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Does *conal* prime CANAL more than *cinal*? Masked phonological priming effects in Spanish with the lexical decision task

ALEXANDER POLLATSEK
University of Massachusetts, Amherst, Massachusetts

MANUEL PEREA
Universitat de València, València, Spain

and

MANUEL CARREIRAS
Universidad de La Laguna, Tenerife, Spain

Evidence for an early involvement of phonology in word identification usually relies on the comparison between a target word preceded by a homophonic prime and an orthographic control (*rait*–RATE vs. *raut*–RATE). This comparison rests on the assumption that the two control primes are equally orthographically similar to the target. Here, we tested for phonological effects with a masked priming paradigm in which orthographic similarity between priming conditions was perfectly controlled at the letter level and in which identification of the prime was virtually at chance for both stimulus onset asynchronies (SOAs) (66 and 50 msec). In the key prime–target pairs, each prime differed from the target by one vowel letter, but one changed the sound of the initial *c*, and the other did not (*cinal*–CANAL vs. *conal*–CANAL). In the control prime–target pairs, the primes had the identical vowel manipulation, but neither changed the initial consonant sound (*pinel*–PANEL vs. *ponel*–PANEL). For both high- and low-frequency words, lexical decision responses to the target were slower when the prime changed the sound of the *c* than when it did not, whereas there was no difference for the controls at both SOAs. However, this phonological effect was small and was not significant when the SOA was 50 msec. The pattern of data is consistent with an early phonological coding of primes that occurs just a little later than orthographic coding.

One important, and controversial, issue in cognitive psychology is the delimitation of the role of phonology in visual word recognition and reading. A growing body of evidence has accumulated in the past two decades showing that phonological information can be obtained automatically and early in the process of word recognition (for reviews, see Frost, 1998; Rayner, 1998). However, there is still an active debate as to whether phonological codes are *always* involved in the process of lexical access (see, e.g., Daneman & Reingold, 2000; Shen & Forster, 1999). In some models, the process of identifying visual words necessarily involves the computation of phonology (e.g., Van Orden, Pennington, & Stone, 1990), whereas in others, words can be identified via an orthographic code without necessarily resorting to the computation of phonology (e.g., the dual-route cascaded [DRC] model of Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001, or the search model of Forster, 1976).

One of the most fruitful paradigms for examining phonological effects in visual word recognition and reading is priming. The typical test for a phonological effect is whether a homophonic prime (e.g., *rait*) speeds response times (RTs) to a target (e.g., RATE) more than an orthographic control (e.g., *raut*) does. However, this procedure clearly rests on the assumption that the homophone and the control are equally orthographically similar to the target. Another concern in priming experiments is whether the effects observed are due to speeded encoding of the target word or to separate encoding of the prime, which may influence later decision or response stages in the processing of the target word. To minimize such *postaccess* phenomena, researchers have often opted to mask the prime in order to make it largely unavailable for conscious report. One such technique, employed here, is the *masked priming technique* (Forster & Davis, 1984; Forster, Mohan, & Hector, 2003), in which the prime is briefly presented between two masking stimuli. Initially, there is a forward mask (usually a string of meaningless characters), followed by a brief (approximately

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33–66 msec) presentation of the prime, followed by the target, which also serves as a backward mask. The preferred task is the lexical decision task, rather than the naming task, because the naming task may have an intrinsic phonological component independent of lexical access.

A finding that a prime facilitates the processing of a phonologically related target word, relative to the control condition (under the conditions described above), should provide strong empirical support for the automatic prelexical involvement of phonology in visual word recognition. However, the empirical evidence for phonological-priming effects with the masked priming technique in the lexical decision task is not entirely conclusive. Most of these reports have focused on experiments in which the prime was homophonic with the target (e.g., *rait*–RATE or *maid*–MADE), and the critical comparison was between a homophone prime (or a pseudohomophone prime) and an orthographic control condition. A homophone or pseudohomophone advantage, relative to an orthographic control, has been found in a number of lexical decision experiments in different languages (French, Ferrand & Grainger, 1992, 1994; English, Lukatela & Turvey, 1990, and Lukatela, Frost, & Turvey, 1998; Hebrew, Frost, Ahissar, Gottesman, & Tayeb, 2003; Dutch, Drieghe & Brysbaert, 2002), but other published reports have failed to show any signs of such an effect (e.g., Davis, Castles, & Iakovidis, 1998; Shen & Forster, 1999). It is not clear why some of the experiments failed to obtain the effect. One possibility is that the phonological effects may arise later than the orthographic effects and that the stimulus onset asynchrony (SOA) needs to be at least 55–60 msec (e.g., in Davis et al.'s and Shen & Foster's experiments, a 50-msec SOA was used). However, the experiments of Frost et al. and Lukatela et al. suggest that phonological priming can be obtained with SOAs less than 30 msec.

A pair of techniques, similar to masked priming, have also provided evidence for early involvement of phonology in word identification in reading. In one (Pollatsek, Lesch, Morris, & Rayner, 1992), a parafoveal preview of a word that was a homophone of the target word speeded processing of the target word when it was later fixated (i.e., reduced fixation time on the target) more than did an orthographic control. Similarly, a homophone *fast prime* presented during the first 30–40 msec of a fixation and then replaced by the target word speeded fixation time on the target word, relative to an orthographic control (Lee, Rayner, & Pollatsek, 1999). In both these paradigms, the primes were rarely, if ever, consciously processed.

These studies provide strong evidence for the involvement of early phonological processing in word identification. However, as was indicated above, they rest on the assumption that the orthographic control is as orthographically similar to the target as the homophone is. Although the controls are usually matched with the homophones on a number of variables, such as the number of letters they share with the target, it is usually not possible to control every factor, including the visual similarity of the letters to those in the target word. The idea of the present study was to test whether this could be a problem, using a new paradigm in which visual and orthographic similarity between priming conditions was perfectly controlled at the letter level. (There are more sophisticated theories of orthography that include levels higher than that of individual letters in their representation. We will discuss these theories in the General Discussion section but, for now, will restrict our discussion to theories in which the representation of orthography is at the level of an ordered sequence of letters.) We used Spanish in the present study partly because the manipulation to be described below is clearer in Spanish than in English (e.g., there is no vowel reduction in Spanish). Related to that, because Spanish has a transparent orthography, the use of phonology in the encoding of printed words may be mandatory (Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998).

For the experimental pairs of items, we selected primes that had the same degree of letter overlap with the target while differing in their phonological overlap, such as the pairs *conal*–CANAL vs. *cinal*–CANAL. (To help clarify the exposition, our examples of target words from the experiment are Spanish words that are also words in English.) We exploited the context-dependent pronunciation of the consonant letter *c* in Spanish (which is analogous to English and several other Western languages). That is, as in English, the letter *c* in Spanish has two separate sounds. When appearing in the combinations *ca*, *co*, and *cu*, the letter *c* is pronounced like /*k*/. When appearing in the combinations *ce* and *ci*, the letter *c* is pronounced like /θ/ in most of Spain, except for the Southern regions and the Canary Islands, where the letter *c* is pronounced like /s/.[1] Thus, *conal* (/*konal*/) is more phonologically similar to CANAL (/*kanal*/) than *cinal* (/*sinal*/) is, even though each differs from CANAL by one vowel letter.

So far, this is the type of logic that has often been employed in demonstrating phonological effects. However, it rests on the assumption that *o* and *i* are equally orthographically similar to *A*. As a control for the possibility that this assumption is false, we used control target–prime pairs, such as *ponel*–PANEL and *pinel*–PANEL. That is, the vowel letters that were changed in the control target–prime pairs were the same as those in the experimental target–prime pairs, and thus the orthographic differences in the two pairs should be identical. However, the critical experimental pairs differed in both the first and the second phonemes of the word, whereas the control pairs differed only in the second phoneme. Thus, any difference in the data in the two cases can unambiguously be ascribed to differences in phonology. For ease of exposition, we will refer to vowel changes (such as *u* to *A*) that do not alter the pronunciation of the preceding consonant as *friendly* vowel changes and changes of vowel (such as *i* to *A*) that alter the pronunciation of the preceding consonant as *unfriendly* vowel changes. Unless there is some confounding of the differences in the visual similarity of the vowel letters, the RTs for all friendly primes should be the same, and the RTs for all unfriendly primes should be the same. (We also included an unrelated-prime condition in order to assess orthographic priming effects.)

It is worth noting that Frost et al. (2003) included a comparison between two prime conditions, in each of which one letter was different from the target: one in which one phoneme was different (one consonant letter was replaced by another letter that represented a different consonant; e.g., KPIZ–KPIT [/*kapiz*/–/*kapit*/]) and another in which two phonemes were different (one consonant letter was replaced by a vowel letter, or vice versa; e.g., KPZT–KPIT; [/*kapezet*/–/*kapit*/]). Frost et al. found a substantial priming advantage for the condition in which one phoneme was different, relative to the condition in which two-phonemes were different, in a psychophysical experiment (i.e., few participants and many sessions per participant, with multiple presentations of the target words). However, this comparison, like most of the homophone manipulations discussed above, rests on the assumption that orthographic differences are equated for when one changes one letter; this assumption needs testing.

Because there is some empirical evidence that suggests that reliable phonological effects may arise for SOAs that are around 55–60 msec (see above), the SOA in Experiment 1 was set to 66 msec, whereas it was set to 50 msec in Experiment 2.

EXPERIMENT 1

Method

Participants. A total of 30 psychology students from the Universidad de La Laguna took part in the experiment to fulfill a course requirement. All were native speakers of Spanish.

Materials. The experimental targets were 90 Spanish words (5 or 6 letters) that were selected from the Spanish word pool of Alameda and Cuetos (1995). All began with the consonant letter *c*; half were high frequency (mean occurrence per million, 70; range, 14–417), and the other half were low frequency (mean occurrence, 2.2; range, 1–4). The mean number of word neighbors was less than one in both groups. The mean number of letters was approximately the same for the high- and the low-frequency words (5.6 and 5.8, respectively). The targets were presented in uppercase and were preceded by nonword primes in lowercase that were (1) the same as the target, except for the substitution of the second letter (always a vowel), so that the prime and the target shared all letters but one, but the initial consonant phoneme changed as well as the vowel phoneme (e.g., *cinal*–CANAL), (2) the same as the target, except for the substitution of the second letter (always a vowel), so that only the vowel phoneme changed (e.g., *conal*–CANAL), and (3) a control condition with an unrelated nonword prime with the same syllabic structure as the word target (e.g., *pover*–CANAL). Since the focus is on the initial phoneme, we will term the first condition the *phoneme-change* condition and the second condition the *phoneme-same* condition.

For the key controls, we selected a set of 90 words of 5 and 6 letters that began with a consonant letter other than *C* or *G*, so that the change of vowel did not alter the pronunciation of the prior consonant. As with the experimental targets, half of the words were high frequency, and the other half were low frequency (mean frequencies, 66 and 2.2 per million, respectively). The mean number of word neighbors was also less than one in the two control conditions, and the number of letters was approximately the same for the high- and the low-frequency words (5.6 and 5.5, respectively). The prime–target conditions for the control targets were the same as those for the experimental targets (e.g., *pinel*–PANEL, *ponel*–PANEL, and *sulor*–PANEL); note that in this case, the two related conditions shared *all but one phoneme/letter* (i.e., *pinel* and *ponel* each share 5 letters and five phonemes with PANEL). One hundred and eighty nonwords of 5 and 6 letters were created for the purposes of the lexical decision task. Half of the nonwords had the consonant *c* as the first letter (experimental targets), and the other half had a different consonant letter as the first letter (control targets). The priming conditions for the nonword targets were analogous to those for the word targets (e.g., *cubur*–COBUR, *cibur*–COBUR, and *bamel*–COBUR for the experimental targets; *futul*–FOTUL, *fitul*–FOTUL, and *lafer*–FOTUL for the control targets). Three sets of materials were constructed so that each (word or nonword) target appeared once in each set, but each time in a different priming condition. Different groups of participants were used for each set of materials. The complete materials (and the mean RTs for individual items) can be obtained from the following Web site: http://www.uv.es/~mperea/maskedp.pdf.

Procedure. The participants were run individually in a sound-attenuated room. The experiment was run using the EXPE software package (Pallier, Dupoux, & Jeannin, 1997) on a PC computer, on which the stimuli were presented as white characters on a black background. Each trial consisted of a sequence of three visual events. The first was a forward mask consisting of a row of eight hash marks (########), which was presented for 500 msec. The forward mask was immediately followed by the prime in lowercase letters exposed for a duration of 66 msec. Finally, the target in uppercase letters (which also served as a backward mask for the prime) replaced the prime and remained on the screen until the response. Each stimulus was centered in the viewing screen and was superimposed on the preceding stimulus. RTs were measured from target onset until the participant's response. The participant was asked to classify each letter string presented in uppercase letters as a word or a nonword. No mention was made of the number of stimuli that would be presented on each trial. The participant indicated his or her decisions by pressing one of two response buttons. When the participant responded, the target disappeared from the screen. Each participant received a different random ordering of targets. Each participant also received 24 practice trials (with the same manipulations as those in the experimental trials) prior to the 360 experimental trials. The whole session lasted approximately 18 min.

Results

Incorrect responses (4.2% of the data for the word targets) and RTs less than 250 msec or greater than 1,500 msec (fewer than 2.8% of the responses to the word targets) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 1, and participant and item analyses of variance (ANOVAs) based on the response latencies for participants and items and the percentages of error in each block were conducted on the basis of a 3 (prime–target relationship: phoneme change, phoneme same, or unrelated) × 2 (type of target: experimental or control) × 3 (list: List 1, List 2, or List 3) design. The list factor was included as a dummy variable to extract the variance due to the error associated with the lists (Pollatsek & Well, 1995). Separate analyses were conducted for the word and the nonword targets.

Table 1
Mean Lexical Decision Times (LDT, in Milliseconds) and Percentage of Errors (PEs) for Word and Nonword Targets in Experiment 1 (66-msec SOA)

	Type of Prime						Priming Effect			
	Phoneme Same		Phoneme Change		Unrelated		Change − Same		Unrelated − Same	
Condition	LDT	PE	LDT	PE	LDT	PE	LDT	PE	LDT	PE
Word trials										
High-frequency experimental	592	3.3	614	2.0	636	3.6	22	−1.3	44	0.3
Low-frequency experimental	686	11.8	706	11.6	729	14.2	20	−0.2	43	2.4
High-frequency control	596	1.6	599	1.6	650	4.0	3	0.0	54	2.4
Low-frequency control	661	6.7	657	11.1	715	8.9	−4	4.4	54	2.2
Nonword trials										
Experimental	743	5.3	740	3.6	732	3.3	−3	−1.7	−11	−2.0
Control	752	5.7	739	5.0	748	6.2	−13	−0.7	−4	0.5

As Table 1 indicates, there was a large (approximately 70-msec) word frequency effect for word targets [$F_1(1,27) = 222.66$, $MS_e = 2{,}440.8$, $p < .01$; $F_2(1,168) = 104.0$, $MS_e = 9{,}301.4$, $p < .01$]. In addition, there was an overall effect of relatedness [$F_1(2,54) = 60.22$, $MS_e = 1{,}327.2$, $p < .01$; $F_2(2,236) = 56.34$, $MS_e = 2{,}247.2$, $p < .01$]. Most crucially, responses were 21 msec faster for the experimental targets when these were preceded by the phoneme-same primes than when they were preceded by the phoneme-change primes [e.g., responses for *conal*–CANAL were faster than those for *cinal*–CANAL; $F_1(1,27) = 7.87$, $MS_e = 1{,}738.4$, $p < .01$; $F_2(1,84) = 10.31$, $MS_e = 1{,}958.2$, $p < .01$], whereas there was virtually no difference between these two conditions for the control targets (less than 1 msec). In addition, the interaction indicating that the magnitude of the priming effect differed as a function of type of target was significant [$F_1(2,54) = 3.98$, $MS_e = 1{,}925.3$, $p < .025$; $F_2(2,236) = 4.87$, $MS_e = 2{,}247.2$, $p < .01$]. As can be seen in Table 1, the interaction was similar for the high- and the low-frequency words (i.e., the F ratio of the three-way interaction was less than 1). The other main effects and interactions were not significant.[2]

In the error data for the word targets, the effect of word frequency was significant [$F_1(1,27) = 92.35$, $MS_e = 62.95$, $p < .01$; $F_2(1,168) = 37.53$, $MS_e = 232.3$, $p < .01$]. The effect of type of target was significant in the analysis by participants [$F_1(1,27) = 11.69$, $MS_e = 34.31$, $p < .01$; $F_2(1,168) = 2.59$, $MS_e = 232.3$, $p > .10$]. The interaction between type of target and word frequency was significant in the analysis by participants [$F_1(1,27) = 7.78$, $MS_e = 26.68$, $p < .02$; $F_2(1,168) = 1.34$, $MS_e = 232.3$, $p > .10$]. The other effects or interactions were not significant. None of these effects suggests that the major effects in the RT data were due to speed–accuracy tradeoffs. There were no significant effects in the RT or error data for the nonword targets.

The results are clear-cut. RTs to a target word such as CANAL were 21 msec shorter when it was preceded by a nonword prime that differed by one letter that shared all phonemes but one (*conal*) than when it was preceded by a nonword prime that differed by one letter that shared all phonemes but two (*cinal*). In contrast, priming to a target word such as PANEL from *ponel* and *pinel* was virtually identical. (We will discuss these results in detail in the General Discussion section.)

EXPERIMENT 2

Method

Participants. A total of 45 psychology students from the Universidad de La Laguna took part in the experiment to fulfill a course requirement. All were native speakers of Spanish.

Materials and Procedure. The materials and procedure were the same as those in Experiment 1, except that the SOA was set to 50 msec.

Results

Incorrect responses (5.3% of the data for the word targets) and RTs less than 250 msec or greater than 1,500 msec (fewer than 5.5% of the responses to the word targets) were excluded from the latency analysis. The statistical analyses were parallel to those in Experiment 1, and the mean RTs and percentages of errors over participants are presented in Table 2.

As Table 2 indicates, there was a substantial word frequency effect for the word targets on the lexical decision latency [$F_1(1,42) = 511.12$, $MS_e = 1{,}903.0$, $p < .01$; $F_2(1,168) = 116.28$, $MS_e = 8{,}928.9$, $p < .01$]. In addition, there was an overall effect of type of target (with shorter RTs for the control targets) [$F_1(1,42) = 43.72$, $MS_e = 1{,}543.5$, $p < .01$; $F_2(1,168) = 7.37$, $MS_e = 8{,}928.9$, $p < .01$]. The overall effect of relatedness was also significant [$F_1(2,54) = 29.68$, $MS_e = 1{,}101.1$, $p < .01$; $F_2(2,236) = 19.40$, $MS_e = 1{,}698.7$, $p < .01$]. However, this effect was essentially due to the differences with the unrelated priming condition. More specifically, there was only a 9-msec interaction reflecting a phonological priming effect: For the experimental targets, responses were 7 msec faster when preceded by the phoneme-same primes than when preceded by the phoneme-change

Table 2
Mean Lexical Decision Times (LDT, in Milliseconds) and Percentage of Errors (PEs) for Word and Nonword Targets in Experiment 2 (50-msec SOA)

	Type of Prime						Priming Effect			
	Phoneme Same		Phoneme Change		Unrelated		Change − Same		Unrelated − Same	
Condition	LDT	PE	LDT	PE	LDT	PE	LDT	PE	LDT	PE
Word trials										
High-frequency experimental	640	1.9	646	1.9	660	2.4	6	0.0	20	0.5
Low-frequency experimental	742	10.1	749	12.3	760	12.0	7	2.2	18	1.9
High-frequency control	636	1.3	629	1.8	664	1.5	−7	0.5	28	0.2
Low-frequency control	700	5.6	703	7.0	730	5.5	3	1.4	30	−0.1
Nonword trials										
Experimental	773	1.8	780	2.0	788	2.2	7	0.2	15	0.4
Control	780	2.4	781	2.8	797	2.1	1	0.4	17	−0.3

primes [e.g., responses to *conal*–CANAL were faster than those to *cinal*–CANAL; $F_1(1,27) = 1.78$, $MS_e = 1{,}036.2$, $p = .18$; $F_2(1,84) = 2.55$, $MS_e = 1{,}780.6$, $p = .11$], whereas the analogous effect for the control targets was −2 msec. (However, the *F*s for the relatedness × type of target interaction were less than 1.) Finally, the interaction between type of target and word frequency was significant in the analysis by participants [the effect of word frequency was greater for the experimental targets; $F_1(1,42) = 22.34$, $MS_e = 1{,}191.0$, $p < .025$; $F_2(1,168) = 3.63$, $MS_e = 8{,}928.9$, $p = .058$]. The other interactions were not significant.

In the error data for word targets, the effect of word frequency was significant [$F_1(1,42) = 105.16$, $MS_e = 62.0$, $p < .01$; $F_2(1,168) = 37.12$, $MS_e = 175.1$, $p < .01$]. The effect of type of target was also significant [$F_1(1,42) = 49.27$, $MS_e = 24.46$, $p < .01$; $F_2(1,168) = 6.88$, $MS_e = 175.1$, $p < .02$]. Finally, the interaction between type of target and word frequency was significant [$F_1(1,42) = 34.51$, $MS_e = 23.37$, $p < .01$; $F_2(1,168) = 4.61$, $MS_e = 1{,}75.1$, $p < .05$]. The other effects or interactions were not significant. There were no significant effects in the RT or error data for the nonword targets, except for a significant priming effect on the latency data in the analysis by participants [$F_1(1,42) = 6.48$, $MS_e = 939.8$, $p < .01$; $F_2(2,350) = 1.68$, $MS_e = 1{,}827.2$, $p > .15$].

In sum, both orthographic and phonological priming effects were smaller in the present experiment (50-msec SOA) than in Experiment 1 (66-msec SOA), and the phonological priming effect was not statistically significant.

GENERAL DISCUSSION

The present experiments provide clear evidence of phonological involvement with a short SOA and heavily masked primes. Moreover, unlike most experiments providing evidence for masked phonological priming, the critical comparison was between sets of primes that had the same orthographic similarity to the target words but differed in phonological similarity (e.g., *conal*–CANAL vs. *cinal*–CANAL vis-à-vis *ponel*–PANEL vs. *pinel*–PANEL). That is, at the 66-msec SOA (Experiment 1), the lexical decision times to a target word such as CANAL were substantially shorter (around 20 msec) when it was preceded by a nonword prime that shared that differed by one letter all phonemes but one (*conal*) than when it was preceded by a nonword prime that differed by one letter that shared all phonemes but two (*cinal*), whereas priming to PANEL from *ponel* and *pinel* was virtually identical. Thus, differences in priming in the former case could not have been due to uncontrolled visual difference between the letters in the primes. It is worth noting that, for the experimental pairs, the phonological priming effect was about the same when the *friendly* vowel change involved the letters *e* or *i* as when it involved the letters *a, o,* or *u* (18 and 22 msec, respectively). (For the control pairs, the parallel effect was less than 5 msec in both cases.)

The question that we attempted to address was whether there were true phonological effects in masked priming or whether reported phonological effects could be ascribed to uncontrolled orthographic differences. As has been argued above, the present paradigm completely equates orthographic differences between experimental and control pairs, so that any difference in the pattern of priming results for those pairs has to be due to phonology. In Experiment 1, with a prime–target SOA of 66 msec, we observed a clear phonological effect: There was a significant 21-msec difference between the phonologically consistent and the inconsistent primes, whereas there was a 0-msec difference between the parallel control conditions (the interaction was also significant). In Experiment 2, with a prime–target SOA of 50 msec, we observed only a hint of a phonological effect: There was a 7-msec difference between the phonologically consistent and the inconsistent primes and a −2-msec difference between the parallel control conditions, but neither the 7-msec priming difference nor the 9-msec interaction was close to significant.

The data thus argue strongly that there is phonological activation from the prime at 66 msec but that there is only a hint of it at 50 msec. In the present paradigm, it is harder to assess the size of a pure orthographic effect, since differences between either of the priming conditions and the unrelated control condition could be due to either orthographic or phonological relatedness between the prime and the target. The most conservative measure of an orthographic priming effect in the present experiments is the difference between the phoneme-change condition for the experimental pairs and the unrelated control, since these conditions differ in the number of letters that overlap between the prime and the target and differ the least in the number of phonemes that overlap. In Experiment 1, the size of this effect was 23 msec [$F_1(1,27) = 20.19$, $MS_e = 794.9$, $p < .01$; $F_2(1,84) = 13.12$, $MS_e = 2{,}013.8$, $p < .01$], and in Experiment 2, it was only 12 msec [$F_1(1,42) = 4.32$, $MS_e = 1{,}720.2$, $p < .05$; $F_2(1,84) = 3.50$, $MS_e = 1{,}798.3$, $p = .06$]. However, data from another experiment in Spanish (Perea & Lupker, 2004) suggest that there might be somewhat more robust orthographic priming effects at a 50-msec SOA. In their study, they compared the priming effects when there was one consonant letter different between the target and the prime (e.g., *casiro*–CASINO) with those when there were two consonants different (e.g., *caviro*–CASINO) and found, in each of two experiments, about a 30-msec difference. Although this manipulation confounds orthographic and phonological differences, if one accepts the 9-msec value we obtained in the present experiments for the effect of a change of one phoneme at a 50-msec SOA as the "true value," that suggests that the "true" orthographic effect for a change of one letter at a 50-msec SOA is over 20 msec and, hence, that the orthographic priming effect at 50 msec is more substantial. In sum, it appears that the best construal of the data is that both orthographic and phonological priming effects are attenuated in the 50-msec SOA condition and that the orthographic priming effect is a bit more fully developed at 50 msec (see Ferrand & Grainger, 1992, for further evidence of the time course of orthographic and phonological priming effects).[3] Moreover, it is worth noting that in some sense, comparing the sizes of these effects, puts the phonological priming effect at a disadvantage. That is, in the phoneme-change experimental condition, the prime and the target agree in all but one letter, whereas in the unrelated control condition, they agree in, at most, one letter: a large difference in orthographic similarity. In contrast, the phonological difference between the phoneme-same and the phoneme-change conditions is small: only one phoneme. Thus, it is quite impressive that in Experiment 1, a one-phoneme difference produced a priming effect of virtually the same size as that produced by a many-letter orthography difference. In Experiment 2, the estimate given above of the orthography difference was twice as big as the phonological difference. However, in both cases, the "orthographic" priming effect was plausibly due to phonological differences, whereas the reverse was not true.

Thus, it appears that unambiguous phonological priming effects emerged only slightly later in the present experiments than unambiguous orthographic priming effects did. This leaves open the question of whether it takes a slightly longer time for the phonological codes to mature or whether the markedly increased priming effects at the 66-msec SOA are due to conscious processing of the primes at the longer SOA. We think that there are two ways to address this question. Perhaps the most direct way is to assess the probability that people can identify the prime; however, there is considerable controversy about the most appropriate measure to use to assess conscious perception. We chose a direct report technique, in which we asked 6 participants to report the letters of the masked prime at the 66-msec SOA. The number of trials per participant was exactly the same as that in the experiments—also including a practice phase. (The participants were instructed to write down the stimulus presented in lowercase letters, and given the difficulty of the task, they were encouraged to guess in cases in which they thought they had not seen anything.) The entire prime was identified correctly on only 1.1% of the trials. Given that the key information that distinguished the phoneme-same and the phoneme-change conditions was the second letter (i.e., *conal* is pronounced /konal/, whereas *cinal* is pronounced /sinal/), we also computed (1) the percentage of the trials on which the initial two letters were identified correctly and (2) the percentage of the trials on which the initial vowel was identified correctly. The values for those two measures were 4.8% and 6.1%, respectively. However, it is worth noting that the identification rates varied quite a bit across participants (with over half the participants having identification rates of the initial vowel less than 2%). Moreover, these are likely to be "generous" upper-bound estimates of identification rates during the priming task, since the sole task for these participants was trying to identify the prime, instead of making a speeded response on the target in conditions in which they were not even told about the existence of the primes.

The analysis above indicates that people can identify some information for the prime occasionally at the 66-msec SOA. The question, then, is whether this small amount of conscious identification can plausibly have been the cause of the phonological priming effect in Experiment 1. To assess this, we examined the group RT distributions in the phoneme-same and phoneme-change conditions, using *all* the correct responses (see Ratcliff, Gómez, & McKoon, 2004, for an extensive discussion of the use of RT distributions in lexical decision). Our reasoning was that if the phonological priming effect was due to conscious identification on a few trials, the bulk of the RT distribution in the two conditions should look approximately the same, but the phoneme-same distribution would have a shorter tail, reflecting those trials in which the prime was consciously processed. That is, if on a few trials in which participants are conscious of the prime, they quickly respond *yes* if the pair is highly related, this should produce a few short responses and, plausibly, more short responses the more phonologically related the prime is to the target. However, there are data

(Perea & Forster, 2005) indicating that repetition priming effects in the masked priming technique in conditions in which there is little or no conscious awareness of the prime are reflected as a shift in the RT distribution with no change in shape, whereas repetition priming effects with unmasked (i.e., visible) primes are reflected as both a shift in the center of the RT distribution and a change in shape (i.e., the RT distribution of the unrepeated targets is more skewed than the RT distribution of the repeated targets). When we examined the RT distributions in the conditions, the effect we reported in the means was clearly due to a shift of the RT distributions. This can be seen in two ways. First, consider the pattern for the medians. For the high-frequency experimental word targets, the medians were 567 and 587 msec, respectively, for the phoneme-same and the phoneme-change conditions, and the analogous medians for the low-frequency word targets were 663 and 679 msec, respectively. Thus, the 18-msec phonological priming effect in the medians (which should be basically unaffected by a few extremely short/long RTs) was virtually the same as the 21-msec effect for the means. Moreover, if one looks at the pattern for the 90%, 70%, 50%, 30%, and 10% quantiles of the distributions (see Figure 1), it seems clear that the differences in the means reported in Table 1 result from shifts of the entire RT distributions. These findings support the hypothesis that the priming effect occurs on virtually all trials and, thus, that it is not due to a few trials in which the prime is consciously processed.

In sum, the present experiments indicate that there is a phonological priming effect in masked priming that cannot be due to uncontrolled orthographic differences. Moreover, our analyses suggest that the fact that a reliable phonological priming effect surfaces only when the prime–target SOA is 66 msec is not due to conscious processing of the prime on a fraction of the trials. Instead, it appears that priming effects when the prime–target SOA is 50 msec are attenuated, and a subtle priming effect (involving the change of only one phoneme) is hard to document. Thus, our results are consistent with the view that phonology plays an important role in the early stages of word recognition and indicate that phonological activation appears to be an automatic part of word identification in Spanish (see also Carreiras & Perea, 2002). Moreover, our findings are consistent with the homophone-priming experiments, some of which were discussed earlier, that indicate early involvement of phonological processing in other, widely differing languages, such as English (Pollatsek et al., 1992), Hebrew (Frost et al., 2003), and Chinese (Pollatsek, Tan, & Rayner, 2000).

It is possible, however, that orthographic similarity is not defined merely at the letter level and that "higher order" units are relevant to the orthographic structure. One obvious candidate in Spanish is an orthographic unit at the syllabic level, since syllables in Spanish (in contrast to English) are completely unambiguous units of the spoken language. As a result, one might think that our data could be explained by assuming that some orthographic syllables are more unitized than others—in particular, that CV syllables starting with the letter *c* are more unitized than those starting with a consonant whose pronunciation is unaffected by the following vowel. However, it is far from clear that a unitization hypothesis would explain our pattern of data, because if all the *c* syl-

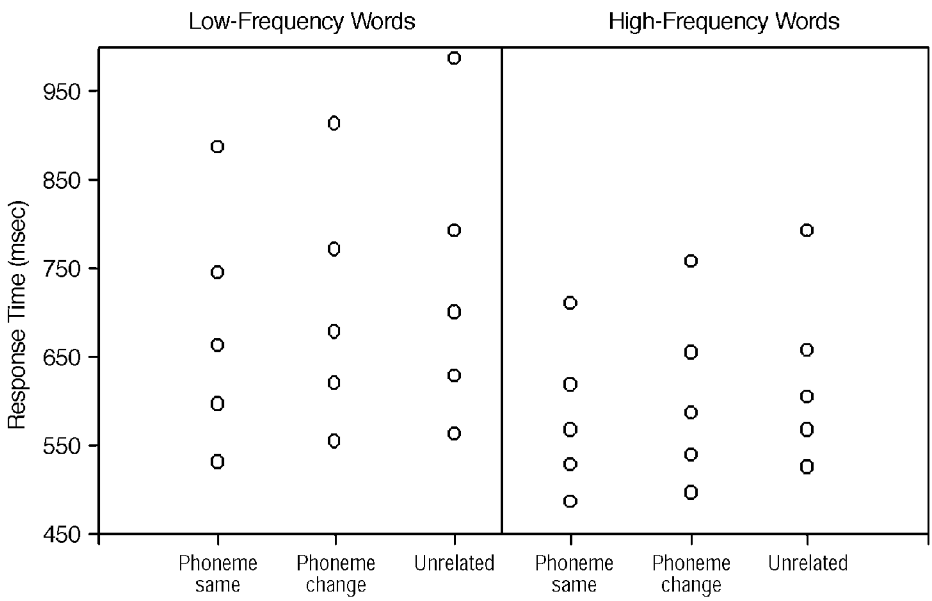

Figure 1. Group response time distributions for the experimental pairs at the 66-msec stimulus onset asynchrony. The circles represent the 10%, 30%, 50%, 70%, and 90% quantiles. These values were computed by computing the quantiles for individual participants and then averaging the computed values for each quantile over the participants.

lables are unitized (and thus markedly dissimilar from each other), one would predict less priming from both friendly and unfriendly *c* primes than from the control primes, rather than differential priming from friendly and unfriendly *c* primes. (It is also the case that in Spanish school instruction about syllables, there is no special emphasis on syllables such as *ci*.) A second possibility, of course, is that, in some sort of orthographic "space," *co* is more similar to *ca* than *ci* is to *ca*, whereas *po* and *pi* are about equally similar to *pa*. This, of course, involves positing that orthographic structure is shaped by (and reflects) features of phonology. Clearly we cannot rule out this possible alternate explanation of our data; however, given this view of the world, the whole question of what is a phonological effect and what is an orthographic effect becomes almost meaningless, especially if one also allows the orthographic structure to shape the phonological structure as well. However, we think that such an explanation may be less plausible for explaining the phonological priming and preview effects that have been observed in Chinese, where the sound of a character is only vaguely related to *phonological radicals*.

It is also of interest that the present phonological effects were similar for low- and high-frequency words. This pattern indicates that phonological coding occurs for all words and, thus, that phonological coding is not merely a *back-up* process for low-frequency words. In fact, since the primes were all pronounceable nonwords, it indicates that, in some sense, the effect is *prelexical*, in that the phonological code extracted from the prime is not merely read off a single lexical entry. However, the effect we observed could result from contacts with several lexical entries (e.g., *conal* activating a set of lexical entries beginning with *co*, which in turn activate the appropriate phonological representation for the *c* sound).[4]

As a result, we think that our phonological priming effect has clear implications for models of visual word recognition. For example, in order to simulate the observed effects, the DRC model (Coltheart et al., 2001) would need to be able to implement very fast computations in the assembled nonlexical route to have an effect on high-frequency words (see also Frost et al., 2003). Similarly, the framework of an interactive-activation model (e.g., Ferrand & Grainger, 1994) typically posits that there are two possible pathways from the letter level to the word level: an orthographic route (sublexical input orthography, as in the original interactive-activation model) and a phonological route (sublexical input phonology). For these types of models, the key task would also be to discover a mechanism that would plausibly enter rapidly enough into the word identification system to allow for such early effects of phonological processing. In addition, we think that our data may pose a problem for the two-stage model of Berent and Perfetti (1995), in which processing of consonants occurs in a first cycle and processing of vowels occurs in a second cycle. That is, if the earliest stage is the processing of consonants (and if, moreover, the first letter of a word should be especially visible), it is unclear why a vowel should have such a large influence on the pronunciation of a consonant in early processing. Our data are not conclusive, however, since one could argue that we have not tapped an early enough stage with our SOAs to get differential effects of consonants and vowels (see also Lee, Rayner, & Pollatsek, 2002). On the other hand, there may be a real difference between English and Spanish in how vowels and consonants are processed, since (among other things) the pronunciation of vowels in Spanish (unlike in English) is quite unaffected by the surrounding consonants and since there is one study in Italian (a language that is close to Spanish in its phonological structure) in which there was no evidence for prior processing of consonants, using the same paradigm as Berent and Perfetti (Colombo, Zorzi, Cubelli, & Brivio, 2003).

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NOTES

1. The pronunciation of Spanish in Latin America is similar to the latter pattern, since *c* in *ci* and *ce* is pronounced like /s/.

2. It is worth noting that, as compared with the unrelated condition, the priming effect for the phoneme-same priming condition for experimental target words (*conal*–CANAL vs. *pover*–CANAL) was around 10 msec smaller than that for the corresponding condition for the control target words (*ponel*–PANEL vs. *sulor*–PANEL; see Table 1). However, the critical interaction did not approach significance (both $ps > .15$).

3. In fact, when an analysis was done on the phoneme-same versus phoneme-change effect on the combined data for the experimental pairs from the two experiments with SOA as a variable crossed with the other variables, the overall 15-msec interaction—indicating a phonological effect—was significant [$F_1(1,69) = 4.91$, $MS_e = 1{,}225.5$, $p < .035$; $F_2(1,84) = 12.14$, $MS_e = 1{,}808.3$, $p < .01$], whereas the interaction of this effect with SOA was not close to significant [$F_1(1,69) = 2.07$, $MS_e = 1{,}225.5$, $p > .15$; $F_2(1,84) = 1.48$, $MS_e = 1{,}930.5$, $p > .15$]. Moreover, when the larger analysis was done with the control pairs included, the same pattern obtained. That is, the interaction between type of target and priming was significant [$F_1(1,69) = 5.65$, $MS_e = 1{,}492.2$, $p < .025$; $F_2(1,168) = 5.69$, $MS_e = 2{,}050.8$, $p < .02$], but the interaction between type of target, priming, and SOA was not close to significant [$F_1(1,69) = 1.10$, $MS_e = 1{,}402.2$, $p > .15$; $F_2(1,168) = 1.40$, $MS_e = 1{,}800.4$, $p > .15$]. This supports the hypothesis that the difference of the phonological effects at the two SOAs is a matter of degree, rather than a qualitative difference.

4. Perhaps the only aspect of our data that seems contradictory to this is that we did not observe any phonological priming effect for our nonword targets. However, we also did not observe any reliable orthographic priming effect for our nonword targets. In general, masked priming effects for nonword targets in a lexical decision task are rather unreliable (see Forster, 1998). One possible reason is that a prime for a nonword target may have two competing effects: On the one hand, the similarity between the prime and the target may help to activate the representation of the nonword and thus facilitate a response, but on the other hand, the resultant ease of encoding might also make the stimulus seem more *wordlike* and, thus, inhibit a nonword response. A second possible reason is that *nonword* responses in this task might largely be produced by a *deadline*, so that if no lexical entry is activated by the deadline, a *nonword* response is made. If so, more or less activation of the nonword would largely be irrelevant to the speed of the response. In any event, a discussion of the issues involved in masked priming for nonwords is beyond the scope of the present study.

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