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On the immunity of perceptual implicit memory to manipulations of attention

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In four experiments, we examined the effect of manipulating study phase attention in a Stroop task on the extent of repetition priming in the lexical decision task (LDT). Experiment 1 replicated the *immunity* of the LDT to division of attention reported by Szymanski and MacLeod (1996), using a standard Stroop configuration. Response times to previously encountered words were identical regardless of whether the participants were required to read the words or name the color in which they were presented. Experiment 2 demonstrated that implementing the Stroop manipulation across separate visual objects reduced but did not eliminate priming of unattended words, provided the words remained in the attended region of the stimulus display. When this constraint was removed in Experiment 3, priming of unattended words disappeared. Experiment 4 demonstrated statistically equivalent priming for attended and unattended words when the Stroop manipulation remained in the same visual object but attention was directed to a single letter of the word. In all four experiments, the Stroop manipulation had a clear effect on recognition. These results qualify claims that the LDT might be immune to manipulations of study phase attention and suggest that the LDT has a lower threshold level of attention at encoding than do other standard implicit tests of memory.

Attention during the encoding of information has a substantial impact on the subsequent recall or recognition of that information. In these *explicit* tests of memory, which encourage effortful retrieval, there is a clear advantage for items that are attended at study over those that are ignored (e.g., Craik & Lockhart, 1972). In contrast, *implicit* tests of memory, in which retrieval may be unintentional, display less consistent effects of study phase attention: Sometimes there is an advantage for attended items (e.g., Mulligan, 2003; Mulligan & Hornstein, 2000; Rajaram, Srinivas, & Travers, 2001; Stone, Ladd, Vaidya, & Gabrieli, 1998); sometimes no effect of attention is found (e.g., Jacoby, Woloshyn, & Kelley, 1989; Mulligan & Hartman, 1996; Parkin, Reid, & Russo, 1990; Szymanski & MacLeod, 1996); and sometimes implicit tests show effects of attention that are absent in explicit tests (e.g., Kinoshita, 1995; Merikle & Reingold, 1991; but see Berry, Shanks, & Henson, 2006).

One clear impediment to resolving the issue of how attention affects implicit memory is the variety of methods and measures used to index memory. The inconsistent effects of attentional manipulations on implicit memory may, in large part, be attributable to the different methods of dividing attention and measuring memory (Stone, Ladd, & Gabrieli, 2000). The implicit memory literature distinguishes between implicit memory tasks according to whether they require conceptual or perceptual processing at retrieval (e.g., Blaxton, 1989), and this distinction appears to capture much of the variability in outcomes. Conceptual priming tasks, such as category exemplar production and free association, are more sensitive to divided attention at encoding (e.g., Gabrieli et al., 1999; Light, Prull, La Voie, & Healy, 2000; Mulligan & Hartman, 1996) than are perceptual priming tasks, such as word fragment completion (e.g., Mulligan & Hartman, 1996), perceptual identification (e.g., Schmitter-Edgecombe, 1996), and lexical decision (e.g., Kellogg, Newcombe, Kammer, & Schmitt, 1996). But, as was noted above, even within the class of perceptual implicit memory tests, there is evidence both for complete immunity to attentional manipulations at encoding (e.g., Jacoby et al., 1989; Parkin et al., 1990; Szymanski & MacLeod, 1996) and for attentional impairments that mirror those found in explicit memory (Crabb & Dark, 1999; Mulligan, 2003; Rajaram et al., 2001; Stone et al., 1998).

A plausible hypothesis tested by Rajaram et al. (2001) is that attentional manipulations affect perceptual implicit memory tests (stem completion, fragment completion, perceptual identification) when the method for dividing attention interferes with the perceptual analysis of the word during study. In support of this hypothesis, Raja-

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ram et al. noted that the majority of studies that reported deleterious effects of divided attention at study used within-modality manipulations (e.g., Weldon & Jackson-Barrett, 1993). By contrast, in studies in which no effect of attention has been reported attention has typically been divided *across* modalities (e.g., tone or digit monitoring; Mulligan & Hartman, 1996). Consistent with the perceptual hypothesis, Rajaram et al. found that priming, as measured by stem completion, was impaired when a Stroop (1935) manipulation was used to divide attention. The Stroop manipulation requires participants to name either the word or the color it is presented in. This is clearly a within-modality manipulation, so the reduced priming found for words subjected to color naming, rather than to word reading, suggests that reporting the color in which the word was presented impaired perceptual analysis of the word as a lexical unit. Such an interpretation is inconsistent with the commonly accepted view that words are processed automatically—an assumption that is critical to most interpretations of the Stroop effect itself (e.g., MacLeod, 1991). Rajaram et al. suggested that these apparent contradictions can be reconciled by assuming that although the word is identified automatically in the color-naming task (MacLeod, 1991), the resultant facilitation is offset by the inhibition associated with *deselecting* the word as the appropriate response. For priming to occur, words need not just to be processed, but also to be selected as the response. In the terminology used by Richardson-Klavehn and Gardiner (1998), implicit memory requires *lexical processing*, not just *lexical access*.

An alternative account of similar data has been proposed by Mulligan and Hornstein (2000). They argued that there is a central bottleneck for information processing and that, when both the distractor and the target are presented at the same time, processing of the target is disrupted and subsequent priming of the target is reduced (Mulligan, 2003). Support for this account has come from two key sources. First, when participants given the Stroop task have been asked to name *both* the color and the word, a significant reduction in priming has still been found, relative to a word-naming-alone condition, despite the requirement to select and respond to the word. Second, systematic comparisons of matched intramodal and cross-modal secondary tasks have shown that the temporal synchrony of targets and distractors is more important than modality or stimulus identification requirements. These findings led Mulligan (2003) to conclude that central attentional resources influence perceptual implicit memory, at least as indexed by perceptual identification tasks.

It was not the aim of the present study to test between these two accounts. Rather, the goal was to follow up a prediction that is common to them both: Implicit memory, as indexed by most of the standard tasks (stem and fragment completion, perceptual identification), will be impaired by attentional manipulations that create competition between target and distractor elements of stimuli. The subsequent decrement in priming may be the result of opposing facilitation and inhibition (Rajaram et al., 2001) or to competition for central attentional resources (Mulligan, 2003). Arguably, both accounts are more consistent with the process view of memory (e.g., Roediger & McDermott, 1993; Roediger, Weldon, & Challis, 1989), because both of them attribute implicit priming to the specific processes invoked by the requirements of the encoding task, rather than to the independent activation of representations in perceptual input systems (e.g., Tulving & Schacter, 1990).

There is, however, one method of assessing implicit memory that appears to be immune to manipulations of study phase attention, even under within-modality conditions. Priming effects in the lexical decision task (LDT) appear to be an exception to the general rule that implicit memory is reduced when encoding attention is compromised effectively by using a within-modality manipulation such as the Stroop task (Rajaram et al., 2001; Stone et al., 1998). The present research therefore focused on how a variety of Stroop manipulations affect implicit memory, as assessed using the LDT.

The study most often cited to support the claim that the LDT is immune to divided attention is one by Szymanski and MacLeod (1996; see also Kellogg et al., 1996), in which a standard Stroop task was used to manipulate attention to words during encoding. Participants received two blocks of trials: In one block, they were asked to read the word and ignore the print color, and in the other block, they were instructed to do the reverse. The participants were then given either a recognition memory test or a lexical decision test. In the recognition test, there was a clear effect of the study manipulation: Words that had been read aloud were remembered better than words for which the participants only had to report print color. In contrast, in the LDT, there was no difference in response times (RTs) for words that had been read or color named. That is, words that had been ignored received just as much priming as those that had been attended. This pattern of results led Szymanski and MacLeod to conclude, "clearly, then, implicit and explicit remembering dissociate with respect to attention" (p. 174). This result is in direct contrast to the reduced priming for color-named words found in perceptual identification and stem completion tasks (Rajaram et al., 2001; Stone et al., 1998).

Why might the LDT show such a clear dissociation? One possibility is that the processing requirements of lexical decision priming are different from those of perceptual identification and stem completion, in that the information necessary to support lexical decision priming can be acquired regardless of whether the stimulus is the subject of focal attention during study (Rajaram et al., 2001; Stone et al., 1998). This is consistent with accounts of the LDT that assume that lexical classification of at least common words can be based on overall lexical familiarity, without complete lexical identification (Grainger & Jacobs, 1996). Thus, even if color naming requires inhibition of the word (e.g., Rajaram et al., 2001) or creates competition between the word and the color (e.g., Mulligan & Hornstein, 2000), there may still be sufficient residual activation to support subsequent priming in the LDT. That is, enough information about the target word may "get through the bottleneck" or transfer appropriately to the lexical processing required for the LDT, even when attention is compromised.

This interpretation is consistent with the view that there is a threshold level of attention at encoding that needs to be exceeded "to create a lasting representation that can support performance on implicit tests" (Bentin, Moscovitch, & Nirhod, 1998, p. 328). The inconsistent results across different implicit measures might reflect differences in the required threshold. The intact priming in LDT implies that lexical classification can be successfully performed at a lower threshold than can other perceptual tests and that, once the threshold is reached, additional attentional resources at study do not add to the size of the observed priming effect. That is, LDT requires less residual lexical activation than does perceptual identification or stem completion, because it simply requires discriminating words from nonwords, whereas perceptual identification and stem completion requires the identification or generation of a *particular* word (cf. Gabrieli et al., 1999).

The focus of the present research was on the extent of the LDT's study phase attention immunity. One possibility, which we will examine here, is that the immunity holds only when both the attended and the unattended elements of the stimulus are part of the same object (as with the standard Stroop configuration). Such situations maximize the potential for what Bentin et al. (1998) have described as the "leaking" of attention to unattended aspects of the stimulus. When the color is an attribute of the target word, it is quite plausible that there will be considerable "leakage" of attention to support priming of unattended words (i.e., those for which only the color had been named) in a subsequent lexical decision test. However, when the word and the color are separated spatially, there is presumably less potential for such "leakage," and one may see the significant differences between priming for attended and unattended items that characterize other measures of implicit memory (cf. Mulligan, 2002; Mulligan & Hornstein, 2000). Indeed, research on the effect of spatial separation in visual selective attention tasks suggests that dividing attention across more than one physical stimulus will have detrimental effects on priming (e.g., Kahneman & Henik, 1981). There is also evidence that the standard Stroop effect is larger when color and word are part of the same object than when they are spatially separated (MacLeod, 1998).

As a preview, Experiment 1 was an exact replication of the experiment in Szymanski and MacLeod (1996), to establish the reliability of their reported effect. In Experiments 2 and 3, we examined conditions in which the attended and the unattended elements of the display occupied separate spatial locations. In Experiment 4, we returned to using integrated stimuli but employed a manipulation that narrowed the focus of visual attention to a particular component of the stimulus (i.e., a single letter).

EXPERIMENT 1

The aim of Experiment 1 was simply to replicate the results in Szymanski and MacLeod (1996). Although the article is quite widely cited, it contains only one experiment and has, to our knowledge, never been replicated. To this end, we gave participants the same word and nonword lists as those used in the original study. The participants performed the Stroop task, in which, in counterbalanced order, they named either the word or its color. Half the participants were then given a recognition memory test, and half an LDT. We predicted a substantial effect of the attentional manipulation on recognition memory but no effect on the magnitude of priming in the LDT.

Method

Participants

One hundred nine undergraduate students from the University of New South Wales completed the recognition task, and 111 completed the LDT, in exchange for course credit.

Materials

The words were taken from Appendix A of Szymanski and MacLeod (1996). There was a total of 108 six-letter words and 36 pronounceable six-letter nonwords created by changing one to three letters of the real words. Three lists of 36 words were created and rotated across word-naming, color-naming, and unstudied conditions, so that each item served an approximately equal number of times in each role. The nonwords were the same for all the participants.

Study Procedure

The experiment was a replication of the Szymanski and MacLeod (1996) study and employed a modified Stroop task. Noncolor words (e.g., *carpet*) were printed in lowercase letters in the colors yellow, red, green, and blue and were presented centered on a black computer screen. The participants received two sets of 36 words. For the word-reading task, they were to read each word aloud, ignoring its color; for the color-naming task, they were to ignore each word and, instead, say aloud the color in which the word was printed. The order of presentation of each stimulus was randomized, and items remained on the screen until the participant responded, followed by a 250-msec delay between items. The order of the tasks was counterbalanced, with half of the participants doing word reading first and the other half doing color naming first. Immediately prior to the study phase, the participants received a practice phase consisting of two sets of 10 number words (e.g., *eight* displayed in blue)—one set for color naming, the other for word reading. All the participants sat at individual computer terminals and completed the experiments in a class setting in groups of 15–20 individuals.[1]

Test Procedure

During the test phase, the words were again presented in lowercase and centered on a black screen, although the words appeared in white, rather than in one of the colors used at study. All the items remained on the screen until the participants responded. Test task was manipulated between subjects (in this and all the other experiments reported), with approximately half of the sample completing the recognition task and the other half completing the LDT (randomly assigned).

Recognition task. The recognition task included the 72 words that had occurred during the study phase, plus an additional 36 unstudied words. The participants were required to decide, as quickly as possible, whether the word had been presented during the study phase (press the "/" key) or not (press the "z" key).

Lexical decision task. Following Szymanski and MacLeod (1996), the LDT test list consisted of the 72 words presented during the study phase, 36 unstudied words, and 36 pronounceable nonwords. The participants were required to decide, as quickly as possible, whether the word presented was a real English word (press the "/" key) or not (press the "z" key).

Results and Discussion

Recognition Test

Table 1 displays the accuracy data for the recognition test. The probability of a *yes* response (i.e., *yes, I have seen*

Table 1
Mean Proportions of *Yes* Responses During the Recognition Test (With Standard Deviations)

		Word		Color		Never Studied	
Experiment	Description	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	Words were read, or the color of the word was named.	.67	.22	.44	.24	.27	.27
2	Words were read, or *same/different* decisions were made for the color of the blocks presented.	.55	.19	.38	.21	.25	.24
3	Words were read, or the color of blocks was named.	.62	.23	.33	.28	.28	.31
4	Words were read, or the color of one letter in the word was named.	.70	.19	.30	.19	.20	.18

Note—*Yes* responses are hits for studied words and false alarms for words that were never studied.

the word before in the study phase) differed significantly for the three types of test words [$F(2,107) = 165.78$, $p < .001$, $\eta^2 = .61$]. Planned comparisons showed that the proportion of *yes* responses was significantly greater for words read during study than for words whose color was named during study [$t(108) = 9.98$, $p < .001$, $\eta^2 = .48$], or for new words [$t(108) = 15.55$, $p < .001$, $\eta^2 = .69$]. Furthermore, *yes* responses were significantly higher for words whose color was named during study than for new words [$t(108) = 10.5$, $p < .001$, $\eta^2 = .51$]. The data show the clear and expected effect of study phase attention on recognition memory: Memory was better for words that were read than for those for which the color of presentation was named.

Lexical Decision Test

Error rates in the LDT are often low and relatively uninformative. However, because the participants were tested in a group setting, we wanted to be sure that they had performed the task appropriately. We excluded 2 participants whose accuracy fell below .80; thus, in the analyzed sample of 109 individuals, accuracies were in the range of .88–1.00. The mean accuracy for words read was .98; for words whose color was named, it was .97, whereas for words never studied the mean accuracy was .95.

The nonword data were excluded from analysis, although RTs are displayed in Table 2 for completeness. RT data were trimmed to remove all responses above 2,000 msec and below 200 msec (1.5% of the responses). All the analyses in this and all the other experiments were conducted on data from trials on which correct responses were made. The mean RTs in the LDT were significantly different for the three conditions involving words [$F(2,107) = 8.88$, $p = .001$, $\eta^2 = .08$]. Planned comparisons indicated that RTs for words encountered before (i.e., words either read or color named) were significantly shorter than those for new words [read, $t(108) = 3.39$, $p < .001$, $\eta^2 = .10$; color, $t(108) = 3.35$, $p < .001$, $\eta^2 = .09$]. However, crucially, RTs for decisions about color-named words and words read did not differ significantly from each other [$t(108) = 0.41$, $p > .97$, $\eta^2 = .00$]. As Table 2 shows, the mean RTs were, in fact, identical, lending considerable weight to Szymanski and MacLeod's (1996) original claim that substantial and *equal* amounts of priming are observed in the LDT, regardless of the degree of attention paid to the words during study.

Table 2
Mean Response Times (in Milliseconds, With Standard Deviations) for Each of the Four Types of Words in the Lexical Decision Task

		Word		Color		Never Studied		Nonword	
Experiment	Description	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	Words were read, or the color of the word was named.	526	81	526	84	542	86	622	141
2	Words were read, or *same/different* decisions were made for the color of the blocks presented.	543	80	559	82	577	85	708	134
3	Words were read, or the color of blocks was named.	614	116	659	154	653	157	860	227
4	Words were read, or the color of one letter in the word was named.	612	114	620	125	643	116	822	159

Experiment 1 provided a clear demonstration of the immunity of repetition priming in the LDT to a manipulation of study phase attention. Having established the reliability of the effect reported by Szymanski and MacLeod (1996), we then sought to examine the boundaries of the effect. Specifically, we examined whether immunity is observed only if the attended and the unattended elements of the stimulus occupy the same physical location (cf. Kahneman & Henik, 1981; MacLeod, 1998; Mulligan, 2002; Mulligan & Hornstein, 2000).

EXPERIMENT 2

In Experiment 2, attention was manipulated across physically separated stimuli, using a manipulation applied by Mulligan and Hornstein (2000) in which the color is placed in blocks flanking the word, rather than the word itself being colored. In Mulligan and Hornstein (Experiment 4), the blocks on either side of the word were the same color, and the participants' task was to either read the word or name the color of the flanker block. In such a setup, it is conceivable that some attention will "leak" to the word when a color judgment is made (Bentin et al., 1998); however, it is also possible that participants will simply attend only to a block on one side and effectively ignore the word. An extreme interpretation of the immunity observed in Experiment 1 is that the mere presence of the target word in a participant's field of view is sufficient to support subsequent priming in the LDT, so priming will be observed even in the arrangement used by Mulligan and Hornstein. Such a prediction is compatible with the commonly accepted view that Stroop interference effects in color naming occur because words are processed automatically (e.g., Ashcraft, 2002; Rayner & Pollatsek, 1989). However, it may be that sufficient attention will leak to the unattended stimulus only if it is in the attended region of space. Thus, in Experiment 2, we ensured that the word was in the attended region when a color judgment was made. To do this, we randomized trials on which the colors of the flanking blocks were the same and trials on which they were different and asked the participants to make a *same/different* judgment on each trial. This necessitated looking at the block on each side of the word, making it, presumably, rather difficult to completely exclude the word from visual attention.

Method

Participants

One hundred nine undergraduate students from the University of New South Wales completed the recognition task, and 119 completed the LDT, in exchange for course credit.

Procedure

The procedure was identical to that in Experiment 1; however, during the study phase, instead of the word appearing in colored print, the participants were required to decide, as quickly as possible, whether two blocks of color presented on either side of the word were the same color (press the "/" key) or different colors (press the "z" key). The blocks of color were 1×2 cm and flanked the word, which was always printed in white. The blocks were green, blue, red, or yellow, and there were equal numbers of trials on which the blocks were the same color or different colors. The participants sat at individual computer terminals and completed the experiment in a class setting in groups of 15–20.

Results and Discussion

Note that for the results, we will use the term *color decision words* to describe words that were present on the trials on which a *same/different* judgment was made about the colors of the flanker blocks.

Recognition Test

Table 1 displays the accuracy data for the recognition test. Consistent with the results of Experiment 1, the probability of a *yes* response differed significantly for the three types of test words [$F(2,107) = 12.03$, $p < .001$, $\eta^2 = .33$]. Planned comparisons showed that the proportion of *yes* responses was significantly greater for words that had been read during study than for color decision words [$t(108) = 7.22$, $p < .001$, $\eta^2 = .33$] or for new words [$t(108) = 9.97$, $p < .001$, $\eta^2 = .48$]. Furthermore, *yes* responses were significantly higher for color decision words than for new words [$t(108) = 7.99$, $p < .001$, $\eta^2 = .37$]. Once again, the predicted effect of study phase attention was shown for recognition memory: Memory for words read was significantly better than that for the color decision words, and both were better than that for the novel words.

Lexical Decision Test

Eight participants had accuracies below .80 and were excluded from analysis. All individual participant accuracies in the analyzed sample of 111 were in the range of .84–1.00. The mean accuracy for both color decision words and words read was .98, whereas for words never studied, the mean accuracy was .95.

The RTs to the different types of words are shown in Table 2. RT data were trimmed to remove all responses above 2,000 msec and below 200 msec (1.2% of the responses). The mean RTs in the LDT were significantly different for the three conditions involving words [$F(2,109) = 35.08$, $p < .001$, $\eta^2 = .24$]. Planned comparisons indicated that RTs for words encountered before (i.e., words read or color decision words) were significantly shorter than those for new words [read, $t(110) = 8.14$, $p < .001$, $\eta^2 = .38$; color, $t(110) = 4.13$, $p < .001$, $\eta^2 = .13$]. However, in contrast to Experiment 1, decisions for words named were significantly faster than those for color decision words [$t(110) = 4.43$, $p < .001$, $\eta^2 = .15$]. The decision time advantage for words read was almost double that for the color decision words (34 and 18 msec, respectively). That is, unlike in Experiment 1, there was now a clear effect of study phase attention on the extent of priming in the LDT, and furthermore, the direction of the effect was consistent with that seen for recognition memory.

Experiment 2 demonstrated a clear boundary on the *immunity* of the LDT to attentional manipulations. Spatially separating the attended and the unattended elements of the stimuli gave rise to a significant difference in the amount of priming of the two elements. Nevertheless, significant priming was still observed for words present on the color decision trials. The priming effect is consistent with some attention "leaking" to the unattended aspect—the word—on these trials. This "leakage" may have occurred because, when the *same/different* color judgment was made, the word entered into the attended region of space. In Experiment 3, we examined whether we would still find priming—albeit reduced—to the unattended aspect when the color task did not necessitate comparing the two color blocks.

EXPERIMENT 3

In Experiment 3, we used the same arrangement as that in Mulligan and Hornstein (2000), in which the color for the words was placed in two flanking blocks that were the same color. The participants were required to either name the color of the block or read the word. In the color-naming condition, the participants needed only to process one color block, because they were identical, and could, therefore, avoid focusing visual attention on the word. If significant priming was found for words present when the block color was named, this would suggest that the LDT has an extremely low attention threshold (i.e., that the mere presence of the word in the stimulus display was sufficient to support priming). If, on the other hand, significant priming was not observed, it would suggest that the word needed to be the focus of visual attention for sufficient processing to "leak" to support priming in the LDT like that observed in Experiments 1 and 2.

Method

Participants

Twenty-six undergraduate students from the University of New South Wales completed the recognition task, and 25 participants completed the LDT, in exchange for course credit.

Procedure

The procedure was identical to that in Experiment 2, with the exception that, on every trial, the blocks presented on either side of the word were the same color (e.g., the blocks were both blue, both green, etc.). The participants were required either to read the word or to name the color of the blocks. The participants were tested individually in single occupant testing rooms.

Results

Recognition Test

Table 1 displays the accuracy data for the recognition test. The probability of a *yes* response differed significantly for the three types of test words [$F(2,24) = 6.88$, $p < .05$, $\eta^2 = .36$]. Planned comparisons showed that the proportion of *yes* responses was significantly greater for words read during study than for color decision words [$t(25) = 3.33$, $p < .05$, $\eta^2 = .31$] or for new words [$t(25) = 3.63$, $p < .05$, $\eta^2 = .35$]. Furthermore, *yes* responses were significantly higher for color decision words than for new words [$t(25) = 2.32$, $p < .05$, $\eta^2 = .18$]. The data once again show the predicted effect of study phase attention: Words read show better memory than do color decision words, and both show better memory than do new words.

Lexical Decision Test

Two participants displayed accuracy below .80. All individual-participant accuracies in the analyzed sample of 23 were in the range of .80–1.00. The mean accuracy for words never studied was .93; and mean accuracy for color decision words was .93, whereas that for words read was .95.

The mean RTs in the LDT are shown in Table 2. RT data were trimmed to remove all responses above 2,000 msec and below 200 msec (4.9% of the responses). Overall, RTs were longer than those in the similar conditions in Experiment 2. The reason for this difference is not entirely clear, but we think it may have been due to the change from a group-testing environment (used in Experiments 1 and 2) to an individual-testing environment (used in Experiments 3 and 4; RTs were also longer overall in Experiment 4; see Table 2). One possibility is that participants are more cautious in responding when tested individually, leading to the longer RTs. However, the size of the priming effects for the word-reading conditions were very similar in Experiments 2 and 3 for both the recognition task and the LDT (there were differences between words read and those never studied of .30 and .34 for the recognition test, and of 34 and 39 msec for the LDT in Experiments 2 and 3, respectively), suggesting that the intracondition comparisons (word vs. color encoding) remain informative.

RTs were significantly different for the three conditions involving words [$F(2,21) = 4.19$, $p < .05$, $\eta^2 = .29$]. Planned comparisons revealed a picture different from that found in Experiment 2: RTs for words *read* before were significantly different from those for new words [$t(22) = 2.64$, $p < .05$, $\eta^2 = .25$]; but RTs for the color decision words were not significantly different from those for the new words [$t(22) = 0.559$, $p > .50$, $\eta^2 = .00$]. In fact, responses to color decision words were numerically *slower* than those to new words. In addition, decisions for words named were significantly faster than decisions for color decision words [$t(22) = 2.92$, $p < .05$, $\eta^2 = .29$]. Thus, when the two elements of the stimuli are separated and the color decision can be made simply by inspecting one (not both) color blocks, significant priming is observed only for attended words (cf. Mulligan & Hornstein, 2000).[2]

The elimination of priming for color-named words is consistent with Mulligan and Hornstein's (2000) original application of this methodology, using a perceptual identification task: Priming was eliminated for words presented in a color categorization task during study. Thus, when the word and the color cue are spatially separated in a manner that allows words to be excluded from the focus of visual attention, LDT repetition priming effects show sensitivity to study phase attention that parallels that found in other tests of perceptual implicit memory.

EXPERIMENT 4

Experiments 2 and 3 showed that diverting study phase attention from the spatial location of the word had a clear effect on priming of the unattended element—either reducing (Experiment 2) or eliminating (Experiment 3) repetition priming in the LDT. These results qualify claims that the LDT is immune to manipulations of study phase attention (e.g., Mulligan, 2003). In contrast, Experiment 1 clearly showed that a standard Stroop task manipulation of study phase attention yielded equivalent (in fact, identical) priming for both the attended and the unattended element of the display.

One explanation of the differences between the priming effects in Experiment 1, by comparison with Experiments 2 and 3, is that automatic lexical processing occurs only when the word stimulus is the sole focus of visual attention; the presence of even nonlexical distractors impairs lexical processing (Kahneman & Henik, 1981). To examine further the relation between visual attention and lexical-access/lexical-processing on the extent of priming in the LDT, in Experiment 4, we employed a manipulation (borrowed from the Stroop task literature) that discouraged treatment of the stimulus as a lexical entity but ensured that the word stimulus (or at least its spatial location) was the sole focus of visual attention.

In a series of experiments, Besner and colleagues (e.g., Besner & Stolz, 1999; Besner, Stolz, & Boutilier, 1997; Manwell, Roberts, & Besner, 2004) have examined the impact of a *single-colored-letter* variant of the Stroop task on the standard Stroop interference effect. In this variant of the standard task, participants are presented with words in which only one letter is colored, and they are asked to name the color of the letter. The location of the to-be-named letter is cued on each trial, and a combination of congruent (color of letter and letter string refer to the same color) and incongruent trials are used. The finding of interest is that Stroop interference is reduced or even eliminated in the single-letter condition (Besner et al., 1997). One explanation of this effect is that cuing a single letter "reduces or prevents activation in the word recognition system" (Besner & Stolz, 1999, p. 99). Besner et al. suggested that the reduction in activation is limited to *semantic* processing, whereas "lexical-level processing (as indexed by repetition and morphemic priming) remains preserved" (p. 222).[3] This account predicts that, in a design similar to that in Experiment 1, a single-colored-letter encoding condition should lead to a level of priming equivalent to that in the read condition—provided that lexical access is sufficient for LDT repetition priming. Alternatively, the narrowing of spatial attention induced via the single-letter cuing may have an impact similar to the diversion of spatial attention induced by the flanker arrangements used in Experiments 2 and 3. If this occurs, the read condition should produce a larger priming effect than does the color decision condition, in spite of the attended and unattended elements' being part of the same stimulus.

Method

Participants

Forty-two undergraduate students from the University of New South Wales completed the recognition task, and 58 completed the LDT, in exchange for course credit.

Procedure

The procedure was identical to that in Experiment 1, with the exception that during the study phase, instead of the entire word appearing in colored print, only one letter of the word appeared in colored print and the remaining letters appeared in white. Following Besner et al. (1997), the colored letter was randomly selected and cued with a white arrow one line above and one line below on every trial (cf. Besner et al., 1997).

Results and Discussion

Recognition Test

Table 1 displays the accuracy data for the recognition test. The probability of a *yes* response differed significantly for the three types of test words [$F(2,40) = 95.25$, $p < .001$, $\eta^2 = .77$]. Planned comparisons showed that the proportion of *yes* responses was significantly greater for words read during study than for words whose color was named during study [$t(41) = 8.81$, $p < .001$, $\eta^2 = .65$] or for new words [$t(41) = 5.06$, $p < .001$, $\eta^2 = .38$]. Furthermore, *yes* responses were significantly higher for words whose color was named during study than for new words [$t(41) = 11.5$, $p < .001$, $\eta^2 = .76$].

Lexical Decision Test

All individual-participant accuracies were in the range of .85–1.00. The mean accuracy for words read was .96; for words color named it was .95, and for words never studied it was .95.

The nonword data were excluded from analysis, although they are shown in Table 2. The mean RTs in the LDT were significantly different for the three conditions involving words [$F(2,55) = 9.90$, $p < .001$, $\eta^2 = .15$]. Planned comparisons indicated that RTs for words encountered before (i.e., words either read or color named) were significantly shorter than those for new words [read, $t(57) = 4.33$, $p < .001$, $\eta^2 = .25$; color, $t(57) = 3.02$, $p < .05$, $\eta^2 = .14$]. Crucially, color-named words and words read did not differ significantly from each other in RT [$t(57) = 1.10$, $p > .27$, $\eta^2 = .02$]. This pattern of statistically equivalent priming for attended and unattended words is consistent with the pattern found in Experiment 1 and is consistent with the view that words are accessed automatically, as long as they are within the focus of visual attention.

GENERAL DISCUSSION

In four experiments, we examined the effect of manipulating study phase attention on the extent of repetition priming in the LDT. Experiment 1 replicated Szymanski and MacLeod's (1996) evidence for the immunity of the LDT to a Stroop task manipulation of attention. Experiment 2 demonstrated that implementing the Stroop manipulation across separate visual objects reduced but did not eliminate priming of unattended words, provided the word remained in the attended region of the stimulus display. Experiment 3 demonstrated that priming of the unattended word disappeared when it was no longer, necessarily, in the attended region of the display. Finally, Experiment 4 demonstrated statistically equivalent priming when the Stroop manipulation remained in the same visual object but attention was directed to a single letter of the word.

Stone et al. (2000) suggested that the pattern of results reported by Szymanski and MacLeod (1996), and replicated in Experiment 1, is not surprising given that the standard Stroop color-naming task neither "diverts attention from the spatial location in which the words are presented . . . [nor eliminates] lexical processing" (p. 344). Nevertheless, a critical question remains as to why that pattern does not hold for other perceptual implicit tasks, such as stem completion, fragment completion, and word identification, in which priming has been found to be significantly reduced following color naming.

As was discussed in the introduction, the decrement found in other tasks is predicted and explained by accounts that propose a bottleneck for information processing (Mulligan & Hornstein, 2000) or inhibition associated with deselecting the appropriate element of the display (Rajaram et al., 2001). We suggested that a possible explanation of why the LDT is not influenced by these factors lies in the nature of the lexical information required to support successful LDT performance (Grainger & Jacobs, 1996). The binary classification requirements of the LDT mean that it can, in principle, be performed on the basis of overall familiarity or "wordlikeness" and does not necessarily require full stimulus identification (e.g., Balota & Chumbley, 1985; Grainger & Jacobs, 1996; Ratcliff, Gomez, & McKoon, 2004). This may make it more sensitive to levels of residual activation than are other perceptual implicit tasks, such as perceptual identification and stem completion.

Besner et al. (1997) claimed that the single-colored-letter manipulation used in Experiment 4 impacts on semantic, but not lexical, aspects of word recognition, leading to the prediction that priming would be similar in the read and color-naming conditions. Experiment 4 showed a clear priming effect for the color decision words—indicating that a requirement to name the color of the letter still led to the encoding of sufficient lexical information about the whole word to support LDT priming. Furthermore, this priming was statistically equivalent to that found in the word-reading condition (the advantage for read words was only 8 msec), suggesting, in line with Besner et al., that the manipulation had very little impact on the encoding of lexical information.

Richardson-Klavehn and Gardiner (1998) argued that lexical identification is a necessary and sufficient condition for perceptual implicit priming, but others have challenged this view (e.g., Mulligan, 2003). The convergence of the results of Experiments 1 and 4 with those in Szymanski and MacLeod (1996) suggests that automatic lexical access may be a sufficient condition for LDT repetition priming, whereas most, if not all, other tests of perceptual implicit memory require, at least, *lexical processing*, which Richardson-Klavehn and Gardiner defined as attending to the stimulus as a lexical entity.

The sensitivity of the LDT to automatic lexical processing may be enhanced by the fact that this task presents the complete stimulus under clear conditions that maximize the perceptual overlap with the prior presentation of the complete word during encoding. That is, using the LDT to assess implicit priming for stimuli presented as whole words during encoding provides the optimum conditions for transfer-appropriate-processing principles to contribute to facilitated performance (Blaxton, 1989). The degraded and partial stimulus formats required in perceptual identification and stem/fragment completion tasks may be more vulnerable to the impact of reduced attention at encoding.

A further reason for the greater sensitivity of the LDT to the automatic encoding of word stimuli can be derived from Moscovitch's (1992) *components of processing* approach, which proposes that perceptual implicit tests reflect reactivation of *perceptual records* that represent presemantic structural information. In the case of words, this information most obviously corresponds to that contained in the orthographic lexicon implicated in all the major models of lexical processing (see Andrews, 2006, for reviews of a number of different models). LDT responses also depend on activating representations in the orthographic lexicon and can, in principle, be made without retrieving semantic information (cf. Besner et al., 1997) or even without identifying which orthographic representation was most active (Grainger & Jacobs, 1996). Thus, residual activity in the orthographic lexicon may be sufficient to facilitate a subsequent LDT response, but not to support the individuated word identification required for successful performance in perceptual identification or stem/fragment completion tasks (Gabrieli et al., 1999).

As well as confirming that the LDT can show immunity to manipulations of study phase attention (e.g., Mulligan, 2003), the present experiments also establish the boundaries of this immunity. Specifically, when study phase attention must be divided between spatially separate word and color stimuli, priming of the unattended element is significantly impaired. Taken together, the results of all four experiments suggest that automatic lexical processing occurs only when the attended and the unattended aspects of the stimulus are part of the *same* visual object and that such automatic processing is robust to a narrowing of attention within that object (as in the single-letter manipulation in Experiment 4).

Attention Threshold

We have argued that our results are consistent with the claim that the LDT has a lower threshold of sensitivity to prior exposure than do other implicit tests. This interpretation parallels a similar conclusion drawn by Bentin et al. (1998) in their examination of the effects of levels-of-processing manipulations on repetition priming in the LDT. Bentin et al. concluded (1) that a threshold level of attention is necessary to establish representations sufficient to support subsequent priming effects and (2) that exceeding this threshold adds little to the magnitude of the priming effect for lexical-level tests (such as the LDT) but that performance in explicit tests (such as recognition) can benefit substantially from exceeding the threshold. The results of Experiments 1 and 4 are entirely consistent with these two conclusions: Priming for attended and unattended items was statistically equivalent, but recognition memory clearly benefited from the "deeper" processing afforded by reading the word at study. Experiment 2 showed that when study phase attention was diverted from the word stimulus but the word remained in the attended region, priming could still be found for unattended items, but at a lower level than for attended items. The fact that priming for unattended items was still observed means that the threshold for supporting LDT performance must have been exceeded for *at least some* words. The fact that priming effects were larger for attended words suggests that they were more likely to exceed the attention threshold.

However, the results of Experiment 3 appear to present a challenge to the threshold account, or at least to the version of the account proposed by Bentin et al. (1998). Their third conclusion was that the attention threshold for explicit recognition is "higher than that needed to sustain performance on implicit tests" (p. 335). This claim was based on studies showing that priming is found on implicit tests in the absence of above-chance performance on explicit tests (e.g., Merikle & Reingold, 1991). Experiment 3 showed the opposite pattern: modest but significantly better recognition memory for unattended words than for novel words, but no repetition priming of unattended words. Such a result is inconsistent with the idea that explicit tests have a *higher* attention threshold, because the recognition test appears to have been more sensitive to previously exposed information than was the LDT.

The claim that explicit tests have higher thresholds of attention has, however, been challenged. Berry et al. (2006) failed, in four experiments, to replicate Merikle and Reingold's (1991) key finding that an implicit test—a contrast judgment—was more sensitive than was recognition to a previously unattended word. Berry et al. pointed out that the pattern they found—as recognition performance on unattended items approached chance, priming effects similarly diminished and did not exceed recognition—is, in fact, a far more commonly reported pattern. Our results also fit this general pattern: Experiments 1, 2, and 4 showed comparable recognition memory effects for unattended over novel items (range, .10–.17) and comparable repetition priming for unattended over novel items (range, 16–23 msec). Experiment 3 showed no significant priming for unattended items and the smallest recognition memory effect for unattended items (a difference from the false alarm rate of only .05). Taken together, these results point toward *quantitative*, rather than *qualitative*, differences between implicit and explicit tests of memory. Consistent with this conclusion, the correlation between the priming effects observed in the recognition memory and LDT tasks across the four experiments was .67, suggesting that similar mechanisms underlie performance in the two tasks. Differences between the measures therefore appear to be due to differential sensitivity, rather than to the involvement of different underlying systems or processes.

The differential sensitivity may arise from the stronger motivation to retrieve exposed information in explicit than in implicit tests of memory. This intention to retrieve information may make it more likely that traces of encoded information, however weak, will be utilized (cf. Schacter, Bowers, & Booker, 1989), leading to the small, but significant, priming effect observed for color-named items in the recognition task in Experiment 3.

Conclusion

The conditions under which LDT repetition priming is immune to manipulations of attention at encoding are limited. However, LDT priming does appear to differ from perceptual identification, stem/fragment completion, and preference judgment tasks in showing statistically equivalent priming for unattended words from a standard and a single-letter Stroop color-naming task. This suggests that the LDT has a lower threshold of sensitivity to prior exposure than do other perceptual implicit memory tasks. Although such a claim might be considered a simple redescription of the data, our analysis has gone beyond this by suggesting reasons *why* the threshold might be lower. The LDT provides the optimum conditions for transfer-appropriate-processing principles to apply, and accurate LDT responses can be made without threshold identification of the stimulus. Our results suggest that the LDT may uniquely tap residual activity that supports word identification. In this sense, it might be argued that LDT priming provides the "purest" measure of a perceptual implicit memory, if this is identified with the residual consequences of recent processing of the item.

AUTHOR NOTE

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NOTES

1. The participants were tested in groups but sat at individual computer terminals. The participants were asked to read words aloud, but in a quiet voice. To reduce potential distraction effects, all the participants were given earplugs to wear.

2. Experiment 3 used a sample size similar to those typically used in investigations of LDT priming. (The Szymanski & MacLeod [1996] study used slightly fewer than Experiment 3: 20 participants per condition, as compared with 25/26.) Despite this, and given the extremely large samples used in Experiments 1 and 2, it is important to ask whether Experiment 3 had enough power to detect a priming effect, for the color decision words, of the magnitude of the effects found in Experiments 1 and 2. Post hoc power calculations using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) indicated an achieved power in excess of .90 for Experiments 1 and 2; however, Experiment 3 had a power of only .54 to detect a medium-sized effect and .17 to detect a small-sized effect similar to that found in Experiment 2. Note, though, that the observed effect in the LDT task in Experiment 3 was *inhibitory* and that, although the priming effect on recognition for the color-named words was very small, it was statistically significant.

3. The discussion of the role of lexical processing is plagued by variations in terminology. In this quote, Besner et al. (1997) appear to be using the term *lexical processing* to refer to what we describe as *lexical access*.

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