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Masked nonword repetition effects in yes/no and go/no-go lexical decision: A test of the evidence accumulation and deadline accounts

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The pattern of masked repetition priming effects for word and nonword targets differs across tasks: Masked-priming effects in lexical decision occur for positive responses (i.e., words), but not for negative responses (nonwords), whereas masked-priming effects in the cross-case same–different task occur for positive responses (*same*), but not for negative responses (*different*)—regardless of lexical status. Here, we examined whether masked nonword priming effects are greater when the task involves an active *go* response to nonwords than when it involves the standard yes/no procedure in lexical decision. The obtained masked repetition priming effect for nonwords was of similar size in yes/no and go/no-go tasks. This finding is compatible with accounts of nonword priming that posit that nonword responses are produced by actively accumulating evidence for the nonword alternative in yes/no and go/no-go procedures, whereas it is inconsistent with the assumption of a deadline for *no* responses in the yes/no task.

In the past few decades, one key methodological tool for researchers studying orthographic, phonological, morphological, and semantic processing has been Forster and Davis's (1984) masked-priming technique (see Grainger, 2008, for a review). In the typical masked-priming experiment, a forward mask consisting of hash marks (######) is presented for 500 msec, followed by the prime in lowercase letters for 40–60 msec. Next, the target stimulus is presented in uppercase letters. Under these circumstances, participants are unaware of the existence of the prime, and the obtained effects are assumed to reflect early and automatic processes (Forster, Mohan, & Hector, 2003).

The experimental procedure most commonly associated with masked priming has been the lexical decision task ("is the uppercase stimulus a word or a nonword?"). A myriad of lexical decision experiments have shown robust masked repetition priming for word targets, but not for nonword targets (for reviews, see C. Davis, Kim, & Forster, 2008; Forster, 1998; Norris & Kinoshita, 2008). (Repetition priming refers to the difference in performance, measured in speed or accuracy, between an unrelated condition and an identity condition.) This dissociation between masked repetition priming for word and nonword targets has been taken as support for a lexical, rather than sublexical, locus of masked priming in lexical decision. As Forster indicated, "if the prime is identical to the target (although in a different case), then the sublexical constituents should be recognized faster no matter whether the target is a word or not" (p. 211). However, a meta-analysis reported by Forster revealed a small, yet significant, masked nonword repetition priming effect of 9 msec across 40 experiments with the standard setup (primes in lowercase and targets in uppercase); note that *only* 3 of these experiments were significant by themselves (see also Forster et al., 2003). We should note that this (putative) sublexical effect may be magnified experimentally when the task involves letter-by-letter processing. For instance, Bodner and Masson (1997) reported a 95-msec masked repetition priming effect for nonwords when the targets were presented in mixed case (e.g., sFiLe); however, this effect was negligible when the targets were displayed in the standard uppercase presentation (e.g., SFILE).

Recently, the story has become more complex. Using the cross-case same–different task,[1] Norris and Kinoshita (2008) found that when the probe and the target were the same (e.g., probe, *maith*; target, MAITH), an identity prime (e.g., *maith*) produced a clear advantage in response time (RT), relative to an unrelated prime (e.g., *fouse*), and the

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size of the repetition priming effect was virtually identical for *same* responses to words and nonwords. In contrast, there were no signs of a repetition priming effect for *different* responses to words/nonwords (see Perea & Acha, 2009, for a similar finding).

Thus, the pattern of masked-priming effects for word and nonword targets differs across experimental tasks. On the one hand, masked-priming effects in lexical decision occur for positive responses (i.e., words), but not for negative responses (i.e., nonwords). On the other hand, masked-priming effects in the cross-case same–different task occur for positive responses (*same*), but not for negative responses (*different*), and this is so *regardless* of the lexical status of the stimulus. Here, we tested two alternative explanations for the nonword priming effects described above.

One explanation for the nonword priming effects (or lack thereof) is that priming occurs only when the response is an active one (i.e., the positive responses *yes* in lexical decision and *same* in the same–different task), whereas priming does not occur for negative responses because they are initiated via a *deadline* criterion (i.e., on the basis of extrastimulus information), as posited in the multiple read-out model (Grainger & Jacobs, 1996) and in the dual-route cascaded model (Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001). As Forster (1998) indicated, "if a 'no' decision is made only when a deadline is reached, then sublexical priming would be undetected unless the deadline were adjusted to take into account the nature of the prime" (p. 211).[2]

An alternative explanation is that masked repetition priming depends on the characteristics of discrimination being made and the *information* that the prime provides to make the response (and not whether the response is positive or negative). This is the explanation provided by the Bayesian reader model (Norris, 2006; Norris & Kinoshita, 2008). In this model, masked priming depends on the hypotheses that support the decision required to make a response. In lexical decision, masked priming is driven mainly by integrating evidence at the word level. In contrast, the same–different decision is made by comparing the likelihood that the target has the same form as the probe with the likelihood that it has a different form, so that masked priming would happen regardless of lexical status when the probe and target are the same, but not when they are different. Simulations on the Bayesian reader model show a masked repetition priming effect for words (but not for nonwords) in lexical decision and a masked-priming effect for *same* responses (for both words and nonwords), but not for *different* responses. Note, however, that a masked nonword repetition priming effect in lexical decision would be produced if participants were locating a word representation that is similar to the input and performing a letter-by-letter check (Norris & Kinoshita, 2008). Given that mixed-case targets seem to induce letter-by-letter processing (see C. Davis et al., 2008), the Bayesian reader model may accommodate the findings reported by Bodner and Masson (1997) with mixed-case targets.

One way to test the *deadline* and Bayesian reader explanations in masked priming is to make negative trials the active and overt responses in a go/no-go lexical decision task (i.e., respond to nonwords). As Siakaluk, Buchanan, and Westbury (2003) indicated, "this procedural change would make the responses to the experimental items more like *yes* responses, because they were the only items requiring an overt response" (p. 104). Similarly, Siakaluk, Pexman, Sears, and Owen (2007, p. 458) argued that the go/no-go task "elicits more extensive processing" than does the yes/no task. Indeed, semantic distance effects for nonexemplars are greater in the go/no-go task than in the yes/no task (Siakaluk et al., 2003; see also Siakaluk et al., 2007, for a parallel finding with homophone effects), and, in a lexical decision task, participants show a bias to respond with the overt response in the go/no-go procedure (Gómez, Ratcliff, & Perea, 2007). Furthermore, in an unprimed lexical decision task, the pattern of effects for *pseudoword* frequency differs in a yes/no task and in a go/no-go task with nonword responses (Perea, Rosa, & Gómez, 2005). Perea et al. (2005) interpreted these findings in terms of an active response process in the go/no-go task and a temporal deadline for *no* responses in the yes/no task.

Thus, in the present experiment, we examined whether masked nonword repetition priming effects are substantially greater when the experimental procedure involves an active *go* response to nonwords than when it involves the usual yes/no procedure. The models that assume that noisy evidence is accumulated over time, such as the Bayesian reader model (Norris & Kinoshita, 2008; see also Gómez et al., 2007, for a diffusion model of the go/no-go task), indicate that the nature of the evidence needed to make the lexical decision does *not* change, regardless of the overt response, and hence, they predict a similar pattern of masked priming in the two tasks.[3] Alternatively, if the go/no-go procedure maximizes the chances that a *no* response will be made via an active process, rather than by a temporal deadline, as suggested by Perea et al. (2005; see also Siakaluk et al., 2007), masked nonword priming effects will be substantially greater in the go/no-go than in the yes/no task. Note that the latter pattern would strongly suggest that it is the type of response (positive vs. negative) that causes the differential pattern of repetition priming effects in the two tasks, and it would pose an important challenge to the Bayesian reader model.

One final methodological consideration is whether the lexical status of unrelated primes has a prime-specific effect on the processing of the target word. Nonetheless, neither Perea, Fernández, and Rosa (1998) nor Norris and Kinoshita (2008) found any signs of an effect of the lexical status of the masked unrelated primes in the yes/no lexical decision task.

METHOD

Participants

Thirty-three students from the University of Santiago de Compostela received course credit for participating in the experiment (15 in the yes/no-task and 18 in the go/no-go task). All of them had either normal or corrected-to-normal vision and were native speakers of Spanish.

Materials

The word targets were 216 Spanish words that were 7–11 letters long (mean number of letters, 8.6; mean frequency, 73 per million in the Spanish database; C. J. Davis & Perea, 2005). The nonword targets were 216 pronounceable pseudowords (e.g., DIDUPADO, FESECINO, etc.) that had been created by changing 2 letters from Spanish words (mean number of letters, 8.6; range, 7–11). The targets were presented in uppercase and were preceded by primes in lowercase that were (1) the same as the target, (2) an unrelated word prime, or (3) an unrelated nonword prime. The list of materials is available at www.valencia.edu/mperea/GNG_PBR_materials.pdf. Three lists of materials were constructed, so that each target appeared once in each list, but each time in a different priming condition. Different groups of participants were assigned to each list.

Procedure

The participants were tested individually in a quiet room. Presentation of the stimuli and recording of RTs were controlled by PC-compatible computers. The experiment was run using DMDX (Forster & Forster, 2003). RTs were measured from target onset until the participant's response. On each trial, a forward mask consisting of a row of hash marks (#s) was presented for 500 msec in the center of the screen. Next, the prime was presented in lowercase in 12-point Courier and stayed on the screen for 50 msec (three refresh cycles, each cycle corresponding to 16.6 msec on the CRT monitor). The prime was followed immediately by the presentation of the target stimulus in uppercase. Both the prime and target were presented in the same screen location as the forward mask. The target remained on the screen until the participants responded. In the yes/no task, the participants were instructed to press one of two buttons on the keyboard to indicate that the uppercase letter string was or was not a Spanish word. In the go/no-go task, the participants were instructed to press one button on the keyboard to indicate whether the uppercase letter string was not a word and to refrain from responses if the uppercase letter string was a word. The participants were instructed to make this decision as quickly and as accurately as possible. They were not informed of the presence of lowercase items. Each participant received a different order of trials. Each participant received a total of 20 practice trials (with the same manipulation as in the experimental trials) prior to the 432 experimental trials. The whole session lasted approximately 20–25 min.

RESULTS

Incorrect responses (3.4% of the data for nonword targets) and RTs shorter than 250 msec or longer than 1,500 msec (less than 2% of the data for nonword targets) were excluded from the present analysis. The mean latencies for correct responses and error rates are presented in Table 1, and participant and item ANOVAs based on the participant and item response latencies and error percentages were conducted on the basis of a 3 (prime type: identity, unrelated word, unrelated nonword) × 2 (task: go/no-go vs. yes/no) × 3 (list: List 1, List 2, List 3) design. List was included as a dummy factor to extract the variance due to the error associated with the lists. All significant effects had p values less than the .05 level.

Nonword Responses

The ANOVA on the latency data showed that the effect of prime type was significant [$F_1(2,54) = 8.92$, $MS_e = 172.6$; $F_2(2,426) = 5.44$, $MS_e = 4{,}486$]. Orthogonal comparisons showed that there were no signs of an effect of the lexical status of the unrelated prime (both Fs < 1), and the average for these two prime conditions showed that responses were significantly slower than those in the repetition prime condition [$F_1(1,27) = 17.24$, $MS_e = 166.6$; $F_2(1,213) = 12.02$, $MS_e = 3{,}981.8$]. The effect of task was significant only in the analysis by items [$F_1(2,27) = 2.49$, $MS_e = 12{,}875.2$, $p = .12$; $F_2(1,213) = 74.86$, $MS_e = 5{,}523.6$]. There were no signs of an interaction between task and prime type (all ps $> .10$).

The ANOVA on the error data showed that the effect of prime type was significant [$F_1(2,54) = 3.22$, $MS_e = 5.19$; $F_2(2,426) = 3.91$, $MS_e = 56.3$]. Orthogonal comparisons showed that there were no signs of an effect of the lexical status of the unrelated prime (both ps $> .10$), and the average for these two prime conditions showed that fewer errors were produced than in the repetition prime condition [$F_1(1,27) = 3.50$, $MS_e = 7.37$, $p = .07$; $F_2(1,213) = 4.97$, $MS_e = 68.6$]. In addition, there was a main effect of task [$F_1(1,27) = 10.45$, $MS_e = 10.6$; $F_2(1,213) = 23.38$, $MS_e = 116.6$]: The participants made more errors on the yes/no task than on the go/no-go task. There were no signs of an interaction between task and prime type (both Fs < 1).

Word Responses

The ANOVA on the latency data in the yes/no task showed a significant effect of prime type [$F_1(2,30) =$

Table 1
Mean Response Times (RTs, in Milliseconds; With Standard Deviations) and Percentages of Errors (ERs) for Word and Nonword Targets in the Experiment

	Task							
	Yes/No				Go/No-Go			
	RT		ER		RT		ER	
Condition	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Word Targets							
Identity	583	65	2.3	2.6	–		2.2	2.7
Unrelated word	635	67	5.6	4.0	–		3.6	2.4
Unrelated nonword	641	58	7.0	3.9	–		4.8	4.5
Repetition priming	55		3.3				2.6	
	Nonword Targets							
Identity	685	72	6.0	4.4	719	87	2.4	3.4
Unrelated word	697	70	4.1	3.6	731	92	2.2	2.6
Unrelated nonword	695	75	4.5	2.6	734	88	1.5	2.0
Repetition priming	11		−1.5		13.5		−0.9	

Note—*Repetition priming* refers to the difference between the average of the two unrelated conditions and the identity condition.

69.96, MS_e = 263.8; $F_2(2,426)$ = 75.20, MS_e = 3,006.9]. Orthogonal comparisons showed that there were no signs of an effect of the lexical status of the unrelated prime (both Fs $<$ 1), and the average for these two prime conditions showed that responses were significantly slower than in the repetition prime condition [$F_1(1,15)$ = 125.85, MS_e = 290.6; $F_2(1,213)$ = 150.45, MS_e = 2,989.9].

The ANOVA on the error responses showed fewer errors in the go/no-go task than in the yes/no task [$F_1(1,27)$ = 11.49, MS_e = 18.63; $F_2(1,213)$ = 27.06, MS_e = 104.4] and also a significant effect of prime type [$F_1(2,54)$ = 7.39, MS_e = 4.53; $F_2(2,426)$ = 7.52, MS_e = 58.7]. More important, there was a significant interaction between the two factors [$F_1(2,54)$ = 14.62; $F_2(2,426)$ = 18.88, MS_e = 55.0], which reflected a greater effect of prime type in the yes/no task [$F_1(2,30)$ = 20.81, MS_e = 8.28; $F_2(2,426)$ = 17.32, MS_e = 72.93] than in the go/no-go task (both ps $>$ .20).

One might argue that the lack of a significant interaction between repetition priming and task for nonwords (11 msec in the go/no-go task and 13.5 msec in the yes/no task) is difficult to interpret. This issue is closely related to the power of an experiment: How confident can we be that the masked repetition priming effect for nonwords is the same size in the two tasks? Or, alternatively, is it reasonable to assume that the priming effect for nonwords in the go/no-go task, with (active) nonword responses, is the same magnitude as the priming effect for words in the yes/no task, with active word responses? To answer this question, we employed a parametric bootstrapping technique similar to the one proposed by Wagenmakers, Ratcliff, Gómez, and Iverson (2004).

In our bootstrapping simulations, we implemented these two hypotheses within an evidence accumulation model: the diffusion model (Ratcliff, 1978; see also Gómez et al., 2007). In both cases, masked-priming effects were assumed to occur in the nondecisional component (i.e., encoding time), because this assumption would be most consistent with the fact that RT distributions across conditions in masked priming differ in the location, and not in the shape (see Pollatsek, Perea, & Carreiras, 2005). The parametric bootstrapping simulation was conducted as follows.

1. Using plausible diffusion model parameters (taken from the lexical decision experiments in Gómez et al., 2007), we generated simulated data for the unrelated conditions in the go/no-go and yes/no tasks. We employed the same number of simulated trials as in the real experiment.

2. In the yes/no task, the effect of masked repetition priming for nonwords was 10 msec in the nondecision time parameter—to be numerically in line with Forster's (1998; C. Davis et al., 2008) estimations.

3. In the go/no-go task, we implemented the two hypotheses by reducing in the simulations the nondecision time parameter by 10 msec and by 50 msec. We chose 50 msec because this is the value of the stimulus onset asynchrony and it closely corresponds to the obtained priming effect for word targets in the yes/no task (see also Forster et al., 2003, for analyses of the parallels of masked-priming effects and stimulus onset asynchronies).

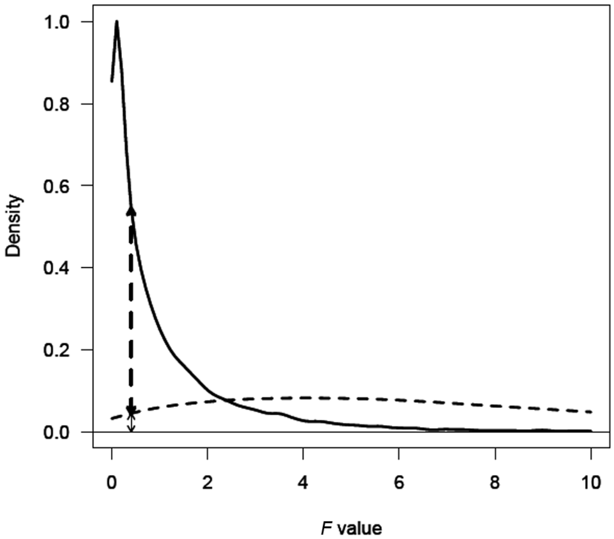

Figure 1. Simulated distributions of F values assuming a 10-msec priming effect (discontinuous line) and assuming a 50-msec priming effect (continuous line). The thick arrows indicate the value of the empirical F values from our experiment. As illustrated, such a value is about 12 times more likely to occur in simulations with 10-msec effects than in simulations that assume 50-msec effects.

4. We repeated Steps 1–3 for 33 simulated participants and computed two F values for the interaction between task and prime type with the simulated data. One of the F values was obtained from the simulated 10-msec scenario, and the other from the simulated 50-msec scenario.

5. We repeated Step 4 10,000 times and obtained two distributions of F values: One was obtained from the simulated 10-msec scenario, and the other from the simulated 50-msec scenario.

6. We computed the likelihood ratio (10-msec model/50-msec model) of the empirical F value: It was 0.406. An $F(2,54)$ = 0.406 is 12 times more likely to happen in the 10-msec model than in the 50-msec model (see Rouder, Speckman, Sun, Morey, & Iverson, 2009, for an introduction to likelihood ratios): The density at F = 0.406 is 12 times larger for the 10-msec model than for the 50-msec model (see Figure 1).

Thus, these simulations support the view that the magnitude of masked-priming effects for nonwords is reasonably similar in go/no-go and yes/no tasks; furthermore, they challenge the view that priming effects with an active nonword response are similar in magnitude to priming effects with words.

DISCUSSION

The results of the present masked-priming lexical decision experiment are clear-cut. First, the present finding represents a demonstration of the reliability, in a single experiment with many trials per condition, of masked repetition priming effects for nonwords in lexical decision. Second, the magnitude of this effect is remarkably similar across task procedures (11 msec in the yes/no task vs.

13.5 msec in the go/no-go task). Third, there are no signs of an effect of the lexical status of the unrelated prime. And fourth, error rates to overt responses are smaller in the go/no-go task than in the yes/no task (Gómez et al., 2007; Perea, Rosa, & Gómez, 2002, 2003).

The presence of a similar masked nonword repetition priming effect in yes/no and go/no-go tasks has clear theoretical implications: It confirms the predictions of models that assume an active response both in the yes/no task and for the *no* response in the go/no-go task (e.g., the Bayesian reader model or the closely related diffusion model). Importantly, the presence of a similar magnitude of masked repetition nonword priming effects for *no* responses in the yes/no task and for *go* responses in the go/no-go task is most compatible with those models that assume that information relevant to the task is accumulated in a noisy fashion, such as the Bayesian reader model. That is, the core information on which decisions are based is not critically different between yes/no and go/no-go procedures (see Gómez et al., 2007, for experimental/modeling evidence across a variety of tasks, including lexical decision). Furthermore, these findings pose a challenge for those models that assume that *negative* responses are initiated via a deadline criterion (i.e., on the basis of extrastimulus information), as in the multiple read-out model or the dual-route cascaded model.

What should also be noted here is that the presence of similar nonword priming effects in the two tasks is not incompatible with the presence of greater effects in go/no-go than in dual-choice *single-presentation* (i.e., unprimed) experiments. The reason is that, unlike masked priming, the effects of the task procedure in single-presentation experiments (e.g., neighborhood frequency with nonwords) affect the skewness (right tail of the RT distribution; see Gómez et al., 2007, and Perea et al., 2005, for analyses of RT distributions with these two task procedures).

Although the main focus of this study was on responses to nonwords, our results with word targets can also tell us something about the nature of masked-priming effects. As usual, the magnitude of the masked-priming effect for words was dramatically higher than that for nonwords (55 vs. 11 msec in the yes/no task; see Table 1). This strongly suggests that there is a lexical component in masked priming, which is consistent with the presence of masked associative/semantic priming effects (Perea & Gotor, 1997).

What is the magnitude of the *sublexical* component in masked-priming lexical decision? The presence of a small (but significant) masked repetition priming effect for nonwords implies that there is a small sublexical component in masked repetition priming (e.g., via the constituent letters or letter clusters). The magnitude of the observed effect (around 10–15 msec) is very close to the estimation of 9 msec given by Forster (1998) in a meta-analysis. We acknowledge that the influence of the sublexical component can be magnified under some circumstances, as in the case of mixed case targets (Bodner & Masson, 1997)—presumably, via letter-by-letter priming (see C. Davis et al., 2008; Norris & Kinoshita, 2008). Although this hypothesis is not explicitly implemented in the Bayesian reader model, our prediction is that this would reflect an effect on the longer RTs (i.e., those that are produced by the nonoptimal, letter-by-letter route in the Bayesian reader model). This was the case in the go/no-go task in the present experiment, in which the nonword priming effect was substantially larger for the slow responses (46 msec in the .9 quantile) than for the mean (13.5 msec; see Table 1).

In sum, we have shown that the magnitude of the masked repetition priming effect for nonwords is not altered in yes/no and go/no-go tasks, thus supporting the predictions from the Bayesian reader model and posing problems for those models using a deadline criterion for *no* responses.

AUTHOR NOTE

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NOTES

1. In the cross-case same–different task, a probe is presented before a target stimulus, which is presented in a different case.

2. Note, however, that the deadline explanation has been recently criticized on the grounds that it cannot readily account for list composition effects (Wagenmakers, Ratcliff, Gómez, & McKoon, 2008).

3. Although the prediction that the go/no-go task and the yes/no task show a similar pattern of data is a prediction of a whole class of noisy evidence accumulation models, we focus on the Bayesian reader model because this model has developed an account of the lexical decision task and an explanation of masked priming.

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