table 3, provide a clear and consistent pattern of results: in the modified visual condition, studied words were identified significantly more accurately than non-studied words (0.31 vs 0.08, $P<0.01$); in the auditory condition, studied words were not identified significantly more accurately than non-studied words (0.13 vs 0.08, $P>0.05$). In addition, identification performance was reliably higher in the modified visual condition than in the auditory condition ($P<0.05$).

Priming was observed on five of the six lists in the modified visual condition, whereas performance fluctuated randomly across lists in the auditory condition.

The foregoing data reflect P.T.'s performance on all words from the modified visual and auditory conditions. As noted earlier, however, P.T. does have some problems spelling words from an auditory presentation. Across lists, P.T. misspelled 0.15 of the target words. However, when the data are conditionalized to include only those words spelled correctly during the auditory study task, mean identification performance across lists (0.12) was virtually identical to overall identification performance (0.13); there was still no evidence of priming, and performance in the auditory condition was significatly lower ($P < 0.05$) than in the visual condition.

Discussion

Previous studies have indicated that priming on the word identification test in normal subjects is severely reduced or eliminated by a study/test modality shift. The finding in Experiment 2 that studied words were identified more accurately than non-studied words in the visual but not auditory condition is consistent with the idea that P.T.'s facilitated word identification performance is based on priming and not explicit memory. The failure to observe priming following auditory study cannot be attributed to fast study times, because study times were slightly faster in the modified visual than the auditory condition.

Although these data lend support to the idea that priming in P.T. depends on access to the word form system, we have not yet shown that *explicit* memory performance in P.T. is unaffected by a study/test modality shift; the observed reduction in priming is consistent with our ideas, but it is still possible that P.T.'s explicit memory performance would be similarly reduced by auditory presentation. If this outcome were observed, then we would not have an empirical basis for rejecting the hypothesis that facilitated word identification performance is attributable to explicit memory. If, on the other hand, P.T.'s explicit memory performance is not affected by visual vs auditory study, then we would be able to reject the foregoing hypothesis.

Exactly how could P.T. use explicit retrieval to achieve word identification? As noted earlier, in view of the fact that P.T. can usually identify the first two-three letters of a word, she might attempt to use these letters as cues to help her think of a studied word that begins with them. Such an explicit retrieval strategy would likely produce a facilitation in identifying previously studied words that could be mistaken for priming. The key question, then, is whether P.T.'s explicit retrieval of recently studied words from initial letter cues is influenced by a study/test modality shift. According to our hypothesis, explicit memory should be no greater following visual than auditory study, in contrast to the pattern of results observed on the word identification test. We evaluated this hypothesis by examining explicit retrieval with a letter-cued recall test that was given following study of words in the modified visual and auditory conditions used in Experiment 2.

EXPERIMENT 3

Method

Materials, design and procedure. The experiment was in most respects identical to Experiment 2, except for the use of a letter-cued recall test. Three study/test lists consisting of 16 high frequency, five-letter abstract words were constructed. For each list, eight words were assigned to the visual study condition and eight words were assigned to the auditory study condition, with word frequency equated in the two conditions. For lists 1 and 3, the auditory condition preceded the modified visual condition; for list 2, the reverse order was used. One primacy and one recency buffer appeared at the beginning and end of each set of eight visual or auditory items. All other aspects of the study phase were the same as described in Experiment 2.

For the cued recall test, P.T. was shown the intial three letters of individual target words on the computer monitor and was asked to try to think back to the immediately preceding study list and remember the correct target item. She was told to come up with an answer for each cue, and to guess if necessary. P.T. was instructed to read aloud each three-letter cue in order to ensure that she identified all the letters correctly; if she misnamed any of the letters the experimenter provided the correct letter name. The cue remained on the computer monitor until P.T. provided a response.

Results

Study times, as indexed by the mean of medians across the three lists, were identical in the modified visual and auditory conditions (3.8 sec).

Table 4. Proportion of words recalled correctly by patient P.T. on a cued-recall test

	Condition	
List	Visual	Auditory
1	0.25	0.63
2	0.38	0.25
3	0.13	0.25
M	0.25	0.38

The critical results are presented in Table 4. These data indicate that cued recall performance was higher in the auditory than the modified visual condition on lists 1 and 3, and was higher in the modified visual than auditory condition on list 2. Overall, recall was somewhat higher in the auditory (0.38) than modified visual condition (0.26). However, the apparent auditory advantage did not achieve statistical significance ($P > 0.05$). As in Experiment 2, P.T. misspelled a small proportion of words in the auditory condition (0.21 of words across the three lists were not spelled correctly). However, when analysis was conditionalized to include only those words that had been spelled correctly, the level of cued recall performance (0.37) was virtually identical to the level of recall in the unconditionalized analysis.

Discussion

Experiment 3 has provided strong evidence that facilitated word identification performance in patient P.T. is not attributable to the use of explicit retrieval strategies. Whereas Experiment 2 showed that priming is eliminated in the auditory study condition, Experiment 3 revealed that explicit memory for studied words is actually somewhat higher (albeit non-significantly) following auditory than visual study. This overall pattern of results indicates that priming, and not explicit memory, is responsible for P.T.'s enhanced ability to identify previously studied words relative to non-studied words.

Although it thus seems clear that some form of priming is involved in the observed facilitation of identification performance, questions can still be raised concerning the level at which priming operates. Specifically, in contrast to our hypothesis that priming depends on the word form system, it is possible that priming occurred at a pre-lexical, letter level. We assume that letter-by-letter study of target words activated appropriate letter detectors. If this activation persisted during the word identification test, it might have helped P.T. to identify more previously studied letters than non-studied letters. It seems reasonable to suggest further that such a priming effect at the letter level could also have enabled P.T. to identify more studied than non-studied words. Thus, priming in P.T. may be explicable as a letter level effect, without hypothesizing any access to the word form system.

One reason to doubt this account is provided by a recent study of priming in normal subjects by RUECKL [33] in which it was found that study of single letters produced no priming on a subsequent test involving identification of briefly exposed pseudowords, whereas letter level priming effects were observed on a task requiring identification of individual letters. This pattern of results suggests that letter level priming effects are not observed when subjects' task is to identify a letter string. These data thus also suggest that letter level effects probably did not play a major role in the priming that we have documented. However, Rueckl's task differed from the one that we used, and it is possible that letter level effects may be more pronounced in a letter-by-letter reader such as P.T. than in non-impaired subjects.

One way to determine whether P.T. exhibits letter level priming effects when identifying briefly exposed letter strings is to use illegal non-words as target materials. Letter-by-letter study of illegal nonwords (e.g. *lvylae*, *dlrloa*) should not involve access to the word form system. The question is whether or not such study will facilitate P.T.'s subsequent performance on a task that requires identification of letters from a brief (i.e. 500 msec) exposure. If priming is observed in this paradigm, if would raise the possibility that the priming observed in Experiments 1 and 2 is attributable to letter level effects, and not to reading via the word form system. If, on the other hand, no priming is observed in this paradigm, there would be empirical grounds for rejecting the hypothesis that word priming in P.T. can be attributed to letter level effects. In Experiment 4, we attempted to distinguish between these two possibilities.

EXPERIMENT 4

To assess the possible contribution of letter level effects to priming in P.T., we used the same basic set of materials and procedures described in Experiment 1, with two major modifications. First, the letters in each target word were re-arranged to form an illegal non-word. Second, the word identification test was modified so that P.T.'s task was to report as many letters as possible from a 500 msec exposure. The question was whether she would report more letters for studied than non-studied non-words.

Method

Materials, design and procedure. Four different study/test lists were used. Three of them had been used in Experiment 1; each of the lists consisted of 32 five/six-letter concrete words that were each re-arranged to form illegal non-words (e.g. *palace* was changed to *aeplca*). Sixteen non-words were presented for study from each list (the same 16 letter strings that were presented on the study list as words in Experiment 1), preceded and followed by two primacy and two recency buffers; the 16 studied non-words were randomly intermixed with 16 non-studied non-words for the identification test. In addition to the three lists used in Experiment 1, a fourth list consisting of 16 studied and 16 non-studied nonwords was constructed from a list of five/six-letter concrete words that had been used for pilot work.

Non-words were presented for study and test in the same manner described for Experiment 1. At study, P.T. was instructed to read aloud each letter name; if she made an error in letter identification she was informed of the mistake and asked to try to report the correct letter. As in Experiment 1, the target item remained on the screen for 30 sec; if P.T. did not identify all letters correctly at that point, the experimenter read aloud the correct letter name for incorrectly identified letters. On the identification test, P.T. was instructed to report as many letters as she could. Target items appeared for 500 msec preceded by a central fixation point.

Two lists were studied and tested in each of two sessions separated by 5 days. All other aspects of study and testing were same as for Experiment 1.

Results and Discussion

P.T.'s mean median latency to report letter names during the study phase was 8.9 sec, averaged across the four study lists. Overall, P.T. identified all letters correctly within the alloted 30 sec for 0.94 of the target non-words.

Table 5. Proportion of letters in illegal non-words identified correctly by patient P.T. from a 500 msec exposure

	Condition	
List	Studied	Non-studied
1	0.35	0.37
2	0.36	0.37
3	0.35	0.35
4	0.36	0.31
M	0.36	0.35

Table 5 presents the mean proportion of letters reported correctly for studied and non-studied nonwords on the identification test. Two scoring criteria were used initially: a *strict* criterion in which a letter was scored as correct only if it was reported in the correct position within the non-word, and a *lenient* criterion in which a letter was scored as correct if it appeared at any position in the non-word. An identical pattern of results was observed with both critieria, so only the data from the strict criterion are reported. As Table 4 indicates, P.T. identified about the same proportion of letters for studied and non-studied words; she was generally able to report 2–3 letters for each word. Performance was relatively consistent from list to list, and there was no evidence of significant priming on any individual list.

These results contrast sharply with the robust evidence for priming when words were used in Experiments 1 and 2, and provide an empirical basis for rejecting the hypothesis that priming in these experiments is attributable to letter level activation. However, our data with P.T. are consistent with RUECKL'S [33] observations concerning normal subjects, insofar as both studies indicate that letter level activation does not play a signficant role in priming on tests that require processing of a letter string. We therefore conclude that priming of word identification in patient P.T. depends on access to the word form system.

GENERAL DISCUSSION

In the article we have reported evidence for priming of word identification performance in a letter-by-letter reader, P.T. Experiment 1 documented that letter-by-letter study of common words produced priming on a subsequent task that required identification of words from a 500 msec exposure, despite P.T.'s severe impairment in identifying non-studied words. Experiment 2 showed that the observed priming was modality specific, and Experiment 3 demonstrated that P.T.'s explicit memory for recently studied words was not modality specific, thereby indicating that explicit retrieval played little or no role in the observed priming effects. Experiment 4 provided evidence against a letter level interpretation of priming by showing that letter-by-letter study of illegal non-words did not facilitate subsequent letter identification performance. Taken together, the experiments suggest that priming in P.T. occurs at the level of the visual word form system.

Our findings provide support for the general view that the visual word form system, a subsystem of the perceptual representation system, subserves priming on the word identification test [38, 47]. Indeed, it was this view that provided the basis for predicting the occurrence of priming in P.T. Our account also leads to the prediction that P.T. should show robust priming on other implicit memory tests in which priming is thought to be mediated by the word form system, such as fragment and stem completion; we intend to evaluate this hypothesis in future research. Studies with the latter tasks might also indicate whether the priming exhibited by P.T. is entirely normal. As discussed earlier, it was not possible to assess whether priming was normal in P.T. because we could not assess word identification performance in control subjects under conditions comparable to those used with P.T.: normal controls perform at ceiling levels with the 500 msec exposure that we used with P.T., whereas P.T. performs at floor levels under conditions that are typically used to assess word identification priming in normal controls. However, it is quite possible that P.T.'s baseline performance on stem and fragment completion tasks is comparable to that of normal subjects, because such tasks do not require rapid processing of briefly displayed information. If this is so, then we can compare her performance directly with appropriate control subjects and assess whether P.T. shows priming effects of normal magnitude.

In addition to providing evidence for the view that word identification priming depends on the visual word form system, our results are consistent with the idea that the word form system is frequently spared in letter-by-letter readers [25]. However, these ideas need not imply that the word form system is spared in *all* letter-by-letter readers. It is worth noting in this respect that some features of P.T.'s performance, such as her poor letter naming skills, are not characteristic of all letter-by-letter readers. Accordingly, it will be important to determine whether priming is observed in other letter-by-letter readers. In addition, PATTERSON and KAY [25] described a subset of patients (Type II patients), characterized by regularization errors in reading, in whom they postulated damage to the word form system itself. By our view, such patients should show little or no priming on word identification and similar tasks.

An important question that is left open by the present study concerns the precise nature of the role played by the visual word form system in the priming exhibited by P.T. Despite our emphasis on the contribution of the word form system to priming, it is premature to conclude that priming is based solely on changes in this system. For example, it is possible that priming in P.T. (and normal subjects) is based in part on activation of the *phonological* features of target words. We cannot rule out the possibility that priming in P.T. depends in part on phonological activation. However, preliminary evidence from a case study that we are conducting of a patient (R.S.) with a severe impairment in generating and producing phonology casts doubt on this idea. We conducted a priming experiment with R.S. that was nearly identical to Experiment 1 of the present article, except that the patient provided only written responses to target words. Despite her inability to read aloud nearly all target items R.S. showed significant priming effects on the word identification test, thereby indicating that priming can occur when phonological activation is impaired or absent. Although phonological activation may have made some contribution to priming in P.T., the modality specificity of the observed priming indicates a major role for the visual word form system.

Within the word form system, one possibility is that priming is based on persisting activation of a pre-existing, abstract representation of the visual form of a word—a visual logogen, to adopt MORTEN'S [24] terminology. An alternative possibility is that letter-by-letter study of a target word created a novel and highly specific word form representation, and that this novel representation was activated by brief exposure to the identical word on the identification test [38]. Our data do not allow us to distinguish between these two possibilities. It is worth noting, however, that a number of studies have shown that priming effects on word identification and similar tests are highly specific [16, 19, 32], although such specificity effects are not observed under all conditions [4, 46]. It is possible that within the word form system, both activation of abstract, pre-existing representations and creation of novel, highly specific representations contribute to priming; the importance of the contribution made by each process may be determined by the nature of the target materials as well as the encoding operations required by a particular study task. Thus, when words are presented in unusual formats [32], or subjects are required to attend to the physical features of target words [12], priming may be based largely on newly-created word form representations, whereas under other circumstances activation of pre-existing representations may play a more prominent role. The data from the present experiments do not allow us to address this issue, but future studies of letter-by-letter readers could shed light on it by assessing whether study/test changes in word font, size, and other attributes reduce the magnitude of priming shown by P.T. or similar patients.

At a general strategic level, we suggest that study of non-amnesic patients with focal lesions, such as P.T., may provide a valuable source of information for research and theorizing about priming and implicit memory. Studies of amnesic patients have contributed greatly to understanding the nature and characteristics of priming [6, 15, 36, 50, 51]; for discussion, see [37, 45, 47]. With the development of hypotheses about specific systems and subsystems that subserve particular types of priming [38, 40, 47], study of non-amnesic patients with focal lesions that are thought to either spare or impair these systems should be highly informative. Such studies would both provide a basis for evaluating claims about the role of particular systems and subsystems in priming, and also broaden considerably the boundaries and implications of research concerning phenomena of priming and implicit memory.

REFERENCES

1. BENNETT, C. A. and FRANKLIN, N. L. *Statistical Analysis in Chemistry and the Chemical Industry*. John Wiley, New York, 1954.
2. BOWERS, J. S. and SCHACTER, D. L. Implicit memory and test awareness. *J. exp. Psychol., Learn., Mem. Cognit.* **16,** 404–416, 1990.
3. BUB, D. N., BLACK, S. and HOWELL, J. Word recognition and orthographic context effects in a letter-by-letter reader. *Brain Lang.* **36,** 357–376, 1989.
4. CARR, T. H., BROWN, J. S. and CHARALAMBOUS, A. Repetition and reading: perceptual encoding mechanisms are very abstract but not very interactive. *J. exp. Psychol., Learn., Mem. Cognit.* **15,** 763–778, 1989.
5. CARROLL, M. and KIRSNER, K. Context and repetition effects in lexical decision and recognition memory. *J. Verb. Learn. Verb. Behav.* **21,** 55–69, 1982.
6. CERMAK, L. S., TALBOT, N., CHANDLER, K. and WOLBARST, L. R. The perceptual priming phenomenon in amnesia. *Neuropsychologia* **23,** 615–622, 1985.
7. COLTHEART, M., BYNG, S., PRIOR, M. and RIDDOCH, J. Surface dyslexia. *Q. J. exp. Psychol.* **35A,** 469–495, 1983.
8. COSLETT, H. B. and SAFFRAN, E. Evidence for preserved reading in "pure alexia". *Brain* **112,** 327–339, 1989.
9. FUNNELL, E. Phonological processes in reading: new evidence from acquired dyslexia. *Br. J. Psychol.* **74,** 159–180, 1983.
10. GRAF, P. and MANDLER, G. Activation makes words more accessible, but not necessarily more retrievable. *J. Verb. Learn. Verb. Behav.* **25,** 553–568, 1984.
11. GRAF, P., MANDLER, G., and HADEN, P. Simulating amnesic symptoms in normal subjects. *Science* **218,** 1243–1244, 1982.
12. GRAF, P. and RYAN, L. Transfer appropriate processing for implicit and explicit memory. *J. exp. Psychol., Learn., Mem. Cognit.*, in press.

13. GRAF, P. and SCHACTER, D. L. Implicit and explicit memory for new associations in normal subjects and amnesic patients. *J. exp. Psychol. Learn., Mem. Cognit.* **11,** 501–518, 1985.
14. GRAF, P., SHIMAMURA, A. P. and SQUIRE, L. R. Priming across modalities and priming across category levels: extending the domain of preserved function in amnesia. *J. exp. Psychol., Learn., Mem. Cognit.* **11,** 385–395, 1985.
15. GRAF, P., SQUIRE, L. R. and MANDLER, G. The information that amnesic patients do not forget. *J. exp. Psychol., Learn., Mem. Cognit.* **10,** 164–178, 1984.
16. HAYMAN, C. A. G. and TULVING, E. Is priming in fragment completion based on a "traceless" memory system? *J. exp. Psychol., Learn., Mem. Cognit.* **15,** 941–956, 1989.
17. HIRSHMAN, E., SNODGRASS, J. G., MINDES, J. and FEENAN, K. Conceptual priming in fragment completion. *J. exp. Psychol., Learn., Mem. Cognit.,* **16,** 634–647, 1990.
18. JACOBY, L. L. and DALLAS, M. On the relationship between autobiographical memory and perceptual learning. *J. exp. Psychol. Gen.* **110,** 306–340, 1981.
19. JACOBY, L. L. and HAYMAN, C. A. G. Specificity of visual transfer in word identification. *J. exp. Psychol., Learn., Mem. Cognit.* **13,** 456–463, 1987.
20. JACOBY, L. L. and WITHERSPOON, D. Remembering without awareness. *Can. J. Psychol.* **36,** 300–324, 1982.
21. KERTESZ, A. *The Western Aphasia Battery.* Grune & Stratton, New York, 1982.
22. KIRSNER, K., MILECH, D. and STUMPFEL, V. Word and picture identification: is representational parsimony possible? *Mem. Cognit.* **14,** 398–408, 1986.
23. KUCERA, M. and FRANCIS, W. *Computational Analysis of Present-day American English.* Brown University Press, Providence, RI, 1967.
24. MORTON, J. Facilitation in word recognition: experiments causing change in the logogen model. In *Processing Models of Visible Language,* P. A. KOLERS, M. E. WROLSTAD and H. BOUMA (Editors). Plenum Press, New York, 1979.
25. PATTERSON, K. and KAY, J. Letter-by-letter reading: psychological descriptions of a neurological syndrome. *Q. J. exp. Psychol.* **34A,** 411–441, 1982.
26. PAVIO, A., YUILLE, J. C. and MADIGAN, S. A. Concreteness, imagery, and meaningfulness values for 925 nouns. *J. exp. Psychol. Mongr.* **78,** 1968.
27. PETERSEN, S. E., FOX, P. T., POSNER, M. I., MINTUN, M. and RAICHLE, M. E. Positron emission tomographic studies of the processing of single words. *J. cognit. Neurosci.* **1,** 153–170, 1989.
28. RAPCSAK, S. Z., RUBENS, A. B. and LAGUNA, J. F. From letters to words: procedures for word recognition in letter-by-letter reading. *Brain Lang.* in press.
29. REUTER-LORENZ, P. A. and BRUNN, J. L. A prelexical basis for letter-by-letter reading: a case study. *Cognit. Neuropsychol.* **7,** 1–20, 1990.
30. RICHARDSON-KLAVEHN, A. and BJORK, R. A. Measures of memory. *A. Rev. Psychol.* **36,** 475–543, 1988.
31. ROEDIGER, H. L. and BLAXTON, T. A. Retrieval modes produce dissociations in memory for surface information. In *Memory and Cognitive Processes: The Ebbinghaus Centennial Conference,* D. S. GORFEIN and R. R. HOFFMAN (Editors). Lawrence Erlbaum, Hillsdale, New Jersey, 1987.
32. ROEDIGER, H. L., WELDON, S. and CHALLIS, B. H. Explaining dissociations between implicit and explicit measures of retention: a processing account. In *Varieties of Memory and Consciousness: Essays in Honor of Endel Tulving,* H. L. ROEDIGER and F. I. M. CRAIK (Editors). Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1989.
33. RUECKL, J. G. Letter-level effects in repetition priming. Unpublished manuscript, 1989.
34. SARTORI, G., MASTERSON, J. and JOB, R. Direct-route reading and the locus of lexical decision. In *The Cognitive Neuropsychology of Language,* M. COLTHEART, G. SARTORI and R. JOB (Editors). Lawrence Erlbaum Associates, London, 1987.
35. SCARBOROUGH, D. L., GERARD, L. and CORTESE, C. Accessing lexical memory: the transfer of word repetition effects across task and modality. *Mem. Cognit.* **7,** 3–12, 1979.
36. SCHACTER, D. L. Priming of old and new knowledge in amnesic patients and normal subjects. *Ann. N. Y. Acad. Sci.* **444,** 41–53, 1985.
37. SCHACTER, D. L. Implicit memory: history and current status. *J. exp. Psychol., Learn., Mem. Cognit.* **13,** 501–518, 1987.
38. SCHACTER, D. L. Perceptual representation systems and implicit memory: toward a resolution of the multiple memory systems debate. *Ann. N. Y. Acad. Sci.* in press.
39. SCHACTER, D. L., BOWERS, J. and BOOKER, J. Intention, awareness, and implicit memory: the retrieval intentionality criterion. In *Implicit memory: Theoretical Issues,* S. LEWANDOWSKY, J. DUNN and K. KIRSNER (Editors). Lawrence Erlbaum Associates, Hillsdale, New Jersey, 1989.
40. SCHACTER, D. L., COOPER, L. A. and DELANEY, S. M. Implicit memory for unfamiliar objects depends on access to structural descriptions. *J. exp. Psychol., Gen.* **119,** 5–21, 1990.
41. SCHACTER, D. L. and GRAF, P. Effects of elaborative processing on implicit and explicit memory for new associations. *J. exp. Psychol., Learn., Mem. Cognit.* **12,** 432–444, 1986.

42. SCHACTER, D. L. and GRAF, P. Modality specificity of implicit memory for new associations. *J. exp. Psychol., Learn., Mem. Cognit.* **15,** 3–12, 1989.
43. SCHACTER, D. L. and MCGLYNN, S. M. Implicit memory: effects of elaboration depend on unitization. *Am. J. Psychol.* **102,** 452–481, 1989.
44. SCHWARTZ, M. F., MARIN, O. S. M. and SAFFRAN, E. M. Dissociations of language function in dementia: a case study. *Brain Lang.* **7,** 277–306, 1979.
45. SHIMAMURA, A. P. Priming effects in amnesia: evidence for a dissociable memory function. *Q. J. exp. Psychol.* **38A,** 619–644, 1986.
46. TARDIF, T. and CRAIK, F. I. M. Reading a week later: perceptual and conceptual factors. *J. Mem. Lang.* **28,** 107–125, 1989.
47. TULVING, E. and SCHACTER, D. L. Priming and human memory systems. *Science* **247,** 301–306, 1990.
48. TULVING, E., SCHACTER, D. L. and STARK, H. A. Priming effects in word-fragment completion are independent of recognition memory. *J. exp. Psychol., Learn., Mem. Cognit.* **8,** 336–342, 1982.
49. WARRINGTON, E. K. and SHALLICE, T. Word-form dyslexia. *Brain,* **103,** 99–112, 1980.
50. WARRINGTON, E. K. and WEISKRANTZ, L. New method of testing long-term retention with special reference to amnesic patients. *Nature, Lond.* **217,** 972–974, 1968.
51. WARRINGTON, E. K. and WEISKRANTZ, L. The effect of prior learning on subsequent retention in amnesic patients. *Neuropsychologia,* **12,** 419–428, 1974.
52. WELDON, M. S. and ROEDIGER, H. L. Altering retrieval demands reverses in the picture superiority effect. *Mem. Cognit.* **15**(4), 269–280, 1987.