Memory & Cognition
2001, 29 (7), 920-930

The effects of attention on perceptual implicit memory

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Reports on the effects of dividing attention at study on subsequent perceptual priming suggest that perceptual priming is generally unaffected by attentional manipulations as long as word identity is processed. We tested this hypothesis in three experiments by using the implicit word fragment completion and word stem completion tasks. Division of attention was instantiated with the Stroop task in order to ensure the processing of word identity even when the participant's attention was directed to a stimulus attribute other than the word itself. Under these conditions, we found that even though perceptual priming was significant, it was significantly *reduced* in magnitude. A stem cued recall test in Experiment 2 confirmed a more deleterious effect of divided attention on explicit memory. Taken together, our findings delineate the relative contributions of perceptual analysis and attentional processes in mediating perceptual priming on two ubiquitously used tasks of word fragment completion and word stem completion.

A theoretically important distinction in the field of memory research involves the distinction between implicit and explicit memory. Implicit memory is measured indirectly by tests that assess the advantage of studying words such as *donkey* on the successful identification of degraded or incomplete words such as _ *o n* _ *e* _ (the word fragment completion task) or *don*_____ (the word stem completion task). Explicit memory is measured directly by tests that assess the participant's ability to recollect studied words such as *donkey* on tests of recall or recognition. Despite this seemingly minor difference in the assessment of the two types of memory, major theoretical differences have been identified between implicit and explicit memory. One difference concerns the dissociation in performance on these tests that amnesics exhibit (e.g., Graf, Shimamura, & Squire, 1985; Graf, Squire, & Mandler, 1984; Tulving & Schacter, 1990). Specifically, amnesics show impaired performance on explicit tests and intact performance on implicit tests. The second major difference, and the one that we focus on here, is the presumed differences in the processing requirements of these tests (Blaxton, 1989; Roediger, Weldon, & Challis, 1989; see Roediger, 1990, and Roediger & McDermott, 1993, for reviews). Within this processing framework, we examine the effects of attentional manipulations on implicit and explicit memory.

Most explicit measures of memory such as recall, recognition, semantic cued recall, or category cued recall largely rely on conceptual processes (Roediger et al., 1989), and division of attention at study adversely affects performance on these tasks. The division of attention in these studies was achieved by adding a secondary task such as digit or tone monitoring or by dichotic listening at study (Eich, 1984; Isingrini, Vazou, & Leroy, 1995; Jacoby, Woloshyn, & Kelley, 1989; Mulligan, 1997; Mulligan & Hartman, 1996; Parkin, Reid, & Russo, 1990; Parkin & Russo, 1990; Schmitter-Edgecombe, 1996; Seamon, Brody, & Kauff, 1983). These methods of dividing attention also adversely affect performance on explicit tests that utilize perceptual cues (Mulligan, 1998; Mulligan & Hartman, 1996; Schmitter-Edgecombe, 1996), because the requirement to access the study episode on these tests involves conceptual processes (see Roediger, Weldon, Stadler, & Riegler, 1992) that are assumed to be sensitive to attentional manipulations. Thus, all explicit tests appear to require attentional resources at study. This outcome may be due to the fact that the availability of greater attentional resources can enhance the degree to which studied information is meaningfully encoded. The manipulation of attention could affect the degree to which studied items are mean-

Parts of the research reported in this paper were presented at the Annual Meeting of the Psychonomic Society in Dallas, 1998. Parts of the research reported in this article were supported by NIH Grant R29MH57345 to S.R.K.S. is now at Kronos, Inc., Chelmsford, Massachusetts. The authors thank Kevin Felker, Mana Heydarpour, and Monica Jefferson for their research assistance throughout the project. Neil Resnick's assistance in data collection in Experiment 1 is acknowledged. Correspondence concerning this article should be addressed to S. Rajaram, Department of Psychology, SUNY at Stony Brook, Stony Brook, NY 11794-2500 (e-mail: suparna.rajaram@sunysb.edu).

ingfully encoded, thereby influencing performance on explicit memory tests (Mulligan & Hartman, 1996). This hypothesis is further supported by reports of impaired performance after division of attention on implicit tests that rely on conceptual processes (see Mulligan, 1997; Mulligan & Hartman, 1996; but see Koriat & Feuerstein,1976; Isingrini et al., 1995)—for example, the category production test (Srinivas & Roediger, 1990).

In contrast to the consistent effects of attention on explicit and implicit conceptual tests, attentional manipulations have had inconsistent effects on such implicit memory tests as word fragment completion, word stem completion, and perceptual identification, which are largely sensitive to perceptual manipulations (Rajaram & Roediger, 1993) but are insensitive to manipulations of meaning (Rajaram, Srinivas, & Roediger, 1998; and see Roediger & McDermott, 1993, for a review). Some published studies have shown little or no effect of dividing attention on such perceptual implicit tests as picture fragment completion, word fragment completion, tachistoscopic identification, fame judgments, and perceptual clarification (Jacoby et al., 1989; Mulligan & Hartman, 1996; Parkin et al., 1990; Parkin & Russo, 1990; Schmitter-Edgecombe, 1996). The division of attention at study in these reports was achieved through tone monitoring or digit monitoring or through the performance of a visual distractor task that did not compete with the processing of the target word (Wolters & Prinsen, 1997). Other published studies have reported deleterious effects of dividing attention on such perceptual implicit tests as word fragment completion, perceptual clarification, lexical decision, and affect judgments (Hawley & Johnston, 1991; Seamon et al., 1983; Smith & Oscar-Berman, 1990; Weldon & Jackson-Barrett, 1993). In these reports, the division of attention was achieved by the shadowing or monitoring of secondary events within the same modality as target words. The key to the discrepancy in these two sets of findings appears to be the degree to which the secondary task interferes with the actual identification of the words at study. For example, Weldon and Jackson-Barrett (1993) reported deleterious effects of attention when the secondary task was combined with brief exposure durations at study (between 2 and 250 msec), which thus made word identification difficult or impossible (see also short-duration conditions in Hawley & Johnston, 1991). Thus, under conditions where attentional manipulations interfere with the perceptual analysis of words at study, perceptual priming is adversely affected.

In summary, these findings suggest that perceptual implicit tests appear to require attentional resources only to the extent needed for the perceptual analysis of words at study and require minimal attentional resources beyond those necessary for the identification of words at study (Mulligan & Hartman, 1996). In the present study, we examined this hypothesis. To this end, we divided attention in a Stroop (1935) paradigm at study, because this paradigm allows the manipulation of attentional resources while ensuring that identification of words takes place in the divided attention condition. In the Stroop paradigm, words printed in different colors are presented for word naming (full-attention condition for the words) or for color naming (divided attention for words, given that words are the irrelevant stimuli for the task at hand). In the divided-attention condition of color naming, words are in fact identified at the lexical and semantic levels despite the fact that they are irrelevant to the task (see Dyer, 1973, and MacLeod, 1991, for reviews). Thus, under the Stroop encoding condition, even though word identification occurs, attentional resources have to be directed away from the word and the word has to be deselected as the appropriate response because it is irrelevant to the task. The question then is, How does the attentional manipulation in the Stroop paradigm affect perceptual implicit measures of memory?

If we assume that such perceptual implicit memory measures as word fragment completion and word stem completion are completely unaffected by the attentional manipulation in the Stroop paradigm, because identification of words indeed occurs in the divided-attention condition, we should observe no reduction in priming with the Stroop encoding task. However, if attentional processes other than those required for simple identification are involved in perceptual priming, reduction in priming may occur. Specifically, if ignoring a word in the Stroop task results in its deselection and inhibition, it is likely that perceptual analysis alone would not support priming. This reasoning is based on the evidence that ignored words or pictures in one trial produce *negative* priming when attended to in a subsequent trial (DeSchepper & Treisman, 1996; Neill, 1977; Tipper, 1985, 2001; Treisman & DeSchepper, 1996). Thus, in the Stroop task of divided attention, facilitation arising from completed perceptual analysis might be entirely or partially offset by inhibition arising from ignoring the word (see Rajaram & Srinivas, 1998). In this case, perceptual priming in the divided-attention condition may be either reduced or eliminated.

Current evidence reported with perceptual (or word) identification (Mulligan & Hornstein, 2000; Stone, Ladd, Vaidya, & Gabrieli, 1998) and lexical decision (Szymanski & MacLeod, 1996) tasks provide preliminary support for this hypothesis. In the perceptual identification task, dividing attention with the Stroop paradigm leads to reduced but significant priming (but see Stone et al., 1998, Experiment 3, for an absence of priming). However, no decrement in perceptual priming was observed with the lexical decision task even though explicit memory measured with recognition was poorer for words studied in the Stroop encoding condition relative to the full-attention condition (Szymanski & MacLeod, 1996). These mixed reports prompt the following question: Are attentional requirements beyond word identification task specific, or can some generalization be made across the representative perceptual priming tasks even though some exceptions (such as the lexical decision task) may exist?

To this end, we compared the effects of Stroop encoding with full-attention encoding on two ubiquitously used perceptual priming tasks, word fragment completion and word stem completion. Our use of these tasks was guided by the following considerations. First, an understanding of the attentional requirements of perceptual priming requires that we explore this relationship across a variety of representative priming tasks. Second, word fragment completion and word stem completion tasks have similar processing demands (Roediger et al., 1992), and therefore, are suited for obtaining converging evidence. Third, fragment and stem completion tasks provide participants with considerably more time to perform the task (on the order of 15–30 sec) than does the perceptual identification task (on the order of 17–100 msec). In the absence of empirical validation, it would be premature to assume that the attentional requirements of these three tasks are isomorphic. Furthermore, Gabrieli et al. (1999) recently reported deleterious effects of divided attention at study on the stem completion task when a secondary task that does not impair priming in implicit word fragment completion was used (Mulligan & Hartman, 1996). Gabrieli et al. did not rule out possible contributions of explicit memory contamination. But, assuming that no such contamination occurred, the noted discrepancy suggests that it is important to determine whether these two tasks would be similarly, or differentially, sensitive to attentional effects created by the Stroop manipulation. Finally, although the processing requirements of implicit fragment and stem completion tasks are strongly perceptual and similar to those of perceptual identification (Roediger & McDermott, 1993), these tasks are less sensitive than perceptual identification to modality changes across study and test (Jacoby & Dallas, 1981; Rajaram & Roediger, 1993; but see Kirsner, Dunn, & Standen, 1989). Therefore, it is necessary to examine the role of attention by testing these effects in the word fragment completion and word stem completion tasks before we can generalize our conclusions to perceptual priming tasks at large.

Additionally, prior studies that reported reduced priming following Stroop encoding (Mulligan & Hornstein, 2000; Stone et al., 1998) did not assess possible contributions from explicit memory, which leaves open the possibility that reduced priming may have resulted from explicit contamination during perceptual identification. Although the use of explicit memory strategies is less likely in such data-limited tasks as perceptual identification, it cannot be definitively ruled out, particularly when the priming in the Stroop condition appears to be significant but reduced in some cases and not significant in others (Stone et al., 1998). Furthermore, the availability of more time in the stem and fragment completion tasks, as compared with perceptual identification, necessitates that the issue of explicit contamination be addressed empirically (Experiments 2 and 3). We predicted that the effects of Stroop encoding would result in reduced priming on the implicit word fragment completion (Experiment 1) and word stem completion (Experiments 2 and 3) tasks on the basis of evidence that these two tasks share more of the processing requirements with the perceptual identification task than with the lexical decision task (Rajaram & Roediger, 1993).

EXPERIMENT 1

Method

Participants

Sixty undergraduates at the State University of New York at Stony Brook participated (48 for partial course credit, and 12 for $5 each).

Design and Materials

One independent variable, type of study, was varied at three levels. Critical words were presented for encoding in the full-attention condition or the divided-attention condition or were nonstudied. In the full-attention condition, the participants were simply asked to read the word as quickly as possible, and no competing task was given. In the divided-attention condition, the participants were asked to name the color in which the word was written. It was assumed that the reading of words would compete with naming the color in this task. The amount of time (in milliseconds) taken to read the word or name the color, respectively, was measured by using keystroke times. The nonstudied words were presented only at test (in the fragmented form) to provide the baseline completion rates. The test phase consisted of a word fragment completion task with implicit retrieval instructions. The accuracy of fragment completion, as well as the time taken (measured by keystroke times) to complete the fragments, was recorded.

One hundred six words were selected to serve as stimuli according to three criteria: All the words were abstract nouns, were 5–7 letters in length, and were of low to medium frequency (4–20 per million frequency according to the Kučera and Francis, 1967, norms). In this set, 72 words were designated as the critical stimuli. Ten words served at buffer stems at the beginning of the test list in order to discourage the participants from using explicit retrieval strategies. The remaining 24 words were used to create filler fragments in the test list in order to maintain a studied to nonstudied ratio of 1:1 for the test stimuli.

Of the 72 critical stimuli, 24 each were assigned to each of the three conditions, nonstudied, divided attention at study, and full attention at study. In the divided-attention condition, the 24 words were presented in each of four colors, red, blue, green, and yellow equally often to create the Stroop effect. Test fragments were created by deleting, on average, 50% of the letters from each test word (i.e., 72 critical stimuli, 10 buffers, and 24 fillers). At study, words in the full-attention condition were presented on the computer in black on a light gray screen. Words in the divided-attention condition were presented in one of four colors on a light gray screen. At test, all fragments were presented in light gray on a black screen.

Twelve study lists were created to achieve three objectives. First, each critical item was presented in each of the three conditions across lists. Second, each word in the divided-attention condition was presented in each of the four colors across lists. Third, the order of divided- and full-attention conditions was counterbalanced across participants. The study conditions were blocked. A single test order was used so that all the critical fragments were presented in a random order with respect to the study condition, all 10 buffer fragments were presented at the beginning of the test list, and the filler fragments were distributed randomly throughout the test list.

Procedure

Study and test stimuli were presented and data were collected on three IBM-compatible 486 PCs and were controlled by the MEL programming language. One to 3 participants were tested at a time. The experiment consisted of three phases: study, distractor, and test. During the study and test phases, the words (or fragments) were presented one at a time.

During study, in the full-attention condition, the participants were instructed to read each word presented on the computer monitor as quickly as possible and to press the key (#9) labeled with a black dot as soon as they had completed reading the word. As soon as the participants pressed the correct key, the computer prompted them to type in the word that was just presented. This task was included in order to ensure that the participants would indeed read the word. In the divided-attention condition, each word was presented in one of four colors, and four keys on the keyboard were mapped with corresponding color dots (1 = red, 2 = blue, 3 = green, 4 = yellow). The participants were asked to identify the color in which the word was written and to press the appropriately colored key as soon as they had identified the color. After the key was pressed, the computer prompted the participants to type in the color they had just identified. This task was included to keep the task demands across the full- and divided-attention conditions constant in all respects except the intended manipulation. The speed and accuracy of task performance were emphasized equally. The instructions for both conditions were provided before the start of the study phase. In addition, the participants were informed that the instructions for each condition would appear on the computer screen again before the start of each block. The study phase was followed by a 5-min distractor period, during which the participants performed an unrelated task of writing down the names of all the U.S. presidents.

During test, 106 word fragments were presented for 15 sec each. The participants were instructed to complete each fragment with the first legal English word that came to mind and to not use proper nouns. The instructions emphasized the need to provide the first solution because of the limited time available. The participants pressed the space bar as soon as they had a solution. This keystroke produced a prompt for typing in the solution. At the end of the word fragment completion task, the participants were debriefed. The entire procedure took approximately 50 min.

Results and Discussion

The mean proportions of accurate fragment completion rates in the full, divided, and nonstudied conditions are presented in Table 1. The alpha level for the statistical analyses in all experiments was set at the conventional level of $p < .05$, unless noted otherwise. Implicit memory, or priming, was calculated in all experiments by subtracting the correct nonstudied completions from studied completions.

Due to program error, the study reaction time (RT) data for 5 participants were lost, leaving data for 55 participants in this comparison. A within-subjects t test showed that the RTs for the full- (M = 705 msec) and divided-attention (M = 941 msec) study conditions differed [$t(54)$ = 5.36, SE = 43.65],[1] indicating that the participants read words significantly faster than they named colors. The differences in RTs were consistent with the error rates, as indicated by very low error rates (full attention = 0 and divided attention = 2% of the trials).

A one-way analysis of variance (ANOVA) on accurate fragment completion rates at test yielded a significant difference among the three conditions [$F(2,118) = 45.79$, $MS_e = 0.008$]. Subsequent paired-comparison t tests comparing fragment completion performance in the full- (M = 0.34) and divided- (M = 0.25) attention and nonstudied (M = 0.18) conditions revealed significant priming in both the full [$t(59) = 10.29$] and the divided- [$t(59) =$ 4.16] attention conditions. Our critical test of a possible reduction in priming for the divided relative to the full-attention condition revealed that priming was indeed significantly reduced in the divided-attention condition compared with the full-attention [$t(59) = 5.05$][2] condition.

EXPERIMENT 2

Experiment 2 was designed to address a number of theoretical and procedural issues arising from our findings in Experiment 1. The theoretical issues are two-fold. First, the smaller but significant perceptual priming for the ignored stimuli requires a systematic replication. If this finding generalizes to another widely used perceptual priming task, the mechanisms that govern priming on such tasks under conditions of divided attention can be better understood. To this end, we used the word stem completion task in this experiment. Second, the effects of divided attention under the present conditions need to be assessed for explicit memory in order to ensure that the results observed in Experiment 1 could not have been due to the use of explicit retrieval strategies by the participants.

The procedural issues pertain to the methodological details of Experiment 1. Longer latencies to name colors were compared with latencies for reading words in Experiment 1. A more accurate measure of interference from reading in the divided-attention condition can be obtained by comparing latencies for naming colors of words with latencies for naming colors of nonlexical stimuli. Therefore, we added a neutral condition in which the trials consisted of strings of Xs presented in different colors. If

Table 1
Means and Standard Errors (*SE*) for the Proportion Correct Performance at Test as a Function of Study Status in Experiments 1, 2, and 3

	Full Attention		Divided Attention		Nonstudied	
Experiment and Condition	*M*	*SE*	*M*	*SE*	*M*	*SE*
Experiment 1—Implicit (word fragment completion)	.34	.06	.25	.06	.18	.05
Experiment 2—Implicit (word stem completion)	.29	.01	.20	.01	.11	.01
Experiment 2—Explicit (word stem cued recall)	.31	.02	.08	.01	.03	.01
Experiment 3—Implicit (word stem completion)	.21	.01	.15	.01	.08	.01

RTs to name colors were longer for words than for strings of Xs, this difference would indicate relatively intact perceptual analysis of words and the processing of word identity in the divided-attention condition.

The second procedural change in Experiment 2 consisted of adding a practice block (consisting of strings of As) before the study phase in order to familiarize the participants with the physical act of making four-choice responses in the divided and neutral conditions.

To reiterate, the goals of Experiment 2 were (1) to replicate the fragment completion findings with a different perceptual implicit task, (2) to contrast the effects of attention on explicit and implicit memory tasks by constructing the tasks to meet the retrieval intentionality criterion so that the retrieval cues were held constant across tasks and only the retrieval instructions were varied (Schacter, Bowers, & Booker, 1989), and (3) to ensure that perceptual processing of words did indeed occur at study but would still result in diminished performance on perceptual implicit and explicit tasks.

Method

The design, materials, and procedure of Experiment 2 were the same as those in Experiment 1, except for the details noted below.

Participants

A new group of 144 undergraduates from the State University of New York at Stony Brook participated in this experiment for partial fulfillment of course requirements. Seventy-two students participated in the implicit version of the word stem completion task, and the remaining 72 students participated in the explicit version of the task.

Design and Materials

The design, materials, and procedure were held constant between the implicit and the explicit groups of participants, except for the test instructions noted in the Procedure section. In both versions, three conditions were included at study: neutral, divided attention, and full attention. In the neutral condition, 24 strings of Xs were presented in six different colors, and in the divided-attention condition, 24 words were presented in six different colors. In the full-attention condition, 24 words were presented in black.

At test, the word-stem completion task was used to measure memory. In the implicit test, the participants were asked to complete the stems with the first solution that came to mind. In the explicit test, the participants were asked to use the word stems as cues to retrieve the words they had seen earlier. In both tests, stems were presented for words from the full-attention, divided-attention, and nonstudied (baseline) conditions.

The set of 106 words used in Experiment 1 served as the stimuli in the implicit and explicit versions of this experiment as well. The assignment of words to conditions was accomplished in the same way as in Experiment 1. The only change was that six, instead of four, colors were used. In the divided-attention condition, four words were presented in each of the six colors, red, blue, green, yellow, white, and purple, to measure color-naming latencies. These six colors were also used equally often in the neutral condition, in which four strings of Xs were presented in each color. Each string consisted of seven uppercase Xs.

For the test stimuli, we created the stems by retaining the first three letters from each test word (i.e., 72 critical stimuli, 10 buffers, and 24 fillers). These stems were created with the constraint that only 1 word from the set of 106 words used in this experiment could serve as the completion (although each stem had multiple solutions with reference to all the words in the English language).

Both the implicit and the explicit versions of the experiment used 18 study lists in order to ensure that (1) each critical item was presented in the divided-attention, full-attention, and nonstudied conditions across lists, (2) each word in the divided-attention condition was presented in each of the six colors across lists, and (3) the order of divided-attention, full-attention, and neutral conditions was counterbalanced across participants. In all other respects, the study and tests lists were constructed as were those in Experiment 1.

Procedure

The implicit and explicit versions of the experiment consisted of four phases: a practice phase, a study phase, a distractor phase, and a test phase. During the study and test phases, the words (or stems) were presented one at a time.

During practice, the participants were presented with 24 trials of strings of As. The task of the participants was simply to identify the color and press the appropriately colored key on the keyboard. During study, the full- and divided-attention conditions were administered as in Experiment 1. In the neutral condition, as in the divided-attention condition, the participants identified the color in which the strings of Xs were presented and wrote down the color name in the booklet. The speed and accuracy of task performance were emphasized equally. The instructions for all three conditions were provided before the start of the study phase. In addition, the participants were informed that the instructions for each condition would appear on the computer screen again before the start of each block. No mention of the test phase, or the nature of the test, was made to either the implicit test group or the explicit test group until the start of the test phase.

The treatment of the two participant groups, implicit and explicit test groups, diverged at this point in the experiment. The participants in the implicit group received the same instructions as those in Experiment 1. The participants in the explicit group were asked to use the stem cues to aid in their retrieval of words that were shown to them earlier in the full-attention and the divided-attention conditions. They were specifically asked to complete only the stems with studied words and were asked to avoid completing the stems with any solution that came to mind. Both groups of participants were given 15 sec to solve each stem. The entire procedure for each group took approximately 40 min.

Results and Discussion

The statistical analyses for the implicit and explicit groups are presented in separate sections below, followed by a direct comparison between the data from the implicit and explicit groups in order to compare how the attentional manipulation influenced these two forms of memory. The mean proportions of accurate stem completion rates for the implicit and explicit groups in the full-attention, divided-attention, and nonstudied stems conditions are presented in Table 1.

The Implicit Memory Group

For study data,[3] a direct comparison revealed that the RTs in the neutral (911 msec) condition were faster than the RTs in the divided-attention (970 msec) condition [$t(71) = 2.1$, $SE = 16.64$], thereby confirming that reading interfered with color naming in the divided-attention condition. As expected, RTs in the full-attention condition were the fastest (598 msec). The error rates in the full (.001), divided (.01), and neutral (.01) conditions were very low.

The accuracy data for implicit word stem completion at test were subjected to a one-way ANOVA, yielding significant differences among the three conditions [$F(2,142) = 106.61$, $MS_e = 0.005$]. Subsequent paired-comparison t tests with the full-attention ($M = 0.29$) and divided-attention ($M = 0.20$) conditions and the nonstudied ($M = 0.11$) completion rates revealed significant priming in both the full-attention condition [$t(71) = 14.09$] and the divided-attention condition [$t(71) = 8.18$]. Importantly, we replicated the critical finding from Experiment 1 of reduced priming in the divided-attention condition, as compared with the full-attention condition [$t(71) = 6.75$], with a different perceptual priming task.

The Explicit Memory Group

Once again, we found that RTs were significantly faster in naming the color in the neutral (865 msec) condition than in the divided-attention (930 msec) study condition [$t(71) = 3.67$, $SE = 17.56$]. This replication of the pattern obtained for the implicit group was expected because, until this point in the experiment, there had been no procedural differences between the groups. Once again, the RTs were fastest in the full-attention condition (511 msec), and the error rates in all study conditions were very low (full = .004, divided = .014, neutral = .02).

A one-way ANOVA carried out to compare the explicit cued recall in the stem completion task revealed significant differences among the three conditions [$F(2,142) = 229.47$, $MS_e = 0.007$]. Focused comparisons were carried out by subtracting the false alarms in the nonstudied condition from the successful completion rates in the full-attention and divided-attention conditions (see Roediger et al., 1992, for this method of analysis). These comparisons revealed that explicit recall of words from the full-attention condition (.31) was significantly higher than the false alarms in the nonstudied condition (.03) [$t(71) = 17.34$]. Explicit recall in the divided-attention condition (.08) was also significantly higher than the false alarms in the nonstudied condition [$t(71) = 6.15$]. Finally, recall of studied items from the divided-attention condition was significantly lower than that from the full-attention condition [$t(71) = 14.21$]. This last finding is consistent with the typical reports that explicit memory for information encoded under conditions of divided attention is poorer than that for information encoded under conditions of full attention.

A Comparison of Implicit and Explicit Groups

The majority of studies in prior literature have shown that the encoding conditions of divided attention produce a disproportionately larger decrement in performance in explicit memory than in implicit memory tests. Additionally, performance in a task under standard encoding conditions, comparable here with the full-attention condition, rises in the explicit memory task, as compared with the implicit memory task, when all the test cues are held constant (e.g., Roediger et al., 1992). We conducted a two-way ANOVA with task instruction (implicit vs. explicit) as a between-subjects variable and study condition (divided vs. full) as a within-subjects variable on the priming (or studied–nonstudied) scores to determine whether these predicted patterns would emerge. The priming/studied–nonstudied scores for the divided- and full-attention conditions across the implicit and explicit groups are presented in Figure 1. This analysis revealed a trend for a main effect of task instructions [$F(1,142) = 2.08$, $MS_e = 0.01$, $p < .15$], a significant main effect of attention [$F(1,142) = 221.44$, $MS_e = 0.008$], and, most importantly, a significant interaction [$F(1,142) = 52.04$, $MS_e = 0.008$]. A comparison of studied–nonstudied scores in the divided-attention condition revealed that performance was higher for the implicit group ($M = 0.09$) than for the explicit group ($M = 0.05$) [$t(142) = 3.62$]. A similar comparison in the full-attention condition revealed a converse pattern; performance was higher for the explicit group ($M = 0.28$) than for the implicit group ($M = 0.18$) [$t(142) = 4.88$]. In other words,

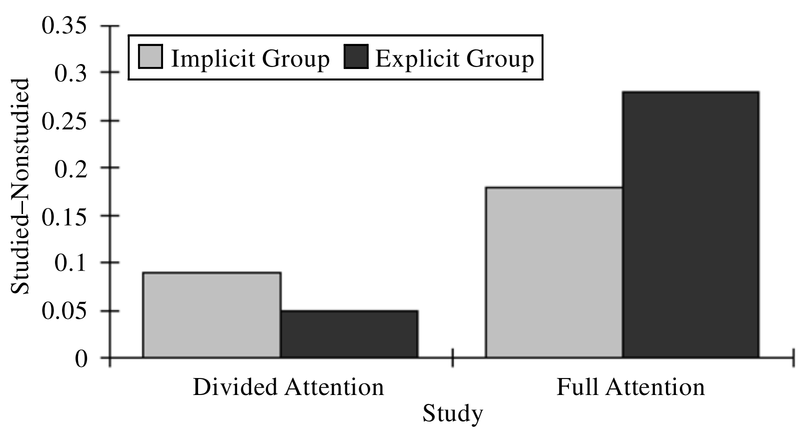

Figure 1. The mean studied–nonstudied measures for the implicit word stem completion and explicit cued recall tasks in Experiment 2.

these patterns nicely confirm the patterns reported in prior literature, even when we equated cues for implicit and explicit tests.

EXPERIMENT 3

Experiment 3 was designed to rule out the potential influence of the following procedural details on the reduced priming in the divided-attention condition of the implicit word stem completion task in Experiment 2. One, although we demonstrated that priming in the divided-attention condition was higher in the implicit task than in the explicit task of word stem completion in Experiment 2, the possibility remains that priming in the divided attention of implicit word stem completion was somewhat contaminated by explicit retrieval strategies. To rule out this possibility, we conducted the implicit word stem completion task again and excluded those participants who reported awareness of a study–test relationship through a posttest questionnaire (Bowers & Schacter, 1990). Two, the colors in which the target words were presented in Experiment 2 varied across the full and divided conditions. We eliminated this procedural difference by presenting the words in six different colors across these two conditions in this experiment. Three, in Experiment 2, we had required the participants to write down the word name in the full-attention condition and the color name in the divided-attention condition in order to ensure that the participants carried out the assigned tasks. However, this procedure may have differentially influenced the postperceptual processes in the two conditions beyond the intended differences in the response competition. In order to rule out this concern, we required the participants to perform only keypresses to process the word/color names and eliminated the requirement to additionally write the word/color names.

Method

Participants

A new group of 89 undergraduates from the State University of New York at Stony Brook participated in this experiment for partial fulfillment of course requirements.

Design and Materials

All aspects of the design, materials, and procedure were the same as in the implicit version of the word stem completion task in Experiment 2, with the following exceptions. First, words were presented in six different colors in the full-attention condition as well. Second, the participants were not required to write down the word/color names following their keypress responses at study. Third, the participants completed a posttest questionnaire following the implicit word stem completion task. This questionnaire included the following items: (1) What was your general strategy in completing the word stems? (2) Describe any characteristics of the words that you used to complete the word stems? (3) What did you think was the purpose of the stem completion test you just finished?

Results and Discussion

We determined whether a given participant had become aware of the connection between the study and test phases on the basis of the responses they gave on the posttest questionnaire. We used a stringent criterion whereby, even if the participants only indicated that some words might have reappeared in the stem completion task but did not intentionally think about the study list or retrieve studied words, we excluded them from further analyses. This procedure resulted in the exclusion of 17 participants. Therefore, the results presented below were obtained from the remaining 72 participants. The mean proportions of accurate stem completion rates for the full-attention, divided-attention, and nonstudied stems are shown in Table 1.

In the study data,[4] RTs in the neutral (776 msec) condition were again found to be faster than the RTs in the divided-attention (802 msec) condition [$t(71) = 4.18$, $SE = 6.25$], thereby confirming that word reading interfered with color naming in the divided-attention condition. Once again, the RTs in the full-attention (646 msec) were fastest, and the error rates in the full (.003), divided (.009), and neutral (.01) conditions were very low.

The accuracy data for implicit word stem completion at test were subjected to a one-way ANOVA, yielding significant differences among the three conditions [$F(2,142) = 59.85$, $MS_e = 0.005$]. Subsequent paired-comparison t tests conducted to compute priming in stem completion performance for the full-attention ($M = 0.21$) and divided-attention ($M = 0.15$) conditions relative to the nonstudied ($M = 0.08$) condition revealed significant priming in both the full-attention condition [$t(71) = 11.4$] and the divided-attention condition [$t(71) = 6.72$]. Importantly, priming was once again significantly reduced in the divided-attention condition compared with the full-attention condition [$t(71) = 4.38$], thereby replicating our results from the implicit word stem completion task in Experiment 2, as well as the implicit word fragment completion task from Experiment 1.

GENERAL DISCUSSION

The results of the three experiments reported here suggest that perceptual implicit memory depends on attentional requirements beyond those needed for simple identification. In three experiments, facilitation for studied words was reduced in the perceptual implicit tasks of word fragment completion and word stem completion when attention at study was directed to a perceptual attribute of the word other than its identity. Yet, word identity was indeed processed, as indicated by the slower response times for the color naming condition compared with the word naming (Experiment 1) or neutral (Experiments 2 and 3) conditions. Moreover, this attentional effect on perceptual implicit tests could not be attributed to the use of explicit retrieval strategies on these tasks for three reasons. First, under the full-attention condition, performance on the explicit stem cued recall test was *enhanced* compared with implicit word stem completion (Experiment 2). Second, performance under the divided-attention condition in the explicit stem cued recall task was *disrupted* compared with implicit word stem completion (Experiment 2). Third, even after the participants who exhibited awareness of the study–test relationship were eliminated from the analyses, reduced, yet significant, priming was observed in the divided-attention condition of the implicit word stem completion task (Experiment 3). Together, these data indicate that both perceptual implicit tests and perceptual/conceptual explicit tests are sensitive to attentional manipulations beyond those of processing word identity. However, explicit tests are influenced by attentional manipulations to a greater extent than are perceptual implicit tests, as demonstrated by our direct comparison of implicit stem completion and explicit stem cued recall tasks.

The reduction in priming on our implicit word fragment completion and word stem completion tasks are similar to the pattern of priming reported for the perceptual identification task (Mulligan & Hornstein, 2000; Stone et al., 1998), demonstrating that the three widely used perceptual priming tasks have similar attentional demands. These findings differ from the intact priming reported for the color-naming condition in a lexical decision task (Szymanski & MacLeod, 1996). As also indicated by prior reports (Rajaram & Roediger, 1993), the present findings suggest that the processing requirements of the lexical decision task may often differ from those of the other three perceptual priming tasks (see also Stone et al., 1998, for similar conclusions). Therefore, we will restrict our discussion of attentional requirements in perceptual priming to the findings obtained with the implicit word fragment completion, word stem completion, and perceptual identification tasks.

Before we turn to a theoretical analysis of the attentional demands in perceptual priming, it is important to note that word identity is indeed processed in the Stroop encoding task. This assumption is based on the ubiquitous demonstration that the processing of word identity increases RTs for color naming (MacLeod, 1991). Also, equivalent priming for words from the color-naming (Stroop) condition relative to the read condition has been reported in at least one task, that of lexical decision, indicating that word identity is fully processed in the Stroop encoding task (Szymanski & MacLeod, 1996). Furthermore, even when participants are required to first name the color and then read the word, priming remains equivalent to the condition in which only color naming is required, but is reduced relative to a condition in which participants only read the word (Mulligan & Hornstein, 2000). Thus, the requirement to name colors involves the processing of word identity, as is also documented in our study by longer RTs in the Stroop condition relative to the neutral condition.

In order to explain the reduction in perceptual priming, we propose that the magnitude of perceptual priming following color naming may be attenuated by the requirement to deselect the word as the target response (Rajaram & Srinivas, 1998). The basis for our claim comes from a series of studies that have documented *negative priming* for objects and words, when the object/word that is ignored on one trial becomes the attended stimulus on another trial (Tipper, 1985). Negative priming has been observed with the Stroop task (Neill, 1977) and over long intervals (DeSchepper & Treisman, 1996). It is thought to occur when the selection of a target for an appropriate response requires the inhibition of distractors that might interfere with the response (Milliken, Tipper, & Weaver, 1994). Given that the divided attention condition in a Stroop task requires the inhibition of the word for the naming of the color (see also Stone et al., 1998, for this assumption), one might expect negative priming to occur on perceptual implicit memory tests because of this inhibition. At the same time, positive priming should occur on perceptual implicit memory tasks for words to the extent that words were processed due to a failure to deploy attention selectively to the color-naming task. Thus, these two effects (negative and positive priming) sum together to produce a reduced priming effect in the divided-attention condition of the Stroop paradigm for perceptual implicit memory tests. Experimentally, then, two conditions have to be met for intact perceptual priming to occur. First, the word identity must be processed, and second, the word has to be selected as the appropriate response to prevent inhibition.

Several lines of evidence support our explanation. It has been shown that if participants are required to ignore a word, but not required to simultaneously deploy attention to another dimension of that same word, there is no reduction in priming for the ignored stimulus (MacDonald & MacLeod, 1998). But if participants are asked to ignore a word and select, or attend to, another word that constitutes the appropriate target, no priming is obtained for the ignored word in tasks of rapid reading (MacDonald & MacLeod, 1998) or perceptual identification and word stem completion (Crabb & Dark, 1999). The Stroop method of dividing attention falls in between these two arrangements so that the word and the secondary dimension are integrated and, as a result, both dimensions are processed (see MacDonald & MacLeod, 1998, for a similar explanation).

It is important that the effects of integration versus separation of the competing stimuli be understood at the processing level, and not at the physical level, to make accurate predictions in regard to the attentional requirements of perceptual priming. Specifically, if the color and the word are physically separated rather than integrated, and the participant is required to attend only to the color, priming fails to be significant for the words under such conditions. However, if the participants are required to attend to both dimensions, the competition in the selection of the appropriate response is instantiated, and the resultant perceptual priming, even though significant, is reduced (Mulligan & Hornstein, 2000).

Our explanation that intact perceptual priming requires processing of word identity, as well as selection of that word as the appropriate response, also derives empirical support from an elegant study reported by Hawley and Johnston (1991) on the effects of dividing attention on the implicit perceptual clarification task. In one of their experiments, they manipulated attention by presenting words flanked by digits at study. In the 0% attention condition, participants were asked to report the sum of the two digits on 100% of the trials, suggesting that 0% attention was paid to the target words. In the 50% condition, participants were asked to report the sum of two digits on 50% of the trials, suggesting that participants paid attention to both words and digits. In the 100% condition, participants were asked to report the words, which would be analogous to the full-attention condition used in the present study. Exposure duration for the display was also manipulated with a short (33 msec) and a long (67 msec) presentation time.

Hawley and Johnston (1991) observed a linear increase in positive priming on the perceptual clarification task in both short- and long-exposure-duration conditions, as a function of the attentional level (0%, 50%, or 100%). Interestingly, in the short- (33 msec) and long- (67 msec) exposure-duration conditions, when the word was ignored (0% condition), subsequent priming was either completely absent (for items from the long-duration condition) or *negative* (for items from the short-duration condition). In fact, this lack of priming or negative priming was obtained even when identification of words under those conditions was assumed to be well above zero.[5] One explanation for this curious finding might be that Hawley and Johnston's experiment required selective attention to digits and inhibition of words for successful performance. To the extent that selective attention to digits was effective in the 0%/short-exposure-duration condition, the irrelevant distractor words were ignored, and thus, negative priming for words was obtained in the short-duration condition. To the extent that selective attention to digits was ineffective in the 0%/long-duration condition, the irrelevant distractor words were processed, and negative priming summed with positive priming to lead to the absence of priming.

This interpretation clearly assumes that in the Hawley and Johnston (1991) study, words were effectively ignored in the 0%/short-exposure-duration condition and were not as easily ignored in the 0%/long-exposure-duration condition. This assumption receives support from their finding that accurate responses on the digit task were equivalent in both the short- and the long-exposure-duration conditions. In other words, equivalent accuracy in the two conditions suggests that extra attentional resources available in the long-exposure-duration conditions were presumably employed in the identification of words. Hawley and Johnston's assumption that, in the long-duration condition word identification was well above zero for the 0% condition, also fits with this hypothesis.

In sum, our data, and the related studies described here, support our hypothesis that intact perceptual priming is a function of processing word identity and selectively attending to the word as the appropriate response. Mulligan and Hornstein (2000) have claimed that reduced priming results not from the inhibition of priming arising from ignoring the word, as we have argued, but from the disruption of memory encoding of the target as a result of response competition between the target word and the competing dimension. Their alternate explanation is based on the evidence that, when participants are asked to first name the color and then name the word itself in a Stroop encoding task, the resultant priming for words on the perceptual identification task remains reduced compared with simply reading the word. The assumption here is that reading the word subsequent to naming the color should remove the inhibition that accrues from response competition and restore full-blown priming. However, according to this argument, it also follows that the disruption of memory encoding in a response competition situation should be overcome when participants read the word subsequent to naming the color. If anything, the opportunity to read the words subsequently should restore disrupted encoding. That perceptual priming is not fully restored despite subsequent reading indicates that the inhibition that accrues from having to deselect the word as the only appropriate response can be long lasting.

It may be argued that the inhibition account of long-term negative priming applies only to nonverbal stimuli (DeSchepper & Treisman, 1996) and not to verbal stimuli. However, three pieces of evidence that might be taken to support the verbal–nonverbal distinction are difficult to evaluate for methodological reasons. First, it appears that familiar, verbal stimuli produce short-term negative priming. However, these negative priming effects have been tested only with immediate trials, making it difficult to directly compare these studies with ours. Even within these short-term tests, however, negative priming with verbal stimuli does appear to last as long as 6–8 sec and survives intervening events (Neill & Valdes, 1992; Tipper, Weaver, Cameron, Brehaut, & Bastedo, 1991; and see Fox, 1995, for a review). Second, the evidence that short-term negative priming for words is obtained with multiple, and not single, presentations (Malley & Strayer, 1995) may seem counter to our inhibition account proposed for single presentations of words. But this comparison is also not appropriate because this outcome has been observed only with separate (as opposed to integrated) target-and-distractor stimuli, and only with immediate probe trials. Third, if a distractor from trial N is inserted again on trial N+1 for responding, before it appears as a probe on trial N+2, there is no negative priming on trial N+2 (Tipper et al., 1991, Experiment 6), suggesting that inhibition dissipates with this procedure. However, when participants first name the color and then name the word immediately afterwards, priming for that word is not fully restored on a later test but remains reduced (Mulligan & Hornstein, 2000). Again, it is difficult to compare these studies because disappearance of negative priming has only been observed in a task situation where the stimuli were repeated many times (as was also noted by Tipper et al., 1991, p. 689), and negative priming was measured only in the short term. There is some evidence, albeit with longer temporal parameters, that negative priming eliminated for novel shapes at short intervals does return at longer intervals (DeSchepper & Treisman, 1996).

Given that the current evidence from which a verbal–nonverbal stimulus distinction of negative priming could be drawn is limited, and given that an explanation based on the nature of stimuli can be mounted only by comparing experiments that differ on a variety of critical dimensions other than the stimulus differences, we favor an interpretation that is more in line with the integrative, theoretical framework of negative priming that Tipper (2001) recently proposed. Tipper's (2001) distinction between encoding-based, forward-acting inhibition and retrieval-based, backward-acting inhibition in negative priming provides a fruitful framework to understand these processes as they may relate to attention as well as memory. Forward-acting inhibition refers to the notion that when an item is deselected at encoding, inhibitory processes arise, and this inhibition may linger. Backward-acting inhibition refers to the notion that when the deselected item is encountered again, the selection mechanism of inhibition employed at encoding is automatically retrieved. In this way, the inhibition that occurred at encoding can have long-lasting effects. Our data and interpretations are consistent with this theoretical proposal.

In conclusion, findings reported in this manuscript advance our understanding of the role of attention in perceptual implicit memory by specifying the relative contributions of perceptual analysis and selective attention. Our findings show that, although diverting attention away from a target is not sufficient to lead to a reduction in perceptual priming, such a reduction occurs when attention is diverted away from the target *and* the competing response to the distractor leads to the inhibition of the processed target. We have demonstrated that this finding generalizes across the ubiquitously used perceptual priming tasks of word fragment completion and word stem completion and that the observed reduction in perceptual priming cannot be attributed to the operation of explicit memory in the priming tasks.

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NOTES

1. This difference in RT between full and divided conditions is a well-replicated finding with the Stroop manipulation. But this difference may, in part, have come about because of differences in response formats across full (simple choice) and divided (four-choice) conditions. However, the response format alone is not responsible for the Stroop effect because, as we demonstrate later, we obtained the Stroop effect even when the response format (four-choice) was equated between full and control conditions at study.

2. In all three experiments, RT was measured for the completion of word fragments and stems. No trends or significant differences were obtained in the RT data because of the small number of observations per subject. However, the important point to note is that the accuracy data are not compromised by a speed–accuracy tradeoff in test performance.

3. Note that in this group of 72 participants, mean RTs of 1 participant had to be replaced with the unadjusted means in each condition because this participant produced RTs that were more than two standard deviations away from the group means within each of the three conditions.

4. In this group of 72 participants, we replaced 2% of the observations in the neutral condition, 3% in the full-attention condition, and 4% in the divided-attention condition with the unadjusted means in order to truncate RTs that exceeded two standard deviations from the group means within each of the three conditions. Note that the pattern, and the statistical significance, of the study RT data did not change as a result of this trimming.

5. Hawley and Johnston (1991) suggest that identification of words in the 0% condition were well above zero, because word identification dropped from 95% to 80% in the 100% and 50% conditions, respectively, for the long-duration conditions. Given that 80% accuracy was found for 50% conditions, it is unlikely that identification dropped to 0 in the 0% conditions.

(Manuscript received November 19, 1997;
revision accepted for publication July 24, 2001.)