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Levels of processing and selective attention effects on encoding in memory

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Abstract

The purpose of the present study was to investigate the effects of selective attention and levels of processing (LOPs) at study on long-term repetition priming vis-a-vis their effects on explicit recognition. In a series of three experiments we found parallel effects of LOP and attention on long-term repetition priming and recognition performance when the manipulation of these factors at encoding was blocked. When a mixed study condition was used, both factors affected explicit recognition, while their effect on repetition priming was determined by the nature of the test. Shallow processing at test did not benefit from long-term repetition, regardless of whether the words had been studied deeply or shallowly. Selective attention affected long-term repetition priming in a semantic, but not in a lexical decision (LD), test. Regardless of study condition, retention lag affected long-term repetition priming only in the semantic test. These results suggest that if the experimental conditions allow scrupulous selection of attended and unattended information or narrow tuning to a shallow, pre-lexical LOP, implicit access to unattended or shallowly studied items is significantly reduced, as is explicit recognition. We suggest a conceptual framework for understanding the effects of LOP, attention, and retention interval on performance of explicit and implicit tests of memory.

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1. Introduction

In their discussion paper, Kelley and Jacoby (this issue) consider how different processes and sources of information contribute to the subjective experience of remembering as well as to objective performance on memory tests. In particular, they contrast the influence of automatic processes and fluency heuristics with that of control processes and conscious recollection. From reviewing their own work and that of others, it is clear that automatic processes outside of conscious awareness contribute not only to performance on implicit tests of memory but also to performance on explicit tests which are accompanied by a subjective experience of familiarity. One of the issues that remains unresolved, however, is the role that attention and deep semantic processing play in memory. From some of the studies reviewed in their paper, it is clear that at very short delays, even material of which subjects are unaware (but which they presumably perceive) can influence performance on implicit tests and even enhance the subjective sense of familiarity on explicit tests. What happens at long delays, however, is much less certain. We know that an item that is masked but perceived without awareness leaves little or no residue in memory when testing is delayed by even a few seconds (Forster and Davis, 1984). But what about material that is merely unattended or processed at a very shallow level? Will it affect performance at long delays on either explicit or implicit tests? We address this question in our experiments and present a model to account for the relation of attention and depth of processing to long-term retention on implicit and explicit tests of memory.

Attention and level of processing (LOP) during encoding of information have a profound influence on explicit memory for studied words as is evident in tests of recall or recognition. In such tests, performance is significantly higher for items that are attended at study than for items that are ignored, and improves dramatically with increase in the depth of processing (for reviews see Craik and Lockhart, 1972; Lockhart and Craik, 1990). In contrast, the influence these variables have (if any) on memory as measured implicitly by repetition priming is less clear (for review, see Roediger and McDermott, 1993). Because these variables play a major role in many models and theories of memory, it is important to gain a better understanding of their influence on explicit and implicit tests of memory. In particular, it is necessary to specify the extent of their influence and the conditions under which they operate for both types of memory. In this study, we show that the influence of LOP and attention on implicit memory, and to a lesser extent on explicit memory, depends crucially on study conditions which in turn determine the effect of retention interval on performance. Based on our results and those reported by others, we offer a conceptual framework which integrates the effects of these variables on explicit and implicit memory.

Of the two factors, LOP has been studied more extensively than attention. Although many investigators reported that the depth at which words are processed at study has little or no effect on long-term repetition priming, some investigators found a substantial effect, yet not as large as that found on explicit tests (for reviews see Brown and Mitchell, 1994; Challis and Broadbeck, 1992; Roediger and McDermott, 1993). For example, Challis and Broadbeck (1992) found that LOP affected performance on fragment completion tests only when the levels were blocked (both within and across participants). When levels were mixed within a single session, performance was equivalent (both within and across participants) regardless of whether processing was shallow or deep. Thapar and Greene (1994) replicated this finding and extended it to other tests of memory based on perceptual and conceptual priming. On the other hand, Craik et al. (1994) and many other investigators cited in the reviews, did not find that LOP effects on fragment completion were influenced by these design manipulations. In that study, however, the factors were not varied in a single experiment. At issue may be the conditions at study which either restrict the application of a deep or shallow orienting task to the study item (as in Challis and Broadbeck, 1992), or which allow the attention to "leak" from one level to another (as in Craik et al., 1994). This interpretation suggests that attention-related factors, such as how effectively an encoding strategy is applied, determines the influence it will have on implicit tests. We will return to this point later.

In contrast to the large number of studies on the putatively differential effects of LOP on implicit and explicit tests of memory, only a handful of experiments have been reported on the effects of attention on implicit tests of memory (Bentin et al., 1995; DeSchepper and Treisman, 1996; Eich, 1984; Gabrieli et al., submitted; Goldberg, 1995; Jacoby, 1991; Jacoby et al., 1993; Merikle and Reingold, 1991; Parkin et al., 1990; Parkin and Russo, 1990; Treisman and DeSchepper, 1996). Unlike the strong effect of attention on explicit recall and recognition, manipulating attention in all of the above studies had only a negligible influence on long-term repetition-priming except if a conceptual component was involved (see Gabrieli et al., submitted; Goldberg, 1995). However, it is possible that, despite the instructions, attention was shifted involuntary to the unattended information since processing of that information was not rigidly controlled or manipulated in any of these studies. It is possible, therefore, that in all of them some attention was allocated to the nominally ignored stimuli, which was sufficient to support long-term repetition priming but not explicit recollection.

From a theoretical perspective, specifying the conditions under which LOP and attention influence priming is important because the differential effects of attention and LOP on long-term repetition priming and conscious recollection are among the empirical pillars supporting many theories of implicit memory. According to one class of such theories, (we refer to them as *systems or representational* theories) stimuli are picked up automatically by perceptual input systems (modules) which form long-lasting, pre-semantic, structural representations of these stimuli (Keane et al., 1991; Moscovitch, 1992; Schacter, 1990, 1992; Tulving and Schacter, 1990). Long-term repetition priming occurs when, on subsequent encounters with studied stimuli, these representations are accessed automatically which, in turn, facilitate stimulus processing. Hence, according to such theories, attention at study should not have a conspicuous effect on priming. By contrast, the representations which support conscious recollection, and their formation, are often semantically based and influenced by attention. Similarly, according to another class of theories (we refer to these as *processing* theories), repetition priming results from transfer of data-driven processes between study and test (Blaxton, 1989; Kolers and Roediger, 1984; Morris et al., 1977; Roediger, 1990; Roediger and Blaxton, 1987). Deeper LOPs at study should have negligible (or even detrimental) effects on processes that are presumed to be data driven at test because it is assumed that there is sufficient overlap between the two conditions in processing low-level information. Although the role of attention is not specified by the latter class of theory, one would expect that if attention itself is presumed to be a process, then performance on implicit tests should reflect the congruence between the level and content of attention at study and that at test. Therefore, evidence regarding the influence of LOP and attention on repetition priming poses different challanges to the above theories which will have to be modified to accomodate such evidence if they are to remain viable.

To address the issue of effective allocation of attention and processing strategy (LOP) on repetition priming and recognition, we used Challis and Broadbeck's finding on the effects of mixed and blocked designs as a point of departure for our experiments. We compared the effects of attention in a mixed and blocked design, the rationale being that attention can be focused better in the blocked than in the mixed condition because an a priori-determined selection set reduces trial-by-trial uncertainty. This manipulation also has the advantage of permitting a comparison between LOP and selective attention in different experimental designs and, by implication, the effects these designs have on the ability to separate different modes of processing.

As part of this investigation we also manipulated the time interval between study and test. According to both representational and processing theories neither attention nor LOP should have much effect on the nature of the representation or process mediating performance on perceptual implicit memory tests. Therefore, assuming that retention interval has an effect on the already established representations, its effect on priming should not be expected to interact with either LOP or attention manipulations at study.

The first experiment was an attempt to test the generality of the finding of Challis and Broadbeck (1992) of differential effects of LOP on priming and explicit memory tests in the blocked but not in the mixed study condition. In the second experiment, we used an analogue of the mixed/blocked manipulation to extend its effects to attention. In the last experiment, the relation between attention and LOP was explored to determine how their interaction affects priming.

2. General method

2.1. Participants

The participants were undergraduate students at the Hebrew University, all native Hebrew speakers, with normal or corrected to normal vision. They participated for payment or credits for an introductory course in psychology. Typically, 64 participants was tested in each experiment. None of the participants was tested in more than one experiment.

2.2. Stimuli

The stimuli were Hebrew words with an average rated frequency, [2] and pseudowords. The pseudowords were orthographically and phonologically legal letter strings obtained by permutation or substitution of letters in real words. The number of words and pseudowords used in each experiment varied. All the words and the pseudowords were presented in a regular undotted [3] Hebrew font, using red or blue or white colors on black background.

2.3. Design

Each experiment consisted of a study phase and two test phases. At study, participants made decisions about stimuli presented visually on a color computer monitor. The nature of the decision at study (which varied across tasks) determined the required LOP and was manipulated within participants. For half of the participants, the LOP or the selective attention instructions (see below) were mixed within session, while for the other half they were blocked. Following the study phase the first ("same-day") test phase was given. In this phase, participants were instructed to distinguish between words that were presented at study and new words presented on the computer monitor one at a time (explicit recognition test) or to make decisions which in most cases were identical to the decisions made at study (repetition priming test). A second test phase, similar to the first was given 24 h later ("next-day") test. Within each test phase the order of the lexical decision (LD) and recognition tests was counterbalanced across participants.

The above procedure led to a mixed-model ANOVA design in which the effect of study condition (mixed or blocked) was assessed between participants, and the effects of study condition (deep/shallow or attended/unattended) and test conditions (same-day/next-day testing and explicit recognition or repetition), were tested within within-subjects, with stimulus as a random factor. Random stimulus-induced variability was controlled, however, rotating all the stimuli among all the 32 possible stimulus lists (see detailed design description for each experiment). Consequently, across 32 participants, the same stimuli appeared in all of the experimental conditions but only the designated stimuli were repeated, and each word was presented at test only once.

[2] No computerized word-frequency data base is available in Hebrew. Therefore, most stimuli in the present experiments were selected from a pool of words whose frequency has been rated by 50 participants on a scale of 1–7.

[3] In Hebrew, most vowels are represented by diacritical marks (points) which are usually omitted from most printed materials (see Frost and Bentin, 1992 for details).

2.4. Procedure

A MEL program was used to control the experiment and randomly assign participants to stimulus lists. Participants were tested individually in a sound-attenuated room. RTs and response category were recorded using button presses. The right hand was used for "positive" responses while the left for "negative" responses (see details for each experiment). Speed and accuracy were equally emphasized. The participants were neither instructed about the forthcoming memory test, nor were they informed about the study–test relationship prior to the priming tests. A short practice session preceded the test list in each study-task.

3. Experiment 1

This experiment tested the generality of the blocked vs. mixed manipulation effect on priming which was previously reported (Challis and Broadbeck, 1992; Thapar and Greene, 1994). The generality was tested by using different tests, dependent variables, orienting tasks, and materials. Whereas Challis & Broadbeck (as well as all the other studies they surveyed) used accuracy to assess priming on perceptual tests such as fragment or stem completion or perceptual identification in English, we used RT to assess priming on LD in Hebrew. Using RTs as a dependent variable, Duchek and Neely (1989) found an LOP effect on long-term repetition priming in a mixed-study condition. However, because they did not include a blocked-study condition, we cannot know whether blocking LOP at study would have enhanced this effect. In addition, unlike the other studies in which the 'deep' orienting tasks at study involved either semantic decisions or pleasantness rating (i.e., addressed a semantic LOP), the deep task in this experiment was a word/nonword-LD task (i.e., addressed a phonological–lexical LOP). Because printed words in Hebrew are usually missing phonologic information (most of the vowels), LDs in Hebrew may require processes different from those in English (Bentin and Frost, 1987). The 'shallow' orienting task in this experiment was discrimination of the color in which the word was printed, an attribute which is extrinsic to the word's orthography. By comparison, the shallow orienting tasks in previous studies involved decisions regarding phonetic features of the stimulus such as rhyming (Duchek and Neely, 1989), or physical attributes which are intrinsic to the orthographic structure of the word, such as letter search, or font detection. If, despite these changes we introduce, LOP effects on priming are found in the blocked but not in the mixed presentation at study, then the view that deep processes contribute to long-term repetition priming is reinforced.

As part of this experiment, the effects of LOP on long-term repetition priming were compared with those on explicit recognition. There is ample evidence that deep processing at study leads to better recognition than shallow processing, but only Thapar and Greene (1994) investigated whether LOP effects on explicit tests are influenced by the mixed/blocked manipulation at study. They found no effect of this manipulation on recognition, free recall, and graphemic cued recall. Because it was the only study of its kind, we thought it important to attempt to confirm their general finding. If the LOP effects are larger in the blocked than in the mixed presentation, it would suggest that participants are better at differentiating between the requirements of each orienting task when they are blocked than mixed, and can influence encoding accordingly.

We examined also the effects of retention interval on memory performance and the interactions of this factor with LOP and mixed/blocked presentation at study. Because retention interval typically affects performance on explicit and implicit tests differently (Graf and Mandler, 1984; Jacoby and Dallas, 1981; Kolers, 1976; Tulving et al., 1982 for a recent review see Roediger and McDermott, 1993), this manipulation may serve as an additional tool for examining the effects of LOP and their interaction with mixed/blocked presentation on explicit and implicit tests.

3.1. Method

3.1.1. Stimuli and design

The stimuli were 320 words and 320 nonwords. Half of the words and half of the nonwords were presented in the study lists, 80 words and 80 nonwords in the LD task and the other 80 words and 80 nonwords in the color discrimination task. For half of the words studied in each task, memory was tested the same day, 20 words in the explicit recognition test and 20 words in the long-term repetition priming test. The other 40 words were tested 24 h later, 20 in the explicit recognition test and 20 in the long-term repetition priming test. Hence each study list contained 160 stimuli (80 words and 80 nonwords), each explicit recognition list contained 80 words (40 'old' (20 studied deep, 20 studied shallow), and 40 'new' words (from among the 160 that were not studied)) and each long-term repetition priming list contained 160 stimuli (80 words (20 studied deep, 20 studied shallow, and 40 new) and 80 nonwords). Because the same word was never presented in two test lists, a complete rotation of the stimuli across all possible experimental conditions required 16 different stimulus lists. In addition, across participants each stimulus was presented once in red and once in blue. Consequently, the number of lists had to be doubled, yielding a total of 32 different stimulus lists.

Two participants were randomly assigned to each list, one in the mixed design condition and the other in the blocked design (see procedures). Hence 64 participants were tested in this experiment. Two mixed-model, ANOVAs were initially used to assess statistical validity of the observed effects, one for explicit recognition and one for repetition priming. The dependent variable in the explicit recognition analysis was the d'. The between-subject factor was study condition (mixed, blocked) and the within-participants factors were LOP (studied deep, studied shallow) and retention interval (same day, next day). For the analysis of the repetition priming effect we calculated first the difference in RT between new and repeated words (separately for those that were studied deep and those that were studied shallow) and used this difference as the dependent variable. The between-subject factor was study design (mixed, blocked), and the within-participants factors were LOP at study (deep, shallow), and retention interval (same day, next day). This analysis was aimed at assessing the interaction between the effects of LOP and mixed/blocked presentation at study on long-term repetition priming, and was followed by more detailed within-subject analyses for each study condition separately. In that analysis the dependent variable was the absolute RTs in each condition.

3.1.2. Procedure

Each trial consisted of two events. The first was a cue indicating the task required on that trial. The cue was either "WORD?" or "RED?" and was exposed for 1250 ms. The second event in a trial was the test stimulus (a word or a nonword, in red or in blue) which replaced the cue immediately (i.e., no ISI). The test stimulus was on the screen for 500 ms and was separated from the next cue by an ISI of 1650 ms. The participants were instructed to make a decision by pressing the right hand button if the answer to the cued question was "yes" (i.e., the test stimulus was a word in the LD or was red in the color discrimination task) and a left-hand button if the answer to the cued question was "no" (i.e., the test stimulus was a nonword or it was blue).

The 320 trials were presented in four blocks of 80 trials each with about 1 min rest between blocks. In the mixed presentation, the deep and shallow processing trials were randomly presented. A practice session of 24 trials (12 LDs and 12 color decisions (CLRDs) preceded the first block. In the blocked design, each task was presented in two consecutive blocks and before each section the participants were given only the relevant instructions and practice trials. However, in order to keep the experimental conditions as similar as possible, the cueing question was presented on each trial. In the blocked study condition half of the participants received first the color discrimination task and the LD task after, while the order was reversed for the other half.

In the explicit recognition tests, the stimulus exposure time was 500 ms and the ISI between stimuli was 2050 ms. In the long-term repetition priming tests, the stimuli were exposed for 500 ms and the ISI between stimuli was 1650 ms.

3.2. Results

Accuracy during study was almost perfect. Across response categories and study condition, reaction times were slower in the (deeper) LD (925 ms) than in the (shallower) color discrimination task (744 ms) ($F(1,62) = 86.58$, $MSe = 12\,113$, $p < 0.001$). However, the LOP effect significantly interacted with the mixed/blocked manipulation. In the shallow task, RTs were longer in the mixed (770 ms) than in the blocked (718 ms) condition, whereas the reverse occurred for the deep task (898 ms vs. 952 ms for the mixed and blocked conditions, respectively) ($F(1,62) = 7.49$, $MSe = 12113$, $p < 0.01$).

The explicit recognition performance was assessed for each session by calculating d's. Separate measures were obtained to reflect the participants' ability to distinguish between old, deeply processed words and new words, and between old, shallowly processed words and new words. The RTs to correct responses in the repeated LD test were averaged separately for old, deep words, old, shallow words and new words. Only very few errors were made during the LD at test and these were equally distributed across conditions. The long-term repetition priming effect was the difference between the RT to new words and the RTs to each of the repeated stimulus types. For each subject, RTs that were longer than, or shorter than 2 s.d. from the subject's mean in each condition have been excluded and the respective mean recalculated. Fewer than 5% of the RTs were outliers.

Explicit recognition was better for deep than for shallow words, and better when tested immediately after study than 24 h later. The effects of LOP seemed to be more pronounced in the blocked than in the mixed presentation and at short than at long delays (Table 1).

The mixed-model ANOVA showed that the main effects of both retention interval and LOP were significant ($F(1,62) = 31.5$, $\mathrm{MSe} = 0.071$, $p < 0.001$, and $F(1,62) = 7.0$, $\mathrm{MSe} = 0.084$ $p < 0.001$ for retention interval and study condition, respectively). The interaction between these two factors was not significant ($F(1,62) = 1.5$, $\mathrm{MSe} = 0.58$, $p = 0.23$). A significant three-factor interaction ($F(1,62) = 8.4$, $\mathrm{MSe} = 0.58$, $p < 0.01$) indicated, however, that a more detailed analysis was necessary. Post-hoc univariate *F*-tests showed that, acrosss study design, the effect of retention interval, was significant for both the deeply studied words ($F(1,62) = 15.1$, $\mathrm{MSe} = 0.14$, $p < 0.001$) and for the shallowly studied words ($F(1,62) = 6.7$, $\mathrm{MSe} = 0.12$, $p < 0.05$). Whereas this effect seemed to be larger in the deep than in the shallow condition, planned *t*-tests (calculated on the basis of the three-way interaction with the difference in d' between the immediate and delayed testing time as dependent variables) revealed that only in the blocked condition the difference between the effects of the retention interval on deeply studied and shallowly studied words was significant ($t(31) = 2.92$, $p < 0.01$). The same trend found in the mixed study design was not significant ($t(31) = 1.18$, $p = 0.24$).

Although there was no significant main effect of mixed/blocked study condition on the d' values ($F(1,62) < 1.00$), the interaction of this factor with the LOP effect was significant ($F(1,62) = 95.4$, $\mathrm{MSe} = 0.08$, $p < 0.001$). Separate ANOVAs for the mixed and for the blocked study conditions showed that although the LOP effect was significant for both conditions ($F(1,31) = 21.95$ in the mixed condition and $F(1,31) = 91.4$ in the blocked condition), the magnitude of this effect was almost twice as large in the blocked (0.45) than in the mixed condition (0.27).

In the implicit test, the RTs were faster for repeated words than for new words (Table 2). The priming effect, however, varied with LOP depending on the study condition. In the mixed condition, LOP had a negligible effect on priming. In contrast, when LOP at study was blocked, priming was considerably stronger for deeply than for shallowly studied words. Unlike explicit recognition, priming was not affected by

Table 1
Explicit recognition performance (mean d' and SEm) at immediate and delayed tests for words studied in (lexical decision) LD and (color decision) CLRD

Levels of processing at study	Retention interval			
	1/2 an hour		24 h	
	Mixed	Blocked	Mixed	Blocked
LD	0.63 (0.06)	0.80 (0.06)	0.42 (0.05)	0.45 (0.06)
CLRD	0.32 (0.05)	0.23 (0.04)	0.22 (0.06)	0.13 (0.05)

Table 2
RTs (SEm) and repetition effects in LD for words that were studied during (lexical decision) LD or (color decision) CLRD

Level of processing at study	Retention interval			
	1/2 an hour		24 h	
	Mixed	Blocked	Mixed	Blocked
New words	610 (11)	611 (14)	587 (10)	604 (12)
Studied in LD	593 (10)	598 (15)	576 (10)	590 (12)
Repetition effect	17 ms	13 ms	11 ms	14 ms
Studied in CLRD	598 (11)	606 (15)	575 (8)	599 (12)
Repetition effect	12 ms	5 ms	12 ms	5 ms

retention interval. Repetition of nonwords had no effect on LD time or accuracy regardless of study condition.

As explained in Section 2, we began the analysis of the priming effects with a mixed-model ANOVA of the repetition effects. This analysis showed the main effect of LOP on long-term repetition priming approached significance ($F(1,62) = 3.83$, $MSe = 400$, $p < 0.06$), and that the interaction between the LOP and the study condition effects was very small ($F(1,62) = 2.04$, $MSe = 400$, $p < 0.16$). No other main effects or interactions approached significance ($F(1,62) < 1.00$).

The RTs during the repeated LD task were further analyzed by separate analyses for the mixed and the blocked study designs. The stimulus repetition factor in these analyses compared three levels: Words repeated from the deep study condition, words repeated from the shallow study condition and new words. In the mixed study design, ANOVA showed that, averaged across retention interval, the long-term repetition effect was significant ($F(2,62) = 7.45$, $MSe = 467.2$, $p < 0.001$), and that, averaged across repeated and unrepeated items, LDs were significantly faster at the long than at the short retention interval ($F(1,31) = 9.76$, $MSe = 2162$, $p < 0.01$). On the other hand, long-term repetition priming was not diminished with retention interval ($F(2,62) < 1.00$). Furthermore, post-hoc univariate F-tests demonstrated that during both sessions, the long-term repetition priming effect was similar for deeply and shallowly studied words ($F(2,62) < 1.00$).

In the blocked study design there was a significant main effect of repetition priming ($F(2,31) = 6.7$, $MSe = 450$, $p < 0.005$) that did not interact with retention interval ($F(1,31) < 1.00$). However, in contrast to the mixed study condition, post-hoc univariate F tests revealed that deeply studied words produced significant priming at both intervals ($p < 0.005$ and $p < 0.025$ for the immediate and delayed tests, respectively), whereas shallowly studied words did not produce significant priming at either interval ($F(1,31) < 1.00$).

A binomial test corroborated the reliability of the differential effect of LOP in the mixed and the blocked study conditions. This analysis showed that in the mixed condition only 52% of the participants showed LOP effects, a proportion that was not significantly different from chance. In contrast, 69% of the participants in the blocked condition showed an LOP effect, a proportion that was significantly different from chance ($p < 0.01$).

3.3. Discussion

The results of the present experiment confirmed that the mixed/blocked study design is a contributing factor to the LOP effects on long-term repetition priming (Challis and Broadbeck, 1992; Thapar and Greene, 1994), even though type of encoding, measure of repetition priming, retention interval and language that were used in this experiment were different from those used in any other study which manipulated mixed/blocked study-condition in the past.

As revealed by separate ANOVAs, in the mixed condition, priming was significant and equivalent for deeply and shallowly studied words. On the other hand, in the blocked condition, long-term repetition priming was greater for deeply than for shallowly studied words. Indeed, in the latter case, long-term repetition priming was not statistically significant. Furthermore, unlike the Thapar and Greene findings, the present results also demonstrated that study condition had comparable effects on explicit recognition. By contrast, retention interval had no effect on the magnitude of long-term repetition priming but did influence recognition, its effect being greatest on deeply studied words.

One explanation for the LOP effect on long-term repetition priming in the blocked study condition is that performance on the implicit test was contaminated by explicit recognition. Our finding that study condition had the same influence on LOP effects in explicit recognition as it did on long-term repetition priming might be taken as support for this hypothesis. The contamination hypothesis, however, cannot accomodate several dissociations that we found between explicit recognition and repetition priming. Despite the large LOP effect on d', in the mixed condition, the long-term repetition priming was equivalent for words studied to a shallow or deep level. Similarly, retention interval had a profound effect on explicit recognition, reducing performance by half in some cases. Yet both in the blocked and the mixed condition, long-term repetition priming remained stable across testing delays. In light of these dissociationss between explicit recognition and long-term repetition priming, it is unlikely that the comparable influence of study condition on LOP effects on these two measures can be explained by a simple contamination hypothesis.

3.3.1. Explicit recognition

Close examination of explicit recognition performance suggests an alternative to the contamination hypothesis. Note that there is a cross-over interaction between LOP and study condition. For deeply processed words, recognition is better in the blocked than in the mixed design whereas the reverse holds for shallowly studied words. This interaction suggests that control of both processing strategies and over allocation of attention is greater in the blocked condition. The unpredictability of the orienting task in the mixed condition might have led to inadvertent deep processing where shallow processing was required which may have enhanced memory for "shallow" words in the "mixed" task and vice-versa. Some support for this possibility was provided by the RT data at study. Switching from blocked to mixed study increased RTs in the shallow task while lowering them in the deep task. In addition, switching from one orienting task to another is probably an attention demanding process which reduces the cognitive resources that otherwise would have been allocated to efficient deep encoding. The smaller d' values found for "deep" words in the mixed relative to the blocked study condition support these interpretations.

3.3.2. Long-term repetition priming

Before applying this analysis to performance on implicit tests, one caveat needs to be raised. Unlike the assessment of explicit recognition in which the recognition task was unrelated to the study task either in the deep or in the shallow study conditions, the assessment of long-term repetition priming effects involved the same task at study and test for the deep study-condition whereas different tasks were used at study and test for the shallow study condition. Consequently, it is possible that greater long-term repetition priming in the lexical study condition than in the color study condition did not reflect LOP at study but rather the correspondence between the tasks at study and test in the deep but not in the shallow study condition. Although the transfer of appropriate processes may indeed enhance priming, such an account does not explain the present data for several reasons. The first is that transfer of appropriate processes should have affected test performance similarly in the blocked and the mixed study condition but we found significant LOP effects only in the blocked condition. The second reason is that task-related repetition priming effects have been found primarily at very short lags and are almost absent at lags of 15 items between repetition and study (e.g., Bentin and Moscovitch, 1988); the lags at which long-term repetition priming was found in the present study were significantly longer than that. Finally, in order to test the influence of task repetition on the size of the repetition effect we have run a similar experiment repeating at test the shallow color discrimination task. In that experiment we found no long-term repetition priming effects either in the deep or in the shallow study condition (the data are available from the first author upon request).

Our interpretation of the differential LOP effect with study condition on long-term repetition priming is also based on the assumption that control of both processing strategies and allocation of attention is greater in the blocked condition than in the mixed condition. By applying this interpretation we can account for the significant reduction of repetition priming for words studied under shallow as compared to deep instructions in the former but not in the latter study condition. The ability to focus more effectively on shallow processing in the blocked design ensured that words in the shallow condition did not receive even the minimal amount of deep processing necessary to support long-term repetition priming. As a result, an LOP effect was evident in the blocked study condition. The equivalent repetition priming under deep and shallow study instructions in the mixed condition suggests that once a threshold of depth of processing is reached, exceeding it is inconsequential for priming. The only exception to this rule of which we are aware are the findings of Duchek and Neely (1989). They observed an LOP effect when rhyme and semantic decisions were mixed at study and long-term repetition priming was assessed in a LD task. Whether the effect would have been greater in a blocked condition is unknown because such a condition was not included in their study. The reason for the discrepancy between our findings and theirs is not apparent. Because the depth of processing at both levels in their study was greater than the corresponding levels in ours, it is possible that the LOP effects they observed were caused by contamination either by explicit memory (but see counterarguments in their paper) or by conceptual implicit memory processes (see Section 5).

Our interpretation implies that at encoding, a threshold level of attention and depth of processing is necessary to establish long term memory representations that may support repetition priming. Exactly how deeply stimuli need to be processed to support long-term repetition priming remains to be established. The present results, however, indicate that it is probably insufficient simply to view the stimulus or to attend only to surface features which are extrinsic to the word's structure.

Although our results are in broad agreement with Thapar and Greene (1994) and Challis and Broadbeck (1992) and the studies they surveyed, there are some differences which should be noted and explained. In the blocked study condition, we found no long-term repetition priming in the shallow condition whereas some such priming was noted in many other studies (see Brown and Mitchell, 1994; Challis and Broadbeck, 1992; Thapar and Greene, 1994). Our experiments, however, used different orienting tasks and a different measure of long-term repetition priming. Thus, one possible reason for this discrepancy is that CLRD was extrinsic to the orthographic aspects of the word and therefore shallower than tasks used in other studies such as letter or font decisions. Another reason is that our priming measure was RT which may be less sensitive to contamination from explicit recognition than measures such as fragment or stem completion (see also Masson and MacLeod, 1992; Moscovitch and Bentin, 1993). Also, our priming test was LD which may tap lexical processes more directly than other long-term repetition priming tests. Last, the time available to study words was much greater in Challis and Broadbeck's and Thapar and Greene's study than in ours. Their participants viewed each word for at least 4 s which provides ample time for processes other than the ones stipulated by the experimenter.

An additional difference between our results and those of Thapar and Greene (1994) was that they found no interaction between LOP and mixed/blocked design in explicit tests of memory whereas we did. We have no ready explanation for this discrepancy except to appeal again to differences between the studies in orienting task and, particularly, in exposure duration at encoding. By choosing a shallow orienting task that was intrinsic to the stimulus and by leaving the stimulus exposed for a long time, Thapar and Greene (1994) may have allowed processing to reach its optimal level for each orienting task.

4. Experiment 2

The few experiments that have been conducted on the effects of attention at encoding on long-term repetition priming demonstrate that such priming is equivalent for attended and unattended items (Bentin et al., 1995; Eich, 1984; Jacoby, 1991; Jacoby et al., 1993; Merikle and Reingold, 1991; Parkin et al., 1990; Parkin and Russo, 1990; Treisman and DeSchepper, 1996). Based on these findings, it has been concluded that in contrast to its effects on conscious recollection, paying attention to stimuli at encoding has little, if any, effect on long-term repetition priming. As with LOP effects, however, the amount of attention which was, in fact, allocated to allegedly ignored stimuli has not been systematically controlled. Because the mixed/blocked manipulation proved to be an extremely effective way of controlling LOP, we sought to apply an analogous procedure to manipulate selective attention. Part of the rationale for doing so is that the LOP effect could, in fact, be mediated by a mechanism common to selective attention. More precisely, it is possible that task instructions direct attention to some aspects of the stimulus while other aspects are ignored. In the same way selective attention determines the information which is encoded. Based on this reasoning, we predicted that, as with LOP, attention manipulations would influence priming in the blocked, but not in the mixed, condition at study. With respect to explicit recognition, we predicted that attention will affect performance in both conditions, but its effect would be more pronounced in the blocked design. As in Experiment 1, we also varied retention interval to see if its effects on priming and explicit recognition were dissociable in the context of attention manipulations.

4.1. Method

4.1.1. Participants

The participants were 64 undergraduates who did not participate in any of the previous experiments. Half of the participants were tested in an analogue to the mixed study condition and the other half in an analogue of the blocked study condition. For convenience we will label these analogues 'mixed' and 'blocked' study-condition, respectively.

4.1.2. Tasks, stimuli, and design

The stimuli in this experiment where the same 320 words and 320 nonwords that were used in Experiment 1.

The study phase comprised of 160 trials. In each trial, two letter strings were presented, one above and one below a fixation point. One of the words was printed in red and the other in blue, and the subject was instructed to attend to one of the words and ignore the other, using word color as the selective filter. In the mixed condition, the attended color was randomly determined in each trial. In this study condition the fixation point was a colored rectangle. In 80 trials the rectangle was red, in the other 80, it was blue. The participants' task was to make a LD for the stimulus whose color matched the color of the rectangle, while ignoring the other stimulus. The attended stimuli were equally located above and below the rectangle. There were 40 trials in which both the attended and the unattended stimuli were words, 40 trials in which both the attended and the unattended stimuli were nonwords, 40 trials in which the attended stimuli were words and the unattended stimuli nonwords, and 40 trials in which the attended stimuli were nonwords and the unattended were words. Hence, at study, the participants attended to 80 words and 80 nonwords and ignored 80 words and 80 nonwords. Half of the stimuli in each of these groups were red and half were blue, half were above the rectangle and half were below.

In the blocked study condition the subject was told a priori which color should be attended, and the attended color was not further changed. In order to avoid distraction of attention, the rectangle between the two words was not presented. Instead, a white asterisk served as a fixation point.

Half of the attended and half of the unattended words were tested the same day and the other half the next day. Each explicit recognition test included 20 different 'old-attended' and 20 'old-unattended' words, as well as 40 new words selected from the 160 words that were not presented at study. The long-term repetition priming task was LD. In each test list there were 20 'attended-repeated' words, 20 'unattended-repeated' words, 40 new words, 20 'attended-repeated' nonwords, 20 'unattended-repeated' nonwords and 40 new nonwords. Across participants each stimulus was presented in each possible study–test condition, yielding 32 different balanced lists. Two participants were randomly assigned to each list, one in the mixed and the other in the blocked study condition.

4.1.3. Procedure

Each study trial began with the presentation of an eye fixation point at the center of the screen (a white asterisk on black background). In the mixed study condition, the fixation point was exposed for 1000 ms after which it was replaced by the colored rectangle to which the two letter strings were added at an SOA of 50 ms. The two words were exposed for 350 ms after which both words and the rectangle were removed. The inter-trial interval was 1800 ms. In the blocked study condition the asterisk was exposed for 1050 ms before the words appeared, and remained on the screen for another 350 ms before the screen was cleared.

The procedures for the same and next day test sessions were identical to those used in Experiment 1. Briefly, participants made old/new discriminations and LDs to stimuli presented one at a time on the screen. Unlike at study, all stimuli at test were white on a black background. Each stimulus was exposed for 400 ms and the ISI was 1650 ms.

4.2. Results

The data analysis was identical to the analysis described in the previous experiment. Explicit recognition performance was assessed by calculating the d' whereas repetition priming effects were assessed by comparing RTs to new and repeated words. Separate measures were obtained for words that were attended at study and words that were not attended at study.

At study, accuracy of LDs for the attended items was nearly perfect. Significantly longer RTs were observed to words in the mixed (827 ms) than in the blocked condition (729 ms) study condition ($F(1,62) = 10.1$ MSe $= 29732$, $p < 0.01$) and did not vary significantly depending on whether the accompanying unattended item was a word or a non-nonword either in the blocked study condition (728 ms vs. 731 ms for the unattended word and unattended nonword trials, respectively) or in the mixed condition (824 ms vs. 830 ms for the unattended word and unattended nonword trials, respectively), $F(1,62) < 1.00$.

As expected, explicit recognition was better at short than at long retention intervals, and better for attended than for unattended words. This pattern was found for both the mixed and the blocked study conditions though both factors had an apparently greater effect in the blocked than in the mixed study condition (Table 3).

A mixed-model ANOVA showed that the main effects of attention and retention intervals were significant ($F(1,62) = 74.92$, MSe = 0.14, $p < 0.001$), and ($F(1,62) = 17.51$, MSe = 0.13, $p < 0.001$, respectively), as was the interaction between these two factors ($F(1,62) = 16.66$, MSe = 0.08, $p < 0.001$).

The between-participants main effect of study condition on d' was not significant ($F(1,62) = 2.41$, MSe = 0.28, $p < 0.13$), but it interacted with attention ($F(1,62) = 11.61$, MSe = 0.14, $p < 0.001$). The interaction between the study condition and retention interval was not significant ($F(1,62)1.00$), while the interaction combining all three factors was significant ($F(1,62) = 7.59$, MSe = 0.07, $p < 0.01$). This three-way interaction suggests that the Attention × Retention Interval interaction was different for the mixed and the blocked study condition. Indeed, this interaction was not significant when attention at study was manipulated in the mixed design ($F(1,31) = 1.13$, MSe = 0.06, $p > 0.29$), while being highly significant when attention at study was manipulated in the blocked design ($F(1,31) = 19.32$, MSe = 0.093, $p < 0.001$).

It is noteworthy that in the mixed study condition the d' values were relatively low for both attended and unattended words. Moreover, for both study condition conditions the d' values for unattended items at the delayed testing session were not significantly greater than 0, i.e., the explicit recognition level was at chance.

In light of the above reduction in explicit recognition performance, the pattern of the long-term repetition priming effects was particularly interesting. As shown in Table 4, the study condition had a very conspicuous influence on these effects. Whereas in the mixed study condition long-term repetition priming was substantial and not affected by attention, in the blocked study condition repetition priming was found only for words that were attended at study. In contrast to explicit recognition, retention interval had no effect on long-term repetition priming. No repetition priming effects were found for nonwords.

The mixed-model ANOVA on the long-term repetition priming effects showed that the main effects of study condition and retention interval, as well as the interaction between these two factors were not significant ($F(1,62) < 1.00$). Neither was the three-way interaction. The attention effect, however, was significant ($F(1,62) = 7.66$,

Table 3
Explicit recognition performance (mean d' and SEm) at immediate and delayed tests for attended and unattended words studied in (lexical decision) LD

Attention at study	Retention interval			
	1/2 an hour		24 h	
	Mixed	Blocked	Mixed	Blocked
Attended	0.55 (0.09)	0.89 (0.08)	0.29 (0.08)	0.48 (0.09)
Unattended	0.25 (0.06)	0.08 (0.06)	0.09 (0.05)	0.14 (0.05)

Table 4
RTs (SEm) and repetition effects in (lexical decision) LD for words that were attended and unattended in the mixed and blocked presentation at study

Attention at study	Retention interval			
	1/2 an hour		24 h	
	Mixed	Blocked	Mixed	Blocked
New words	573 (12)	553 (12)	569 (13)	529 (13)
Attended	560 (11)	533 (11)	557 (14)	512 (14)
Repetition effect	13 ms	20 ms	12 ms	17 ms
Unattended	559 (12)	551 (11)	557 (13)	529 (13)
Repetition effect	14 ms	2 ms	12 ms	0 ms

MSe = 572, $p < 0.01$) and it significantly interacted with the effect of study condition ($F(1,62) = 8.44$, MSe = 572, $p < 0.005$). The nature of this interaction was further investigated in separate within-subject ANOVAs for each study condition.

Comparing the RTs for new words with attended and unattended old words in the mixed study condition, ANOVA showed that the main effect of repetition priming was significant ($F(2,62) = 7.62$, MSe = 428, $p < 0.001$), while the main effect of retention interval was not ($F(1,31) < 1.00$). The interaction between these two main effects was not significant ($F(2,62) < 1.00$). Post-hoc univariate F tests revealed that the long-term repetition priming effect was significant for both attended ($F(1,31) = 4.47$, $p < 0.05$) and unattended words ($F(1,31) = 5.88$, $p < 0.025$). In the blocked condition, on the other hand, both main effects were significant ($F(1,31) = 14.34$, MSe = 1711, $p < 0.001$ and $F(2,62) = 13.68$, MSe = 496, $p < 0.001$), respectively), while the interaction between these two main effects was not ($F(2,62) < 1.00$). Moreover, post-hoc univariate F tests revealed that while at both retention intervals the long-term repetition priming effect was significant for attended words ($F(1,31) = 17.46$, $p < 0.001$ and $F(1,31) = 10.47$, $p < 0.001$ for the immediate and delayed tests, respectively), unattended words did not produce significant long-term repetition priming at either retention interval ($F(1,31) < 1.00$).

4.3. Discussion

The effects of attention and study condition on explicit and implicit measures of memory in this experiment parallel, in almost every detail, the effects of LOP and mixed/blocked manipulation in Experiment 1. The main new finding, consistent with our hypothesis, is that even on implicit tests of memory, a minimal amount of attention to target stimuli is necessary at encoding to establish a lasting representation that can support long-term repetition priming. In the blocked condition, where attention can be controlled effectively, repetition priming was found only for attended words. When it was more difficult to allocate attention selectively, as in the mixed condition, significant and equivalent long-term repetition priming is found for both attended and unattended words. This interpretation is corroborated by the differential effects study condition had on attended and unattended words in explicit recognition. There we found a crossover interaction between level of attention and study condition. Attended words were recognized better in the blocked than in the mixed condition, whereas the reverse was true for unattended words.

As in Experiment 1, contamination by explicit memory processes are unlikely to account for the differential effects of attention on long-term repetition priming. Although recognition dropped with retention interval, sometimes by half, retention interval had no effect on long-term repetition priming. Moreover, at long delays, when recognition for unattended words was at chance, significant long-term repetition priming was found if the study was in the mixed design, but it was absent if the study was in the blocked design. Accounts based on simple perceptual factors (such as not "seeing" the words presented in the irrelevant color) can also be discarded for several reasons. First, both the attended and the unattended words were presented at the center of the screen, both well within the foveal space. Second, the relevant color was presented equally above and below the fixation point, in random order. Third, the same presentation conditions were used in the "mixed" study design where unattended words were evidently processed.

These results indicate that a threshold level of attention is necessary to create a lasting representation that can support performance on implicit tests. Once that threshold is reached, repetition priming benefits very little from the allocation of additional attention resources. The attention threshold for supporting explicit memory may be higher, and performance continues to benefit substantially by exceeding it.

This interpretation is at odds with views suggesting that stimulus encoding necessary for long-term repetition priming can occur without attention. Such views are based on studies in which selective attention affected performance on explicit but not on implicit tests of memory (Bentin et al., 1995; Eich, 1984; Jacoby, 1991; Jacoby et al., 1993; Merikle and Reingold, 1991; Parkin et al., 1990; Parkin and Russo, 1990; Treisman and DeSchepper, 1996). To reconcile our findings and interpretation with these studies, we suggest that in all of them, as in the present mixed condition, the procedures used to select the attended items in each trial allowed for some attention to leak to the designated unattended items. This leakage was sufficient to exceed the attention threshold for supporting performance on implicit tests, but did not reach the threshold necessary for explicit memory. In other words, evidence of chance or near chance performance on explicit tests is not a sufficient basis for assuming that attention was completely absent at encoding. Cheesman and Merikle (1984, 1986) made a similar argument regarding unconscious perception.

The similarity of the effects that LOPs and attention at study had on memory performance suggests that these two manipulations may share a common mechanism. One possibility is that deep LOPs typically require more attention resources than do shallow levels. [4] If our hypothesis is correct that encoding of unattended and shallowly processed items into memory depends on the leakage of some of those resources, then by increasing the depth of processing of attended items, the amount of resources available to the unattended items by leakage should be diminished. Such a

[4] It might be the case that any task, whether shallow or deep, that increases the use of cognitive resources would have the same effect (cf. Bentin and McCarthy, 1994).

consequence should be reflected by a reduction in the amount of long-term repetition priming observed from the unattended items. In Experiment 3 we tested this prediction by combining the selective attention paradigm with a deeper decision at study.

5. Experiment 3

Although in Hebrew LD may be considered a deep task, we assumed that living/ nonliving decisions require additional semantic elaboration of the attended stimulus. Consequently, more cognitive resources should be required to perform a semantic decision than an LD and, therefore, fewer resources would be available to leak and enable encoding of unattended stimuli. As a result, we predicted that when attended items required semantic processing, long-term repetition priming for unattended words in the mixed study condition should drop to the level of long-term repetition priming in the blocked study condition. Similarly, study condition will no longer influence explicit recognition. Because we substituted a more conceptual implicit test of memory for the LD task, other aspects of the results which are peculiar to conceptual priming may emerge. In particular, because many of the variables that affect performance on explicit tests also affect conceptual priming (Roediger and McDermott, 1993), we anticipated that there would be a closer match in the pattern of performance across retention intervals between explicit recognition and long-term repetition priming.

5.1. Method

The design and procedures in this experiment were identical to those used in Experiment 2. The stimuli, however, were changed to fit the living/ nonliving task. In addition, because the pattern of repetition priming effects in the mixed study condition in this experiment turned out to be different from those found in the previous two experiments, the mixed condition has been replicated once, each time testing a different group of 32 participants. Since the pattern of the results has been very similar in both replications, the results of all 64 participants have been collapsed and analyzed together. In the blocked design condition 32 participants were tested. Hence, the total number of participants tested in this experiment was 96. All participants were undergraduates from the same participant pool that was used in the previous experiments. None of these participants participated in the previous experiments.

5.1.1. Stimuli

The stimuli were 320 words. Among those, 160 denoted animate items and 160 inanimate items. At study, each subject saw 160 words in 80 trials. In each trial, one word was attended and one unattended. There were 20 trials in which both the attended and the unattended words were "living", 20 trials in which both the attended and the unattended were "nonliving", 20 trials in which the attended word was living and the unattended nonliving, and 20 in which the attended word was nonliving and the unattended living. Thus, at study each subject attended to 80 words (40 living and 40 nonliving) and ignored 80 words. Across participants each word appeared in the attended and unattended condition. In addition the 160 studied and 160 unstudied words were also counterbalanced across participants.

The test sessions were identical to those used in the previous experiments except that the task to assess long-term repetition priming was the semantic decision.

5.2. Results

The semantic decisions at study were almost perfectly accurate. RTs in the mixed condition were significantly longer than in the blocked condition (856 and 704 ms, respectively, $F(1,62) = 23.5$, MSe = 29567, $p < 0.001$). When the unattended word was from the same response category as the attended word (living/nonliving), RTs to the attended words were shorter than when the unattended word was from the alternate response category (771 and 790 ms, respectively, $F(1,62) = 5.97$, MSe = 1909, $p < 0.025$). This "response compatibility effect" was similar, however, for the blocked study condition (695 ms vs. 713 ms) and for the mixed study condition (846 ms vs. 866 ms), $F(1,62) < 1.00$.

As in the previous experiments, explicit recognition performance was assessed by calculating the d' in each of the test sessions separately for words that were attended or unattended at study. Long-term repetition priming was assessed by subtracting the semantic decision RT for old attended and old unattended words from the RT to new words.

As expected both attention and retention interval had strong effects on explicit recognition performance. The d' values were greater for attended than for unattended words, and for the short, than the long, retention interval (Table 5).

The mixed-model ANOVA showed that the main effects of attention and retention interval were significant ($F(1,94) = 119.48$, MSe = 0.16, $p < 0.001$ and $F(1,94) = 32.53$, MSe = 0.18, $p < 0.001$, respectively) and so was the interaction between these two factors ($F(1,94) = 21.53$, MSe = 0.10, $p < 0.001$). This interaction reflected the difference between the attention effect at short (0.62) and at long retention times (0.32). The between-participants main effect of study condition was not significant and it did not interact significantly with either the effect of attention ($F(1,94) < 1.00$) or retention time ($F(1,94) = 1.90$, MSe = 0.18, $p < 0.18$).

The RTs in the semantic repetition priming task were faster for repeated than for new words. Unlike in the previous experiment, long-term repetition priming was in-

Table 5
Explicit recognition performance (mean d' and SEm) at immediate and delayed tests for attended and unattended words studied in semantic decision

Attention at study	Retention interval			
	1/2 an hour		24 h	
	Mixed	Blocked	Mixed	Blocked
Attended	0.81 (0.06)	0.87 (0.09)	0.47 (0.05)	0.38 (0.07)
Unattended	0.21 (0.05)	0.21 (0.07)	0.15 (0.03)	0.05 (0.05)

Table 6
RTs (SEm) and repetition effects in semantic decision for words that were attended and unattended in the mixed and blocked presentation at study

Attention at study	Retention interval			
	1/2 an hour		24 h	
	Mixed	Blocked	Mixed	Blocked
New words	677 (20)	597 (28)	647 (18)	591 (25)
Attended	643 (17)	572 (24)	636 (17)	581 (25)
Repetition effect	34 ms	25 ms	11 ms	10 ms
Unattended	670 (12)	591 ms	649 (19)	597 (27)
Repetition effect	7 ms	6 ms	−2 ms	−6 ms

fluenced by attention in the mixed as well as in the blocked study condition (Table 6).

The mixed-model ANOVA of the repetition priming effects showed significant main effects of attention ($F(1,94) = 11.73$, $\mathrm{MSe} = 2525$, $p < 0.001$) and of retention interval ($F(1,94) = 5.38$, $\mathrm{MSe} = 3574$, $p < 0.025$). The main effect of study condition, however, was not significant ($F(1,94) < 1.00$). None of the interactions was significant in this analysis ($F(1,94) < 1.00$).

As in the previous experiments, long-term repetition priming was also examined. RTs to semantic decisions for new words were compared with the RTs for each of the old word categories within-subject ANOVAs separately for the mixed and the blocked study conditions. In both ANOVAs repetition priming was significant; semantic decisions for repeated words were faster than for new items ($F(2,126) = 8.00$, $\mathrm{MSe} = 2437$, $p < 0.001$ and $F(2,62) = 6.34$, $\mathrm{MSe} = 996.8$, $p < 0.005$) for the mixed and the blocked study conditions, respectively. The effect of retention interval was not significant either in the mixed or in the blocked study condition ($F(1,63) = 2.57$, $\mathrm{MSe} = 13559$, $p > 0.11$ and $F(1,31) < 1.00$, respectively). The interaction between these two main effects approached significance in the mixed study condition ($F(1,126) = 2.48$, $\mathrm{MSe} = 1782$, $p < 0.09$) while being insignificant in the blocked study condition ($F(2,62) = 1.09$, $\mathrm{MSe} = 914$, $p > 0.33$). Post-hoc univariate F-tests, showed that for both study conditions the only reliable difference between semantic decisions for new and repeated words occurred for initially attended words at short retention intervals.

5.3. Discussion

Attention significantly influenced both priming and explicit recognition regardless of study condition. This confirmed our main prediction that deeper LOPs should reduce long-term repetition priming for unattended words in the mixed study condition. The compatibility effect on RTs at study suggested that the unattended words, nonetheless, were processed automatically to a semantic level. RTs for semantic decisions were relatively longer than those for the LDs measured in the previous experiments. This difference suggests that semantic decisions indeed required more elaborate processing. This pattern of results also supports our interpretation that the long-term repetition priming observed in Experiment 2 was caused by "leakage" of attention resources which occurred when processing the attended items was not demanding enough. This interpretation is supported further by the finding that the mixed/blocked manipulation in the present experiment did not influence the attention effect on explicit recognition.

As anticipated, both long-term repetition priming and explicit recognition were diminished as the retention interval increased. The pattern of these results which are different from those observed in Experiments 1 and 2, is consistent with the idea that the long-term repetition priming test in this experiment was conceptual and differed from the more data driven, LD test. There is ample evidence that a number of variables, such as LOP, affect perceptual and conceptual tests differently (for a review see Brown and Mitchell, 1994). As the present results suggest, retention interval, as well as study condition and attention, may be added to the list, though there are still too few studies to say so with certainty. The nature of these differences will be addressed more fully in Section 6.

6. General discussion

An enduring question in the literature on implicit memory is whether performance is sensitive to manipulations of LOP and/or attention at encoding. In a series of three experiments we found that the effects of these manipulations depend on the study condition and on whether the implicit test was lexical or semantic. In Experiment 1, using a different paradigm, a different index of repetition priming and a different language, we extended previous findings on the effects of LOP on long-term repetition priming. Our findings supported the hypothesis that LOP can influence long-term repetition priming if the levels are kept distinct at study. In Experiments 2 and 3 we demonstrated that, contrary to accepted views, attention can also influence long-term repetition priming. Significant attention effects were found in the blocked study condition, whereas in the mixed study condition these effects were present in the semantic repetition priming test, but absent in the lexical repetition priming test. These results indicate that if the experimental conditions allow scrupulous selection of attended information or narrow tuning to a shallow, pre-lexical level of processing, the activation of mental representations of items that are unattended or shallowly processed is limited, and the implicit influence of such activation on subsequent performance is significantly reduced, as is explicit recognition.

On the basis of the present study the following general principles can be formulated: (1) A threshold level of attention at encoding is necessary to establish a long lasting representation which can influence performance on subsequent implicit tests of long-term memory. (2) Even when the stimuli are attended, they must be processed at a minimal depth (at both study and test) to obtain implicit memory effects. (3) For tests at the lexical level, exceeding the thresholds adds little to the magnitude of the priming effect; for semantic tests, additional processing may benefit priming to a greater extent. (4) A higher threshold of attention and LOP needs to be reached for conscious recollection on explicit memory tests. Performance on these tests improves with increases in attention and LOP beyond the threshold. We discuss each of these principles separately.

6.1. Attention threshold

Across the few studies in which attention at encoding has been manipulated, the effects of this manipulation on long-term repetition priming were inconsistent. Using spelling bias of auditorily-presented homophones (e.g. deer/dear), Eich (1984) found significant repetition priming for unattended words which was less than for attended words. Bentin et al. (1995), however, found equivalent long-term repetition priming in an auditory LD task for words that were attended or unattended at study. In both studies, attention was manipulated at study using a dichotic presentation in which participants were biased to attend to one ear. Using visually presented words, Merikle and Reingold (1991) found greater priming for unattended than for attended words that was reduced during the course of testing. In their study, selective attention to one of two words in each display was manipulated by a simultaneously presenting arrows pointing to the target word. Treisman and DeSchepper (1996) found long-lasting equivalent but negative repetition priming for unattended and attended novel nonsense shapes. On the other hand, they did not find any priming for unattended words. At encoding, two overlapping stimuli were exposed, each in a different color, while the participants were instructed a priori to match stimuli of one color to a monochromatic target. Jacoby (1991), Jacoby et al. (1993) and Parkin et al. (1990), all used a dual task paradigm at encoding and found equivalent repetition priming for words studied under focused and divided-attention conditions. Parkin and Russo (1990), found a similar effect for the identification of fragmented line drawings.

Our finding that the effects of attention on long-term repetition priming vary with mixed/blocked study condition and type of test provides some insight for resolving the inconsistency in the literature. In our study, when attention was more rigorously controlled, as in the blocked design, a significant attention effect was found. This effect was found despite evidence that the unattended items were processed automatically to a semantic level (Experiment 3). When focusing attention was more difficult, as in the mixed design of Experiment 2, the "implicit" threshold was reached even for unattended words, and significant long-term repetition priming was found, which was equivalent for attended and unattended words. All the above studies, except Eich's, conformed to the second pattern. These findings suggest that indeed in all these studies some minimal attention was paid to the unattended items which was sufficient to reach the implicit, but not the explicit, threshold. Although there is no direct evidence to indicate that this was the case, in several studies that showed priming for unattended items (Bentin et al., 1995; Jacoby, 1991; Jacoby et al., 1993; Parkin and Russo, 1990), the encoding task was not designed to prevent attention from leaking to the unattended items. The observation that explicit recognition for unattended items was above chance in these two studies confirms that even the higher, explicit threshold was reached. For the other studies (Merikle and Reingold, 1991; Treisman and DeSchepper, 1996), explicit recognition was at chance, at least in some conditions. The results of the present study, however, indicates that chance recognition is no guarantee that the implicit attention threshold has not been reached. In Experiment 2, chance recognition for unattended words was found for both the blocked and the mixed study condition, but only in the latter was long-term repetition priming significant. Experiment 3 addressed this issue by using a task that required deeper processing of attended words at study, which demanded greater resources, and hence limited the amount of attention that could leak to the unattended words. As predicted by our interpretation, this manipulation prevented leakage and consequently unattended items did not lead to long-term repetition priming even in the mixed condition.

The results of Eich's study differed from the others in that priming for unattended words, although significant, was smaller than for attended words. Note, however, that in all the other studies cited above, priming was tested at a lexical level (LD or word identification), whereas Eich's was the only study to test priming at a conceptual level (contextual disambiguation of homophones). This difference between Eich's study and the others is similar to the difference between Experiments 2 and 3 in the present study supporting our suggestion that attention may affect conceptual and lexical tests of priming differently (see point 3 above). The significant long-term repetition priming effect for unattended words in Eich's study (as opposed to ours), may result from the greater difficulty participants had in ignoring words in dichotic listening than in visual selective attention paradigms. ERP studies provide some support for this modality effect. While Nobre and McCarthy (1994) found no (electrophysiological) evidence for processing unattended words in visual selective attention, Bentin et al. (1995), using dichotic listening, found evidence that unattended words were indeed processed at study.

6.2. Levels of processing threshold

The absence of a long-term repetition priming effect for shallowly processed words in the blocked but not the mixed design confirms Challis and Broadbeck's (1992) findings. These results indicate that when processing is sufficiently well controlled, as in the blocked design, the minimal LOP needed to sustain long-term repetition priming was not reached in the shallow condition. On the other hand, in the deep condition, that threshold is reached and even surpassed; consequently, an LOP effect was obtained. In the mixed design, even shallowly processed words reached that minimal level so that further increases in depth of processing at study had little or no effect on repetition priming (see discussion of Experiment 1 for consideration of other interpretations and discrepancies with other studies).

Implicit memory traces can be formed at different levels of processing, and they contain whatever information has been extracted up to that point (Moscovitch et al., 1993). The present results suggest that the minimal level of processing at encoding which is needed to obtain long-term repetition priming for words has to address at least the structural (orthographic or phonologic) aspects of the lexicon. This consideration is in agreement with suggestions by other investigators that repetition priming for words is mediated by abstract lexical information (Blaxton, 1989; Craik et al., 1994; Roediger and McDermott, 1993; Weldon, 1991) contained in the word-form system (Moscovitch, 1992; Schacter, 1992; Tulving and Schacter, 1990; Warrington and Shallice, 1980). More generally, to obtain long-term repetition priming for words and nonlinguistic material, a level of representation must be established that permits at least a structural, pre-semantic interpretation of the item.

6.3. Pre-semantic vs. semantic tests of repetition priming

The present results also suggest that even if attention at encoding is adequate and the LOP sufficiently deep, the type of repetition priming test may also bias the influence these factors have on long-term repetition priming. If the test addressed a semantic level (as in Experiment 3) attention effects were evident even if encoding was in a mixed study condition. A similar pattern was found when LOPs were manipulated in other studies; that is, LOP has a larger effect on tests that are more conceptual than on those that are more data driven (Blaxton, 1989; Brown and Mitchell, 1994; Roediger et al., 1989; Roediger and McDermott, 1993). These studies have shown that increasing the depth of processing even beyond the implicit threshold, enhances priming in the more conceptual tests. In contrast, in tests that are more data driven, increasing the depth of processing at encoding beyond threshold, has relatively little additional effect on repetition priming (but see Duchek and Neely, 1989). A general rule might be that above implicit threshold, the effect of LOP on long-term repetition priming is influenced by the amount of conceptual processes required by the test. With respect to attention, the same rule may apply. The few studies that examined the effect of attention on long-term repetition priming are generally supportive but more are needed to validate this hypothesis.

6.4. Explicit tests of memory

As expected, LOP and attention had large effects on explicit recognition. The results showed that both LOP and attention effects were accentuated in the blocked relative to the mixed study condition. This pattern corroborates our working hypothesis that LOP are more distinct and attention is more focused in the blocked than in the mixed design. However, when processing at each level is optimal, LOP effects may not vary from one design condition to another (Thapar and Greene, 1994 and our discussion of our Experiment 1).

As in conceptual implicit tests of memory, performance on explicit tests improves with increasing depth of processing and attention even beyond threshold. The present study and others in the literature (e.g. Jacoby et al., 1993; Merikle and Reingold, 1991; Treisman and DeSchepper, 1996) indicate that the minimal threshold for explicit recollection is higher than that needed to sustain performance on implicit tests of memory. This claim is based on evidence that long-term repetition priming can be obtained even under conditions in which conscious recollection is absent.

6.5. The inter-relationship of retention interval, attention and LOP

Although retention interval was not a primary concern in the present study, we wish to call attention to the very interesting, differential effects it had in the various experimental conditions explored here. Explicit recognition was significantly reduced by test delay in all conditions. The effect of retention interval on long-term repetition priming, on the other hand, was more complex. In Experiments 1 and 2, which involved LDs, once the implicit threshold was reached repetition priming was unaffected by retention interval. [5] This held equally for attended and unattended words and for words encoded at deep or shallow levels. Similar results were reported by Treisman and DeSchepper (1996) for novel nonsense shapes and by Jacoby et al. (1993) for words. In contrast, in Experiment 3, in which the task used to assess long term repetition priming was semantic, the magnitude of repetition priming effect was reduced with delay. This pattern of results suggests that where long-term repetition priming benefits little from increases in LOP and/or attention, it is also resistant to the effects of retention interval. Conversely, when memory improves with LOP and attention, it also deteriorates with retention interval.

What can account for the related effects of LOP, attention, and retention interval? One interpretation is that increases in repetition priming beyond threshold are caused by factors associated with explicit memory. Although plausible, this interpretation is unlikely because performance on implicit tests, even when they are conceptual, can be dissociated from that on explicit tests both in normal (Brown and Mitchell, 1994) and amnesic people (e.g., Butters et al., 1990; Graf and Schacter, 1985, 1987). Moreover, even if correct, this interpretation does not explain why these factors are so strongly inter-related in explicit as well as implicit tests. We wish to offer an alternative interpretation which, though speculative, might provide a unified account of the above findings.

As noted earlier, memory traces that mediate performance on implicit tests can be formed at different levels of processing and the traces contain whatever information has been extracted at each level (Moscovitch, 1992; Moscovitch et al., 1993, 1994; DeSchepper and Treisman, 1996). Traces created at a perceptual level involve neural structures that are modular in the sense that they are designed to be highly constrained both in terms of the information they pick-up and in terms of the operations they perform on it (see also Tulving and Schacter, 1990; Schacter, 1992). The operation of such structures requires finite but small amounts of attention and is not easily influenced by higher-level (semantic) processes. Consistent with the characteristics of these structures, traces at perceptual levels, need only a minimal amount of attention to be created fully, and benefit little from deeper levels of processing. Because these traces are tightly bound into the structures that process them, they are very stable. Such a mechanism may explain why a minimal threshold of attention and LOP at encoding is needed to support perceptual priming and beyond this threshold these factors as well as retention interval have little additional influence.

[5] We refer here to retention intervals beyond a few seconds. At short intervals, repetition priming is reduced significantly with lag (Bentin and Moscovitch, 1988; Ratcliff et al., 1985) or delay (Sloman et al., 1988). We believe that at these delays, the high level of immediate repetition is mediated by a combination of lexical priming (demonstrated, for example, by masked priming, Forster and Davis, 1984; Rajaram and Neely, 1992) and explicit episodic factors that may no longer operate at longer retention intervals (Bentin and McCarthy, 1994; Monsell, 1985, 1987).

Memory traces created at a conceptual level are dependent on structures involved in interpreting the perceptual input. In contrast to the perceptual structures, the conceptual structures integrate information across various domains, both semantic and perceptual. The deeper the level of encoding, the more fully integrated are these structures. Consequently greater attention resources are needed to maintain the efficient operation of these structures at deep LOPs. Given their intricacy, these operations are vulnerable to disruption and destruction. As before, conceptual memory traces take on the characteristics of the structures that mediate them. The minimal thresholds of attention and LOP necessary to create them are higher than those needed for perceptual traces. As well, conceptual traces benefit from increases in attention and LOP above these thresholds. This framework explains the counterintuitive observation that despite their initial strength, these traces are less durable.

What holds for conceptual implicit tests of memory, applies as well or even more so to explicit tests of memory. In addition to drawing on conceptual processes, explicit tests draw on conscious processes which may require even higher levels of cognitive resources to maintain. This explains the massive LOP and attention effects seen on explicit tests as well as the relatively rapid forgetting.

Although the above account is speculative, it is consistent with neuropsychological evidence. Performance on perceptual implicit tests of memory is associated with variation in activation of circumscribed structures located in the posterior neocortex that are also involved in perception (Blaxton et al., 1996; Schacter et al., 1995; Squire et al., 1992). Damage to these structures leads to domain specific loss of perceptual priming (Blaxton, 1992; Keane et al., 1991, 1995; Schacter, 1992). The locus at which attention at a perceptual level operates is co-extensive with these regions (Corbetta et al., 1991; Haxby et al., 1994a, b; Kohler et al., 1995; Posner, 1995; Smith and Jonides, 1995). In contrast, more extensive networks are activated on conceptual implicit and explicit tests of memory (Blaxton et al., 1996; Fletcher et al., 1995; Haxby et al., 1994a, b; Kapur et al., 1994; Moscovitch et al., 1995; Shallice et al., 1994; Tulving et al., 1994). These include not only posterior neocortical regions but also the medial temporal lobes, the pre-frontal cortex, anterior and posterior cingulate gyrus, and cerebellum. Similarly, performance on these tests can be impaired in various ways by a variety of focal or diffuse brain lesions, the nature of the impairment being determined by the contribution each of the structures make to encoding, retention, and retrieval (for reviews, see Moscovitch, 1992, 1994; Moscovitch et al., 1993, 1994).

6.6. Implications for system and process theories of memory

The account we offered is consistent with a component process account of memory (Moscovitch and Umiltà, 1990, 1991; Moscovitch, 1992, 1994) which combines features of both systems and processing theories. Our results, however, can also be incorporated into more traditional systems and processing theories. Theories of both types must acknowledge that there are lower limits of attention and levels of processing beyond which perceptual and conceptual priming for patterned stimuli, such as words and objects, cannot be obtained. For systems theories, the lower limit is set at the system necessary for structural representation. Similarly, for processing theories, it is not sufficient that data-driven processes at study overlap with those at test but that these processes must operate on stimulus configurations. Although our results cannot be used to adjudicate between the system and processing theories, and between them and the component process approach, we are satisfied that the results provide constraints for current theories and suggest a unified framework for explaining the inter-relation of LOP, attention, and retention interval on explicit and implicit tests of memory.

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