

Understanding the Intervener Effect in Masked Priming

by

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Abstract

In the masked priming paradigm, responses to a target are faster if the prime and target are identical (*repetition priming*). Forster (submitted) provides evidence that repetition priming consists of a semantic component, due to the shared meaning of the prime and target, and an orthographic component, due to the shared letters. When an unmasked unrelated word intervenes between the prime and target, repetition priming was reduced, but orthographic priming was unaffected. When this intervener was masked, repetition priming was reduced whereas orthographic priming was eliminated. The unmasked intervener may block a semantic component of priming, and a masked intervener blocks the orthographic component. Experiment 1 replicated Forster's results and confirmed the results were not due to an SOA confound. Experiment 2 included semantically-related primes in an attempt to examine the intervener's effect on semantic priming, however, our materials did not yield semantic priming even when no intervener was present.

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Understanding the intervener effect in masked priming

The study of processes involved in word recognition has commonly used a technique called masked priming. In one version of this procedure, subjects are first presented a mask, consisting of a row of symbols (e.g., &&&&&), followed by the prime, and then the target. Subjects' task is to respond to the target as quickly as possible, one common task being lexical decision, in which subjects decide whether the target is a word or a nonword. The mask, combined with a duration of the prime as brief as 40-60 ms, contributes to make subjects unaware of the prime's presence. Ensuring that primes are not detected enables researchers to study word recognition processes that are not contaminated by deliberate or conscious strategies that subjects might apply to the primes. Masking the primes also works to prevent the formation of episodic memories for the primes (Forster & Davis, 1984; but see Masson & Bodner, 2003). Once these masking conditions are in place, manipulating the prime's relationship to the target permits researchers to discover what processing operations are applied to the prime as revealed by its effect on the target. One robust priming effect occurs when subjects are faster to respond to the target when the prime is identical to the target (e.g., doctor-DOCTOR) relative to when the prime is a word unrelated to the target (e.g., truck-DOCTOR; Forster & Davis, 1984). One explanation of this effect accounts for repetition priming by stating that processing the prime opens its entry in a mental lexicon, which contains all of the words possessed by the individual (Forster & Davis, 1984). As a result, the target is responded to faster due to its lexical entry already being open, allowing faster access to information concerning the word relative to if its entry had not already been opened, as would be the case if the preceding word was unrelated to the target.

Despite wide-spread use of the masked priming, there has been little research investigating what mechanisms are at work. The repetition priming effect in the masked priming paradigm has also not been sufficiently explained. It has been hypothesized that masked repetition priming may in fact consist of different components. Evett and Humphreys (1981) found that identification of a briefly presented target was facilitated by immediate prior presentation of a nonword that was only one letter different from the target (e.g., dactor-DOCTOR). This effect has been referred to as orthographic priming because the benefit does not appear to stem from visual similarity of the prime and target but the fact that the prime and target share abstract letter codes. Evett and Humphreys found that the benefit of the orthographically-similar prime was not as large as when the prime was identical to the target, as is typically reported in the masked priming literature (Forster, Mohan, & Hector, 2003). Evett and Humphreys hypothesized that this was likely due to both orthographic and semantic activation being activated by the prime, whereas only orthographic activation of the target is activated by an orthographically-similar prime.

A recent phenomenon in the masked priming paradigm has been interpreted as suggesting that repetition priming consists of an orthographic and semantic component. Forster (in press) reported the interesting effect of inserting an unrelated word between the prime and target. Three types of primes were included in Forster's experiment: A repetition prime, an orthographic prime that was one letter different from the target, and an unrelated prime. When the intervening word was unmasked by presenting it for a duration of 500 ms, repetition and orthographic priming were equivalent. These priming effects were compared to priming effects generated when the prime and target were not separated by an intervening word, referred to as adjacent priming. Relative to adjacent priming, it was revealed that the unmasked intervener had

reduced repetition priming, but orthographic priming was unaffected. A different pattern was obtained when the intervener was masked by presenting it for only 60 ms. Here, repetition priming was again reduced relative to the adjacent priming condition, but orthographic priming was completely eliminated.

The pattern of results produced by the intervening unrelated word is not easily explained by most accounts of word recognition. Most accounts would predict that inserting an unrelated word between the prime and target would eliminate repetition priming. For example, according to the lexical-entry model proposed by Forster & Davis (1984) described earlier, the intervening unrelated word will close the entry opened by the prime. The intervener's entry will then be opened, preventing the prime from facilitating target processing. Similarly, interactive-activation models would predict that the intervener would either overwrite any information activated by the prime or would reset the activation levels in all word units, again preventing any priming effects (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996). One account of masked priming that permits priming to extend across an intervening word is the memory-recruitment account (Bodner & Masson, 2001; Masson & Bodner, 2003). According to this account, the processing of the prime creates a memory resource that is recruited by the target. When this memory resource contains information that is relevant to processing the target, as it does when the prime is identical to the target, target processing is facilitated and subjects will respond faster relative to targets preceded by unrelated primes. Because this account is memory-based, it allows a long-term influence of the prime, which may be recruited by the target despite intervening items. However, it is not clear how the memory-recruitment account would explain the full pattern of results produced by an unmasked and masked intervener.

Forster (in press) offered an explanation for the effect of the intervener in terms of the lexical-entry model. First, Forster states that when the prime is identical to the target, target processing may be facilitated as a result of its orthographic similarity and conceptual similarity to the prime. The intervening unrelated word selectively affects one of these two sources of facilitation produced by the repetition prime depending on whether or not the intervener is masked. First considering the case of an unmasked intervener, the repetition prime opens its corresponding lexical entry, and the orthographic prime would also open the target's entry in addition to other possible entries. The intervener opens its corresponding entry but it is closed once the intervener is identified. The entry for the unidentified prime remains open, leading to an orthographic processing benefit from the repetition and orthographic primes when the target is presented. However, semantic processing of the intervener overwrites any semantic information activated by the repetition prime. As a result, repetition and orthographic priming are similar because they represent the same source of facilitation of the target, namely, facilitation due to orthographic similarity. In the case of a masked intervener, the prime and intervener open their corresponding entries, and both remain open because neither word is identified. When the target is presented, processing three words in parallel may exceed the capacity of the lexical processor, which may lead to closing the entry for the earliest word (i.e., the prime). Closing the prime's entry effectively eliminates any orthographic benefit. However, the semantic information activated by the repetition prime may survive the intervener because maintaining semantic representations of the prime and intervener may be possible at an unconscious level. Thus, only repetition priming is present when the intervener is masked. Figure 1 provides an illustration of how the different components of priming are affected by the presence of unmasked and masked interveners.

Forster (in press) admits that the explanation detailed in the previous paragraph is speculative at this point, but this proposed explanation emphasizes the degree to which existing models of word recognition may need to be modified in order to account for the effect of the masked and unmasked intervener on repetition priming. The lexical-entry account, for example, would require the addition of a mechanism that keeps track of the order in which entries are opened, which would allow for the earliest entry to be closed when the capacity of the lexical processor is reached. However, further understanding of the intervener effect is necessary before it can be decided what modifications may be required of existing models. The goal of the present study was to examine Forster's claim that repetition priming consists of semantic and orthographic components that are selectively blocked by the masked and unmasked interveners.

Previous studies have investigated the effect of an intervening unrelated word within the semantic priming paradigm using unmasked primes. Forster (in press) notes a difference between these studies and his own: In previous studies the prime and target were related by meaning (e.g., dream-sleep), but in Forster's study the prime and target are similar in form. However, part of Forster's account of the intervener effect is that an intervener selectively blocks the semantic component of repetition priming, and it is reasonable to assume that the semantic component of repetition priming is the same mechanism that is responsible for priming between semantically-related pairs. Thus, the effect of an intervener on semantic priming appears to be relevant. Early investigations found that semantic priming was present when an unrelated word separated a prime and target (Davelaar & Coltheart, 1975; Meyer, Schvaneveldt, & Ruddy, 1972). However, it was possible that the long SOAs in these studies, and the use of a binary response task, allowed subjects to engage in a strategy of "semantic matching" (Neely, 1991; Ratcliff & McKoon, 1981), in which subjects make word judgments based on whether or not the

target was related to the preceding prime. When the likelihood of this strategy is reduced, the influence of the semantic prime appears to be eliminated by the intervener (Deacon, Grose-Fifer, Hewitt, Nagata, Shelley-Tremblay, & Yang, 2004; Gough, Alford, & Holley-Wilcox, 1981; Masson, 1991; Ratcliff & McKoon, 1988). Joordens and Besner (1992) pointed out that there did appear to be a small priming effect in these later studies, and in their own study reported significant semantic priming spanning an unrelated word. The mixed results of these studies prevent any clear conclusions about the influence of an intervening word. An advantage of examining this issue with masked priming is that preventing awareness of the prime eliminates any possible role of post-access strategies, and thus will provide a strong test of whether semantic priming survives an intervener.

In summary, inserting an unmasked or masked unrelated word between the prime and target has interesting effects on repetition and orthographic priming that are not easily explained by most accounts of word recognition processes (Forster, in press). Identifying the nature of the intervener's influence will pave the way towards reconciling the pattern of results with the different accounts. Our first experiment was an attempt to replicate Forster's findings, plus address a potential confound in his design: A longer lag between the prime and target is produced by inserting an unmasked intervener between the prime and target. Thus, the results reported by Forster may not be due to subjects' different levels of awareness of the intervener, but due to different prime-target stimulus onset asynchronies (SOA; the duration from prime-onset to target-onset). This issue may be addressed by considering two aspects of Forster's data. First, if the reduction in repetition priming was related to the lag between prime and target, the size of the reduction should have been influenced by the size of this lag. However, the reduction of repetition priming was roughly equivalent whether the prime-target SOA was 560 ms in the

unmasked intervener condition or 120 ms in the masked intervener condition. Second, orthographic priming was larger when the lag was longest in the masked intervener condition, suggesting that increasing the delay did not lead to a decrease in the amount of orthographic priming. Findings from Ferrand (1996) indicated that increasing the lag should affect the magnitude of repetition priming. He measured masked repetition priming in a naming task as a function of different interstimulus intervals (ISI), and found that priming quickly decreased as the lag between prime and target increased. Repetition priming was unchanged up to an ISI of 150 ms, but dropped sharply at an ISI of 500 ms such that it was no longer present. Although it is unlikely that different lags were responsible for Forster's pattern of results, we believe it important to eliminate this possibility.

Experiment 1

Experiment 1 was designed to replicate the results of Forster (submitted), and address a confound present in his experiments. As described above, the effects of the unmasked intervener may not have been due to the intervener being visible to subjects but due to the increased lag produced by the intervener's longer duration. We investigated the effect of this increased lag by creating a masked intervener condition with a prime-target SOA equivalent to that of the unmasked intervener condition. The prime duration of the masked intervener in this new duration remained at 45ms, but a mask was inserted between the intervener and the target such that the prime-target SOA was 500ms, identical to the unmasked intervener condition. Selection of an appropriate item that would successfully mask the prime and intervener was crucial, as pilot testing revealed that either the prime or intervener was still identifiable when the initial mask (&&&&&&&) was repeated. The most effective mask is another word, due to its function as a conceptual mask (Intraub, 1981, 1984), and this is the typical post-mask for the

prime when it is followed by the subsequent target. However, using a filler word as a mask would then be examining the effect of two intervening stimuli when the present studies are examining the effect of only one intervener. The post-mask selected for the masked intervener long SOA condition was a random string of letters, which served as a successful mask due to its structural similarity to the preceding items (Enns, 2004; Fehrer, 1966; Harmon & Julesz, 1973). These letter-strings did not contain vowels, rendering them unpronounceable, which ensured that they did not resemble actual words.

According to the account provided by Forster (in press), the pattern of results in Experiment 1 should be as follows. In the unmasked intervener condition, repetition and orthographic priming should be roughly equivalent, as the semantic component of repetition priming is blocked. In the masked intervener short SOA condition, which is virtually identical to the one employed by Forster, repetition priming should be present and orthographic priming should be eliminated. If the effect of the intervener in the unmasked condition is due to the increased lag between the prime and target, then the masked intervener long SOA condition should yield a pattern of results similar to the unmasked intervener condition. However, if the results reported by Forster (in press) are due to the masked or unmasked status of the intervener, and not the different lags, the long SOA condition should resemble the masked intervener short SOA condition.

Method

Subjects. Eighty-six subjects participated in Experiment 1 for course credit. Subjects were randomly assigned to one of three groups. However, unequal numbers of subjects participated in each group: Thirty-four subjects were tested with an unmasked intervener, 28 with a masked intervener short SOA, and 24 with a masked intervener long SOA.

Materials. A set of 90 words and 90 nonwords were selected for use as targets in the lexical decision task. In order to obtain maximal orthographic priming, all stimuli were eight letters in length (Forster, Davis, Schoknecht, & Carter, 1987). The mean frequency of the words was 7.5 per million (Kucera & Francis, 1967) and the mean neighbourhood size, which refers to the number of words that are one letter different (e.g., *attitude* is a neighbour of *altitude*), was 0.34 (Balota et al., 2007). Nonwords were created such that they consisted of legal strings of letters (e.g., *jinulate*, *folimony*, *beblital*). Each target was paired with three different types of primes: (1) A repetition of the target, (2) an orthographically similar nonword created by altering one letter of the target, and (3) an item unrelated to the target. Items were counterbalanced such that targets were paired with each type of prime equally often, which led to each condition containing 30 items. All word and nonword targets were paired with an additional unrelated word that served as the intervener.

Procedure. Subjects were tested individually using a Macintosh G3 computer. All stimuli were displayed in black on a white background, and presentation of the stimuli was synchronized with the raster scan of the computer's monitor to ensure precise control of presentation duration. Subjects sat approximately 40 cm from the monitor.

For subjects in the unmasked intervener and masked intervener short SOA conditions, each trial of the lexical decision task consisted of four consecutive events (see Figure 2): (1) a forward mask, consisting of a row of ampersands (&&&&&&&), presented for 500 ms, (2) the prime presented in lowercase for 45 ms, (3) the intervener presented in lowercase for 500 ms if unmasked and 45 ms if masked, and (4) the uppercase target. Subjects in the masked intervener long SOA condition were presented the same events as subjects in the masked intervener short SOA condition except that a mask was inserted between the intervener and target, and presented

for 455ms. This backward-mask consisted of a string of consonants randomly created for each trial. Targets remained on the screen until subjects made their response using a button-box connected to the computer. Subjects were informed that their task was to decide whether or not the target was a word, pressing the right button if the target was a word and the left button if the target was a nonword. Decisions were to be made as quickly as possible but not so quickly as to compromise their accuracy. Feedback was given after each trial if the subject had made an incorrect response, or if their response time was longer than 1500ms. The computer recorded subjects' response times. Once subjects had completed the lexical decision task, they were asked a number of questions designed to explore the extent of their awareness of the masked item(s), e.g., "Did you notice anything present after the &'s, but before the uppercase target word?"

Results

Correct response times and error rates were averaged by condition for each group, and the means are presented in Figure 3. Priming effects, calculated by subtracting the response times for repetition and orthographic prime trials time from the unrelated prime condition, are presented in the right panels of Figure 3. Trials with response times below 300 ms and above 1850 ms were excluded from the analyses, leading to less than 0.5% of response times being excluded as outliers (Ulrich & Miller, 1994). An alpha value of .05, and a marginally significant value of .10, was used for all analyses reported in this article.

Response times. A mixed-model analysis of variance (ANOVA) with group (unmasked intervener, masked intervener-short SOA, masked intervener-long SOA) as a between-subject factor and prime-type (unrelated, repetition, orthographic) as a within-subject factor was conducted on the response time data. In this analysis, there was a significant effect of group, such that subjects in the masked intervener short SOA group had the slowest response times,

$F(2, 83) = 4.93$, $MSE = 25088$. It is possible that the shorter SOA provided subjects with less time to prepare for the upcoming target. There was also an effect of prime-type, with the response times for the unrelated, repetition, and orthographic prime conditions being 657 ms, 640 ms, and 650 ms, respectively, $F(2, 166) = 9.59$, $MSE = 650$.

The important result in the present study is whether or not repetition and orthographic priming is present in each intervener condition. Separate repeated measures ANOVAs with prime-type as the within-subject factor were conducted for each condition, accompanied by planned comparisons determining if significant priming occurred in that intervener condition. For the unmasked intervener condition, there was a significant effect of prime-type, $F(2, 66) = 6.04$, $MSE = 675$. Planned comparisons revealed that subjects were significantly faster on repetition-prime trials (623 ms) relative to unrelated-prime trials (645 ms), $F(1, 33) = 12.22$, $MSE = 666$, but only marginally faster with orthographically-related primes (633 ms) relative to unrelated primes (645ms), $F(1, 33) = 3.38$, $MSE = 706$. For the masked intervener short SOA intervener condition, the effect of prime-type was not significant, $F(2, 54) = 1.92$, $MSE = 845$. According to the planned comparisons, subjects were marginally faster on trials with repetition primes (684 ms) relative to unrelated-prime trials (700 ms), $F(1, 27) = 4.01$, $MSE = 801$, but response times for orthographic-prime trials and for unrelated prime trials did not differ significantly (700 ms vs. 694 ms), $F < 1$. Finally, for the masked intervener long SOA condition, there was a significant effect of prime-type, $F(2, 46) = 3.64$, $MSE = 386$. Importantly, the pattern of results in this condition resembled the masked-short SOA condition. Planned comparisons revealed a significant repetition priming effect, as subjects were faster when the prime was a repetition relative to an unrelated prime (610 ms vs. 624 ms), $F(1, 23) = 5.716$, MSE

= 424. As in the masked-short SOA intervener condition, response times for orthographic prime trials and unrelated prime trials did not differ (624 ms vs. 622 ms), $F < 1$.

In addition to determining whether or not significant repetition and orthographic priming was present in each intervener condition, we compared the magnitude of priming effects within each intervener condition. In the unmasked intervener condition, a comparison of the magnitude of orthographic and repetition priming revealed that they did not significantly differ, $F(1, 33) = 2.61$, $MSE = 654$. In the masked intervener short SOA condition, orthographic priming should be eliminated by the intervener, and yet repetition and orthographic priming did not differ, $F(1, 27) = 1.04$, $MSE = 1092$. Forster (in press) reported a difference between these priming effects in the masked intervener condition, and our failure to find a difference may have been due to insufficient power. We performed a power analysis using the effect size in Experiment 4 of Forster (in press) as an estimate of the difference between the repetition and orthographic priming effects (Cohen's $d = 0.40$), and found that our lexical decision task had moderate power of 0.50 to detect an effect of a similar size to the one reported by Forster. Thus, it is possible that our failure to find a difference between repetition and orthographic priming may be due to relatively low power. In the masked intervener long SOA condition, the repetition priming effect was marginally larger than the orthographic priming effect, $F(1, 23) = 3.68$, $MSE = 473$. The masked intervener conditions were pooled in order to increase the power of our analysis, but the comparison of repetition and orthographic priming was still only marginal, $F(1, 51) = 3.57$, $MSE = 792.36$.

Error rates. A mixed-model ANOVA revealed significant effects of group, $F(2, 83) = 3.85$, $MSE = 44.7$, and prime-type, $F(2, 166) = 3.81$, $MSE = 20.0$. We conducted repeated-measures ANOVAs for each of the groups, as well as planned comparisons to investigate

repetition and orthographic priming effects. The only effect that neared significance was a marginal repetition priming effect in the unmasked intervener condition, as subjects made less errors on repetition-prime trials (6.7%) relative to unrelated-prime trials (8.4%), $F(1, 33) = 3.30$, $MSE = 19.1$.

Nonwords. There was a significant effect of group, $F(2, 83) = 3.57$, $MSE = 730$. The only other significant effect for the nonwords was orthographic priming in the error rate for the unmasked intervener condition, $F(1, 33) = 7.50$, $MSE = 22.21$.

Discussion

Importantly, we replicated the pattern of results reported by Forster (in press). When the intervener was unmasked, we found both repetition and orthographic priming, albeit orthographic priming was only marginal. By Forster's description, the intervener in this case selectively blocks the semantic component of priming, which results in reducing repetition priming to a magnitude similar to orthographic priming, as only the orthographic component of repetition priming remains. When the intervener was masked, and presented with a short prime-target SOA, repetition priming was present but orthographic priming was not significant. Under these masking conditions, the intervener selectively blocks the orthographic component of priming, which results in the reduction of repetition priming and elimination of orthographic priming. However, this claim is weakened by the fact that the magnitude of repetition and orthographic priming did not statistically differ. Of key interest was the condition that addressed the SOA confound present in Forster (submitted), in which we equated the prime-target SOAs of the masked and unmasked intervener conditions by inserting a string of consonants between the masked intervener and the target. This new condition resembled the masked intervener condition, in which repetition priming was present in reduced form but orthographic priming was

eliminated. Not only was orthographic priming not significant, it was also marginally smaller than repetition priming. The results from the masked intervener long SOA condition support Forster's conclusion that the pattern of results in the unmasked intervener condition was likely due to the visibility of the intervener and not an extended period of time separating the prime and target.

We assert that repetition priming was reduced in both intervener conditions, however, we acknowledge that we did not include a condition that would allow the comparison of priming effects with and without an intervener. Forster (submitted) included such a baseline condition, which consisted of presenting the intervening word before the prime so that the prime and target were adjacent. We chose not to include an adjacent priming condition because of our concern with prime visibility. If adjacent primes were included in the unmasked intervener condition, the masked prime would separate the visible intervener and target, which creates a noticeably different visual experience relative to when the target immediately follows the intervener. The noticeable difference created by an adjacent prime in the unmasked intervener condition may have directed attention to the prime more than in the condition where the prime and intervener are both masked.

Some evidence for a reduction in the magnitude of repetition priming in the present study comes from a comparison of our results with the findings of Forster (submitted). Comparisons across experiments are not always warranted, and may not serve as the basis for firm conclusions, but the stimuli used in Experiment 1 were similar in length, frequency, and neighbourhood size to the stimuli used by Forster. When the prime immediately preceded the target, Forster reported repetition priming effects of 49ms and 53ms when the prime was preceded by the unmasked and masked intervener, respectively. In addition, repetition priming

effects in the masked priming literature are typically in the 40ms range (Forster & Davis, 1984; Forster, Mohan, & Hector, 2003; Forster et al., 1987). The repetition priming effects we reported, 22ms and 15ms in the unmasked and masked intervener short SOA, respectively, are clearly reduced relative to the effects reported by Forster (submitted) and in the literature. Experiment 2 included an adjacent priming condition, which will allow further conclusions about the extent of reduction of repetition priming when an intervener is present.

Experiment 2

The purpose of Experiment 2 was to address the claim that a semantic component of priming is being influenced by the unrelated word inserted between the prime and target. In order to examine this issue, we used a design similar to Experiment 1 but added a condition that included primes semantically related to the target. According to Forster's (in press) account, if the intervener affects how the semantic information activated by the repetition prime influences the subsequent target, the intervener should similarly affect the influence of the semantically-related prime. The pattern of results should be the following. In the unmasked intervener condition, the intervener blocks the semantic component priming, which should lead to reduced repetition priming, intact orthographic priming, and absent semantic priming. In the masked intervener condition, the intervener blocks the orthographic component of priming, resulting in an elimination of orthographic priming, reduced repetition priming, and semantic priming should be present.

As mentioned in the introduction, research into the effect of an intervening unrelated word has typically involved semantically-related priming conditions. Initial investigations found that semantic priming did survive an interpolated unrelated word, however, these were under conditions that potentially allowed a strategy of semantic-matching (Davelaar & Coltheart, 1975;

Meyer et al., 1972). When conditions were established that discouraged the use of a post-access strategy, even one intervening item was enough to eliminate the influence of a semantically-related prime (Deacon et al., 2004; Gough et al., 1981; Masson, 1991; Ratcliff & McKoon, 1988; but see Joordens & Besner, 1992). These experiments involved a clearly visible prime, and it is not certain what effect an intervening unrelated word would have on the influence of a masked prime.

Experiment 2 was similar in design to Experiment 1. An adjacent priming condition was included, in which there was no intervener or delay separating the prime and target. This condition was included to determine whether our stimuli were able to produce semantic priming. The only other intervener condition was the masked intervener long SOA condition, as semantic priming should be evident in this condition, which would serve as a further test of whether our stimuli produced semantic priming. The masked intervener should selectively block the orthographic component, so we should not find orthographic priming in the masked intervener long SOA condition. The no-intervener condition should yield repetition and orthographic priming, and repetition priming should be the larger of these two effects, as is typical in the masked priming literature.

Method

Subjects. Forty-four subjects participated in Experiment 2 for course credit. Subjects were randomly assigned to one of two groups: Twenty-two subjects were tested without an intervener, and 20 with a masked intervener- long SOA.

Materials. Stimuli were constructed in the same way as in Experiment 1. However, a new set of materials was created to allow for maximally-related pairs needed for the semantically-related priming condition. A set of 120 seven- and eight-letter words was selected

for use as targets. The mean frequency of these words was 12.7 per million (Kucera & Francis, 1967) and the mean neighbourhood size was 0.28 (Balota et al., 2007). Each target was paired with the same prime types as in Experiment 1 in addition to semantically-related primes. Our determinant of semantic relatedness was the Latent Semantic Analysis (LSA) model, a representative example of models of high-dimensional semantic space (Landauer & Dumais, 1997). This model provides a measure of relatedness by quantifying the degree to which words occur in similar contexts. Semantically-related primes were selected using the LSA website (<http://lsa.colorado.edu/>) and the suggested topic space of 300 factors, which represents a general reading level up to 1st year of college. The “Pairwise Comparison” application computes a similarity value between -1 and 1 for pairs of words depending on the strength of their relatedness, e.g., a related pair like *shampoo-haircut* receives a high value of 0.57, and the relatively unrelated pair *graduate-assassin* is assigned a value closer to 0 of 0.07. Pairs in our semantically-related condition had a mean similarity value of 0.36, with a range of 0.16 and 0.90. Pairs in the unrelated condition had a mean similarity value of 0.03 and a range of -0.10 and 0.21. Nonword targets could not have semantically-related primes, so they were merely paired with twice as many repetition-primes.

Procedure. The procedure was identical to Experiment 1 with the addition of a condition in which no intervener was present. In no-intervener condition, the presentation duration of the intervener and of the masking stimulus between the intervener and the target was set to 0, so that the target immediately followed the masked prime. Accordingly, these subjects were informed that they would first see a row of ampersands, followed by the uppercase target. The masked-long SOA condition was run identically to Experiment 1.

Results

Correct response times and error rates were averaged by condition for each group, and the means are presented in Figure 4. Trials with response times below 300 ms and above 1650ms were excluded from the analysis (less than 0.5%, Ulrich & Miller, 1994).

Response times. A mixed-model ANOVA with group (no-intervener, masked intervener-long SOA) as the between-subject factor and prime-type (unrelated, repetition, related, orthographic) as the within-subject factor was performed. There was a significant effect of group, $F(3, 120) = 14.24$, $MSE = 640$, and a marginal interaction, $F(3, 120) = 2.30$, $MSE = 640$. This interaction was a result of the much larger repetition and orthographic priming effects in the condition with no intervener.

Separate repeated-measures ANOVAs were conducted for each intervener condition to determine the presence of each of the three forms of priming: Repetition, semantic, and orthographic. For the no-intervener group, there was a significant effect of prime-type, $F(3, 57) = 11.78$, $MSE = 725$. Planned comparisons revealed subjects were significantly faster when targets were preceded by a repetition prime (586ms) relative to targets preceded by an unrelated prime (630ms), $F(1, 19) = 22.61$, $MSE = 872$. Response times were numerically lower on semantically-related prime trials (619ms) relative to unrelated prime trials (630ms), but this difference was not significant, $F(1, 19) = 1.27$, $MSE = 1047$. Finally, subjects were significantly faster on orthographic-prime trials (594ms) relative to unrelated-prime trials (630ms), $F(1, 19) = 18.87$, $MSE = 679$. In the masked intervener long SOA intervener condition, there was a significant effect of prime-type, $F(3, 63) = 3.05$, $MSE = 563$. Repetition priming was significant, with faster responses on repetition prime trials (608ms) relative to unrelated prime trials (627ms), $F(1, 21) = 7.34$, $MSE = 575$. The semantic priming effect, however, was not

significant, with statistically equivalent response times for semantically-related and unrelated prime trials (622ms vs. 627ms), $F < 1$. Unexpectedly, the orthographic priming effect was marginally significant, with faster responses to orthographic prime trials (613ms) relative to unrelated prime trials (627ms), $F(1, 21) = 3.29$, $MSE = 729$.

We also conducted comparisons between the magnitude of the priming effects. In the no-intervener condition, both the repetition and orthographic priming effects were significantly larger than the semantic priming effect $F(1, 19) = 16.76$, $MSE = 644$, and $F(1, 19) = 10.78$, $MSE = 546$, respectively. The repetition and orthographic priming effects did not differ, $F(1, 19) = 1.31$, $MSE = 565$. In the masked intervener long SOA condition, repetition priming did not differ significantly from orthographic priming, $F < 1$, but repetition priming was marginally larger than semantic priming, $F(1, 21) = 4.35$, $MSE = 509$. Orthographic and semantic priming did not differ significantly, $F(1, 21) = 1.35$, $MSE = 487$.

Error rates. The mixed-model ANOVA revealed a marginally significant interaction of group and prime-type, $F(3, 120) = 2.14$, $MSE = 11.1$. The only other significant effects in the errors were in the no-intervener condition. There was a significant effect of prime-type, $F(3, 57) = 3.99$, $MSE = 9.44$. Planned comparisons revealed significantly less errors to repetition-prime trials relative to unrelated-prime trials (2.3% vs. 5.2%), $F(1, 19) = 9.72$, $MSE = 8.33$. There was also significantly less errors to orthographic-prime trials relative to unrelated-prime trials (2.9% vs. 5.2%), $F(1, 19) = 7.29$, $MSE = 11.14$.

Nonwords. None of the effects with the nonwords were significant.

Discussion

An important result of Experiment 2 is that when no intervener separates the prime and target, stimuli with characteristics similar to those used in Experiment 1 produce substantial

repetition and orthographic priming, with repetition priming the larger of the two effects. It was an important conclusion in Experiment 1 that repetition priming was reduced by the presence of the intervener, yet we did not have a proper baseline repetition priming condition in that experiment. We are now in a position to state that, relative to the repetition priming effect in the no-intervener condition (44 ms), repetition priming effects in Experiment 1, which ranged from 14 ms to 22 ms, was clearly reduced by the insertion of an unrelated word.

The purpose of Experiment 2 was to examine the effect of an intervening stimulus on the semantic component of priming. However, our stimuli did not produce significant semantic priming, even when no intervener was present. It is surprising that our related primes did not lead to significant priming considering that LSA, which was used to select primes related to the targets, has effectively accounted for various results in the word recognition literature (Chwilla & Kolk, 2002; Hutchison et al., in press; Landauer & Dumais, 1997). There is one aspect of our stimuli that may have contributed to our lack of semantic priming: We used relatively longer words to ensure that we would obtain orthographic priming. However, Hutchison et al. (in press), in their investigation of what stimulus qualities predict semantic priming, found that there was an inverse correlation between the length of the prime and the magnitude of the semantic priming effect—longer primes led to smaller semantic priming. Longer primes are more difficult to identify than shorter primes, which may result in less processing applied to the prime before the target is presented. Our lab is currently investigating the intervener's effect on masked semantic priming with primes relatively short in length. It is also likely that our experiment did not have sufficient power to detect a semantic priming effect, and an increase in the number of subjects may be appropriate. This possibility is suggested by the fact that our semantic priming

effect of 12 ms is in fact comparable to the magnitude of semantic priming commonly reported in the literature.

The masked intervener long-SOA condition, with the addition of the semantic priming condition, only partially replicated the pattern of results in the masked intervener condition in Experiment 1. The magnitude of repetition priming was comparable between experiments, but orthographic priming in Experiment 2 unexpectedly neared significance. The masked intervener should block the influence of an orthographically-similar prime. Orthographic priming was severely reduced by a masked intervener in the experiments reported by Forster (submitted), as well as in the first experiment of the present study, so it is surprising that we obtained marginal orthographic priming. It is true that the stimuli used in Experiment 2 were different from Experiment 1, but the word-lengths, frequencies, and neighbourhood sizes were very similar, so it is not clear what aspect of the new stimuli may have encouraged orthographic priming. Perhaps the way in which the orthographic primes were constructed in Experiment 2 slightly differed relative to Experiment 1. For example, consider the prime-target pair *explomer-EXPLORER*. Not only does the target and its orthographically-similar prime differ by one letter, but the consonant that is replaced in the prime also subtly changes the pronunciation of the “o.” It is possible that not as many of these subtle pronunciation differences in the orthographic priming condition occurred in Experiment 2, leading to greater phonological overlap and subsequently greater priming.

Another possible explanation for orthographic priming in the masked intervener long SOA condition of Experiment 2 is that the degree of orthographic priming was in some degree influenced by the inclusion of semantically-related primes. Masking the primes should have prevented any awareness of the relatedness of primes and targets. However, one way by which

context may have influenced the degree of priming is that by inclusion of the semantically-related condition, the proportion of semantically-related and repetition prime trials was increased from 33% in Experiment 1 to 50% in Experiment 2. There is research suggesting that, even when primes are masked, increasing the proportion of repetition and semantically-related prime trials leads to an increase in the magnitude of priming effects (Bodner & Masson, 2001; Bodner & Masson, 2003; Kinoshita, Forster, & Mozer, 2008; Masson & Bodner, 2003). These studies investigated repetition and semantic priming, but it is possible that a higher proportion of related prime trials would also lead to an increase in orthographic priming. The slightly larger repetition priming in Experiment 2 relative to Experiment 1 is consistent with the possibility that priming was influenced by the higher proportion of related trials. The occurrence of orthographic priming in the masked intervener condition in our experiments is revisited in the general discussion.

General Discussion

A number of conclusions can be made concerning the effect of an intervening unrelated word. First, we replicated Forster (in press) and confirmed that the pattern of results was not due to different prime-target SOA's in the unmasked and masked intervener conditions. In Experiment 1, in addition to the unmasked and masked conditions, we included a masked condition in which the duration between the onset of the prime and the onset of the target was identical to the unmasked condition by inserting a mask between the masked intervener and the target (i.e., the masked intervener long SOA condition). With this backward-mask in place, we found that the results resembled the mask intervener short SOA condition, suggesting that the pattern of results does not appear to be influenced by increasing the lag between the prime and target but due to the masked status of the intervener. In both masked intervener conditions,

repetition priming was present but orthographic priming was eliminated, consistent with Forster's claim that the masked intervener selectively blocks the orthographic component of priming. In the unmasked intervener condition, repetition priming was again reduced and orthographic priming was roughly equivalent to the repetition priming effect, consistent with the claim that an unmasked intervener overwrites any semantic information activated by the prime, but leaves the orthographic component of priming intact. Our replication was weakened by the fact that repetition and orthographic priming did not differ, or differed only marginally, in the masked intervener conditions, whereas Forster reported larger repetition priming relative to orthographic priming. It is likely that our experiment did not have sufficient power to detect this difference.

Experiment 2 attempted to determine the intervener's influence on semantic priming with the inclusion of primes that were semantically-related to the target. However, our materials did not yield significant semantic priming even in a condition that did not present an intervener, thus we could not draw any conclusions about the intervener's effect on the semantic component of priming. The failure to obtain semantic priming may have been due to the length of our words, and we plan to collect data using materials of shorter length.

One method that may be well-suited to investigate the nature of the intervener effect involves event-related potentials (ERP). The use of ERPs is an excellent method for identifying underlying processing, as it provides a continuous measure of the brain activation that is evoked by stimulus presentation. In addition, ERPs are well-suited to examine Forster's proposed explanation of the intervener effect because electrophysiological research has identified two ERP components that appear to be signatures of semantic and orthographic processing: The N400 and N250. The N400 is sensitive to the degree of semantic mismatch between a target and its context

(Kutas & Hillyard, 1980; Besson, Kutas, & Van Petten, 1992). For example, when a prime and target are related (e.g., doctor-NURSE), the waveform is slightly more negative-going relative to when the prime and target are not related approximately 400ms after onset of the target, even when the prime is masked (Grossi, 2006). The N400 effect also occurs for masked repetition primes (Misra & Holcomb, 2003; Holcomb & Grainger, 2006; Kiyonaga, Grainger, Midgley, & Holcomb, 2007; Schnyer, Allen, & Forster, 1997). The lesser-known N250 appears to be sensitive to the degree of orthographic overlap between a prime and target, even when the prime is masked (Grainger, Kiyonaga, & Holcomb, 2006; Holcomb & Grainger, 2006). There is a smaller negative deflection approximately 250ms after onset of the target when the prime and target are orthographically-similar (e.g., teble-TABLE) relative to when the prime and target do not share letters. The size of the N250 is even more reduced when the prime is a repetition of the target, presumably due to greater orthographic overlap.

Forster's (in press) account of the intervener effect would predict that the masked status of the intervener would dissociate the N250 and N400 components in the following way. With an unmasked intervener, where the semantic component of priming is blocked, the N400 on trials featuring repetition trials should be identical to trials with unrelated trials. The orthographic priming component should be intact in the unmasked intervener condition, thus repetition prime trials should lead to a smaller N250 than unrelated prime trials. With a masked intervener, the orthographic component of priming should be blocked, resulting in equivalent N250 components for repetition and unrelated prime trials. However, the masked intervener does not affect the semantic component of priming so that repetition prime trials should have a smaller N400 than unrelated prime trials. An advantage of using ERPs is that it is not necessary to include

orthographic or semantic priming conditions in order to infer what components of repetition priming may be blocked. Repetition prime trials may be studied more or less directly.

One direction mentioned by Forster (in press), and inadvertently addressed in Experiment 2, is the effect of replacing the word interveners with a non-lexical item, e.g., *wltrpdms*. If the same results were obtained when the intervener is a non-lexical item, it would argue against Forster's lexical explanation. For example, semantic priming is blocked with an unmasked intervener because it overwrites semantic information activated by the masked prime. However, if the intervener was not a real word it should not produce any semantic activation and thus not overwrite any current semantic activation. Experiment 2 included such a condition with the masked intervener-long SOA, in which the masked prime and intervener were followed by a backward mask, which consisted of a string of random consonants, presented for 455ms. If the effect of the intervener did not depend on it being a word, the visible consonant-string should have had the same effect as the visible intervener and selectively blocked the semantic component of repetition priming. However, orthographic priming was eliminated in the masked intervener-long SOA condition, but repetition priming was still only reduced, the semantic component of repetition presumably intact. This result is consistent with a previous study reporting that an intervener reduced semantic priming only if the intervener was a word, and not a neutral stimulus, such as a row of X's (Masson, 1995). A further test of the importance of the lexical status of the intervener would be to replace word-interveners with legal nonwords, as these are word-like in orthography and pronunciation, but should not have lexical representations.

A general concern with the masked priming paradigm is how confident we can be that subjects are indeed unable to identify the masked primes, with some researchers claiming that

there is in fact no evidence for unconscious perception of masked primes (Holender & Duscherer, 2004). Typically, masked priming experiments are accompanied by either an objective test of subjects' awareness of the primes, which requires subjects to respond to the primes themselves, or a subjective test of awareness, which entails asking subjects if they are aware of the prime stimuli (Cheesman & Merikle, 1984, 1986). Unconscious perception is demonstrated when there is an effect of the masked primes during the experimental task despite subjects showing no awareness of the primes on an objective or subjective test of awareness. Prime-awareness may be relevant to the present investigations of the intervener effect, because orthographic priming is found with masked primes, but unmasked primes lead to a reduction of orthographic priming and in some cases may cause *interference*, i.e., slower responses on trials with orthographically-similar primes relative to trials with primes unrelated to the target (Colombo, 1986; Evett & Humphreys, 1981; Humphreys, Evett, Quinlan, & Besner, 1987; Segui & Grainger, 1990). Primes are generally well-masked with a visible intervener, and consequently they produce facilitation from orthographically-similar primes in the present studies and in Forster (in press). However, our impression is that primes appear less-successfully masked when followed by a masked intervener.

That masked stimuli may be more visible in the masked intervener condition than in the unmasked intervener condition is relevant because, when the intervener is masked, Forster reports orthographic priming effects of -2ms and 3ms, and we report slightly larger orthographic priming effects of 6ms, 2ms, and 15ms. It is possible that the elimination of orthographic priming in Forster's masked intervener condition may be the result of relatively visible primes, which would be consistent with previous research involving unmasked orthographically-similar primes (Colombo, 1986; Humphreys et al., 1987; Segui & Grainger, 1990). We used a

presentation duration for masked stimuli in our experiments lower than that used by Forster (45ms vs. 60ms). As a result, it is possible that the masked primes in our masked intervener conditions were relatively more successfully masked than in Forster (in press), which may explain the slightly larger orthographic priming in our studies. According to our prime-awareness questions following the experiment, subjects appeared to be mostly unaware of the primes, with no more than 4 subjects in each group having some awareness of the primes on some percentage of trials. Forster does not report any prime-awareness data, so it is not certain whether masked stimuli were more visible in his design than in our own.

The account provided by Forster (in press) suggests that the influence of a repetition prime depends on two dimensions on which the prime is similar to the target: Orthography and semantics. This division may be problematic because it ignores the many other ways in which a repetition prime may be similar to the target. For example, the repetition prime also shares phonological information with the target, i.e., overlap in how the words are pronounced. Forster may not have considered a phonological component of repetition priming because it is commonly believed that phonological information does not play a role in visual word recognition (Rastle & Brysbaert, 2006). However, after controlling for orthographic similarity, many studies have reported priming from phonologically-similar primes under masked conditions in a lexical decision task, leading some researchers to emphasize the role of phonology in visual word recognition (Ferrand & Grainger, 1992; Perfetti, Bell, & Delaney, 1988; Perfetti & Bell, 1991; Rastle & Brysbaert, 2006). Thus, repetition priming may consist of semantic, orthographic, and phonological components. The role of phonology in the intervener effect may be identified by introducing phonologically-related primes and observing in what way they are affected by an intervening unrelated word.

There may be limitations as to the effectiveness of the intervener paradigm at identifying component parts of the repetition priming effect. First, consider the unmasked intervener condition, in which repetition priming and orthographic priming are equivalent, supposedly because the semantic component of repetition priming is blocked. However, it may not be safe to assume that repetition and orthographic priming in this condition are both the result of the same underlying priming component merely because they are similar in magnitude. Second, it may not be safe to assume that the influence of a masked orthographic prime is strictly one of shared orthography. Research on the N250 ERP component mentioned above has been shown to be sensitive to the overlap in orthography of the prime and target (Grainger, Kiyonaga, & Holcomb, 2006; Holcomb & Grainger, 2006). It was also found, however, that orthographically-similar primes modulated the N400 component, suggesting that semantic information of the target is being activated by the prime. Thus, an orthographic condition may not be a strict measure of priming due to orthographic similarity but contain a semantic component. Consequently, it is curious that in the intervener conditions where orthographic priming is blocked but semantic priming intact Forster (in press) did not find small priming in the orthographic condition due to the potential semantic component of orthographic priming. This semantic effect may simply be small, and perhaps is evident in the small nonsignificant orthographic priming effects we reported in the two masked conditions of Experiment 1.

In summary, the intervener effect appears to be a replicable phenomenon that has implications for many existing accounts of word recognition. The pattern of results revealed with unmasked and masked interveners are not predicted by most of these accounts. The explanation provided by Forster (in press), that an unmasked intervener blocks semantic priming but leaves orthographic priming intact and a masked intervener blocks orthographic priming but

leaves semantic priming intact, is plausible but is yet to be convincingly supported and may leave out other potential components of priming, e.g., phonological priming. However, there appear to be several methods with which to examine Forster's explanation, such as the inclusion of a semantic priming condition and the use of ERPs to identify the presence or absence of different priming components. Determining the exact nature of the intervener effect will aid in strengthening current word recognition models.

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Figure Captions

Figure 1. This figure illustrates the components of priming that Forster (in press) claims underlies each priming effect under the different intervener conditions.

Figure 2. Illustration of the intervener conditions presented in Experiments 1 and 2.

Figure 3. Mean response times and error rates for Experiment 1. The right panel presents the amount of repetition and orthographic priming present within each intervener condition, calculated by subtracting the repetition or orthographic condition from the unrelated condition. Error bars represent 95% within-subject confidence intervals (Loftus & Masson, 1994; Masson & Loftus, 2003). Open circles represent the priming values obtained by Forster (in press) for the corresponding intervener conditions, which are included here for comparison with the obtained results. For priming effects, bars marked with a “*” signify that the priming value differs from zero with a p -value less than .05, and a p -value less than .10 if marked with a “^”.

Figure 4. Mean response times and error rates for Experiment 2. The right panel presents the amount of repetition and orthographic priming present within each intervener condition. Error bars represent 95% within-subject confidence intervals (Loftus & Masson, 1994; Masson & Loftus, 2003). Open circles represent the priming values obtained by Forster (in press) for the corresponding conditions, which are included here for comparison with the obtained results. For priming effects, bars marked with a “*” signify that the priming value differs from zero with a p -value less than .05, and a p -value less than .10 if marked with a “^”.

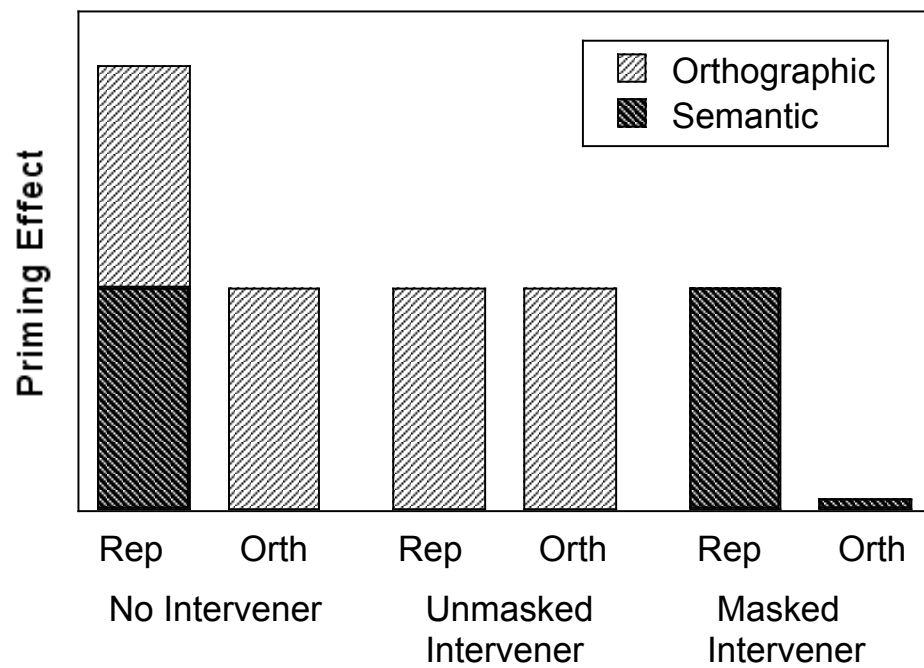
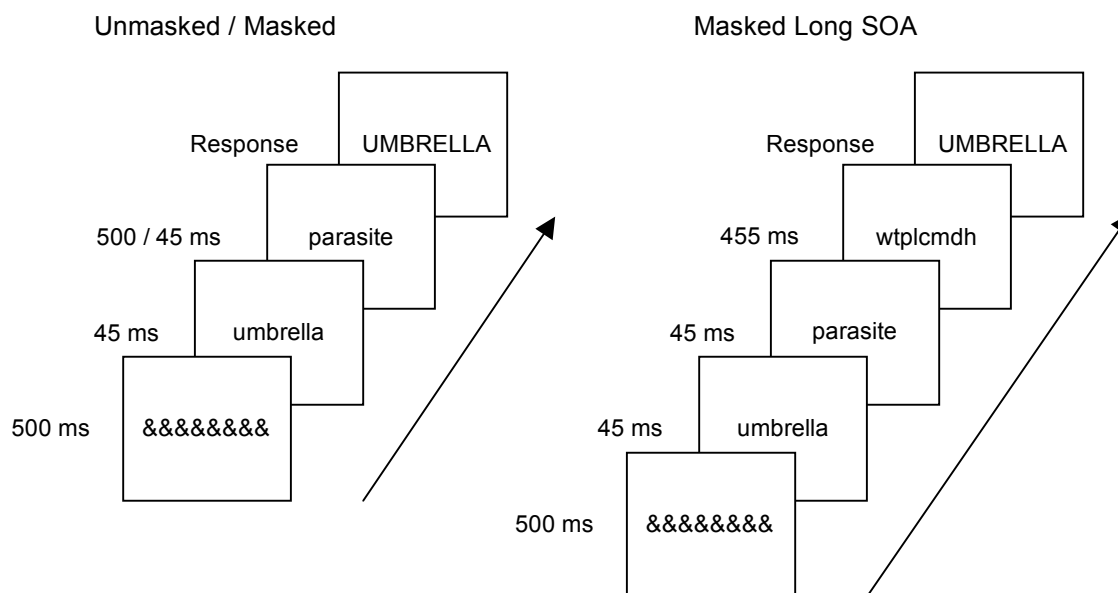


Figure 1

Experiment 1



Experiment 2

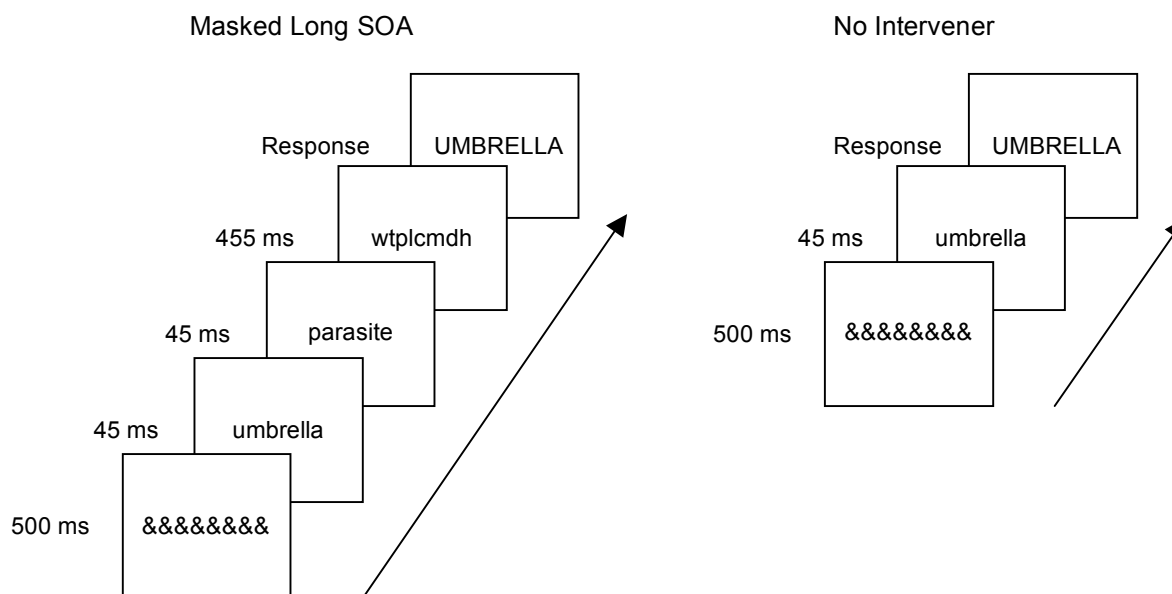


Figure 2

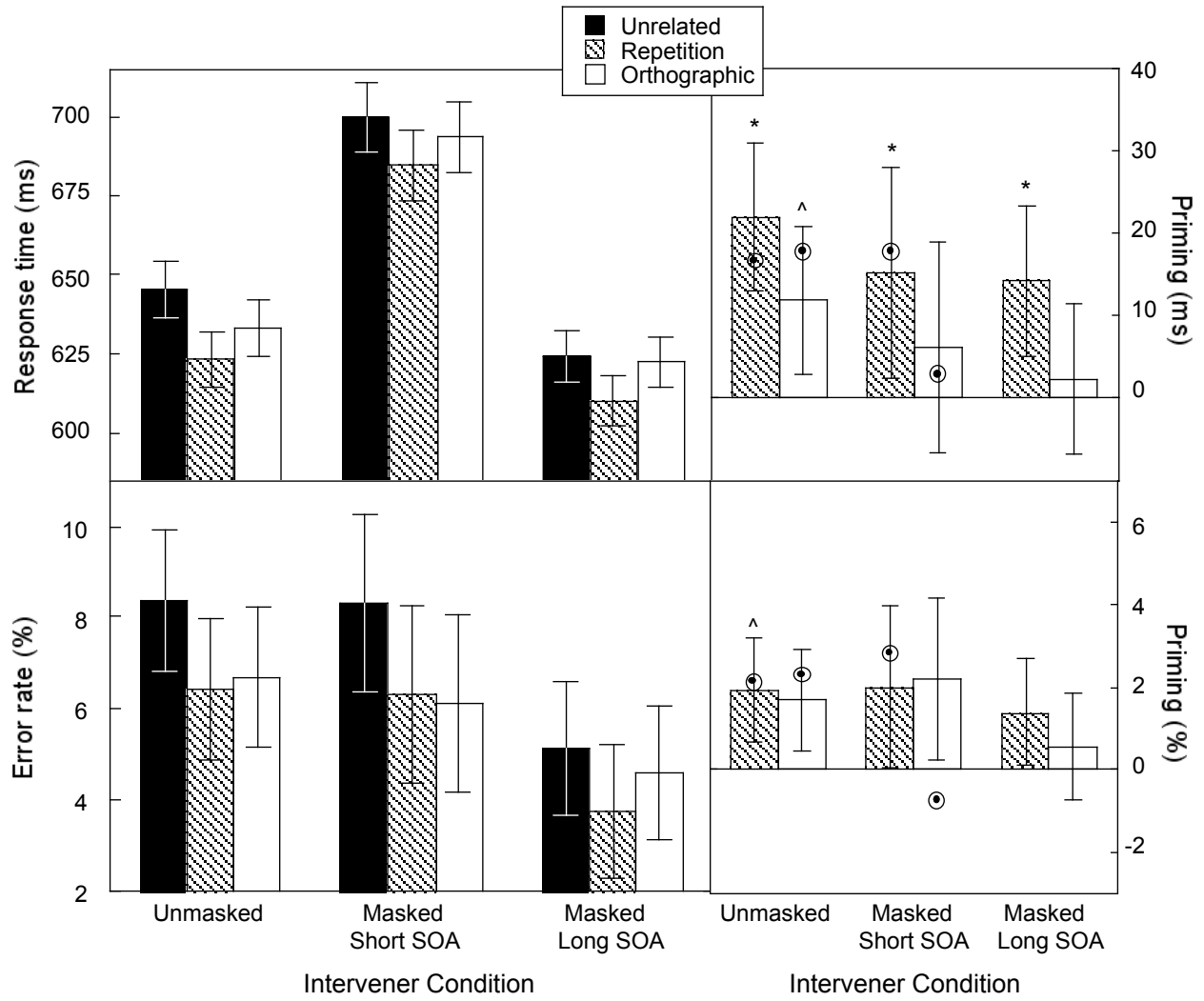


Figure 3

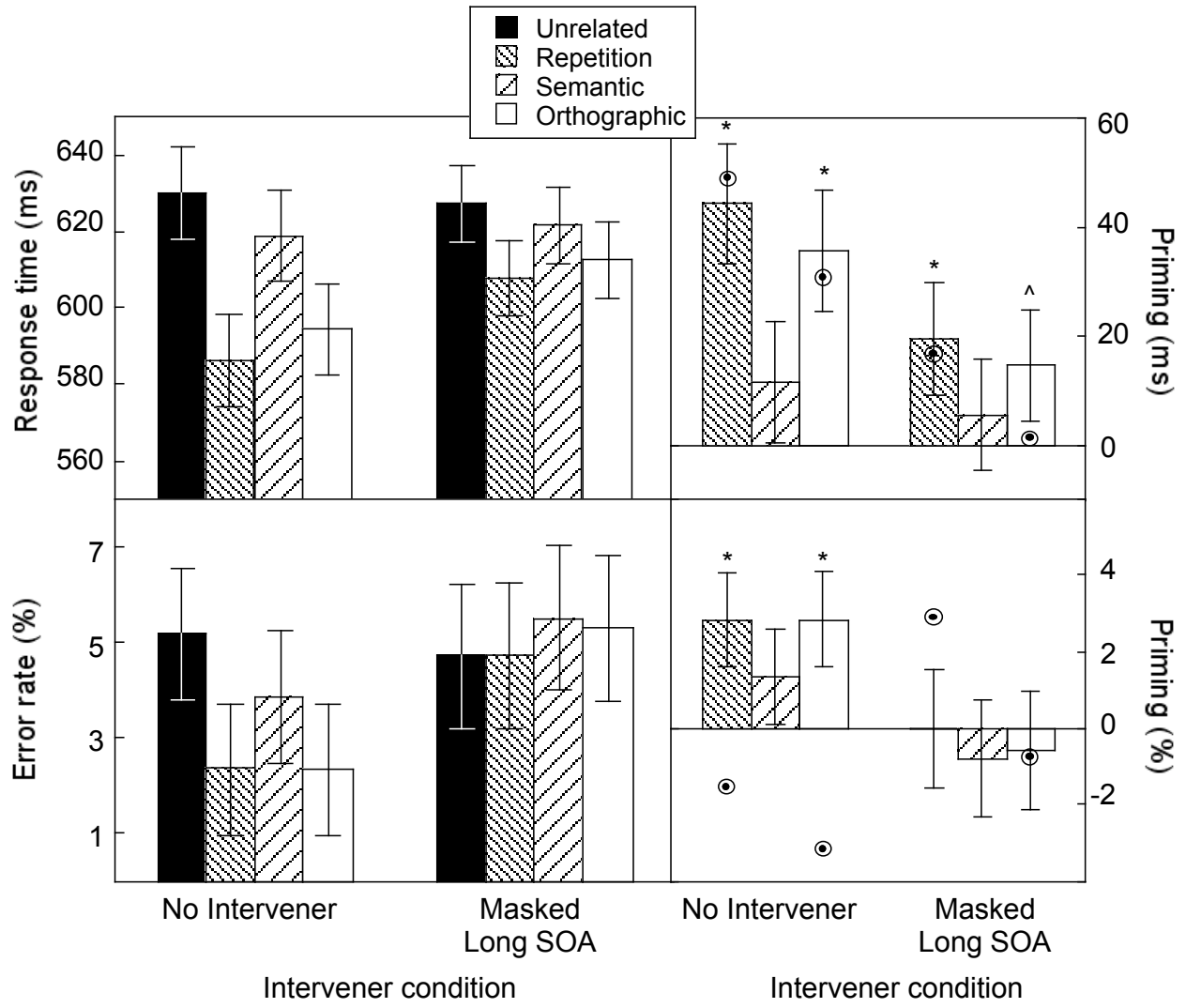


Figure 4