Research Article

The Sound of Enemies and Friends in the Neighborhood

Phonology Mediates Activation of Neighbor Semantics

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Abstract. Previous studies (e.g., Pecher, Zeelenberg, & Wagenmakers, 2005) found that semantic classification performance is better for target words with orthographic neighbors that are mostly from the same semantic class (e.g., *living*) compared to target words with orthographic neighbors that are mostly from the opposite semantic class (e.g., *nonliving*). In the present study we investigated the contribution of phonology to orthographic neighborhood effects by comparing effects of phonologically congruent orthographic neighbors (*book-hook*) to phonologically incongruent orthographic neighbors (*sand-wand*). The prior presentation of a semantically congruent word produced larger effects on subsequent animacy decisions when the previously presented word was a phonologically congruent neighbor than when it was a phonologically incongruent neighbor. In a second experiment, performance differences between target words with versus without semantically congruent orthographic neighbors were larger if the orthographic neighbors were also phonologically congruent. These results support models of visual word recognition that assume an important role for phonology in cascaded access to meaning.

Keywords: word recognition, orthographic neighbors, phonology, semantic processing

Readers must access the meanings of words in order to understand what they are reading. Most theories of meaning access assume that written words activate orthographic representations which in turn activate semantic representations. According to cascaded models of visual word recognition (Becker, Moscovitch, Behrmann, & Joordens, 1997; Harm & Seidenberg, 2004; Masson, 1995), semantic information is activated before orthographic processing has been completed. Recent studies (Boot & Pecher, 2008; Bowers, Davis, & Hanley, 2005; Duñabeitia, Carreiras, & Perea, 2008; Pecher, de Rooij, & Zeelenberg, 2009; Pecher, Zeelenberg, & Wagenmakers, 2005) find support for these models by observing that semantic features of orthographic neighbors affect processing of target words. Most cascaded theories assume that phonology also plays a role in accessing the meaning of visually presented words. However, the majority of experiments addressing the cascaded nature of visual word recognition have focused on orthographic processing. In the present study we therefore investigated the role of phonology in the cascaded activation of meaning.

Models of word recognition typically assume that visual presentation of words activates not only the orthographic features of the presented word, but also of orthographically similar words (i.e., orthographic neighbors). Depending on the model, some form of competition or selection process takes place between orthographically similar words to determine the most likely lexical candidate (Andrews, 1997; Carreiras, Perea, & Grainger, 1997; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; McClelland, 1979; McClelland & Rumelhart, 1981). Models differ in their assumptions about the point in processing at which semantic information is accessed. Strictly form-first models propose that a word's semantic properties are activated only after orthographic processing has completed and a unique word has been identified and selected for further processing (Forster, 2006; Forster & Hector, 2002). In most models (Becker et al., 1997; Harm & Seidenberg, 2004; Masson, 1995) however, activation between the orthographic, phonological, and semantic level proceeds in a cascaded fashion. As soon as a word's orthography starts getting activated, information from the orthographic level is used as input for subsequent levels. Thus, semantic information gets activated before processing of orthography has completed. Evidence for cascaded activation comes from studies showing that semantic processing of a word is affected by the semantic features of the word's orthographic neighbors (Boot & Pecher, 2008; Bowers et al., 2005; Duñabeitia et al., 2008; Pecher et al., 2005, 2009). This effect is expected if the semantic features of the target word's orthographic neighbors (i.e., its competitors) are activated before orthographic processing has completed. In contrast, if semantic activation only occurs after orthographic completion, there should not be any semantic effects of orthographic neighbors.

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A variety of tasks and paradigms have confirmed predictions arising from the assumption of cascaded processing (Boot & Pecher, 2008; Bourassa & Besner, 1998; Bowers et al., 2005; Duñabeitia et al., 2008; Pecher et al., 2005, 2009; Rodd, 2004). Most relevant, for the present study, are experiments using semantic classification tasks such as animacy (i.e., living/nonliving) decisions. In these studies, semantic processing of a word is facilitated (compared to a neutral condition) if the semantic features of the target's neighbors are congruent with the target word, and harmed if the semantic features of the target's neighbors are incongruent with the target word. Pecher et al. (2005) asked participants to decide whether a presented word was living (*mare*) or nonliving (*road*). They found that performance was better for target words that had mostly orthographic neighbors from the same semantic class (e.g., *living*) compared to target words that had mostly orthographic neighbors from the opposite semantic class (e.g., *nonliving*) (see also Bowers et al., 2005; Forster & Hector, 2002; Rodd, 2004). Similar findings have been reported in a number of other studies by using long-term priming manipulations. In two related experiments, Pecher et al. (2005; also see Boot & Pecher, 2008) found that prior presentation of a living neighbor (*hare*, *toad*) in an earlier block of the same task facilitated performance for a living target, but harmed performance for a nonliving target compared to a neutral condition in which no prior neighbor was presented. In contrast, prior presentation of a nonliving neighbor (*fare*, *load*) facilitated performance for a nonliving target, but harmed performance for a living target. Thus, performance in semantic tasks is facilitated by semantically congruent orthographic neighbors but harmed by semantically incongruent orthographic neighbors. These semantic congruency effects support the claim that the semantic features of orthographic neighbors are activated by the presentation of a target word and this semantic activation contributes to performance. The exact effect of the neighbors on performance depends on whether the activated semantic features are congruent or incongruent with respect to the categorization of the target word.

As most evidence supports cascaded activation during word processing, in the present study we attempt to further specify the nature of cascaded processing.[1] In particular, we examine the role of phonology in the cascaded process that gives rise to meaning. Whereas some researchers have proposed that word recognition proceeds from orthography to phonology to meaning (Frost, 1998; Lukatela & Turvey, 1994; Stone & Van Orden, 1994; Stone, Vanhoy, & Van Orden, 1997; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988; Van Orden, Pennington, & Stone, 1990; Ziegler, Montant, & Jacobs, 1997), others have proposed a weaker role for phonology by stating that in addition to the phonological route, there is also a direct route from orthography to meaning (Coltheart et al., 2001; Harm & Seidenberg, 2004; see Rastle & Brysbeart, 2006, for a review). Thus, although theories differ as to whether phonology is essential for meaning activation, both types of theories acknowledge that phonology is relevant for the processing of written words and is at least a partial mediator between orthography and semantics.

The role of phonology in visual word recognition becomes evident when one considers the role of phonological consistency. In languages such as English, which has an inconsistent spelling-to-sound mapping, orthographic neighbors can be phonologically congruent (*book-hook*) or phonologically incongruent (*sand-wand*). That is, for languages like English, the same letter can be pronounced in different ways depending on the context (word) in which the letter is embedded. Many studies have shown that phonology affects performance in visual word recognition (Lukatela & Turvey, 1994; Pexman, Lupker, & Jared, 2001; Stone & Van Orden, 1994; Stone et al., 1997; Van Orden, 1987; Van Orden et al., 1988, 1990; Ziegler et al., 1997). The activation of phonology may have important consequences for the semantic congruency effect. For example, the phonology of *ook* in *book* and *hook* are very similar and therefore phonologically congruent, whereas the phonology of *and* in *sand* and *wand* are incongruent. If phonology plays a mediating role between orthography and meaning, the meaning of orthographic neighbors with congruent phonology should be activated more strongly than the meaning of orthographic neighbors with incongruent phonology. As a consequence, the semantic congruency effect should be larger for phonologically congruent orthographic neighbors than for phonologically incongruent orthographic neighbors.

In visual word recognition tasks, there is evidence that the phonological neighbors of presented target words are activated (Bowers, Damian, Havelka, 2002; Grainger, Muneaux, Farioli, & Ziegler, 2005; Yates, 2005). However, the effect of phonological neighbors on semantic processing is not yet clear. Yates (2005) demonstrated that phonological neighborhood size facilitates semantic categorization. However, Yates did not control for or manipulate semantic congruency of the neighbors. Thus, his conditions might have differed in semantic congruency of the neighbors and this may be (partially) responsible for the obtained effects. Boot and Pecher (2008) obtained equal semantic congruency effects for orthographic neighbors that rhymed with the target word compared to orthographic neighbors that did not rhyme with the target word, suggesting that phonology does not affect semantic congruency effects. However, because the spelling-to-sound mapping in Dutch is highly consistent (van Heuven, Dijkstra, & Grainger, 1998; Martensen, Maris, & Dijkstra, 2003) changing one letter in a word often results in changing only one phoneme. As a result, the phonological difference between rhyming and nonrhyming orthographic neighbors was modest. The current study addresses this concern by using English, which allows larger phonological differences even when all but one letter are kept the same between a target and its neighbor.

In the present study we aimed to further study the role of phonology in semantic congruency effects using English to

[1] An alternative explanation has been offered by Forster (2006). For more elaborate discussions we refer to Forster (2006) and Pecher et al. (2009).

more strongly manipulate phonology separate from orthography. We independently manipulated the phonological and semantic congruency of a word's orthographic neighbors. We expected better performance for semantically congruent neighbors than for semantically incongruent neighbors, as observed in prior studies (Boot & Pecher, 2008; Pecher et al., 2005; Rodd, 2004). The question is whether this semantic congruency effect would be modulated by phonological congruency. If activation from orthography to semantics is mediated by phonology, one would predict a larger semantic congruency effect for phonologically congruent neighbors than for phonologically incongruent neighbors. Note that no main effect of phonological congruency is expected. Phonologically congruent neighbors might activate their semantic features more strongly, but the direction of the effect depends on the semantic congruency of those features; more strongly activated semantically congruent features should lead to better performance whereas more strongly activated semantically incongruent features should lead to worse performance.

Experiment 1

In Experiment 1 we presented orthographic neighbors of the target word in a priming phase prior to the presentation of the target words in the final phase of the experiment in a long-term priming paradigm. For each target, one of two orthographic neighbors was presented in the priming phase. The prime was either a semantically congruent orthographic neighbor or a semantically incongruent orthographic neighbor. If prior presentation of a word increases the strength or speed with which associated semantic information is activated, the cascaded models outlined above predict that prior presentation of a semantically congruent neighbor will lead to better performance than will prior presentation of a semantically incongruent neighbor. In other words, if the presentation of a target word activates orthographic neighbors, and if those neighbors more readily activate their associated semantics (i.e., if they are more available) due to this long-term priming manipulation, then the prior presentation of semantically congruent primes should aid performance as compared to the prior presentation of semantically incongruent primes.

For one group of target words, both neighbors were phonologically congruent (i.e., the shared graphemes were all pronounced identically in the neighbor and target word), whereas for the other group of target words, both neighbors were phonologically incongruent (i.e., at least one of the shared graphemes was pronounced differently in the neighbor than in the target).

Method

Participants

One hundred fifty-seven students at one of three US universities (Indiana University, Florida State University, and the University of California, San Diego) participated for course credit. The data from eight participants were removed because their error percentages exceeded 25% and the data from one additional participant were removed to ensure that the design remained counterbalanced. Thus, 148 participants remained in the data analysis.

Stimuli

A set of 60 targets with 2 primes each was created. Each prime differed by one letter from the target. For each target, one prime was from the same semantic category (living/nonliving), and the other prime was from the opposite semantic category. Different targets were used in the phonologically congruent and phonologically incongruent conditions. For 30 targets, both primes were phonologically congruent with the target (i.e., phonology differed only for the letters that were not shared, e.g., the target *book* with primes *hook* and *cook*). These are sometimes referred to as phonographic neighbors (Adelman & Brown, 2007; Peereman & Content, 1997). For the remaining 30 targets, the primes were phonologically incongruent with the target (i.e., the pronunciation of the overlapping orthography was dissimilar, e.g., the target *mare* with primes *maze* and *male*). The two sets of targets were matched on CELEX (Baayen, Piepenbrock, & van Rijn, 1993) log word frequency (2.28 and 2.26), length (both sets 4.23 letters), and total number of neighbors (11.73 and 11.67), all *p*s > .90.[2] All target and prime words are listed in the Appendix.

We created two lists so that targets were counterbalanced over the semantic congruency conditions. On each list, there were 15 targets in each of the 4 conditions of the experiment (phonologically-congruent/semantically-congruent, phonologically-congruent/semantically-incongruent, phonologically-incongruent/semantically-congruent, and phono-

[2] After data collection, we looked up additional variables for the target stimuli in the norms provided by Balota et al. (2007). Of the 60 target words, 58 were listed in the norms. The two sets did not differ significantly on number of syllables, number of phonemes, and bigram frequency. The set with phonologically congruent primes had more phonological neighbors (22.6 vs. 16.4, $t(56) = 2.29$, $p < .05$) and more phonographic neighbors (8.0 vs. 4.4, $t(56) = 3.67$, $p < .05$) than the set with phonologically incongruent primes. As targets were counterbalanced over semantic congruency conditions, these differences are not problematic for interpretation of the semantic congruency effect itself. Moreover, because the targets in the phonologically congruent set had more overall neighbors (combined orthographic and phonological) than the targets in the phonologically incongruent set, the effect of strengthening one neighbor should have less impact. In other words, being louder (priming) in a large crowd (more neighbors) might not produce as much of an effect as being equivalently louder in a small crowd. Thus, to the extent that neighborhood size produces any effect, it should be to work against our hypothesis that semantic congruency effects are larger for phonologically congruent neighbors. We note, however, that this argument is somewhat speculative because there are currently no data specifying the nature of priming on phonographic or phonological neighborhoods.

logically-incongruent/semantically-incongruent). Semantic congruency of the target depended on the prime presented earlier in the experiment. Across lists, each target was presented once in the semantically congruent condition and once in the semantically incongruent condition. Each participant received only one list.

Procedure

Participants were instructed to make a living/nonliving decision to each word. The experiment started with 20 practice trials, followed by a short self-paced break. Then the 60 primes were presented, followed by a short break. After the break, all 60 primes were presented again, followed by another break. Finally, the 60 targets were presented.

Each trial started with a fixation stimulus (* * * * *) for 500 ms in the center of the computer screen. The fixation stimulus was replaced immediately by a word, which remained on the screen until a response was made. A "living" response was made by pressing the m-key on the computer keyboard, a "nonliving" response was made by pressing the z-key. If the participant made an error, the word "ERROR" was presented for 1,500 ms. If the response was not made before 1,800 ms had elapsed, the stimulus word was removed from the screen and the phrase "TOO SLOW" was presented for 1,500 ms. If the response was correct and fell within 1,800 ms after onset of the stimulus, no feedback was provided. A blank screen was presented for 500 ms before the next trial started. Within a block, all stimuli were presented in random order. Different random orders were generated for each subject.

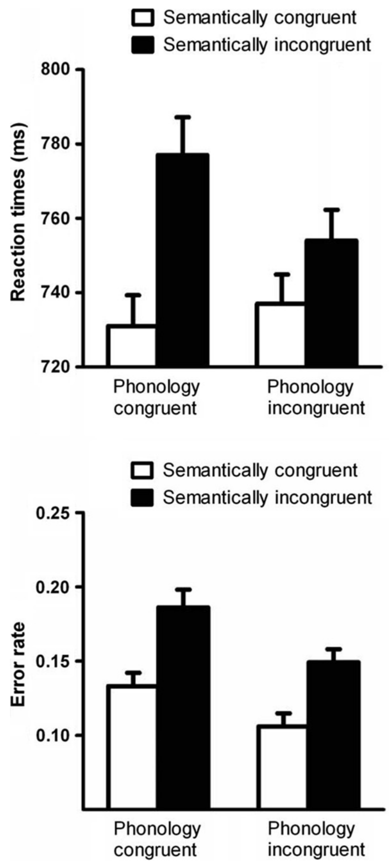

Figure 1. Reaction times and error rates for living decisions in Experiment 1 (error bars represent standard error of the mean).

Results

Reaction times and accuracy for target responses were analyzed. Reaction times were excluded if the responses to the target or prime were incorrect (14.3% and 15.9% of the RTs) or if the reaction time deviated more than three standard deviations from the participant's mean (0.7% of the correct RTs). The mean reaction times and error rates are presented in Figure 1. The reaction times were submitted to a 2 (semantic congruency) × 2 (phonological congruency) ANOVA. Participants responded faster to targets for which a semantically congruent prime had been presented earlier in the experiment than to targets for which a semantically incongruent prime had been presented earlier in the experiment, $F(1, 147) = 49.50$, $p < .001$, $MSE = 3{,}678.5$, $\eta^2 = .25$. This finding replicates the semantic congruency effect obtained by Pecher et al. (2005). Responses were faster to targets with phonologically incongruent than phonologically congruent neighbors, $F(1, 147) = 6.38$, $p < .05$, $MSE = 3{,}149.5$, $\eta^2 = .04$ (note that these were different sets of items). More important, the interaction between semantic congruency and phonological congruency was significant, $F(1, 147) = 9.72$, $p < .01$, $MSE = 3{,}571.8$, $\eta^2 = .06$; the semantic congruency effect (i.e., the difference between the semantically congruent and semantically incongruent conditions) was larger if the prime was phonologically congruent ($M = 46$ ms) than if it was phonologically incongruent ($M = 18$ ms).[3] Post hoc analyses showed that the semantic congruency effect was significant for both the phonologically congruent and phonologically incongruent conditions, $t(147) = 6.41$, $p < .001$ and $t(147) = 3.29$, $p < .01$, respectively.

Accuracy data for targets were included in the data analysis only if the responses to the prime were correct. A 2 (semantic congruency) × 2 (phonological congruency) ANOVA showed a similar pattern as that for reaction times. Responses were more accurate for targets for which a semantically congruent prime had been presented earlier in the experiment than for targets for which a semantically

[3] Analyses using a mixed-effects model with crossed random effects for subjects and items (Baayen, Davidson, & Bates, 2008) showed that the main effect of semantic congruency and the interaction between semantic and phonological congruency were both significant for the RTs. The main effect of semantic congruency was significant for the accuracy data.

incongruent prime had been presented earlier in the experiment, $F(1, 147) = 22.45$, $p < .001$, $MSE = 0.019$, $\eta^2 = .13$. Responses were more accurate to targets with phonologically incongruent than phonologically congruent neighbors, $F(1, 147) = 28.03$, $p < .001$, $MSE = 0.007$, $\eta^2 = .16$. More important, there was some indication that the semantic congruency effect was larger if the prime was phonologically congruent ($M = 5.3\%$) than if it was phonologically incongruent ($M = 4.3\%$); this interaction effect approached significance, $F(1, 147) = 3.12$, $p = .08$, $MSE = 0.008$, $\eta^2 = .02$. Post hoc analyses showed a semantic congruency effect for both the phonologically congruent and phonologically incongruent conditions, $t(147) = 4.43$, $p < .001$ and $t(147) = 3.40$, $p < .01$, respectively. Thus, the reaction time effects do not appear to be due to a speed-accuracy tradeoff, and, if anything, there was a similar effect of phonology on accuracy.

Experiment 2

In Experiment 1 we found that the semantic congruency effect was modulated by phonological congruency. The manipulation of semantic congruency was achieved by prior presentation of one of the target word's neighbors. To evidence the effect of phonology in a different way, Experiment 2 did not use priming but instead tested whether performance differs for different target words depending on the phonology of the target word's orthographic neighbors; in Experiment 2 we selected different target words based on their preexisting neighborhood characteristics. Four sets of target words were selected. Targets had either only semantically congruent or only semantically incongruent neighbors, and for each group those neighbors were either all phonologically congruent or phonologically incongruent. Again, we expected a larger effect of semantic congruency for phonologically congruent neighbors than for phonologically incongruent neighbors.

Method

Participants

One hundred fifteen students at the University of California at San Diego participated for course credit. The data from 11 participants were removed because their error percentages exceeded 25%. Thus, 104 participants remained in the data analysis.

Stimuli

Four sets of 26 targets each were created. These sets varied in the characteristics of orthographic neighbors (neighbors were defined as all words in the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993) of equal length that differed by only one letter) for each target. For 52 targets, all orthographic neighbors that could be classified in the living decision task (i.e., words that referred to concrete entities) were semantically congruent with the target (e.g., target: *monkey*, neighbor: *donkey*), whereas for the other 52 targets all orthographic neighbors were semantically incongruent (e.g., target: *mitten*, neighbor: *kitten*). For each of these groups, 26 targets had phonologically congruent neighbors, and the other 26 targets had phonologically incongruent neighbors. Thus, semantic congruency and phonological congruency of the target's neighbors were manipulated orthogonally. The four sets were matched on word length, word frequency, neighborhood size, and number of living targets within each set, all Fs < 1 (see Table 1 for details). After we collected the data, we compared the targets on five additional variables from Balota et al. (2007): phonological neighborhood size, phonographic neighborhood size, bigram frequency, number of phonemes, and number of syllables. Demonstrating that the sets of target words differed in the desired manner, phonographic neighborhood size differed significantly between the phonological congruency conditions, $F(1, 95) = 13.52$, $p < .05$, but not between the semantic congruency conditions, $F < 1$. The targets did

Table 1. Mean values for matching variables for items used in Experiment 2

	Phonology			
	Congruent		Incongruent	
	Semantics		Semantics	
	Congruent	Incongruent	Congruent	Incongruent
Number of letters	5.73	5.73	5.69	5.73
Log word frequency	2.01	2.04	2.02	2.04
Neighborhood size	1.85	1.96	1.69	1.81
Number of living targets	12	12	12	13
Balota et al. (2007) norms (N = 99):				
Phonological *N*	4.7	5.7	6.7	5.3
Phonographic *N*	1.50	1.68	0.65	0.88
Log bigram frequency	3.22	3.22	0.65	0.88
Number of phonemes	4.62	4.52	4.48	4.64
Number of syllables	1.73	1.64	1.65	1.80

not differ on any of the other variables, all Fs < 1. We also analyzed whether the four sets of items differed in the position of the letter that differed between target and neighbor. Using a short-term priming paradigm, Perea (1998) showed that the effect of neighbor primes was largest for neighbors that differed in letters on positions 3 and 4 (all words were 5 letter words). Thus, neighbors that differ in middle positions should have greater effects on performance than neighbors that differ in initial or final positions. However, the phonologically congruent items had fewer neighbors with differing letters in middle positions (11 and 10 for semantically congruent and semantically incongruent, respectively) than the phonologically incongruent items (15 and 16). Thus, letter position cannot explain the present pattern of results. Finally, some of the phonologically incongruent items had phonological neighbors that were not orthographic neighbors. The semantic congruency of the phonological neighbors was not different between the two sets of phonologically incongruent items, $t(49) = 0.12$, $p = .91$. All experimental target words are listed in the Appendix.

An additional set of 20 words was used for practice and 6 words were used as fillers to have an equal number of living and nonliving responses in the entire experiment.

Procedure

The presentation procedure for individual trials was identical to Experiment 1. There was no priming phase and each of the 130 items (practice, filler, and experimental targets) were presented once during the entire experiment. About halfway through the experiment there was a short self-paced break.

Results

Reaction times and accuracy for target responses were analyzed. Reaction times were excluded if the response was incorrect (15.4% of all data) or if the reaction time deviated more than three standard deviations from the participant's mean (1.6% of the correct RTs). The mean reaction times and error rates are presented in Figure 2. The reaction times were submitted to a 2 (semantic congruency) × 2 (phonological congruency) ANOVA. Responses were faster for targets with semantically congruent neighbors than for targets with semantically incongruent neighbors, $F(1, 103) = 89.44$, $p < .001$, $MSE = 1{,}530$, $\eta^2 = .47$. This replicates the semantic congruency effect obtained in previous studies (Pecher et al., 2005; Rodd, 2004). There was no main effect of phonological congruency in the reaction times, $F < 1$. More important, the effect of semantic congruency was larger if the neighbors were phonologically congruent ($M = 47$ ms) than if they were phonologically incongruent ($M = 25$ ms); this interaction effect was significant, $F(1, 103) = 6.16$, $p < .05$, $MSE = 2{,}118$, $\eta^2 = .06$. A semantic congruency effect was found for targets with phonologically congruent neighbors, $t(103) = 8.40$, $p < .001$, as well as for targets with phonologically incongruent neighbors, $t(103) = 4.06$, $p < .001$.

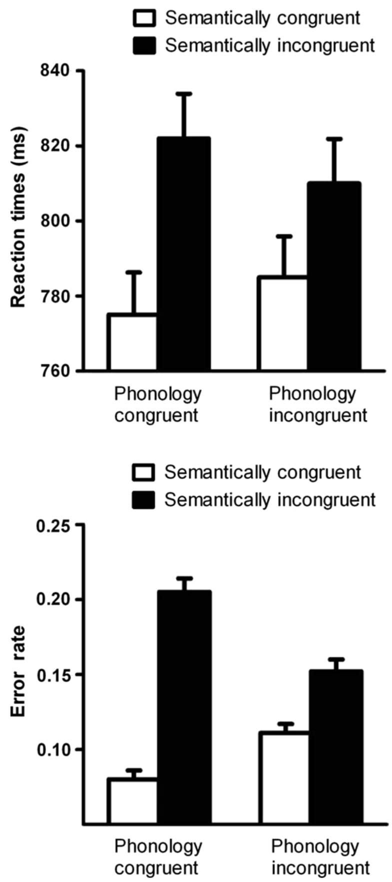

Figure 2. Reaction times and error rates for living decisions in Experiment 2 (error bars represent standard error of the mean).

There was a similar pattern for the accuracy data. Responses were more accurate for targets with semantically congruent neighbors than for targets with semantically incongruent neighbors, $F(1, 103) = 161.32$, $p < .001$, $MSE = 0.004$, $\eta^2 = .61$. The semantic congruency effect was larger if the neighbors were phonologically congruent ($M = 11.7\%$) than if they were phonologically incongruent ($M = 4.1\%$), $F(1, 103) = 49.45$, $p < .001$, $MSE = 0.003$, $\eta^2 = .32$. A semantic congruency effect was found for targets with phonologically congruent neighbors, $t(103) = 13.32$, $p < .001$, as well as for targets with phonologically incongruent neighbors, $t(103) = 5.35$, $p < .001$. There was a main effect of phonological congruency, $F(1, 103) = 6.14$, $p < .05$, $MSE = 0.004$, $\eta^2 = .06$.[4]

General Discussion

In the present study we found that the meaning of orthographic neighbors affected performance to target words in

[4] Analyses using a mixed-effects model showed that the main effect of semantic congruency was significant for the RTs and accuracy data.

a semantic classification task (i.e., animacy decision). Responses to targets were faster when their neighbors were semantically congruent than when they were semantically incongruent. In Experiment 1 we used a long-term priming paradigm to study congruency effects. When an orthographic neighbor from the same semantic class was presented earlier in the experiment, performance was better than when an orthographic neighbor from the opposite semantic class was presented earlier in the experiment. In Experiment 2, we investigated the effect of semantic congruency by taking advantage of the differences between words in terms of their preexisting neighborhood structure (rather than using a long-term priming paradigm). Performance for words with only semantically congruent neighbors was better than performance for words with only semantically incongruent neighbors. Most important for the purpose of the present study, we found that in both experiments the size of the semantic congruency effect was modulated by the extent to which neighbors and targets shared phonology. That is, larger semantic congruency effects were found with phonologically congruent neighbors than with phonologically incongruent neighbors. These results are consistent with earlier findings that likewise found evidence that the meaning of neighbors is activated during semantic processing of target words. The current results expand on these findings by showing that phonology plays a mediating role in semantic congruency effects.

These findings appear to contradict the results of Boot and Pecher (2008), who failed to find rhyming effects in a semantic categorization task. However, there is a much higher degree of regularity in the orthographic to phonology mapping for Dutch compared to English and so the effect size is likely to be greatly reduced with Dutch. In fact, the phonological similarity for rhyming and nonrhyming orthographic neighbors was approximately equal in the Boot and Pecher study. The present findings also appear to contradict the results of Bowers et al. (2005), who used English and found that semantic congruency effects were not modulated by the amount of phonological overlap. However, unlike our manipulations, they used subset and superset neighbors. For example, the word *heel* has a subset neighbor *eel* and a superset neighbor *wheel.* In their study, semantic "no"-responses (e.g., *heel* is not an *animal*) were slower if a word's subset or superset neighbor was an exemplar of the semantic category. The size of this effect was the same for neighbors with congruent and incongruent phonology. Thus, their study suggests that in visual word processing, semantic information is activated directly by orthography without any mediating role for phonological information. It is not clear why their use of subset/superset neighborhoods produced different results. Furthermore, the results of Pecher and Boot and Bowers et al. seem to be at odds with other studies that find effects of phonology in semantic tasks (Jared & Seidenberg, 1991; Siakaluk, Pexman, Sears, & Owen, 2007). For example, Van Orden (1987) found that performance in a category verification task was harmed if a nonexemplar was a homophone of an exemplar (*flower-rows*) compared to spelling controls (*flower-robs*). Similar to these studies, our study also finds evidence that phonology plays a role in semantic decision tasks with visually presented words.

There are a number of accounts explaining how phonology can affect activation of a neighbors' meaning during processing of a target word. One account assumes that orthography and phonology both activate meaning in parallel. Thus, if target and neighbor share phonology, the activation of a neighbor's meaning is greater due to two sources of activation than if they share only orthography. This explanation is predicted by Harm and Seidenberg (2004), who proposed a distributed model with three interconnected sets of units that represent orthography, phonology, and semantics. Their simulations demonstrated that the activation of meaning units is driven by both direct links between orthographic units and semantic units and by indirect links from orthographic units via phonological units.

A second account of these phonological effects assumes that activation of meaning proceeds from orthography through phonology without direct activation of meaning by orthography. This account predicts a strong and necessary role for phonology considering that the only way to activate meaning is through phonology. In contrast, the dual route explanation considered above can plausibly produce relatively weak effects of phonology. At first glance, an account supposing phonology as a necessary mediator appears at odds with the finding that there are still semantic congruency effects for neighbors that are phonologically incongruent. However, neighbors that are phonologically incongruent may still be activated to some degree due to some overlapping phonology (even phonologically incongruent neighbors are not entirely unrelated in terms of phonology). Nevertheless, the phonological overlap between neighbors and targets was extremely small for the phonologically incongruent conditions of our experiments, which argues against an explanation of our results that only allows meaning activation via phonology.

A third account assumes that meaning is activated through lexical units or "hubs" that are connected to meaning representations.[5] Lexical units can be activated by bidirectional links from both orthography and phonology but there are no direct links from either orthography or phonology to semantics. In such a model, phonological congruency can influence the degree of meaning activation because lexical units of phonologically congruent neighbors will be more strongly activated than those of phonologically incongruent neighbors. After all, lexical units of phonologically congruent neighbors will receive activation via both orthographic and phonological links whereas lexical units of phonologically incongruent neighbors receive very little activation via phonological links. This account differs from the accounts that we described above because there are no direct links from phonology to meaning. Nevertheless, it is consistent with our conclusion that phonology plays an important role in the access of meaning, albeit indirectly.

[5] While we use the term lexical "unit" for lack of a better term we do not wish to imply that only connectionist models can account for our results.

To summarize, in two experiments we showed that semantic congruency effects in a semantic decision task are modulated by phonological congruency. Phonologically congruent neighbors of the target had a larger impact on performance than phonologically incongruent neighbors. These results provide compelling evidence that phonology plays an important role in cascaded access to meaning.

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Appendix

Table A1. Targets and primes used in Experiment 1

Phonology					
Congruent			Incongruent		
	Semantics			Semantics	
	Congruent	Incongruent		Congruent	Incongruent
Target	Prime	Prime	Target	Prime	Prime
bean	dean	beam	axe	ale	ape
book	Hook	cook	bacon	baton	baron
clock	block	flock	banker	barker	banner
cone	zone	bone	bar	bag	ear
cone	zone	bone	bar	bag	ear
dam	jam	yam	bather	father	lather
dime	dome	lime	bearer	beaver	beaker
dock	rock	duck	boat	bolt	boar
doe	toe	hoe	bomb	tomb	womb
fist	fish	list	box	bow	boy
gin	bin	fin	bull	gull	hull
goose	moose	noose	cost	post	host
king	wing	ring	cow	cop	cot
lace	lake	face	crow	brow	chow
letter	fetter	setter	diver	liver	river
lodger	dodger	ledger	fowl	fool	bowl
louse	mouse	house	golf	gold	wolf
noodle	doodle	poodle	head	herd	heap
page	cage	sage	hose	hole	host
paw	jaw	saw	loot	soot	foot
pig	fig	wig	mall	mail	male
pill	sill	gill	mare	male	maze
pound	mound	hound	mover	lover	cover
rail	sail	tail	pear	dear	gear
rat	cat	hat	pink	pint	pine
road	load	toad	shack	shank	shark
rye	eye	lye	stew	step	stem
sender	lender	fender	wand	sand	hand
sinner	winner	dinner	wire	wipe	wife
train	drain	brain	word	cord	lord
tub	pub	cub	youth	mouth	south

Table A2. Targets used in Experiment 2

Phonology			
Congruent		Incongruent	
Semantics		Semantics	
Congruent	Incongruent	Congruent	Incongruent
baker	baize	antler	banner
bleach	barrier	belly	barley
bottle	beacon	birch	bidder
bounty	brew	buffet	bowl
fridge	bride	casino	castle
gable	bruiser	cowman	comet
grill	cloth	diaper	daisy
grocer	clown	floor	dorm
hunter	cortex	foremen	earner
jogger	cross	gauge	firearm
lawyer	cruiser	gland	flirt
lodge	gibbon	globe	graph
lotion	kennel	hovel	lather
matron	locker	monkey	mitten
melon	muffin	padlock	mortar
nylon	permit	pastry	novice
parrot	portal	plaid	paisley
person	ripple	ringlet	parent
poppy	sheep	silo	pariah
purist	salve	skirt	postage
salve	squire	trainee	ranger
sandbag	twine	twin	salmon
scanner	umpire	waffle	salon
sledge	vandal	waiter	senior
squid	victor	watcher	sultan
staple	willow	worker	whale