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Emotional arousal enhances word repetition priming

Laura A. Thomas and Kevin S. LaBar
Duke University, Durham, USA

Three experiments were conducted to determine if emotional content increases repetition priming magnitude. In the study phase of Experiment 1, participants rated high-arousing negative (taboo) words and neutral words for concreteness. In the test phase, they made lexical decision judgements for the studied words intermixed with novel words (half taboo, half neutral) and pseudowords. In Experiment 2, low-arousing negative (LAN) words were substituted for the taboo words, and in Experiment 3 all three word types were used. Results showed significant priming in all experiments, as indicated by faster reaction times for studied words than for novel words. A priming × emotion interaction was found in Experiments 1 and 3, with greater priming for taboo relative to neutral words. The LAN words in Experiments 2 and 3 showed no difference in priming magnitude relative to the other word types. These results show selective enhancement of word repetition priming by emotional arousal.

It is well known that emotionally arousing events and experiences are usually remembered better than emotionally neutral ones (Christianson, 1992). Emotional arousal has multiple effects on explicit (declarative) memory, which has been a topic of investigation for decades. In one of the first studies, Kleinsmith and Kaplan (1963) showed that emotional arousal at the time of encoding affects memory consolidation, as evidenced by differential retention curves over time (see also LaBar & Phelps, 1998). Heuer and Reisberg (1990) found that the beneficial recall of emotionally arousing segments of a story comes at a cost; namely, by concomitant forgetting of peripheral information that is less important to the narrative gist (see also Cahill & McGaugh, 1995). Similar effects have been reported in eyewitness testimony, where Loftus has argued for a narrowing of attention on central detail, as in ''weapon focus'' (Christianson & Loftus, 1987; Loftus, 1979). Emotional arousal not only impacts the

Correspondence should be addressed to Kevin S. LaBar, Center for Cognitive Neuroscience, Box 90999, Duke University, Durham, NC 27708-0999, USA; E-mail: klabar@duke.edu

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accessibility and focus of memories, but also their experiential qualities. Research on autobiographical memory suggests that emotional arousal enhances the vividness of the memory as well as other features, such as its coherence and the sense of reliving that accompanies the act of recollection (Reisberg, Heuer, McLean, & O'Shaughnessy, 1988; Rubin & Kozin, 1984; Talarico, LaBar, & Rubin, 2004). Long-lasting memories for unexpected, novel events high in emotionality and consequentiality—so-called ''flashbulb memories''—are held high in confidence (Brown & Kulik, 1977; Talarico & Rubin, 2003). Yet, as in eyewitness testimony (Loftus, 1975; Loftus & Zanni, 1975; Yuille & Cutshall, 1986), there is debate as to the degree to which these memories are susceptible to distortion and reconstruction over time (Neisser & Harsch, 1992; Schmolck, Buffalo, & Squire, 2000).

Despite these advances in delineating the behavioural effects of emotional arousal on explicit memory, little is understood about its influence on implicit (nondeclarative) memory. Squire's (1992) taxonomy divides nondeclarative memory into four basic subsets that are mediated by different brain systems: simple conditioning, procedural learning (motor, perceptual, and cognitive skills and habits), priming, and nonassociative learning (e.g., habituation). Of these, fear conditioning is the well-studied form of implicit emotional memory for which psychological and neural mechanisms have been detailed across species (LaBar & LeDoux, 2001). Fear conditioning is highly dependent on the arousing properties of the unconditioned stimulus, but it is unknown if arousal is critical for modulating other forms of implicit memory, such as motor skill acquisition or priming.

The study of emotional influences on implicit memory also has implications for clinical populations, such as those suffering from major depressive disorder, anxiety disorders, and posttraumatic stress disorder. Posttraumatic stress disorder (PTSD) is an anxiety disorder characterised by hypervigilance for potentially threatening events, as well as involuntary retrieval of disturbing episodic memories, taking the form of nightmares, intrusive thoughts, and flashbacks. People suffering from PTSD may be plagued by repetitive memories of their trauma, which suggests that the memory structures related to the traumatic event are easily activated (Coles & Heimberg, 2002). There is evidence of explicit memory biases in PTSD, with heightened recall of emotional as compared to control words (McNally et al., 1998). Implicit memory biases have not been studied as often as explicit memory biases in patients with in PTSD. However, it has been postulated that implicit memory biases for threat information in PTSD could be more apparent by using conceptual rather than perceptual paradigms (McNally & Amir, 1996).

It is well established that depression is associated with facilitated explicit memory for negative emotional stimuli (e.g., Mathews & Bradley, 1983). The explicit mood-congruent memory (MCM) bias is reported by depressed patients to pervade their conscious experience and it has been postulated that it could be

involved in the continual maintenance of the disorder. In terms of a comparison between MCM in explicit and implicit memory, the most common finding is that depressives show facilitated explicit memory, but not implicit memory, for negative information (Watkins, Mathews, Williamson, & Fuller, 1992). Whereas people with major depression show clear explicit MCM bias, the data are not nearly as clear when it comes to implicit MCM. It might take certain types of implicit tasks, specifically those that rely on conceptual mechanisms, to demonstrate implicit MCM bias in depression (Watkins, Martin, & Stern, 2000; Watkins, Vache, Mueller, & Mathews, 1996). However, in anxiety disorders, including phobias, the reverse is true; there is clear evidence for implicit but not explicit MCM bias for threatening information (Williams, Watts, Macleod, & Mathews, 1988; Mathews, Mogg, May, & Eysenck, 1989). The modulation of implicit memory by emotional arousal is thus a topic that may help differentiate among different forms of psychopathology.

The main objective of the present study was to investigate the influence of emotional arousal on repetition priming. There are several different forms of priming that have different operating characteristics and dependencies on different brain regions (Fleischman & Gabrieli, 1995; Schacter & Buckner, 1998). For example, semantic priming involves facilitation in performance to a target stimulus by presentation of a preceding prime that is related in meaning (Neely, 1991). Semantic priming is a short-lived phenomenon found only with small stimulus onset asynchronies (SOAs) between primes and targets. The facilitation in performance is thought to depend on spreading activation in semantic networks between related concepts and categories whose organisation is based on pre-existing knowledge. Some semantic priming studies have manipulated the affective relationship between the prime and target (reviewed in Fazio, 2001). In these cases, affective categorisation responses are faster when the prime and target are of the same valence, compared to when their valences vary, for SOAs of 300 ms or less (Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Hermans, De Houwer, & Eelen, 1994, 2001; Klauer, Rossnagel, & Musch, 1997; Wentura, 2000).

In contrast to short-term semantic priming effects, long-term priming effects are thought to be mediated by reactivation of stimulus representations in the neocortex (Schacter & Badgaiyan, 2001). One method of inducing long-term priming is through item repetition, which is defined as facilitation in performance or change in response bias with repeated stimulus exposure (Fleischman & Gabrieli, 1998; Squire, Knowlton, & Musen, 1993). A typical item repetition priming task is divided into two phases, a study phase and a test phase. In the test phase, the material from the study phase is repeated along with new material, and participants make a cognitive or perceptual judgement about each presented stimulus without reference to the prior study episode. Priming is typically observed in the test phase as a savings in reaction time (RT) in response to the old (studied) items relative to the novel items. Repetition

priming studies are usually preserved in amnesia and are thus independent of explicit memory (Shimamura, 1986).

The present study developed a new paradigm to determine if repetition priming for words is modulated by their arousal properties. In Experiment 1, participants studied high-arousing negative (taboo) and neutral words and subsequently made lexical decision judgements about these words, novel words, and pseudo-words in the test phase. Lexical decisions involve making word/nonword judgements about the stimuli and are a common testing procedure in both semantic priming and word repetition priming studies (Meyer & Schvaneveldt, 1971; Neely, 1976, 1977; Perez & Gotor, 1997). In both the study and test phases, the emotional manipulation was incidental to the task. In Experiment 2, low-arousing negative words were substituted for the taboo words to control for valence effects. Experiment 3 utilised all three types of words in both the study and test phases. We hypothesised that all experiments would show a main effect of priming for studied vs. novel words. We further predicted a priming $\times$ emotion interaction in Experiments 1 and 3, such that taboo words would show greater priming magnitude than neutral and LAN words. If supported, these results would demonstrate that emotional arousal incidentally facilitates priming in addition to its role in fear conditioning and in the modulation of explicit memory. Such results would expand the known role of emotion in implicit memory with implications for possible mechanisms of implicit memory biases in anxiety disorders.

EXPERIMENT 1

Method

Participants

A total of 55 healthy young adults (32 women, 23 men) participated in this experiment (mean age = 21 years; age range = 18–28 years). Of the participants, 76% were Duke University undergraduates who took part in the study for course credit. The remaining participants were Duke University students recruited through posted advertisements and were reimbursed at a rate of $10/hour. Recruitment method was included as a factor in the analysis and did not yield any significant effects for Experiments 1–3; therefore, participants were pooled across recruitment methods. All participants were native English speakers, and were screened by a self-report questionnaire for history of neurologic and psychiatric illness, substance abuse, and current psychotropic medication use. The experimental protocol and human subjects procedures were approved by the Institutional Review Board at Duke University.

Materials

Thirty high-arousing negative (taboo) and 30 neutral words were selected from two sources: the Affective Norms for English Words (ANEW) (Bradley & Lang, 1999), and additional words normed by 150 New York University (NYU) undergraduates (courtesy of Dr Elizabeth Phelps). All ANEW words were rated for valence and arousal on 9-point scales (1 = low pleasure/low arousal, 9 = high pleasure/high arousal). The words normed by NYU undergraduates were rated for valence and arousal on 5-point scales (1 = low pleasure/low arousal, 5 = high pleasure/high arousal). The 9-point scores were converted into 5-point scores before doing the analyses. Paired *t*-tests revealed that the taboo words were rated as significantly more unpleasant, $t(25) = 8.41$, $p < .0001$, and more arousing, $t(25) = 22.25$, $p < .0001$, than the neutral words (Table 1).

The taboo and neutral word lists were submitted to Latent Semantic Analysis (LSA) to ensure that they did not differ in semantic cohesiveness (Landauer, Foltz, & Laham, 1998; Landauer & Kintsch, 1998). LSA is a mathematical technique that extracts ratings of semantic similarity for word pairs from bodies of text. Previous research has shown that human participants judge semantic similarity comparable to LSA (Landauer & Dumais, 1997). LSA yielded an average within-list semantic similarity estimate (±*SEM*) of 0.11 (.008) for taboo words and 0.11 (.006) for neutral words. These means did not differ statistically, $t(26) = 0.46$, $p = .65$. Word frequency was calculated using the Kucera-Francis

TABLE 1
Mean valence and arousal ratings (± *SEM*), and word lists for taboo, low-arousing negative (LAN), and neutral words.

Word type	*Valence*	*Arousal*	*Word lists*
Taboo	3.49 (0.24)	3.88 (0.04)	anus, bitch, cancer, cum, cunt, dildo, ejaculate, faggot, feces, fuck, hate, herpes, incest, kill, murder, mutilate, nigger, nipple, orgasm, orgy, penis, plague, pussy, rape, schlong, slut, suicide, tits, tumor, twat
LAN	3.40 (0.07)	2.85 (0.11)	angry, bastard, blister, blood, burn, crash, crisis, destroy, detest, doom, fire, fright, grime, handicap, impair, inferior, lazy, meek, mucus, obesity, piss, pity, slave, sorrow, tense, threat, vacate, vomit, waste, weep
Neutral	1.33 (0.06)	1.60 (0.09)	advisor, aisle, bar, bass, belief, branch, cafe, column, desk, drawing, fabric, flag, inch, jacket, layer, league, lever, owner, patrol, pond, poster, quart, saddle, scan, seller, shade, thumb, truck, viewer, wire

written frequency count (Kucera & Francis, 1967). The lists did not differ in word frequency, although these conclusions are qualified by the fact that only 43% of the taboo words were found in the database. The word lists also did not differ in word length, concreteness, or parts of speech (all ts < 1.00). Concreteness norms were taken from the MRC Psycholinguistics Database (Clark, 1997).

Thirty novel highly-arousing negative and 30 novel neutral words were selected from the ANEW database to create pseudo-words. These words were formed by altering one consonant in the middle of the word to create an orthographically plausible but nonexistent word in English. All stimuli were presented on a 17 inch Dell monitor powered by a Dell Dimension XPS T-500 computer (Dell Corporation, Round Rock, TX). Superlab Version 2.0 (Cedrus Corporation, San Pedro, CA) was used to generate the experiment.

Design and procedure

There were two phases in this experiment, a study phase and a test phase. In the study phase, participants were shown 15 taboo and 15 neutral words one at a time in the center of the computer screen for 3000 ms, with a fixation point presented for 500 ms during the interstimulus interval. Words were presented in bold Ariel font against a mid-grey background. After the presentation of each word, the participant was asked to semantically categorise the word as either ''concrete'' or ''abstract''. The following instructions were presented on the screen: ''In the first part of the experiment, you will press the '1' key if the word is concrete, or press the '2' key if the word is abstract. A concrete word is one which refers to an actual, specific thing, and a word is characterised as abstract if it does not refer to a specific thing, but rather a concept, idea, or attitude''. Participants were instructed to respond as quickly and as accurately as possible when the word appeared on the screen, although the word remained on the screen for 3 full seconds. Participants were randomly assigned to one of four versions of the task. Word assignment to the study or test phase was counterbalanced, and the sequential order of words within each phase was pseudo-randomised. There was a 1 minute delay before the test phase began.

During the test phase of the experiment, participants were presented with the same 30 words from the study phase, along with 15 novel taboo and 15 novel neutral words. Sixty nonwords were also included in the test phase. Participants categorised what was presented on the screen as either a word or a nonword using a two-alternative forced-choice lexical decision response (pressing '1' on the numberpad for ''word'' or '2' for ''nonword''). The visual format of the words was identical to that in the study phase. The word stayed on the screen until the subject made a response, when it advanced to a fixation point for 500 ms. If the participants did not respond within 3 s the trial automatically advanced. Participants were instructed to respond as quickly and as accurately as

possible when the stimulus appeared on the screen. RT in both phases of the experiment was recorded as the dependent measure. Total testing time was approximately 20 min.

Statistical methods

Prior to any analyses, we rejected any RTs that were more than 2 standard deviations above each subject's mean, and any RTs below 300ms. On average, this procedure reduced the dataset by 2%.

Study phase. Study phase RT data was analysed by a paired *t*-test as a function of emotional category (taboo, neutral). For the test phase, RT was analysed by a repeated-measures ANOVA with emotion (taboo, neutral) and memory (primed, novel) as within-subjects factors. Accuracy levels were almost at ceiling in all experiments and are not considered further. Alpha levels of .05 were used to determine significance for all statistical analyses.

Test phase. In the test phase, a main effect of priming was quantified by significantly shorter RTs to studied words as compared to novel words. The magnitude of the priming effect was further examined as a function of emotional content (priming × emotion interaction). A benefit of emotion on priming would be seen as an increase in priming magnitude for taboo as compared to neutral words.

The priming data were analysed in two different ways. First, the data were analysed using absolute priming scores in which raw RTs in ms were compared for studied vs. novel items. This is the standard measure of priming in the literature. However, absolute measures do not account for possible baseline differences in responding as a function of emotional category. This is important to consider because novel taboo words typically cause an overall increase in RT relative to novel neutral words (LaBar & Phelps, 1998; MacKay et al., 2004; McGinnis, 1949; Siegrist, 1995; Williams & Evans, 1980). Therefore, the data were also analysed using relative priming scores in which RT for studied words was expressed as a proportion of the RT for novel words of the same category within participants (Keane, Gabrieli, Growdon, & Corkin, 1994). In this way, baseline RTs are normalised across the two emotional categories. For this analysis, paired *t*-tests were computed as a function of emotional category (taboo, neutral).

Results

Study phase. Analysis of RT data from the study phase showed a main effect of emotion. Participants took longer to semantically categorise taboo words (mean $\pm$ *SEM* = 1304 $\pm$ 39 ms) than neutral words (mean $+\pm$ *SEM* = 1183 $\pm$ 33 ms), $t(54) = 5.99$, $p < .0001$. Concreteness ratings made by

participants were compared with the ratings taken from the MRC database. Concordance between subjects' ratings and the MRC database was calculated as the percentage of subjects' ratings that agreed with those of the MRC database. The average concordance rate for the neutral words in Experiment 1 was 79%. There were only four of the taboo words in the MRC database, but the average concordance of these words was 76%. A paired *t*-test revealed no significant difference between the concreteness ratings of the neutral and taboo words in the MRC database and the subjects' ratings (*p*s > .99). There was also no significant difference between the concordance rates for taboo and neutral words, $t(2) = 0.95$, $p < .52$. Again, these values are qualified by the fact that very few (only 4) of the taboo words were found in the MRC database.

Test phase. A 2 × 2 repeated-measures ANOVA computed on RTs from the test phase revealed a main effect of priming, $F(1, 54) = 65.46$, $p < .0001$, and an emotion × priming interaction, $F(1, 54) = 6.08$, $p < .02$. The main effect of priming indicates that, overall, participants responded faster to studied words than to novel words. However, this main effect was qualified by an interaction that showed larger priming magnitudes for taboo words (9 %) than for neutral words (6 %) (Figure 1). Because RTs were longer for novel taboo vs. novel neutral words in the test phase, $t(54) = 2.54$, $p < .01$, proportional priming scores were also analysed. The results showed a significant effect of emotion, $t(54) =$

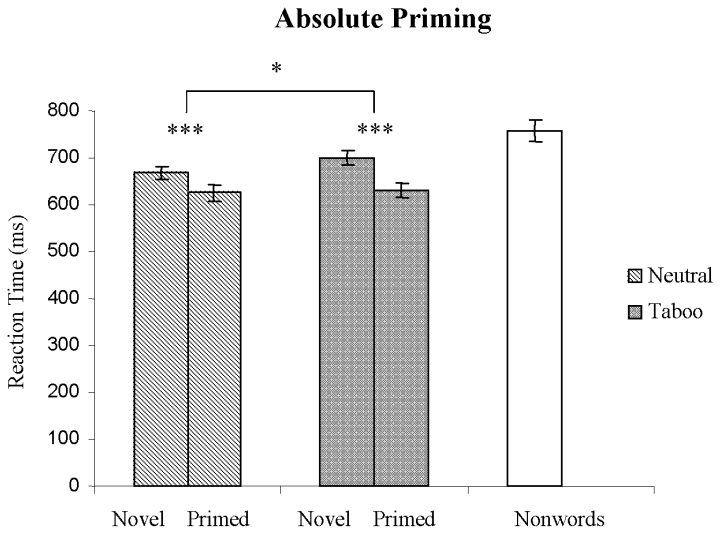

Figure 1. Word repetition priming for taboo and neutral words (Experiment 1). Priming is shown for absolute reaction time (RT) scores. There is a significant emotion ± priming interaction. Error bars indicate *SEM*. * $p < .05$; *** $p < .0001$.

4.11, $p < .05$, with greater proportional priming for taboo words than for neutral words. Thus, convergent data from both absolute and proportional priming measures indicate an enhancement of priming magnitude by emotion.

Discussion

Experiment 1 showed greater word repetition priming for taboo words compared to neutral words. This effect held even when baseline differences in RT across emotion categories were controlled by proportional scoring. Although the taboo and neutral word lists were equated for semantic relatedness and other linguistic features, it is unknown whether the priming modulation was based on the arousal or valence properties of the taboo words. Manipulation of arousal and valence could also influence study phase RT and the corresponding relationship between study phase RT and priming magnitude. To clarify these issues, Experiment 2 was administered using low-arousing negative (LAN) words instead of taboo words. The taboo words in Experiment 1 and the negative words in Experiment 2 differed in their arousal properties but not their valence. In this way, the underlying emotional factor influencing the enhanced priming for taboo words in Experiment 1 could be more precisely identified—Did the taboo words elicit greater priming than neutral words because they were highly arousing or merely because they were negatively valenced?

EXPERIMENT 2

Method

Participants

A total of 53 healthy young adults (33 women, 20 men) participated in this experiment (mean age = 22 years; age range = 18–31 years). The same participant criteria were applied as in Experiment 1. None of the participants were in Experiment 1. The experimental protocol and human subjects procedures were approved by the Institutional Review Board at Duke University.

Materials

The methods were the same as in Experiment 1, except that 30 LAN words were used instead of 30 taboo words. These negative words were rated as significantly more unpleasant, $t(29) = -21.56$, $p < .0001$, and more arousing, $t(29) = 8.99$, $p < .0001$, than the neutral words. The taboo words used in Experiment 1 were rated as significantly more arousing than the LAN words used in Experiment 2, $t(25) = 7.79$, $p < .0001$, although they did not differ in valence, $t(25) = 0.42$, $p = .68$.

The lists of negative and neutral words were submitted to Latent Semantic Analysis (LSA). LSA yielded an average within-list semantic similarity estimate

(±*SEM*) of 0.12 (0.007) for negative words, and 0.11 (0.006) for neutral words, which were not statistically different, $t(29) = 1.81$, $p = .08$. The word lists also did not differ in word frequency, word length or parts of speech. Concreteness norms were taken from the MRC Psycholinguistics Database (Clark, 1997). A paired *t*-test revealed no significant difference between the concreteness ratings of the neutral and LAN words in the MRC database, $t(12) = 0.69$, $p = .5$. The same pseudowords were used in Experiment 2 as in Experiment 1. Table 1 presents the complete list of LAN words.

Design, procedure, statistical methods

The experimental design and procedures were the same as in Experiment 1. The same statistical methods were used as in Experiment 1.

Results

Study phase. Reaction time data from the study phase showed a main effect of emotion. Participants took longer to semantically categorise LAN words (mean $\pm$ *SEM* = 1127 $\pm$ 34 ms) than neutral words (mean $\pm$ *SEM* = 1032 $\pm$ 32 ms), $t(49) = 4.60$, $p < .0001$. Concreteness ratings made by participants were compared with the ratings taken from the MRC database. Concordance rates between subjects' ratings and the MRC database were 84% for the neutral words and 66% for the LAN words. As stated previously, there was no significant difference between the MRC database concreteness ratings for the neutral and LAN words. However, there was a significant difference between the subjects' ratings of neutral and LAN words, $t(26) = -4.65$, $p < .0005$, with the LAN words rated as more abstract.

Test phase. An ANOVA computed on absolute priming scores in the test phase revealed a main effect of priming, $F(1, 49) = 40.75$, $p < .0001$. The main effect of priming indicates that, overall, participants responded faster to studied words than to novel words (5.5 % priming magnitude, on average) (Figure 2). There was no significant emotion $\times$ priming interaction, $F < 1$. Because RTs to novel negative words were significantly greater than to novel neutral words, $t(49) = 4.27$, $p < .0001$, proportional priming scores were also analysed. The results revealed no effect of emotion on priming magnitude, $F < 1$. Thus, convergent data from both absolute and proportional priming measures show no interaction between emotional category and priming.

Discussion

Experiment 2 showed a main effect of priming, indicating that participants responded faster for studied vs. novel words. Unlike in Experiment 1, however, the size of the priming effect was not significantly different as a function of

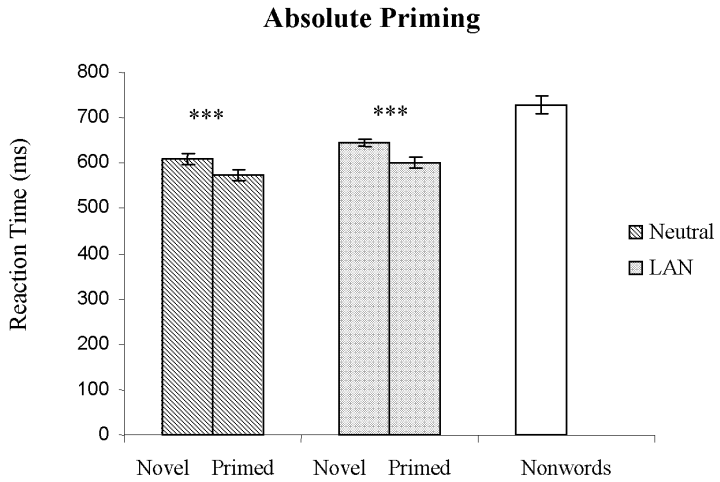

Figure 2. Word repetition priming for low-arousing negative (LAN) and neutral words (Experiment 2). Priming is quantified using absolute reaction time (RT) scores. There is no significant emotions × priming interaction. Error bars indicate SEM. *** $p < .0001$.

emotional category. This pattern of results held for both absolute and proportional scoring methods. The LAN words used in Experiment 2 were equated to the taboo words in Experiment 1 for valence but not arousal. Collectively, these findings suggest that the facilitation of priming by taboo words in Experiment 1 was related to their high arousal properties and not merely their negative valence.

Although Experiment 1 demonstrated significantly greater priming for taboo vs. neutral words and Experiment 2 showed no difference in priming magnitudes between neutral and LAN words, these were distinct experiments with different subject populations. A direct between-experiment analysis revealed a significant emotion × priming × experiment (Experiments 1 and 2) interaction, $F(1, 103) = 4.27$, $p < .05$, with a significant emotion × priming interaction observed only for subjects in Experiment 1. To confirm these results, we ran a version of the study incorporating all three word categories in a single, within-subjects design (Experiment 3).

EXPERIMENT 3

Method

Participants

A total of 63 healthy young adults (36 women, 27 men) participated in this experiment (mean age = 20.5 years; age range = 18–30 years). None of the participants were in Experiments 1 or 2. The same subject criteria applied as Experiments 1 and 2.

Materials

The same neutral words from Experiments 1 and 2 were used, as well as the taboo words from Experiment 1 and the LAN words from Experiment 2. The pseudo-words were the same in all three experiments.

Design, procedure, statistical methods

The experimental design was the same as Experiments 1 and 2, except that all three word categories were presented together. In the study phase, participants were shown 15 taboo, 15 LAN, and 15 neutral words, and during the test phase of the experiment, participants were presented with the same 45 words from the study phase, along with 15 novel taboo, 15 novel LAN and 15 novel neutral words. The same 60 pseudo-words were also included in the test phase that were used in Experiments 1 and 2.

Statistical methods were the same as in Experiments 1 and 2 with the exception that all three word categories were included in the analyses. Subject exclusion criteria were the same as Experiments 1 and 2.

Results

Study phase. Concreteness ratings made by participants in the study phase were compared with those taken from the MRC database. The average concordance rates were as follows: neutral words (60%), LAN words (80%), and taboo words (68%). There were no significant differences between the concreteness ratings of the neutral, LAN, and taboo words in the MRC database (all ts < 1). However, there was a significant difference between the subjects' subjective ratings of neutral and LAN words, $t(29) = -5.96$, $p < .0001$, with the LAN words rated as more abstract. Participants also rated taboo words as more concrete than LAN words, $t(29) = -3.44$, $p < .002$.

RT data from the study phase revealed a main effect of emotion, $F(2, 124) = 28.77$, $p < .0001$. All of the post hoc tests were statistically significant. Participants took longer to semantically categorise LAN words (mean $\pm$ *SEM* = 1271 $\pm$ 28 ms) than neutral words (mean $\pm$ *SEM* = 1189 $\pm$ 25 ms), $t(62) = 4.33$, $p < .0001$. Participants took longer to semantically categorise taboo words (mean $\pm$ *SEM* = 1345 $\pm$ 29 ms) than LAN words, $t(62) = 3.15$, $p < .005$. Participants took longer to semantically categorise taboo words than neutral words, $t(62) = 8.30$, $p < .0001$.

Test phase. A 2 $\times$ 3 repeated-measures ANOVA computed on absolute priming scores from the test phase revealed a main effect of priming, $F(1, 62) = 55.71$, $p < .0001$, and a trend for an emotion $\times$ priming interaction, $F(2, 164) = 2.73$, $p = .07$ (Figure 3). The main effect of priming indicates that, overall, participants responded faster to studied words than to novel words. However,

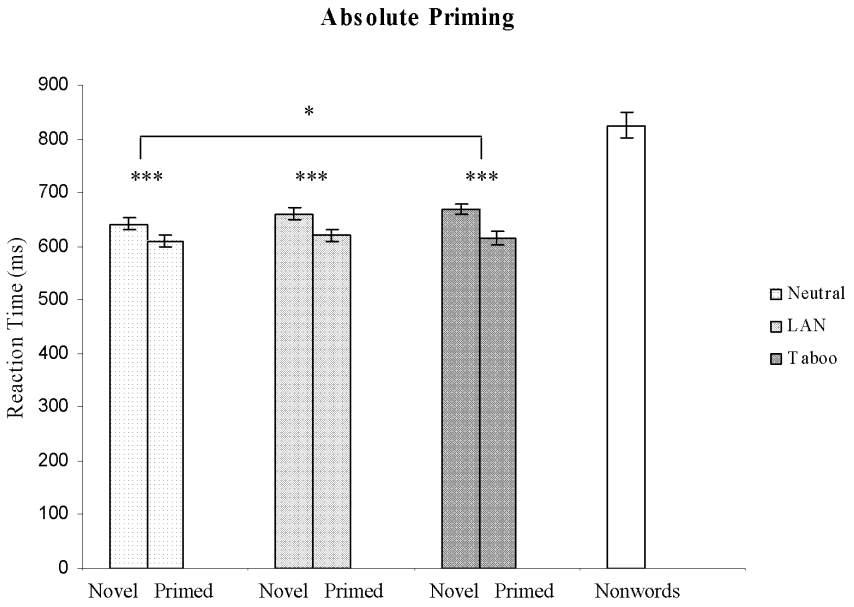

Figure 3. Word repetition priming for taboo, low-arousing negative (LAN) and neutral words (Experiment 3). Priming is quantified using absolute reaction time (RT) scores. There is a significant difference between the absolute and proportional priming magnitudes for neutral and taboo words only. Error bars indicate *SEM*. * $p < .05$; *** $p < .0001$.

this main effect was qualified by an interaction that showed larger absolute priming magnitudes only for taboo words compared to neutral words, $t(62) = 2.32$, $p < .02$. Absolute priming magnitudes between LAN and neutral words were not significantly different, $t(62) = 0.92$, $p = .4$, nor was the difference in priming between LAN and taboo words, $t(62) = 1.34$, $p = .18$. Because there was an overall significant difference for RTs to novel words in the test phase, $F(2, 124) = 8.75$, $p < .0001$, proportional priming scores were also analysed. The interaction between proportional priming and word type was not significant, $F(2, 124) = 2.1$, $p = .13$. However, there was a significant difference in proportional priming between taboo and neutral words, $t(62) = 2.03$, $p < .05$. Proportional priming magnitude for LAN words was not significantly different from either the neutral words, $t(62) = 0.92$, $p = .4$, nor the taboo words, $t(62) = 1.4$, $p = .2$.

Discussion

The results from Experiment 3 support the data from Experiments 1 and 2 in that taboo words elicited greater priming than neutral words, whereas LAN words showed no priming magnitude differences relative to the other word categories.

As in Experiments 1 and 2, the results held for both absolute and proportional priming measures. Even when combined with LAN words in a within-subject design, words high in emotional arousal show the greatest benefit of prior exposure.

GENERAL DISCUSSION

Since the seminal experiments of Kleinsmith and Kaplan (1963), it has been demonstrated that emotionally arousing content enhances long-term retention on explicit memory tasks. For example, LaBar and Phelps (1998) reported shallower forgetting slopes for taboo words relative to neutral words over a 1 hour retention interval on a free recall task. The present study was undertaken to determine whether emotional arousal has a similar beneficial impact on implicit memory. Specifically, we addressed whether repetition priming for words was modulated by emotional content within the context of a lexical decision task. The results of Experiment 1 showed a significant emotion $\times$ priming interaction, with greater priming for taboo words relative to neutral words. This result held true even when baseline differences in RT across emotional categories were normalised by proportional scoring. However, it was unclear whether this effect was driven by the arousal or valence properties of the taboo words. In Experiment 2, LAN words were substituted for the taboo words. Here, a main effect of priming was found overall, but there was no emotion $\times$ priming interaction. Since the LAN words were equated to the taboo words for valence but not arousal, we conclude that the high arousal properties of the taboo words were critical for their enhanced priming. These observations were confirmed in Experiment 3, which combined all three word categories in a single design. Note that the emotional manipulation in all experiments was incidental to the task; that is, explicit encoding of emotional content was not necessary for priming modulation to occur. Altogether, these results reveal a novel arousal-mediated memory effect in the implicit domain.

There are two primary differences between the current experiments and previous affective priming studies. First, we used a repetition priming paradigm involving a study phase and a test phase where priming is observed over long time intervals (min). In contrast, previous studies investigated the impact of emotional content on semantic priming tasks whose influence is found only with short SOAs between primes and target words (Fazio, 2001). For instance, Hermans and colleagues (2001) reported maximal affective priming effects with SOAs of 150 ms, whereas no priming occurred with an SOA of 1000 ms. The necessity of short SOAs suggests that this form of priming is an automatic process that involves spreading activation between related concepts in semantic memory. Although the mechanism underlying the priming effect in the present studies remains to be specified (see discussion below), it is clear that the operating characteristics of these two emotional priming phenomena are distinct.

Second, the current experiments reveal an influence of the arousal-based properties of emotional words, whereas the affective priming experiments investigate the valence-based semantic relationship between prime and target words (Fazio et al., 1986; Hermans et al., 1994, 2001; Klauer et al., 1997; Wentura, 2000). Our results are broadly consistent with the Taboo Stroop experiments in MacKay et al. (2004), who also found differences in the effect of stimulus repetition across taboo and neutral words. In their experiments, participants showed greater RT savings for Stroop colour naming across repeated presentations of taboo relative to neutral words. However, these effects emerged after 5 or 10 stimulus repetitions, whereas the effects in the present study emerged after each word was studied once. Moreover, the MacKay et al. (2004) study was not designed as a priming study in which repeated words were contrasted with novel words. They examined Stroop interference over multiple repetitions of taboo and neutral words.

How does stimulus arousal achieve this effect? Item repetition priming is thought to rely on reactivation of stimulus representations in neocortex. The facilitation in responding to repeated presentations of stimuli is hypothesised to relate to neural ''tuning'' so that their representations become more specific. These ideas have been supported by neuroimaging studies, which have revealed reductions of activity in sensory-specific processing regions during repetition priming, although some regions show activity increases (reviewed in Schacter & Badgaiyan, 2001; Schacter & Buckner, 1998). Many behavioural studies have indicated that emotionally arousing stimuli have privileged access to information-processing mechanisms due to their importance to the organism. For example, fear-relevant stimuli are processed subliminally and can selectively enhance performance on conditioning and attentional tasks in the absence of awareness (Öhman & Mineka, 2001). In addition, taboo words modulate performance on perceptual vigilance (Wagstaff, 1974) and attentional blink (Anderson & Phelps, 2001) tasks. Such covert processing of emotional salience may act in consort with mechanisms of priming to rapidly fine tune neural representations and adaptively protect the organism from potential sources of threat in the environment. This may occur automatically within sensory neocortex (Desimone, 1996; Wiggs & Martin, 1998) or through top-down influences of frontolimbic regions sensitive to emotional arousal (Bentley, Vuileumier, Thiel, Driver, & Dolan, 2003). Neuropsychological and neuroimaging studies have shown that the amygdala is critical for mediating arousal effects on explicit memory via interactions with frontotemporal components of the declarative memory system (reviewed in Hamann, 2001). Future studies are needed to determine whether the amygdala serves a similar function in arousal-mediated priming via feedback projections (Amaral & Price, 1984) to category-specific sensory processing regions where stimulus representations are tuned by prior exposure.

The use of a lexical decision task in the test phase of the current study is important when considering at what level of processing emotional arousal is influencing behaviour. Lexical decision is a common task used in priming studies (Meyer & Schvaneveldt, 1971). It is thought that making a lexical decision reflects processing that does not require access to detailed meaning-based information (Forde & Humphreys, 1997), and thus priming in such tasks occurs at a lexical, not a semantic, level (Shelton & Martin, 1992). However, others have proposed that lexical decisions involve automatic semantic activation (Gellatly et al., 1994). If it is the case, as many believe, that lexical decisions involve the *automatic* evaluations of words (whether at the presemantic or semantic level), the current study provides evidence that emotional arousal interacts with stimulus repetition to modulate decision making based on early stages of word processing. Alternatively, it is possible that emotional arousal interacts with stimulus repetition to reduce post-decision monitoring processes that occur prior to response selection. In either case, our results indicate that taboo words initially have a response cost in terms of lexical decision making that is reduced with repeated exposure. Importantly, even when this initial response cost was controlled through proportional scoring, a priming benefit still emerged with taboo words.

Experiment 5 in MacKay et al. (2004) tested the time it took to make a lexical decision to taboo vs. neutral words, and did not find a significant RT cost for taboo words on a lexical decision task, although the influence of stimulus repetition was not examined in this task. Nonetheless, they did report a non-significant increase in RT for taboo words, and the present study used a larger list of words and a larger population sample. Again, the MacKay et al. (2004) study did not examine repetition priming for taboo and neutral words, but evaluated RTs to lexical decision responses.

The selection of words in the present experiments was made based on their normative ratings of arousal and valence. Previous research has shown that taboo words elicit larger skin conductance responses than neutral words but that LAN words do not (LaBar & Phelps, 1998; Phelps, LaBar & Spencer, 1997). In other words, high self-ratings of arousal are associated with engagement of autonomic responses. Although the LAN words were rated higher in arousal than the neutral words (Table 1), their level of arousal was significantly lower than the taboo words. It appears, then, that the priming modulation occurs only if a sufficiently high threshold of arousal is reached. Future studies should be conducted to determine if autonomic engagement is a necessary prerequisite for this phenomenon.

A few caveats and limitations to the present study should be discussed. First, there is a potential confound between study phase RT and priming magnitude across the word categories. Specifically, emotional words had longer RTs than the neutral words during the study phase, which could contribute to the difference in priming magnitude observed during the test phase. To address this issue,

we conducted correlational analyses between the *difference in study phase RT* for emotional versus neutral words and the *difference in priming magnitude* for emotional vs. neutral words in all three experiments. For the study phase RT data, we subtracted the mean RT for the neutral words from the mean RT for the emotional words to obtain a RT difference score for each participant. For the priming data, we subtracted the mean priming score for the neutral words from the mean priming score for the emotional words to obtain a priming difference score for each participant. Pearson correlation coefficients were then calculated across the study phase RT difference scores and the priming difference scores. Correlations were computed for both absolute and proportional priming measures. For Experiment 3, taboo and LAN words were compared to the neutral words in separate analyses.

The correlational analyses revealed no significant effects, and the *r*-values were small in all cases. In Experiment 1, the correlation between the study phase RT difference and the absolute priming score difference was $r(54) = -.04$, $p = .78$. The correlation with the proportional priming score difference was $r(54) = -.004$, $p = .98$. In Experiment 2, the correlation between the study phase RT difference and the absolute priming score difference was $r(49) = -.14$, $p = .34$. The correlation with the proportional priming score difference was $r(49) = -.11$, $p = .44$. In Experiment 3, for LAN words, the correlation between the study phase RT difference and the absolute priming score difference was $r(62) = -.06$, $p = .61$. The correlation with the proportional priming score difference was $r(62) = -.10$, $p = .42$. In Experiment 3, for taboo words, the correlation between the study phase RT difference and the absolute priming score difference was $r(62) = -.06$, $p = .64$. The correlation with the proportional priming score difference was $r(62) = -.08$, $p = .51$.

These results indicate that the difference in study phase RT across the word categories did not significantly influence the difference in priming scores across the word categories. In other words, time-on-task related to semantic elaboration during the concreteness judgements in the study phase bore no systematic relationship to priming magnitude as a function of emotional category, consistent with the idea that lexical decision priming is primarily perceptually driven (Fleischman & Gabrieli, 1998). We also note that we controlled for stimulus exposure in the study phase by limiting the duration of the words to 3 seconds irrespective of the participants' RT. Furthermore, baseline differences in RT during the *test* phase were controlled by proportional priming scores, which yielded the same results as with absolute priming scores. Nonetheless, future studies should attempt to control for RT differences across the word categories in order to more definitively rule out their influence on priming magnitude.

Another possible limitation of the present study is the difference in subjective concreteness ratings as a function of word category during the study phases of each experiment. Even though the neutral, LAN, and taboo words did not differ

in concreteness according to the MRC database, the experimental participants rated neutral words as more concrete than LAN words in Experiments 2 and 3, and taboo words as more concrete than LAN words in Experiment 3. It is unlikely that this difference influenced the priming results, since the LAN and neutral words had equivalent priming magnitudes in both Experiments 2 and 3. Moreover, in Experiment 1 priming was modulated by taboo words that were equated to the neutral words in terms of subjects' concreteness ratings.

The data from these three experiments indicate that it is the arousal-based properties of emotional words, not their valence-based properties, which facilitate repetition priming. However, all three experiments involved negatively valent words. If the arousal hypothesis holds, greater priming should be seen for highly-arousing positive words vs. neutral words, and no priming difference should be observed between low-arousing positive and neutral words. Our experience suggests that it is difficult to equate positive and taboo words for arousal, since most positively valent words have arousal levels equivalent to that of the LAN words used in the current experiments. Future studies using arousing positive words would help generalise the present results beyond the realm of negative affect.

In conclusion, the present series of experiments demonstrates that repetition priming for words is facilitated by emotionally arousing content. During lexical decision making, this effect may occur early in the stream of word processing, prior to semantic elaboration. The findings reported here are distinct from the semantic priming literature, which shows facilitation of emotional word processing over a short period of time (hundreds of ms). In combination, these observations suggest that emotion can have multiple effects on indirect tests of memory, as previously found on direct tests of memory. In clinical settings, administration of emotional priming tasks may be useful in differentiating mechanisms that lead to implicit memory biases for mood-congruent stimuli across various forms of psychopathology.

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