DO ORTHOGRAPHY AND PHONOLOGY INTERACT IN MASKED PRIMING?

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Using a new technique to vary phonological overlap while keeping orthographic overlap constant, this study investigates phonological priming at different prime durations (40ms, 60ms and 70ms). In the first and second experiments, significant priming was obtained in both phonological similar (O+P+) and phonological dissimilar (O+P-) conditions, and there was no interaction between priming and phonological overlap, nor was there any appreciable effect of prime duration. However in the third experiment, priming was obtained only for the O+P+ condition; there was no priming in the O+P- condition. Once again, there was no effect of prime duration. The results suggest that orthography and phonology do interact in masked priming, but not in all circumstances.

INTRODUCTION

Masked phonological priming has been regarded as an important phenomenon that any model or theory about visual word recognition has to address. The issue is whether the recognition of a target word (e.g., *MADE*) is facilitated by the prior presentation of a homophonic word (*maid*), or nonword (*mayd*). In order to prevent conscious anticipation of the target, the prior stimulus (the prime) is presented very briefly immediately following a masking stimulus, so that participants are not aware of the prime. Whether such a form of priming exists is the focus of the debate between "weak phonological" theorists and the "strong phonological" theorists. The "strong phonological" theorists (e.g. Frost, 1998; Lukatela & Turvey, 1994; Xu & Perfetti, 1999) argue that the existence of masked phonological priming indicates that there is an early, rapid and automatic phonological assembly. The processing of phonological information plays a leading and perhaps even obligatory role in visual word recognition. Their claim is that the core representations of the mental lexicon are phonological by definition, and priming requires the orthographic stimulus be mapped onto a phonological representation (e.g., Frost, 1998; Frost, Ahissar, Gotesman, & Tayeb, 2003; Van Orden, Pennington & Stone, 1990; Lukatela, Frost & Turvey, 1998). In contrast, the "weak" position holds that phonological activation generated by the orthographic stimulus merely "assists" in activating the lexical representation. Word recognition proceeds through both a direct orthographic route (from orthographic code to semantic code) and an indirect phonologically mediated route. There is some phonological influence on visual word recognition, but this route is secondary and nonessential (Seidenberg 1992; Perfetti, Zhang & Berent, 1992).

There are many demonstrations of phonological priming under masked conditions (Lukatela & Turvey, 1994; Humphreys, Evett & Taylor, 1982), but there are a number of methodological issues that limit the persuasiveness of the existing findings. First, in some experiments, strong phonological effects are obtained when the task is to read aloud the target word, but not in a lexical decision task, where the task is to decide whether it is a word or not (Kim & Davis, 2003; Shen & Forster, 1999). Rastle and Brysbaert (2006) argue that the reading aloud task is not the best task to use since phonological processing of the target is required, and hence the involvement of phonology is not surprising. Instead, they recommend the use of a lexical decision task.

Another major methodological issue concerns the question of whether the priming is really due to phonological overlap rather than orthographic overlap. For example, in the item *maid-MADE,* the homophonic prime shares the first two letters with the target, and the third is also shared, but not in the same position. This orthographic overlap may be sufficient to produce a reliable priming effect. To test whether there is a phonological contribution, an orthographic control prime is used (e.g. *malt-MADE*), which is assumed to have the same degree of orthographic overlap with the target as the homophonic prime. If the phonological prime facilitates processing of the target more than the orthographic control prime, then the additional priming must be due to phonological overlap alone.

The major problem with this technique, however, is how to ensure that the orthographic and phonological primes have the same degree of orthographic overlap with the target. Typically, early experiments controlled the number of shared letters in common positions across phonological primes and targets (Humphreys et al., 1982; Perfetti, Bell & Delaney, 1988; Lukatela & Turvey, 1994). Therefore, *maid* shares the first two letters with *MADE*, and so does *malt* although *malt* does not contain *d*. Recent research on transposition priming has shown that strong priming can be obtained with primes in which two letters have been transposed, e.g., *jugde-JUDGE* (Perea & Lupker, 2003), so it is possible that *maid* is more similar to *MADE* than *malt* is. Other examples raise similar questions. Humphreys et al (1982) used the item *towed-TOAD,* which involves an overlap of three letters, whereas the orthographic control *today* shares four letters; similarly, the phonological prime *brake* used by Lukatela and Turvey (1994) shares all five letters with the target *BREAK* while the orthographic control *freak* shares only four.

Rastle and Brysbaert (2006) noted this problem and proposed a scheme in which the orthographic control prime and the phonological prime shared onset, nucleus and coda with the target, but this still permits counterintuitive results. For example, in the item *wraze-RAISE,* they argue that the prime onset *wr-* does not match the target onset *r-*, nor does the nucleus (*a_e* vs. *ai_e*), nor the coda (-*z* vs. -*s*). Thus, we can reach the conclusion that there is zero orthographic overlap between the phonological prime and the target: therefore, the orthographic control can be anything we like [*berne* is their pick, but presumably it could have been *xxxxx*].

Rastle and Brysbaert are to be commended for adopting a systematic approach to the problem, but the fact is that there is no detailed, empirically supported theory of orthographic similarity; hence, it is difficult to decide whether orthographic overlap has been adequately controlled. One way to avoid this problem is to use a language in which orthography and phonology are not correlated. It is worth noting that two studies using this approach (Shen & Forster, 1999, in Chinese; Kim & Davis, 2003, in Korean) failed to find phonological priming in a lexical decision task but did obtain phonological priming in a pronunciation task. Of course, the reason for this might be that the phonological value of the prime cannot be derived from the orthography alone as it can in languages with an alphabetic script.

Another possible solution is to eliminate any need for an orthographic control. This can be done by reducing the orthographic difference between prime and target to an absolute minimum (i.e., a single letter). For example, a phonologically similar (O+P+) item might be *headline-DEADLINE*, while a phonologically dissimilar (O+P-) item would be *laughter-DAUGHTER.* The baseline in each case is an all-letter-different word. The assumption is that if there is any additional priming observed in the O+P+ condition compared with the O+P- condition, it must be due to phonological overlap alone. The only alternative would be to argue that the *h* in *headline* is more similar to the *D* in *DEADLINE* than the *l* in *laughter* is to the *D* in *DAUGHTER*. Over many items, any systematic effect seems unlikely. Moreover, the only relevant similarity would be a visual similarity, and it is known that masked priming is not any greater when the prime and target contain visually similar letters (e.g., *cC*, *sS*) compared with dissimilar letters (e.g., *gG, aA*) (Bowers, Vigliocco, & Haan, 1998).

This procedure allows us to address several issues. First, it is well known that primes that differ from the target by just one letter produce strong form priming, provided that the number of neighbors (words that differ from the target by one letter) is kept to a minimum (Forster, Davis, Schoknecht, & Carter, 1987; Ferrand & Grainger, 1992). This is usually interpreted as an orthographic effect, but the possible role of phonology has not been systematically examined. Second, previous experiments on phonological priming have all used primes and targets that are homophonic. Using items such as *headline-DEADLINE* tests whether a phonological effect can be obtained when the prime is not homophonic with the target but is a phonological neighbor of the target. Third, studies that have examined the role of phonology have typically used nonword primes (Ferrand & Grainger, 1992, 1993; Lukatela, et. al., 1998), whereas in the present study, the primes are words. This has implications for models of lexical access that stress the importance of competitive processes between words. The assumption of models based on the interactive activation model (McClelland & Rumelhart, 1981) is that a prime such as *headline* activates the word unit for the target *deadline* as well as its own word unit. Thus, when the target *DEADLINE* is presented, its major competitor is in a highly active state, which inhibits the growth of activation in the target's word unit. As a result, one would not expect any priming effect when the prime is a word. Support for this assumption has been provided by Davis and Lupker (2006), who reported that word primes tended to produce inhibitory effects, especially if the prime was higher in frequency than the target. Forster and Veres (1998) also found no form priming in a lexical decision task when the prime was a word and the word-nonword discrimination was difficult.

Besides the manipulation of phonological similarity, another consideration in this study involves prime duration. Previous research found that phonological facilitation tended to occur at longer prime durations than was the case for the orthographic facilitation. Ferrand & Grainger (1993) suggested that orthographic facilitation was found with prime durations from 17 ms to 50 ms, whereas phonological facilitation only started to emerge at exposure of 50 ms. They also pointed out that at very short prime exposures (e.g. 29 to 32 ms), only orthographic similar primes would facilitate subsequent target recognition, whereas at longer prime exposure (e.g. 43 to 64 ms), only homophonic primes would benefit target recognition, regardless of their orthographic similarity to the target (Ferrand & Grainger, 1994). Similar results have been reported by Grainger, Spinelli, Diependaele, Ferrand, & Farioli (2003), where phonological effects were obtained with a 67 ms prime. Given this time-course hypothesis one would predict that P- and P+ items would show almost the same amount of priming at 40ms, but a stronger priming effect in the P+ condition and no priming effect in the P- condition at 60ms.

EXPERIMENT 1

The first experiment served as a preliminary investigation of phonological priming using phonologically similar words compared with phonologically dissimilar words. Two prime durations of 40ms and 60ms were included to test the time course hypothesis (Ferrand & Grainger, 1992, 1993, 1994). In addition, all items are 6-8 letters in length, on the assumption that longer words produce more reliable form priming effects than shorter words (Forster et. al., 1987; Van Heuven, et. al., 2001).

Method

Participants. A total of 27 undergraduate students enrolled in an introductory psychology course at the University of Arizona participated in the experiment, for which they received course credit.

Materials and design. A total of 48 pairs of words that differed by a single letter were selected such that half had similar pronunciations (e.g., *headline-deadline*, *protect-project*), and half had very different pronunciations (e.g., *laughter-daughter, hideous-hideout*). All items were six to eight letters in length, and the mean number of neighbors was 1.8. One member of each pair was selected at random to be the prime, and the other to be the target. In addition, 48 orthographically legal nonwords were constructed with a similar distribution of lengths to the words and with a similar distribution of number of neighbors (between 1 and 2). There is no distinction of P+ and P- in nonword primes since it is unreasonable to assume a pronunciation for a nonword. Two counterbalanced lists of items were prepared so that across both lists, each target word and nonword was primed by a related prime and an unrelated prime, but not in the same list. Each list was presented at prime durations of 40 ms and 60 ms, but to different subjects.

Procedure. The experiment was controlled by a Pentium PC, using the Windows DMDX software developed by J.C. Forster at the University of Arizona (Forster & Forster, 2003). Items were presented as black letters on a white background (Courier New12 pt font) using a color monitor with a refresh cycle of 10 ms. The forward mask which began each trial was a row of hash marks (########), presented for 500 ms. The mask was then replaced by the prime which was presented in lower case letters for 40 ms or 60ms. The prime was then replaced by the target in upper case letters, which also acted as a backward mask and was displayed for 500 ms. The forward and backward masks effectively prevented the conscious detection of the prime and no participant reported being aware of it.

The task was a standard lexical decision task. The participants were instructed to respond as quickly as possible without making excessive errors by pressing one of two keys marked “Yes” and “No”. Feedback after each trial informed the participant of the speed and accuracy of their response. Items were presented in a different pseudorandom order for each participant. After the participant responded and the feedback was displayed, the next trial was initiated automatically. A rest interval was provided every 24 trials. Prior to the experiment beginning, 12 practice items were used.

Results

The data from three participants were rejected due to the high error rates (> 20%). Thus, the analysis was based on the data from 24 participants. Incorrect responses were discarded, and outliers were treated by setting them equal to cutoffs established two *SD* units above and below the mean for each subject. In addition, any reaction times longer than 1500 ms or shorter than 300 ms were discarded, with the result that 4.8% of the data were modified. The mean reaction times and error rates are presented in Table 1. Two analyses of variance were performed, one treating subjects as a random effect (F_1), the other treating items as a random effect (F_2). The factors for the analysis were Groups (subject groups in the subject analysis, item groups in the item analysis), Phonology (P+ vs P-), and Prime Type (related vs unrelated). The Groups factor was included to remove variance due to the counterbalancing procedure, and was a non-repeated factor in both analyses. The factor of Phonology was a repeated measures factor in the subject analysis, but not in the item analysis. Prime type was a repeated measures factor in both analyses.

Table 1. Mean Lexical Decision Times in ms
Mean lexical decision times (in ms) for phonologically similar priming condition (P+), phonologically dissimilar prime condition (P-) at the prime duration of 40 ms and 60 ms.

	40 ms		60 ms	
	P+	P-	P+	P-
Related	526	529	531	538
Unrelated	536	547	548	557
Priming	**10**	**18**	**17**	**19**

A four-way ANOVA of the lexical decision times indicated a significant main effect of Priming, both for the subject analysis, F1 (1, 20) = 10.38, p<. 01, and for the item analysis, F2 (1,88) = 12.01, p=. 001, indicating that lexical decision was faster to words primed by a related prime. Surprisingly, priming was slightly stronger for P- targets than for P+ targets, but this interaction was not significant, either by subjects, F1 (1,20) < 1, or by items, F2 (1,88) < 1. In addition, there were no significant effects of prime duration.

Discussion

At first glance, the results indicate that phonology plays no role at all in priming. The reliable priming effects for the phonologically dissimilar items (P-) at both 40 and 60 ms cannot be attributed to phonological overlap, which disconfirms the prediction from the strong phonological recoding hypothesis. Further, the priming effects for the phonologically similar items (P+) are equivocal, since they could have been produced by either phonological or orthographic overlap. However, failing to find any hint of a phonological contribution to priming at the 40 ms prime duration is perhaps what might have been expected, given Ferrand and Grainger’s (1992, 1993) data suggesting that phonology does not become involved until the prime duration reaches 60 ms. As can be seen in Table 1, priming in the P+ condition increases from 10 to 17 ms with a 60 ms prime, and this could be taken as partial support for a phonological effect. A corresponding effect for the P- items would not be expected, since phonological similarity is minimal for these items. Thus, the pattern of results is not entirely inconsistent with the phonological hypothesis. However, the three-way interaction between Prime Duration, Phonological Overlap, and Priming was not significant (both Fs < 1), nor was the 7 ms improvement in priming for the P+ condition with a 60 ms prime (both Fs < 1).

One possible reason for the failure to find a reliable phonological effect is that the primes were not phonologically *identical* to the target, as in all previous experiments investigating this issue. Instead, the P+ primes in this experiment differed by one phoneme. But if this is the reason for the absence of any phonological effect, it would mean that phonological priming is fundamentally different from orthographic priming, where robust effects are obtained when primes and targets differ by one letter, as in the P- condition. Another difference from earlier experiments is that the primes and targets contained more than one syllable, whereas all previous experiments have used monosyllables. Whatever the explanation, the main conclusion from this experiment is that orthographic overlap produced strong facilitation in the absence of any phonological overlap, despite the fact that the prime was a lexical neighbor of the target.

EXPERIMENT 2

A possible weakness in the design of the first experiment is that the relative frequencies of the prime and target were not controlled. On average, the primes were higher in frequency than the targets, but this was not systematic. Previous experiments have found that form priming is reduced when the prime is a higher frequency neighbor of the target (Segui and Grainger, 1990; Davis & Lupker, 2006), and it is conceivable that this factor is somehow connected with the absence of a phonological effect. Accordingly, the same materials used in Experiment 1 were run again, this time with the lower frequency member of each pair being the prime. An additional change was an increase in the prime duration to 70 ms, which according to Ferrand and Grainger (1992) should virtually eliminate any orthographic priming, while still providing favorable conditions for a phonological effect.

Method

Participants. Twelve students from the same subject pool participated in this experiment. No participant was rejected.

Materials. The prime-target word pairs used in Experiment 1 were rearranged so that prime was always the lower-frequency member of the pair. The average frequency of the primes was 12.8 per million vs. 68.4 per million for the targets.

Procedure. The only change from the procedure in Experiment 1 was an increase in prime duration to 70 ms.

Results & Discussion

The mean lexical decision times averaged over individuals for each of the masked priming conditions are shown in Table 2. Once again, strong priming is obtained for both P+ and P- conditions, with slightly stronger priming in the P- condition.

Table 2. Mean Lexical Decision Times in ms
Mean lexical decision times (in ms) for phonologically similar priming condition (P+), phonologically dissimilar prime condition (P-) at the duration of 70 ms.

	P+	P-
Related	515	521
Control	539	553
Priming	**24**	**32**

A three-way ANOVA test of the lexical decision times indicated a significant main effect of Priming, both in the subject analysis, F1 (1, 10) = 6.38, p<. 05, and in the item analysis, F2 (1,60) = 11.62, p<. 01. However, the interaction of priming and phonological overlap was not significant by subjects or items, both Fs < 1.

This pattern of results is surprising, since at a prime duration of 70 ms, orthographic priming effects are expected to be much weaker, as found by Ferrand and Grainger (1992). However, their words were generally quite short (4-5 letters), whereas the range in the current experiment was 6-8 letters. It is possible that the critical variable is the *ratio* of matching to mismatching letters, which is much higher in the present experiment than in Ferrand and Grainger's experiment. In addition, it is clear that modifying the design so that the primes were always lower in frequency than the targets has not affected the pattern of results observed in Experiment 1.

EXPERIMENT 3

One potential problem with the previous experiment is that there were several items with very high error rates, e.g., reverie-REVERSE, mystery - MASTERY and living-DIVING. Similar concerns were expressed by Davis and Lupker (2006). The problem is that the mean RT in a given condition in the item analysis can be distorted by items for which there are very few correct responses. This problem is created by the difficulty of finding enough longer word pairs that differ by only one letter. Accordingly, in the next experiment, the high error rate items were replaced, and the power of the experiment was increased by adding extra items. The prime durations were 40 and 60 ms.

Method

Three P- items were replaced due to the high error rate (reverie-REVERSE, mystery-MASTERY, and living-DIVING). Eight more item pairs were added (e.g., fasten-HASTEN, pointer-PAINTER, mouthful-YOUTHFUL, bridle-BRIDGE, etc.) which made up a total of 20 items for each condition. In each case, the prime was the lower-frequency member of the pair.

The same experimental procedure was followed as in Experiment 1. Twenty-two from the same subject pool participated in this experiment. Two were rejected due to high error rate (> 25%). The following analysis was based on the data from twenty subjects.

Results & Discussion

The mean lexical decision times averaged over individuals for each of the masked priming conditions are shown in Table 3. The pattern of priming effects is quite different from the first two experiments in that the priming for P- items in now weaker than for P+ items.

Table 3: Mean Lexical Decision Times in ms

Mean lexical decision times (in ms) for phonologically similar priming condition (P+), phonologically dissimilar prime condition (P-) at the duration of 40 ms and 60 ms.

	40 ms		60 ms	
	P+	P-	P+	P-
Related	510	520	528	547
Control	532	531	557	550
Priming	**22**	**11**	**29**	**3**

For the prime duration of 40ms, a three-way ANOVA test of the lexical decision times indicated a significant main effect of Priming, both for the subject analysis, F1 (1, 18) = 7.86, p<. 05, and for the item analysis, F2 (1,76) = 7.42, p<. 05. The interaction of priming and phonological overlap, however, was not significant by subjects or items, F1 (1,18) = 2.28, p>.05; F2 (1,76)= 0.44, p>.05.

For the prime duration of 60ms, a similar result was obtained. There was a significant main effect of prime type, both for the subject analysis, F1 (1, 18) = 7.80, p<. 05, and for the item analysis, F2 (1,76) = 11.86, p<. 05. The interaction of priming and phonological overlap was significant by subjects, F1 (1,18) = 6.79, p<. 05, but not by items, F2 (1,76)= 1.64, p>.05.

The fact that P+ priming now appears to be stronger than P- priming is the most striking difference from the previous experiments although there is no obvious reason for this, apart from changes in the items and participants. However, in none of the three experiments was the interaction of priming and phonological overlap significant in both the subject and item analyses, so strictly speaking, there is no disagreement in findings. Nevertheless, the difference in phonological priming at a prime duration of 60 ms (29 ms vs 3ms) seems too large to be overlooked. The interaction here was significant in the subject analysis; hence, it might be argued that at 60 ms, there is at least some indication of phonological involvement. Of course, it must still be explained why this was not the case in the first two experiments.

Since high-error rate items were deleted and new items were added in the current experiment, it is conceivable that the difference in results might come from the changes in items. To test this, we went back to Experiment 2 (where the targets were also higher in frequency than the primes) and reanalyzed the data using only those items that were common between these two experiments. This analysis showed that the items in P+ condition behaved in a very similar way in both experiments, but P- items behaved very differently, showing strong priming in Experiment 2 (37 ms) and no priming at all in the present experiment (-1 ms). The reliability coefficient for the estimates of priming across the two experiments for the P+ condition was reasonable ($r = 0.54$), but was very low for the P- condition ($r = 0.14$). Clearly, the P- items were being treated quite differently in the two experiments, suggesting that performance on P- items is very unstable. This instability is indicative of some kind of conflict situation, in which phonological dissimilarity interferes with the beneficial effects of orthographic similarity. But why this conflict should be resolved in different ways across the two experiments is not at all clear, unless this is due to differences in participants. There is some precedent for this, since Holyk and Pexman (2004) carried out the same phonological priming experiment twice, getting a clear priming effect in one case but not in the other. Their interpretation was that participants who were higher in phonological skills showed a phonological priming effect. Applied to the current context, one might suggest that these participants were more likely to show interference from phonological dissimilarity.

GENERAL DISCUSSION

The major aim of these experiments was to determine whether masked form priming is controlled by phonological overlap, using a design that provides greater assurance that the degree of orthographic similarity between prime and target is not confounded with phonological overlap. This design involved several features that have not been commonly used in past research. Words were used as phonological primes rather than nonwords, and in addition, they were non-homophonic, differing from the target by one phoneme. In two experiments, primes that were phonologically dissimilar to the target showed as much priming as primes that were phonologically similar to the target, regardless of the prime duration. However, in the final experiment, phonologically similar primes did show stronger priming at a long prime duration (60 ms), although this interaction was significant only in the subject analysis. This finding provides some support for the involvement of phonology, but only for relatively long prime durations, since the interaction was not significant at 40 ms, which supports the general conclusions of Ferrand and Grainger (1993). The important difference is that the problem of designing adequate orthographic controls was avoided with the current design.

However, the interpretation of this effect is problematic. In the first two experiments, it is clear that phonological similarity is quite irrelevant to the amount of form priming. It was only in the third experiment that any phonological influence was detected, but in this case it appears that the orthographic effect has been suppressed, not that the phonological effect has been enhanced. If the results of the first two experiments were ignored, then the results of the last experiment would imply that form priming can only be obtained when phonological overlap between prime and target is high. However, we know this is not the case from the first two experiments.

It is usually assumed that phonological similarity facilitates form priming, but there is also the possibility that phonological dissimilarity interferes with priming. This could occur if phonology enters into the post-access checking process for the target. For example, one way to determine whether the correct entry has been activated would be to check whether the spelling of the candidate entry matches the input. Another might be to check whether the phonology of the candidate entry matches the (assembled) phonology of the input. This latter strategy could be compromised if the phonological activation produced by a P- prime persists, and causes the error-check to fail.

This raises the question of how the prime phonology is activated. The usual assumption is that it is generated pre-lexically (e.g., by means of grapheme-phoneme correspondence rules). This means that whether priming is obtained may depend on whether the target is regular or irregular. For example, if the target is regular (e.g. MINT), the assembled phonology of the P- prime *pint* will be similar to the phonology extracted from the lexical entry for the target. But if the target is irregular (e.g. PINT), the assembled phonology of the P- prime *mint* will not be as similar to the target. How to apply this reasoning to the items actually used in these experiments is difficult to determine. For example, which is the irregular member of the following pairs: *laughter-daughter, mature-nature, lesion-lesson*? Is the difference between *hideous* and *hideout* a difference in regularity or a difference in morphological structure? It is possible that subtle variations between the items used in each experiment with respect to regularity are responsible for the different results we obtained, but we have not been able to discern any systematic effects.

As mentioned earlier, a further possibility exists, and that is that the participants in Experiment 3 were more susceptible to phonological influences than the participants in the earlier experiments Without further evidence, however, this possibility cannot be evaluated.

Finally, the fact that word neighbor primes produced strong facilitation in all three experiments raises problems for models of word recognition that rely on competitive mechanisms operating at the lexical level. The normal expectation would be that the activation of the target due to orthographic overlap with the prime would be more than offset by the inhibition produced by the higher level of activation in a competitor of the target (especially a higher-frequency competitor, as in Experiment 2).

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