Memory & Cognition
2004, 32 (1), 1-11

Beyond binary judgments: Prime validity modulates masked repetition priming in the naming task

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Bodner and Masson (2001) reported that masked repetition priming of lexical decisions is often greater when the repetition primes appear on a high, rather than a low, proportion of trials. They suggested that processing episodes are constructed for masked primes and that recruitment of those episodes is affected by the probability that the prime will be useful for processing the target. If context-sensitive recruitment of primes is a general mechanism, a similar effect should also occur in a nonbinary response task. In accord with this hypothesis, using the naming task and a 45-msec prime duration, we show that masked repetition priming effects for uppercase words, case-alternated words, and pseudohomophones were greater when .8 rather than .2 of the trials involved repetition (vs. unrelated) primes. Prime validity effects are consistent with a memory recruitment view of priming but may be difficult to explain using activation-based mechanisms.

Studies of how people recognize words commonly employ a technique called *priming*, in which researchers measure how subjects' responses to targets in a given task are affected by the prior presentation of various types of primes. Typically, researchers compare the speed and/or accuracy of responses to targets (e.g., PAIL) following at least two types of primes: (1) primes that do not seem to contain information that might be valid or helpful for processing the target (e.g., *shoe*, *xxxx*, or *slib*) and (2) primes that do seem to contain such information (e.g., *pail*, *bucket*, or *fail*). Priming occurs when response latencies to targets (e.g., word/nonword lexical decisions, vocal naming responses, etc.) differ systematically following invalid versus valid primes. For example, repetition priming occurs when target responses are facilitated on repetition prime trials (e.g., *pail*–PAIL) relative to unrelated-prime trials (e.g., *shoe*–PAIL). By examining the influence of various prime types as a function of such variables as the difference in time between the onsets of the prime and the target (i.e., stimulus onset asynchrony, or SOA), it is hoped that clues about the cognitive processes and brain systems used for the recognition of words will be revealed.

An important variation of the priming technique, introduced by Forster and Davis (1984), involves presenting a visual mask before the prime, followed by a very brief prime in lowercase letters (e.g., SOAs of 60 msec or less), followed by an uppercase target that serves to postmask the prime. A cardinal advantage of the masked priming technique is that the primes are typically unavailable for conscious report. Indeed, most subjects are unaware that any primes have been presented. The absence of awareness afforded by masked primes has been assumed to prevent subjects from doing two things: (1) encoding the prime into memory and then recruiting this memory to guide target processing (e.g., Forster & Davis, 1984) and (2) modulating their use of the primes in a context-sensitive manner (e.g., Forster, 1998). If these two assumptions are correct, masking the primes might actually provide an especially clear view of the specialized mechanisms responsible for visual word recognition.

Although early indications have provided a good deal of support for both assumptions (see Forster, 1998), more recent evidence has suggested that although masking undoubtedly reduces conscious awareness of the primes, this technique does not prevent the operation of a memory-based, contextually sensitive process (see Masson & Bodner, 2003, for a review). Demonstrations of masked priming of novel nonword targets (e.g., Bodner & Masson, 1997; Masson & Isaak, 1999), of larger masked priming

The Natural Sciences and Engineering Research Council of Canada supported this research through discovery grants to G.E.B. and M.E.J.M. Thanks are extended to Marnie Zimmerman and Norann Richard for assisting in this research and to Ken Forster, Steve Joordens, and Jenn Stolz for providing very helpful comments. Correspondence concerning this article should be addressed to G. E. Bodner, Department of Psychology, University of Calgary, 2500 University Drive NW, Calgary, AB, T2N 1N4 Canada (e-mail: bodner@ucalgary.ca).

effects for low-frequency than for high-frequency word targets (Bodner & Masson, 2001), and of long-lasting masked repetition priming effects (Masson & Bodner, 2003) are consistent with the contribution of a memory-based process to masked priming. Evidence that priming also operates in a contextually sensitive manner is summarized below and serves to introduce the present research. Far from impugning its utility, these findings suggest that the masked priming paradigm provides an especially valuable tool for investigating the contextual sensitivity of processes that contribute to skilled word recognition without subjects' awareness.

Influences of Prime Validity on Masked Priming in Binary Judgment Tasks

In this article, we provide an important empirical extension of a recent masked priming phenomenon that we believe has significant consequences for theories of visual word recognition, memory recruitment, and consciousness. We term this class of evidence a *prime validity effect*, which can be broadly defined as an increase in the size of priming effects when the proportion of valid versus invalid primes in the stimulus list is higher in one condition relative to another. The existence of prime validity effects is not news. For example, a *relatedness proportion effect* refers to the long-standing finding that semantic priming (e.g., *nurse*–DOCTOR) is typically greater when the proportion of related prime–target pairs is high (see Neely, 1991, for a review). Historically, though, relatedness proportion effects have been examined only with plainly visible primes and have typically been observed only with a relatively long prime–target SOA (above 240 msec). This pattern suggested that when the proportion of valid primes was high, subjects who were plainly able to see the primes could, for example, develop a conscious, strategic intention to use the prime to predict the target (e.g., an *expectancy* strategy; see Neely, 1991). In contrast, when most primes were not informative about their targets, subjects learned that there was little point in trying to intentionally use prime–target contingencies to influence their responding.

A new and, we think, very exciting discovery is that prime validity effects have been obtained with *masked* primes and very short prime–target SOAs with a variety of prime–target relationships and in a variety of tasks. These display conditions were unlikely to permit the formation of conscious, strategic intentions, and yet subjects were better able to capitalize on prime–target contingencies when prime validity was high, rather than low. The first study to demonstrate the sensitivity of masked priming to prime validity was Bodner and Masson (2001). Under a variety of conditions, masked repetition priming for word targets in the lexical decision task (with SOAs of 45 or 60 msec) was greater when the proportion of repetition primes in the stimulus list was .8, rather than .2 (a *repetition proportion effect*, here termed an *RP effect*). RP effects occurred for words from various frequency ranges, whether targets were presented in uppercase or in case alternation (e.g., pOwEr) and whether the nonwords sounded like real words (i.e., pseudohomophones, such as BRANE) or not (e.g., BRONE, or even BRFND). Using the same procedure, Bodner and Masson (2003) found that masked semantic priming in the lexical decision task also increased when subjects received a high, rather than a low, proportion of semantic primes (i.e., a relatedness proportion effect) and also when high validity was induced by a combination of semantic and repetition primes.

Two further studies have shown that the influence of prime validity on masked priming extends beyond word stimuli and the lexical decision task. Using the same procedure as that described above, Bodner and Dypvik (2004) reported that prime validity can also modulate masked priming of number judgments with both number word and Arabic digit stimuli. Odd/even parity judgments were facilitated by masked primes whose parity matched the target's parity (e.g., 4 primed 8 better than 7 primed 8), and parity valid priming was stronger when the proportion of parity valid trials in the stimulus list was .8, rather than .2. In contrast, when subjects made magnitude judgments (i.e., whether the target was less or greater than 5), magnitude valid priming occurred (e.g., 7 primed 8 better than 4 primed 8) and was greater when .8, rather than .2, of the trials were magnitude valid. Bodner and Dypvik concluded that the influence of a masked number prime depends on the listwide validity of the primes for performing the task at hand.

Finally, Jaskowski, Skalska, and Verleger (2003) have shown that prime validity can also affect masked priming with nonalphanumeric stimuli. In their paradigm, four prime displays and a target display each consisted of a pair of side-by-side outlined squares. On each trial, the subject's task was to decide whether the left or the right target square had two small segments removed from its vertical sides (i.e., the *cut square*). Each prime display was shown for 12 or 13 msec and was masked by the subsequent prime (or by the target). In each prime display, the cut square was on either the same side (valid trials) or the opposite side (invalid trials) as the cut-square target. Jaskowski et al. found that responses on valid trials were faster when .8, rather than .2, of the trials contained valid primes. This benefit was associated with a higher error rate on invalid-prime trials, a pattern also seen with the prime validity effects shown in binary judgment tasks with words (Bodner & Masson, 2001) and numbers (Bodner & Dypvik, 2004).

These studies have shown that masked priming can be remarkably sensitive to manipulations of prime validity. By implication, the mechanism that underlies masked priming must also be context sensitive. Prior demonstrations of contextual modulations of masked priming have typically varied the types of targets presented (e.g., Ferrand & Grainger, 1996), the task conditions (e.g., Greenwald, Abrams, Naccache, & Dehaene, 2003; Naccache, Blandin, & Dehaene, 2002), or the task itself (e.g., Klinger, Burton, & Pitts, 2000)—all aspects of the testing situation of which subjects would be aware and, hence, to which they could consciously react. In contrast, manipulations of masked prime validity involve the same task, the same task conditions, the same types of primes, and exactly the same set of targets in both validity groups; there is no salient difference between being in the low- or the high-validity group. By most accounts, then, masked primes should be processed identically in the two validity groups. Therefore, accounts of priming that assume that primes automatically activate abstract localist representations, such as lexical entries (e.g., Forster & Davis, 1984), orthographic representations (e.g., Bowers, 2000, 2003), phonological representations (e.g., Berent & Perfetti, 1995; Hino, Lupker, Ogawa, & Sears, 2003), semantic representations (e.g., Neely, 1991), magnitude representations in the case of number stimuli (e.g., Koechlin, Naccache, Block, & Dehaene, 1999), or a distributed representation of a concept (i.e., a learned pattern of activation across a set of processing units in a connectionist network; e.g., Masson, 1995), may be challenged by the finding that prime validity affects masked priming.

A Memory Recruitment View of Priming and Prime Validity Effects

The occurrence of prime validity effects with masked primes in word, number, and nonalphanumeric domains suggests that at least one influence on priming may not be peculiar to word recognition after all. To accommodate these and other masked priming results mentioned above, we have employed an account of priming originally put forward by Whittlesea and Jacoby (1990) that we call the *memory recruitment account* (e.g., Bodner & Dypvik, 2004; Bodner & Masson, 1997, 2001, 2003; Masson & Bodner, 2003; Masson & Isaak, 1999). This view begins with the assumption that any processing operations applied to a prime, whether the prime is masked or not, are encoded into a new memory resource (e.g., Kolers & Roediger, 1984). The encoding of a masked prime represents a new instance of episodic learning (e.g., Logan, 1988), of which the subject is unaware. This unique processing resource can later be recruited to assist with subsequent target processing if the test conditions foster its recruitment. In support of this view, Whittlesea and Jacoby (1990) found larger repetition priming effects in a naming task (relative to various within-subjects control conditions) when the second of two primes was degraded through case alternation (e.g., GREEN–pLaNt–GREEN), rather than being presented in uppercase letters (e.g., GREEN–PLANT–GREEN)—a result they attributed to an increased need to recruit the memory of the first prime event to help process the second prime event when it was degraded. Note that the enhanced repetition priming seen when the second prime was degraded implies that processing of the first prime was somehow contingent on the nature of the second prime. The temporal constraints of this contingency support the idea that at least some critical processing of the first prime occurred retrospectively (after the second prime had been encountered).

The prime event is assumed to encode into memory a set of processing operations whose later recruitment will facilitate task performance when the target event requires recapitulating some of the same processing operations (e.g., Hughes & Whittlesea, 2003). Processing a target relies on the recruitment of prior learning experiences, and in a masked priming task the prime episode is particularly likely to be recruited, because it was encoded milliseconds earlier in the same experimental context. Prime encoding and recruitment can thus explain, to take one example, why processing of nonword targets, which have no preexisting lexical representation for a prime to activate, can benefit from masked repetition priming (e.g., Bodner & Masson, 1997; Masson & Isaak, 1999). Masson and Bodner (2003) reviewed other results that appear to favor a memory-based account of priming, rather than a purely activation-based account.

To explain prime validity effects, the memory recruitment account appeals to an established characteristic of memory recruitment: its sensitivity to contextual factors. For example, recruitment of prior experiences is more likely when the overlap in processing operations between the study and the test situations is greater (e.g., transfer-appropriate processing; Morris, Bransford, & Franks, 1977). The form of this contextual overlap can range from cues in the physical environment (e.g., Smith & Vela, 2001) to whether a low or a high proportion of studied items is reinstated on the test list (e.g., Allen & Jacoby, 1990; Jacoby, 1983). In the latter pair of studies, long-term repetition priming in a masked word identification task increased when a high rather than a low proportion of targets was presented in an earlier study phase. In both studies, it was argued that because more of the study context was reinstated at test in the high-overlap condition, the test context better facilitated recruitment of the study episodes. By analogy, Bodner and Masson (2001) suggested that recruitment of masked prime episodes is also encouraged when prime and target processing are more likely to overlap in a task-relevant way—that is, when prime validity is higher, resulting in an increase in priming. A context-sensitive memory recruitment process can therefore accommodate prime validity effects found with word, number, and nonalphanumeric stimuli. Subjects come to depend on the masked prime context to a greater or lesser extent according to its usefulness for the task at hand.

An Important Test: Masked Prime Validity Effects in a Nonbinary Judgment Task?

The generality of masked prime validity effects across various types of prime validity and task requirements suggests that subjects can tune into the usefulness of a contextual element and can modulate their use of this element accordingly, even when they are unaware of the element, its usefulness, and/or their modulation of its use. Although the occurrence of masked prime validity effects across domains suggests a general mechanism, there remains a rather serious limitation to the effects we have reported to date: They have been demonstrated only in binary judgment tasks. If a general mechanism underlies prime validity effects, such effects should also be found in tasks that require complete identification of targets, rather than mere classification of targets into one of two broad categories.

The present experiments represent the first investigation of whether a specific type of prime validity, the proportion of repetition prime–target pairs in the stimulus list (i.e., RP), affects masked repetition priming in a commonly used identification task—the naming task. In this task, subjects must name each target aloud as quickly and accurately as possible. Prior studies have already established that masked repetition priming occurs in the naming task (e.g., Forster & Davis, 1991; Masson & Isaak, 1999; Sereno, 1991), but no studies have examined whether RP influences priming. The stimuli in Experiment 1 were low-frequency words, and the targets were presented in uppercase letters. Experiments 2 and 3 provided replications that test the generality of the results of Experiment 1. To this end, Experiment 2 was a replication of Experiment 1, using case-alternated targets, and Experiment 3 used pseudohomophone stimuli. If identification task performance, like classification task performance, were to benefit from a high proportion of valid primes, the possibility that a common mechanism underlies priming effects in both types of tasks would be supported.

EXPERIMENT 1
Initial Test Using Low-Frequency Words

To test whether subjects can modulate the influence of masked primes on the reading aloud of words, a low-RP group received repetition primes on .2 of the trials, and a high-RP group received repetition primes on .8 of the trials. Unrelated words with onsets that matched those of their corresponding targets served as unrelated primes on the remaining trials in each group. Forster and Davis (1991) showed that when the task is to name a target word, subjects on occasion mistakenly enunciate the prime word's onset. Therefore, if unrelated primes have onsets that differ from their targets' onsets, part of the resulting priming effect will reflect an onset effect (Forster & Davis, 1991). By using matched onsets in the unrelated prime condition, we avoided inclusion of onset priming effects in our estimates of priming. Low-frequency words were used to maximize repetition priming effects, and the prime–target SOA was 45 msec, to avoid the subjects' becoming aware of the primes, while allowing the primes sufficient processing time to have a measurable effect.

Method

Subjects. The subjects in these experiments were undergraduates at the University of Victoria, who participated for course credit. No subject served in more than one experiment. In Experiment 1, 30 subjects were randomly assigned to each RP group.

Materials and Design. The critical targets were 200 words, four to six letters in length, that ranged in frequency from 1 to 10 per million (median = 3; Kučera & Francis, 1967). Each target was paired with an unrelated prime of the same length. Unrelated primes began with the same onset sound but, otherwise, shared no other letters in the same position and shared no more than two other letters with the target (e.g., *sack*–SOFA, *ladder*–LOUNGE). Most unrelated primes were also between 1 and 10 in frequency, although 35 were between 11 and 20 in frequency (median = 5). Twenty more items with these characteristics were used for practice trials.

To maximize power, none of the blocks of critical target words was treated as a filler block. Instead, the assignment of five blocks of 40 critical targets to prime conditions was counterbalanced. In the high-RP group, the targets in four blocks were paired with repetition primes, and the targets in the fifth block were paired with unrelated onset-matched primes (RP = .8). The reverse was true for the low-RP group (RP = .2). The RP of the practice items matched that of the critical items.

Procedure. The subjects were tested individually using a Macintosh computer. The subjects were told that several briefly displayed items would be shown on each trial in the center of the monitor, but they were not specifically told about the primes. Each trial began with a 495-msec premask (a row of uppercase Xs matched for length with the prime and the target), followed by a 45-msec prime in lowercase, followed by a target in uppercase. The 12-point Courier font stimulus displays were synchronized with the screen refresh cycle of the monitor, using a C++ timing routine whose accuracy was verified with a storage oscilloscope. A four-letter word subtended a visual angle of 1.4° when viewed from a distance of 40 cm. The target remained in view until the subject read it out loud (under the instruction to respond as quickly and as accurately as possible). Vocal responses were detected with a microphone connected to a voice relay. Detection of a response erased the target from the screen. If the subject took more than 3 sec to respond, a tone sounded, and a message (TOO SLOW) appeared for 1 sec. The experimenter coded the correctness of the subject's response (correct vs. error), and the next trial began 1 sec later. If the microphone was triggered by a noise other than a vocal response or if it failed to trigger, the trial also was scored as an error.

The 20 practice trials were presented in random order followed by 200 critical trials, also in random order. A rest break occurred after every 50 critical trials. After the experiment, we assessed subjective awareness of the primes in the following way. The subjects were asked what they had seen on each trial, just before the target appeared. If they initially reported having seen only the mask (a typical response), they were also asked follow up questions (e.g., "Did you notice anything else?").

Results

To be consistent with our earlier investigations of prime validity effects (Bodner & Dypvik, 2004; Bodner & Masson, 2001, 2003), we used the following conventions throughout. Trials with response latencies below 300 msec or above 3 sec were excluded (0.48% across Experiments 1–3, in line with the recommendation of Ulrich & Miller, 1994, to trim fewer than 0.5% of responses). Separate mixed-factor analyses of variance (ANOVAs) with RP (low or high) as the between-subjects factor and prime type (repetition or unrelated) as the within-subjects factor were computed on the mean response latencies and error rates, treating subjects as the random variable. The means and their associated 95% confidence intervals for Experiments 1–3 are shown in Figure 1. The significance level was set at .05 for all analyses.

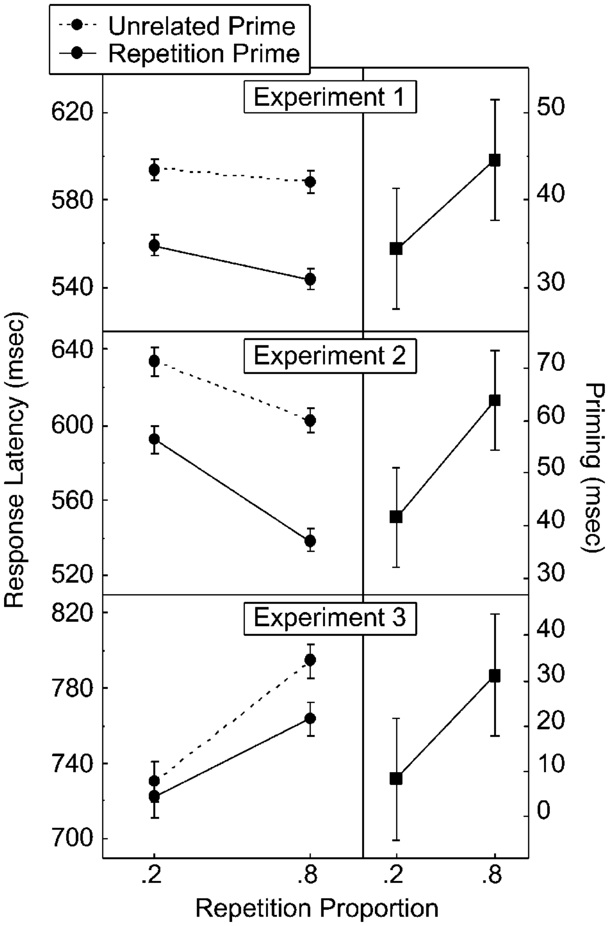

Figure 1. Mean response latencies (left panels) and priming effects (right panels) in Experiments 1 (uppercase word targets), 2 (case-alternated word targets), and 3 (pseudohomophone targets). Error bars for response latencies are 95% within-subjects confidence intervals and are appropriate for comparing means across prime conditions within each repetition proportion group (Loftus & Masson, 1994; Masson & Loftus, 2003). Error bars for priming effects are 95% between-subjects confidence intervals and are appropriate for comparing means across repetition proportion groups.

In Experiment 1, responses were 40 msec faster on repetition prime trials than on unrelated prime trials [$F(1,58) = 261.56$, $MS_e = 178$]. This main effect of priming was qualified by a significant interaction of RP and priming [i.e., an RP effect; $F(1,58) = 4.26$, $MS_e = 178$], which reflected greater repetition priming in the high-RP group than in the low-RP group (44 vs. 34 msec). There was no overall difference in response latency between the two RP groups ($F < 1$).

According to their subjective reports, 37% of the low-RP group (11 of 30) and 23% of the high-RP group (7 of 30) had some (typically minimal or infrequent) awareness that another stimulus had appeared between the mask and the target. To verify that the RP effect we observed was not driven by prime awareness, we reanalyzed the data with these subjects removed. The mean priming effects for unaware subjects in the high- and low-RP groups were 44 and 30 msec, respectively, and the interaction of RP and priming was significant [$F(1,40) = 6.00$, $MS_e = 171$].

The mean error rates appear in Table 1. There were no reliable effects in the error rates, either in the full sample (Fs < 1.96) or when prime-aware subjects were excluded (Fs < 1.16), and there was no indication of a speed–accuracy tradeoff in the means.

Discussion

The subjects who received a preponderance of repetition prime trials (high-RP group) showed larger repetition priming effects than did the subjects who received a preponderance of unrelated-prime trials (low-RP group). The generality of the influence of prime validity on masked priming has already been established in binary judgment tasks involving word (Bodner & Masson, 2001, 2003), number (Bodner & Dypvik, 2004), and nonalphanumeric (Jaskowski et al., 2003) stimuli. As in the binary judgment studies, the RP effect was not dependent on prime awareness. The present result extends the generality of this context sensitivity to a nonbinary judgment task—word reading—where repetition primes must have an influence that is qualitatively different from biasing one of two response alternatives. Specifically, the results of Experiment 1 lead to the interesting conclusion that without being aware of it, people can adaptively modulate the influence of masked primes on their ability to read words aloud. The remaining experiments tested the generality of RP effects in the naming task, using case-alternated word targets (Experiment 2) and pseudohomophone stimuli (Experiment 3).

EXPERIMENT 2
Replication With Case-Alternated Targets

The main purpose of Experiment 2 was to replicate the RP effect in the naming task, which was more modest than the RP effect Bodner and Masson (2001) typically found in the lexical decision task. Averaged across eight data sets, Bodner and Masson (2001) found priming effects of 32

Table 1
Mean Percentages of Error and Repetition Priming as a Function of Prime Validity in Experiments 1–3

Prime Validity	Unrelated Prime Trials		Repetition Prime Trials		Priming Effect	
	M	*SD*	*M*	*SD*	*M*	*SD*
			Experiment 1			
Low	3.7	2.5	3.5	3.4	0.2	3.5
High	5.4	1.2	4.2	0.9	1.2	3.8
			Experiment 2			
Low	7.1	7.3	4.3	4.9	2.8	4.8
High	8.0	7.3	3.7	5.3	4.4	4.9
			Experiment 3			
Low	4.0	4.3	2.9	4.2	1.1	3.2
High	7.5	9.9	7.0	7.9	0.5	5.7

and 57 msec in the low- and high-RP groups, whereas in Experiment 1 these means were 34 and 44 msec. This difference is not too surprising, given that priming effects tend to be larger in the lexical decision task, but nevertheless, in Experiment 2, we sought to obtain a more robust RP effect. To do so, we took advantage of the finding that masked priming tends to increase when targets are presented in a less familiar format (i.e., target degradation; e.g., Bodner & Masson, 1997), possibly due to an increase in prime recruitment (Whittlesea & Jacoby, 1990). Thus, the targets in Experiment 2 were presented in case-alternation, rather than uppercase, letters. We reasoned that a high RP (which increases recruitment) in combination with degradation (which increases recruitment) might produce especially robust priming, whereas a low RP (which decreases recruitment) might work against priming even when targets are degraded. If target degradation increases priming only when RP is high, the RP effect should be larger in Experiment 2 than it was in Experiment 1.

Method

Twenty subjects were randomly assigned to each RP group. Experiment 2 was identical to Experiment 1, except that targets were case alternated (e.g., sPiDeR), beginning with a lowercase letter.

Results

As was expected, the use of case-alternated targets resulted in a robust overall priming effect of 53 msec [$F(1,38) = 255.55$, $MS_e = 218$], which interacted with RP [$F(1,38) = 11.36$, $MS_e = 218$]. Repetition priming was greater when RP was high, rather than low (64 vs. 42 msec). The main effect of RP was not significant ($F < 2.20$). As in Experiment 1, removal of the subjects who had some awareness of the primes in the high-RP (15%; 3 of 20) and low-RP (25%; 5 of 20) groups had little effect on the interaction of RP and priming [62 vs. 42 msec; $F(1,30) = 7.35$, $MS_e = 220$].

In the analyses of error rates (see Table 1), there was a main effect of priming, reflecting fewer errors on repetition prime trials than on unrelated-prime trials, in both the full sample [$F(1,38) = 21.29$, $MS_e = 11.87$] and when prime-aware subjects were excluded [$F(1,30) = 18.71$, $MS_e = 12.58$]. None of the other effects was significant in either error rate analysis (Fs < 1.06).

Finally, we compared the size of the RP effect in response latency in Experiments 1 and 2, using an ANOVA with RP (low or high), prime type (repetition or unrelated), and experiment (Experiment 1 with uppercase targets or Experiment 2 with case-alternated targets) as factors. Priming was greater when RP was high, rather than low [52 vs. 37 msec; $F(1,96) = 16.15$, $MS_e = 194$], of course. More important, priming was also greater in Experiment 2 than in Experiment 1 [53 vs. 39 msec; $F(1,96) = 11.01$, $MS_e = 194$], showing that target degradation increased priming. Although the three-way RP $\times$ priming $\times$ experiment interaction did not reach significance [$F(1,96) = 2.29$, $MS_e = 194$, $p = .13$], post hoc tests confirmed that priming reliably increased from Experiment 1 to Experiment 2 when RP was high [44 vs. 64 msec; $F(1,48) = 13.01$, $MS_e = 348$], but not when RP was low (34 vs. 42 msec; $F < 1.48$).

Discussion

Presenting targets in alternating case produced a robust replication of the RP effect found with uppercase words in Experiment 1. On average, the subjects showed 22 msec more masked repetition priming when RP was high, rather than low, and removal of prime-aware subjects had very little effect on this result. Priming increased with case-alternated targets in Experiment 2, but the RP effect was not significantly larger than that in Experiment 1. Nonetheless, post hoc tests showed that target degradation reliably increased priming only when RP was high, giving the RP effect the intended boost. These effects await within-experiment verification, but they suggest that especially robust masked repetition priming may occur when RP is high and targets are degraded—conditions that both work to increase prime recruitment.

Finally, although one might suspect that masked priming of case-alternated targets was partly due to the physical match between the lowercase letters of the prime and the lowercase letters of the case-alternated targets, Bodner and Masson (1997) demonstrated that this degree of physical match was not adequate to produce any reliable priming. Thus, the priming effects seen in Experiment 2 most likely stem from the same mechanism as the one that generates masked priming when prime and target words share no physically matching letters, as was the case in Experiment 1.

EXPERIMENT 3
Replication With Pseudohomophones

In our last experiment, we investigated whether RP might also modulate masked priming of naming responses with stimuli that are not lexically represented. It has already been shown that nonword targets can benefit from masked repetition priming (Bodner & Masson, 1997; Masson & Isaak, 1999; Sereno, 1991). If a common mechanism generates priming for both word and nonword targets, we should expect to see an RP effect emerge with both types of target item. Unlike the lexical decision task, the naming task is free of the conflict between processing fluency afforded by a repetition prime and the requirement to classify a primed nonword target as a nonword (Bodner & Masson, 1997; Masson & Isaak, 1999). Thus, a clear opportunity to observe RP effects with nonword targets presents itself with the naming task.

Rather than using typical nonwords (e.g., NOYAL), we used pseudohomophones (e.g., SOYAL) that sounded like real words (e.g., SOIL) but were presented in a novel orthographic form. We reasoned that there might be less variability in the pronunciation of pseudohomophone nonwords than in typical nonwords and that the subjects would be less hesitant in responding if they knew they were generating a plausible, familiar pronunciation. Except for the change in stimulus class, Experiment 3 was identical to Experiment 1.

Method

Twenty subjects were randomly assigned to each RP group. The critical targets were 200 pseudohomophones, four to six letters in length, whose base words ranged from three to eight letters in length and whose median frequency was 33 per million (range = 0–343). Each target was paired with an unrelated pseudohomophone prime of the same length (median base word frequency = 35). Unrelated primes had the same phonemic onset but, otherwise, did not share more than a letter or two with the target and shared no other letters in the same position (e.g., *newn*–NOOD, *kewbik*–KAYOSS, *swett*–SOYAL). Twenty more items with these characteristics were used for practice trials. The design and procedure were the same as those in Experiments 1 and 2.

Results

Latencies to name pseudohomophones were relatively long, of course, but use of these stimuli replicated the pattern of priming results found with uppercase (Experiment 1) and case-alternated (Experiment 2) word targets (see Figure 1). In the response latency analysis, there was a main effect of priming [20 msec; $F(1,38) = 17.62$, $MS_e = 445$], which interacted with RP [$F(1,38) = 5.84$, $MS_e = 445$]. Once again, the repetition priming effect was larger in the high-RP group than in the low-RP group (31 vs. 8 msec). A post hoc test showed that priming was not significant in the low-RP group ($F < 1.35$). Although response latencies appeared to be somewhat longer in the high-RP group, the main effect of RP was not significant ($F < 2.17$; see below).

Only 3 subjects in the high-RP group (15%) and 1 in the low-RP group (5%) reported any knowledge that another stimulus had appeared between the mask and the target. Removal of these subjects did not dampen the priming advantage in the high-RP group relative to the low-RP group [33 vs. 6 msec; $F(1,34) = 7.47$, $MS_e = 440$].

Forster (1998) has suggested that a nonword that is one letter different from its base word may still open the base word's lexical entry, thereby facilitating pronunciation of the target. Of our 200 targets, 158 differed from their base word by at least two letters. In a post hoc analysis, we found that priming for these 158 items was again greater in the high-RP than in the low-RP group [33 vs. 5 msec; $F(1,38) = 4.92$, $MS_e = 752$], even when prime-aware subjects were excluded [34 vs. 3 msec; $F(1,34) = 5.58$, $MS_e = 745$]. Thus, both repetition priming and an RP effect can occur for pseudohomophones that are two or more letters different from their base words.

The subjects' pronunciations of the pseudohomophones were generally as accurate as those with case-alternated words in Experiment 2. The only effect that approached significance in the error rates was the main effect of RP (see Table 1), reflecting marginally more errors in the high-RP than in the low-RP group [7.2% vs. 3.4%; $F(1,38) = 3.34$, $MS_e = 10.60$, $p < .10$]. Removal of the few prime-aware subjects produced a similar marginal result. None of the other effects was significant in either data set (Fs < 1.36).

An inspection of individual subject data revealed 1 unusually slow subject (mean response latency of 1,154 msec) and 1 unusually error-prone subject (mean error rate of 31%) in the high-RP group. Removal of these 2 subjects did not reduce the RP effect in either the full sample [$F(1,36) = 6.16$, $MS_e = 420$] or the analysis excluding prime-aware subjects [$F(1,32) = 8.00$, $MS_e = 410$] but did eliminate any trend toward a main effect of RP in the corresponding response latencies (Fs < 1.15) and error rates (Fs < 1.53).[1]

Discussion

The benefit the subjects accrued from a masked repetition prime when naming a subsequent pseudohomophone target was modulated by RP such that significant priming occurred only in the high-RP group. As with word targets (Experiments 1 and 2), the RP effect occurred whether or not prime-aware subjects were excluded from analysis. Experiment 3 extended Experiments 1 and 2 by showing that RP can affect masked priming even for stimuli that are not lexically represented (e.g., Bodner & Masson, 2001). Priming and an RP effect were observed even when the analysis was restricted to pseudohomophones at least two letters different from their base word (cf. Forster, 1998). The lack of a masked priming effect in the low-RP group in the naming task contrasts with our earlier finding of robust masked repetition priming of pseudohomophone targets in the lexical decision task (Bodner & Masson, 1997, Experiment 3). Masked priming effects are typically larger in the lexical decision task, however, and the RP in our earlier experiment was .5, which is considerably higher than the RP of .2 used in the low-RP group here. In any event, our experiments show that the naming of both words and nonwords can benefit from masked repetition priming and that, in both cases, this effect is modulated by prime validity.

GENERAL DISCUSSION

The act of naming a target stimulus (e.g., RAFT) can be facilitated by a masked repetition prime (e.g., *raft*), relative to an unrelated prime with the same onset (e.g., *robe*; see, e.g., Forster & Davis, 1991; Masson & Isaak, 1999; Sereno, 1991). The present experiments replicate and extend this finding in an important way by demonstrating that the facilitation provided by a repetition prime in the naming task is greater when repetition primes occur more frequently in the stimulus list. Priming of both low-frequency words (Experiments 1 and 2) and pseudohomophones (Experiment 3) was greater when .8, rather than .2, of the trials involved masked repetition primes shown for 45 msec. Across our experiments, 21% of the subjects reported having some awareness of the presence, if not the identity, of another stimulus between the mask and the target. Importantly, removal of these subjects had little effect on the size of the priming or RP effects we obtained. Thus, it seems reasonable to draw the conclusion that the subjects' use of the masked primes to guide their pronunciations of the targets was modulated by RP in an adaptive yet unintentional way. This conclusion is bolstered by recent demonstrations that prime validity effects in the lexical decision task with word stimuli (Bodner & Masson, 2003), in parity and magnitude decision tasks with number stimuli (Bodner & Dypvik, 2004), and in a left–right decision task with nonalphanumeric stimuli (Jaskowski et al., 2003) were consistently observed when subjects who reported having had even minimal prime awareness were excluded from analysis. Moreover, subjects' ability to make judgments about brief masked primes has not been found to be positively correlated with their masked priming effects (e.g., Bodner & Dypvik, 2004; Bodner & Masson, 2003; Damian, 2001; Jaskowski et al., 2003; Naccache & Dehaene, 2001). Thus, the evidence to date suggests that awareness of masked primes is not necessary for prime validity to influence priming.

Prior to the present study, we had examined prime validity effects with masked primes only in binary judgment tasks. Thus, it might have been possible to claim that prime validity affects only subjects' ability to classify a target into one of two broad response categories (e.g., word vs. nonword). If so, the influence of prime validity on priming might be attributed to a binary response bias or to the activation of the motor representations associated with the two possible response alternatives (e.g., Damian, 2001; Dehaene et al., 1998; see Bodner & Dypvik, 2004, for a discussion). In the naming task, in contrast, subjects must identify targets and generate a unique response to each one, rather than merely classify them into one of two categories. The fact that prime validity influences naming responses therefore does not appear to favor a specialized mechanism that accounts for priming through the biasing of a binary decision. Instead, the present results favor a more general mechanism that capitalizes on contextual contingencies within a broad range of processing situations.

Although we have found that RP affects masked repetition priming in one identification task (i.e., naming), others have failed to find analogous prime validity effects in a masked identification task in which subjects try to identify a brief masked target that follows a brief masked prime. With Dutch stimuli, Brysbaert (2001) found that the increase in target identification (e.g., IEP) following a masked homophone prime (e.g., *ieb*), relative to an unrelated prime (e.g., *gad*), was the same whether .72 or .14 of the trials involved homophone primes. Also using Dutch stimuli, Pecher, Zeelenberg, and Raaijmakers (2002) found that the increase in target identification following a masked associative prime (vs. an unrelated prime) was not reliably greater when .9, rather than .1, of the trials involved associatively related prime–target pairs.

These results (and others; see Bodner & Masson, 2001) suggest that the scope of conditions under which prime validity affects task performance is limited. To identify the relevant boundary conditions, it will be necessary to examine (1) whether RP modulates priming in the masked identification task, (2) whether the proportion of homophonic or semantic primes modulates priming in the naming task, and (3) whether effects of prime validity vary across languages. For example, it may turn out that the cognitive system cannot gauge the usefulness of the prime context when *both* the prime and the target are masked and briefly presented. Under such circumstances, the high degree of difficulty associated with target identification may lead to consistent prime recruitment, even when prime validity is low (see Bodner & Masson, 2001). In contrast, when plainly visible primes are encoded in a separate study phase (i.e., a long-term priming paradigm), subsequent masked target identification is improved when the proportion of studied targets on the test is high, rather than low (Allen & Jacoby, 1990; Jacoby, 1983). Discovering the basis for the different outcome in the present experiments versus those in Brysbaert (2001) and Pecher et al. (2002) should provide insights regarding the mechanisms that produce priming and prime validity effects.

Our recent investigations, summarized in Masson and Bodner (2003), have led us to suggest that although the context-sensitive memory recruitment mechanism we propose remains underspecified, it nonetheless provides a useful way of characterizing both priming and prime validity effects, as well as a source of ideas for future research. As was described in the introduction, the memory recruitment account posits that an episodic record of the encoding of the masked prime is created and recruited moments later to assist target encoding. Recruitment of prime encoding operations is more likely to occur in contexts in which prime- and target-processing operations frequently overlap (e.g., when RP is high). The dissociations between masked and long-term priming that originally cast doubt on the possibility that learning and memory contribute substantially to masked priming (e.g., Bowers, 2000; Forster, 1998; Forster & Davis, 1984) have each been questioned by recent findings summarized in Masson and Bodner (2003). We suggest, instead, that the similarity between masked and long-term priming has been underestimated and, in fact, encourages the postulation of a common underlying mechanism.

Activation-based accounts of visual word recognition will need to incorporate a mechanism by which prime validity can affect masked priming (Bodner & Masson, 2003). One possibility is that RP has no influence on prime activation. Instead, a low-RP group might learn to delay responding to the target because of the tendency to mistakenly begin pronouncing the (typically unrelated) prime item, perhaps by extending a time criterion for initiating a naming response (e.g., Jared, 1997; Lupker, Brown, & Colombo, 1997) or by reducing the rate of processing within the word recognition architecture (e.g., *input gain*; see Kello & Plaut, 2000, 2003). This delay could reduce the influence of both valid and invalid primes if the activation produced by a masked prime decays rapidly, thus producing an RP effect.[2] A general response delay should also make the low-RP group slower to respond overall, a prediction consistent with the response latency trends in Experiments 1 and 2, but inconsistent with the reverse trend in Experiment 3 (see Figure 1). More important, a delay account would not provide an explanation of RP effects in the lexical decision task, because unrelated word primes produce no response conflict for responding to word targets, since both repetition and unrelated word primes would bias the correct "word" response. The low-RP group would, therefore, not benefit from delaying lexical decisions. Hence, different mechanisms may be needed to explain RP effects in naming versus lexical decision tasks.

An alternative way to preserve a purely activation-based account might be to suggest that the activation level of representations of primes increases when prime validity is high or is blocked when prime validity is low. Such a mechanism potentially could explain the greater facilitation on valid prime trials observed across experiments when prime validity was high, rather than low (e.g., Bodner & Dypvik, 2004; Bodner & Masson, 2001; Jaskowski et al., 2003). An increase in prime validity in these studies, however, also produced a concomitant cost in the form of an increase in response latency or errors on invalid-prime trials in the high-validity group relative to the low-validity group (what we call here an *interference effect*). According to the memory recruitment view, this interference effect is incurred because increased prime recruitment under conditions of high prime validity interferes with target processing on invalid trials. How an activation process could produce validity-dependent interference on invalid trials remains to be explained by proponents of activation-based accounts.

Interestingly, in the naming task used here, we did not see much evidence of an interference effect on unrelated trials in the high-RP group, relative to the low-RP group (see Figure 1). The absence of interference might, therefore, seem to raise problems for the memory recruitment account. The lack of interference effects, however, might reflect the fact that the unrelated primes were not completely unrelated to their targets: Their onsets matched the onset of the targets, although their remaining segments did not. Thus, increased prime recruitment in the high-RP group may have produced a mixture of facilitation (speeded responding with repetition primes, relative to a low-RP group) and interference effects on unrelated-prime trials.

Future experiments potentially could test this notion by comparing RP effects as a function of whether or not the unrelated primes have matching onsets. An increase in RP should be more likely to elevate response latency or error rate in the unrelated-prime condition when those primes do not have matching onsets. One reason we have not pursued this possibility, however, is that the evaluation of facilitation and interference effects across RP groups is a statistically noisy enterprise. Bodner and Masson (2001) and Bodner and Dypvik (2004) had to pool multiple experiments to demonstrate reliable facilitation and interference effects induced by an increase in prime validity. In the present study, too, the pattern of response latencies across the RP groups was rather different in Experiment 3 than in Experiments 1 and 2 (see Figure 1).

It should be possible to measure facilitation and interference effects within subjects by including a set of neutral primes within each RP group. We are currently pursuing this approach, although we feel it has two inherent limitations. First, as others have noted, the choice of neutral prime (e.g., *xxxx* vs. *blank*) may influence the relative size of the obtained interference and facilitation effects (e.g., Jonides & Mack, 1984). Second, adding neutral primes to either the high-RP group or the low-RP group necessitates changing the proportions of repetition or unrelated primes in the stimulus list, which in turn may affect the cognitive system's adaptation to prime validity. For example, inclusion of neutral trials might reduce the contrast between valid and invalid trials, effectively weakening the validity manipulation and the cognitive system's ability to gauge the usefulness of the primes.

Indeed, one consequence of the sensitivity of masked priming to manipulations of prime validity is that the notion of a "gold standard" for the proportion of valid versus invalid primes one "should" employ in an experiment—like the notion of what constitutes a "true" neutral prime baseline—disappears. If a particular type of priming effect is shown to vary across a range of prime mixtures, researchers must be cautious when drawing conclusions about the effectiveness of various types of primes on the basis of data obtained with a single level of prime validity (e.g., an RP of .5). For example, pseudohomophones showed no repetition priming in Experiment 3 when the RP was .2, but a robust effect emerged when the RP was .8. Thus, the appropriate question is not *whether* priming occurs but, rather, *under what conditions* does priming occur? Without examining priming across a range of prime validities, experimenters risk drawing conclusions that may be of limited generality and, worse, that may fail to capture important context-sensitive properties of word recognition in natural reading situations.

In addition, it may be risky to compare results across studies that employ different mixtures of prime types (and that, therefore, have different levels of prime validity). For example, we have noticed that studies of orthographic, phonological, and morphological contributions to masked priming often employ many different types and mixtures of primes, and across studies there is not always good agreement over outcomes (e.g., Berent & Perfetti, 1995, vs. Lukatela & Turvey, 2000). Viewed in a more positive light, however, careful study of the influence of various prime mixtures on masked priming may provide an exciting window onto how our cognitive systems—without our awareness—use contextual information to optimize classification and identification responses, as well as other types of goal-directed behavior.

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NOTES

1. Consistent with our previous prime validity studies (Bodner & Dypvik, 2004; Bodner & Masson, 2001, 2003), we do not report detailed item analyses, because words were not randomly selected from the population of words, nor were any item variables manipulated. For readers interested in item analyses, however, we can stipulate that the priming advantage in response latency for the high-RP group over the low-RP group in the item analysis was similar to that reported in the subject analysis for Experiment 1 [45 vs. 36 msec; $F(1,199) = 3.02$, $MS_e = 1,323$, $p = .08$], for Experiment 2 [69 vs. 48 msec; $F(1,199) = 7.47$, $MS_e = 2,950$], and for Experiment 3 [36 vs. 7 msec; $F(1,198) = 4.10$, $MS_e = 9,922$]. Moreover, in Experiment 3, the interaction was significant in the item analysis for pseudohomophones at least two letters different from their base word [43 vs. 0 msec; $F(1,157) = 6.97$, $MS_e = 10,854$].

2. We thank Ken Forster for suggesting this possible interpretation.

(Manuscript received March 21, 2003;
revision accepted for publication July 15, 2003.)