“With a little help from my friends”: Orthographic influences in spoken word recognition

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ABSTRACT

An auditory lexical decision task was used with feedback-consistent items having either many or few friends in their phonological neighborhood. The items with many friends yielded faster RTs than words with fewer. This finding is consistent with the hypothesis that orthography shapes the perception of spoken words because orthographic knowledge restructures phonological representations.

« Avec un petit coup de main de la part de mes amis » : impact de l’orthographe en reconnaissance auditive de mots

RÉSUMÉ

Dans la présente étude, une tâche de décision lexicale auditive a été utilisée avec des mots consistants (dans la direction phonie-graphie) ayant beaucoup, ou au contraire, peu « d’amis » au sein de leur voisinage phonologique. Les mots ayant beaucoup d’amis ont conduit à des temps de décision de lexicalité plus courts que ceux en ayant peu. Ce résultat est en accord avec l’hypothèse selon laquelle l’orthographe façonne la perception des mots entendus du fait d’une restructuration des représentations phonologiques par les connaissances orthographiques.

Over the last decade, evidence has accumulated in support of the hypothesis that orthography is activated when we hear spoken words. In the seminal study of Seidenberg and Tanenhaus (1979), participants took less time to make rime judgments on spoken words when they shared identical orthographic rimes than when they did not. Many studies have subsequently reported evidence of the involvement of orthography

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The authors wish to thank José Morais, Bob McMurray, Diane Pecher and an anonymous reviewer for very helpful comments on a previous version of the paper.

in spoken word recognition in other metalinguistic tasks (e.g., Muneaux & Ziegler, 2004), as well as in on-line tasks such as lexical decision (Petrova, Gaskell, & Ferrand, 2011; Ventura, Morais, & Kolinsky, 2007; Ziegler & Muneaux, 2007), shadowing (e.g., Ziegler, Muneaux, & Grainger, 2003), semantic categorization (Peereman, Dufour, & Burt, 2009) and in EEG recordings (Pattamadilok, Perre, Dufau, & Ziegler, 2009). Although orthographic effects in spoken word recognition are now broadly accepted, influential models of spoken word recognition do not take them into account (e.g., McClelland & Elman, 1986).

Most studies have used *feedback consistency* to investigate orthographic influences in spoken word recognition. Feedback consistency refers to the degree of systematicity of the phonological-to-orthographic (PO) mappings. The consistency of a word decreases when there are multiple orthographic renderings for a given sound unit. For example, the French word "*bague*" is feedback-consistent because its rime is always spelled the same ("-ague"), whereas the word "*beurre*", whose rime can be spelled in different ways (-"*eure*", "*-eurre*", or "*-oeur*"), is feedback-inconsistent. Ziegler and Ferrand (1998) found that inconsistent words yielded longer lexical decision RTs than consistent ones. Ziegler and Muneaux (2007) showed that orthography effects on spoken word processing are closely linked to the acquisition of literacy, since these effects were observed in literate children but not in pre-readers. The feedback consistency effect has also been observed in semantic and gender categorization tasks (Peereman et al., 2009), thus ruling out an interpretation in terms of strategic responses.

Feedback consistency effects have been accounted for within interactive frameworks, and more particularly in Grainger and Ferrand's (1996) Bimodal Interactive Activation model. According to this model, the processing of a heard word results in the simultaneous activation of both phonological and orthographic codes. This model makes three major assumptions, which are directly relevant to the present study: (i) there are lexical and sublexical links between phonological and orthographic codes; (ii) there are adjacent (lateral) inhibitory links within each representational level, and (iii) excitatory links are postulated between the different levels of representation (e.g., between lexical and sublexical phonological (orthographic) units). Due to the high degree of systematicity between the phonological and orthographic codes in consistent words, the activation level of phonological codes is reinforced by orthographic code activation, either at a sublexical or at a lexical level. This, in turn, speeds up the word recognition process. In contrast, for feedback inconsistent words, the multiple orthographic renderings are activated, leading to a competition which takes some time to be resolved. This view, referred to as the "co-activation" account, posits that orthography shapes the perception of spoken words in "real-time" through PO mappings.

Another (complementary) view concerning the influence of orthography in spoken word recognition assumes that orthographic effects are the result of residual "*off-line*" outcomes, which stem from literacy acquisition. According to this view, called the "structural account", literacy acquisition restructures phonological codes corresponding to (holistic) words into more fine-grained representations (Ziegler & Goswami, 2005; Ventura et al., 2007). Indeed, while learning to read and write, children store associations between the phonological forms of words they already know with orthographic codes. This, in turn, directly affects the quality of the phonological codes. Orthographic knowledge is assumed to guide the restructurating process more narrowly when the same orthographic pattern always transcribes the same sounds than when there are different orthographic patterns for the same sound. Even though there is some doubt as to the precise mechanism which underlies restructurating, it has been suggested that learning to read and write leads to changes in the resting activation levels of phonological codes (Muneaux & Ziegler, 2004). As a result, the better a phonological representation is restructured, the faster it will subsequently be accessible. Feedback consistency effects in spoken word recognition can thus be accounted for by assuming that the phonological representations of inconsistent words have not been fully specified during literacy acquisition, and therefore become accessible more slowly than those of consistent words (Ziegler, Ferrand, & Montant, 2004).

To date feedback consistency effects in speech perception have mainly been taken to support the coactivation account (e.g., Ziegler et al., 2003). However, Perre, Pattamadilok, Montant and Ziegler (2009) observed that feedback consistency effects in EEGs were restricted to the left temporo-parietal area, which is thought to be involved in phonological processing (Duffau, 2008). Though disputable but in line with the structural account, Perre et al. (2009) suggested that these effects do not reflect the on-line activation of orthographic units, but are due to the restructuring of phonological representations. However, this proposal is weakened by the fact that it was based on a null result, that is to say no evidence was found for relevant activation in the occipito-parietal area, believed to code orthographic information (Cohen & Dehaene, 2004).

In our opinion, feedback consistency is not the only way to address the issue of orthographic involvement in spoken word recognition. Another interesting way to investigate this question is to consider orthographic neighbors. Traditionally, two types of neighbors have been used to study word recognition: orthographic and phonological neighbors. Some

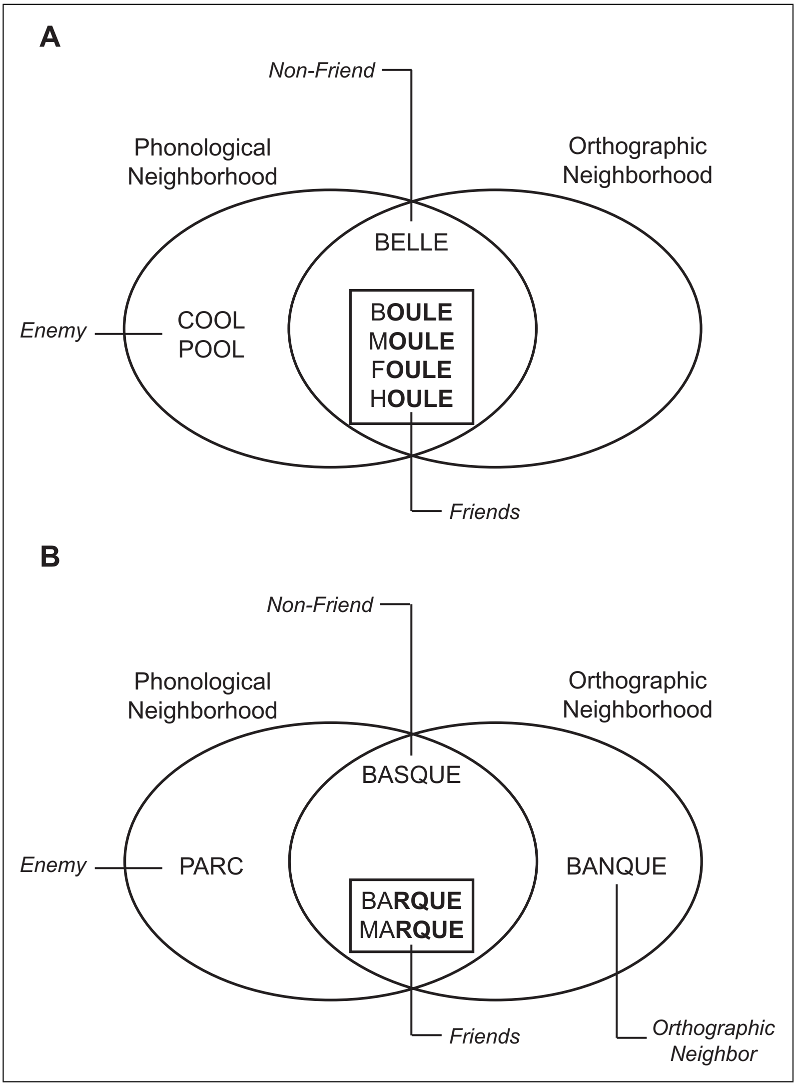

Figure 1. Illustration of different kinds of neighbors for words with many friends (A) and few friends (B), with the same Friends/Enemies ratio.

neighbors can be both phonological and orthographic neighbors. We shall refer to them as "friends" when they share the same rime, and "non-friends" when they do not share it. As illustrated in Figure 1, the

French words *barque* and *marque* are friends because they share the same orthographic rendering "ARQUE" to transcribe the rime "/*ark*/", whereas *barque* and *basque* are "non-friendly" neighbors because they use a different rime. Finally, neighbors are called "enemies" when they share the same rime but the rime has at least two different orthographic renderings (e.g., *barque* and *parc*). This distinction makes sense because feedback consistency has sometimes been conceived as a *ratio* between friends and enemies (Ziegler et al., 2003).

Previous studies have addressed the issue of the influence of orthographic codes in spoken word recognition by investigating neighborhood density effects (Ziegler & Muneaux, 2007). In lexical decision and shadowing, Ziegler et al. (2003) replicated the *inhibitory* effects of Phonological Neighborhood (PN) density (i.e., words with a dense PN recognized slower than words with a sparse PN). Importantly, they also observed a *facilitation* effect of Orthographic Neighborhood (ON) density (words with a dense ON were recognized faster than those a sparse ON). However, the latter effect was no longer reliable when feedback consistency (i.e., the *friends/enemies ratio*) was entered as a covariate. According to Ziegler et al. (2003), ON density effects surface in spoken word recognition times because words with many orthographic neighbors are also more feedback-consistent than those with fewer neighbors.

If we follow Ziegler et al.'s (2003) line of reasoning, ON effects in spoken word recognition are attributable to a confound between neighborhood density and feedback consistency. However, our hypothesis is that one type of orthographic neighbors—friends—has a constraining effect on spoken word recognition independently of feedback consistency. This hypothesis draws support from observations of a specific impact of *friends* in various tasks. In word naming, Peereman and Content (1997) have found that the ON facilitation effects are due to a subset of neighbors, namely the friends. Also, in neighbor generation, Muneaux and Ziegler (2004), have shown that, when participants produced a "similar sounding" word in response to target words, they produced friends at above-chance level. Thus, it is important to assess the possible contribution of friends, independently of feedback consistency, in spoken word recognition. From an empirical point of view, this will provide us with a deeper understanding of the role played by orthographic neighbors and their potential use for the investigation of spoken word recognition. More importantly, the use of orthographic friendly neighbors, permits to contrast two predictions that derive from the coactivation account and from the structural account respectively. Words with many friends have by definition also many orthographic neighbors. According to the coactivation account, a facilitation effect of the number of friends is predicted because words with many friends also are, in general, more feedback-consistent than those having fewer. Importantly, however, when feedback consistency is held constant across the two types of words, the orthographic reinforcement that takes place by means of highly systematic sublexical mappings should be beneficial to both of them. In this case, the coactivation account predicts an *inhibitory* effect of the number of friends because of the lateral inhibition that takes place within the orthographic lexical units (Ziegler et al., 2003), that is to say, the more friends a word has, the more lateral inhibition it will receive. Thus, the prediction from the coactivation account is that words with many friends should be recognized *slower* than those with fewer friends.

The structural account assumes that the learning of the correspondences between phonology and orthography during childhood leads to changes in the quality of the phonological representations (Muneaux & Ziegler, 2004). In the case of words having friends (e.g., *boule*), children learn that the same pattern of letters is often used by certain other words to transcribe the same rime (e.g., the rime */oul/* is spelled "OULE" as in *foule*, *moule*, etc.). In contrast, other "non-friend" neighbors (e.g., *belle*) use a similar pattern of letters to transcribe a different rime, whereas its *enemies* (e.g., phonological neighbors like "cool") use a different pattern of letters (e.g., "OOL") to transcribe the same rime (e.g., */oul/*). Consequently, a reasonable assumption is that friends are the most constraining types of neighbors during literacy acquisition. Thus, the extent to which the phonological representations of words are restructured would depend on their number of friends, that is to say words with many friends (see Figure 1A) would be more orthographically constrained during literacy acquisition, and should be restructured more extensively than words with fewer friends (see Figure 1B). If the restructuring process leads to an increase in the resting activation level of the words, then the more friends a word has, the faster its phonological codes should be accessed. Thus, provided that words have the same feedback consistency, a prediction from the structural account is that spoken words with many friends (e.g., *boule*) should be recognized *faster* than words having fewer friends (e.g., *barque*).

METHOD

An auditory lexical decision task was used to test whether the number of friends has an influence in spoken word recognition when the feedback consistency of the words is controlled for.

Participants. Thirty-five psychology students native speakers of French from Clermont University took part and received course credits. All reported normal hearing abilities.

Stimuli. Forty-two monosyllabic words were selected. Half of the words had many phonographic neighbors, i.e., "friends" below, while the other half had few.

The two sets of stimuli were matched on lexical frequency, number of phonemes and letters, acoustic duration and uniqueness point (see Table1). Importantly, the two sets were controlled for body (VC) consistency (by type and token).

We created 42 nonwords from existing words by substituting a single phoneme. For each nonword, the number of phonological neighbors was computed. Two types of nonwords were created: Nonwords having a dense phonological neighborhood and nonwords having a sparse phonological neighborhood. Importantly, dense and sparse nonwords were matched on number of phonemes and acoustic durations (see Table 1). Each item was recorded by a French male speaker with SoundEdit 16.2. The words are listed in the Appendix.

Apparatus. The stimuli were presented through headphones (Sony MDR-A 106 LP). The experiment was run on a Macintosh computer and the presentation of the stimuli was controlled by PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993).

Procedure. Participants were tested individually in a quiet room. The experiment proper was preceded by a training phase. Each trial began with a fixation point (*) displayed in the middle of the screen for 500 ms. Next, a stimulus was randomly presented through headphones at a comfortable sound level. Participants decided as fast as possible whether or not each item they heard was a real word (assigned to the dominant hand) using two keys on the keyboard. The interval between trials was 3,000 ms.

RESULTS

The data from two participants were discarded because of a high error rate (> 20%) and those of two others because of technical errors. For each experimental condition, RTs that were 2 SD below or above both the participant and item means were discarded (7% of the data). ANOVAs were performed on both RTs and errors, with lexicality and the number of friends as experimental factors and with participants (F_1) and items (F_2) as random factors. The by-items analyses on RTs were run with acoustic duration introduced as a covariate.

Reaction times. RTs were shorter for words than nonwords (see Figure 2), $F1(1, 30) = 122.2, MSE = 924.05, p < .001$; $F2(1, 82) = 56.7, MSE = 231.92$, $p < .001$. The main effect of the number of friends was not significant (both Fs < 1). However, lexicality interacted significantly with the number of friends, $F1(1, 30) = 34.66$, $MSE = 50562.8$, $p < .001$; $F2(1, 82) = 8.27$, $MSE = 31204.4$, $p < .01$.

Table 1. Statistical characteristics of the experimental words and nonwords

	WORDS			NONWORDS		
	Many Friends	**Few Friends**	**P values**	**Many PN**	**Few PN**	**P values**
Mean number of Friends	6 [5-8]	1 [0-1]	< .001	32 [27-45]	11 [2-16]	< .001
Onset (C1) consistency	.99 (.99)	.99 (.99)	Ns.	-	-	-
Vowel (V) consistency	.77 (.83)	.65 (.67)	Ns.	-	-	-
Coda (C2) consistency	.81 (.83)	.74 (.86)	Ns.	-	-	-
Rime (VC) consistency	.85 (.86)	.88 (.95)	Ns.	-	-	-
Acoustic duration (in ms)	515.5	521.5	Ns.	580.2	588.7	Ns.
Number of phonemes*	3.95 [3-5]	3.8 [3-5]	Ns.	3 [3-3]	3.3 [3-4]	Ns.
Number of letters	5 [4-6]	5.28 [4-7]	Ns.	-	-	-
Uniqueness point*	3.9 [3-5]	3.8 [3-5]	Ns.	-	-	-
Adult Word frequency (log)*	.99 [.02- 1.6]	.85 [.19 -1.5]	Ns.	-	-	-
Diphone frequency (log)*	2.77 [1.9 – 3.5]	2.62 [1.5 – 3.5]	Ns.			
Initial diphone frequency (log)*	2.77 [2 – 3.2]	2.6 [1 – 3.46]	Ns.			
Orthographic N (Lexop)	9.9 [6-17]	4.19 [1-11]	< .001	-	-	-
Phonological N	20.1 [2-31]	12 [2-25]	< .01	-	-	-
Onset frequency (log) **	2 [1.59-2.14]	1.96 [1.17-2.14]	NS.	-	-	-

Notes. Consistency scores from LEXOP (Peerman & Content, 1999) by type (by token); orthographic N = number of orthographic neighbors as defined by Coltheart, Davelaar, Jonasson and Besner (1977) taken from LEXOP (Pereman & Content, 1999); Phonographic N = number of phonographic neighbors, from LEXIQUE (New, Pallier, Brysbaert, & Ferrand, 2004); Phonological N = number of phonological neighbors (as defined by Luce & Pisoni, 1998), Onset frequency taken from VOCOLEX (Dufour, Peereman, Pallier, & Radeau., 2002); * = taken from LEXIQUE; ** = from VOCOLEX

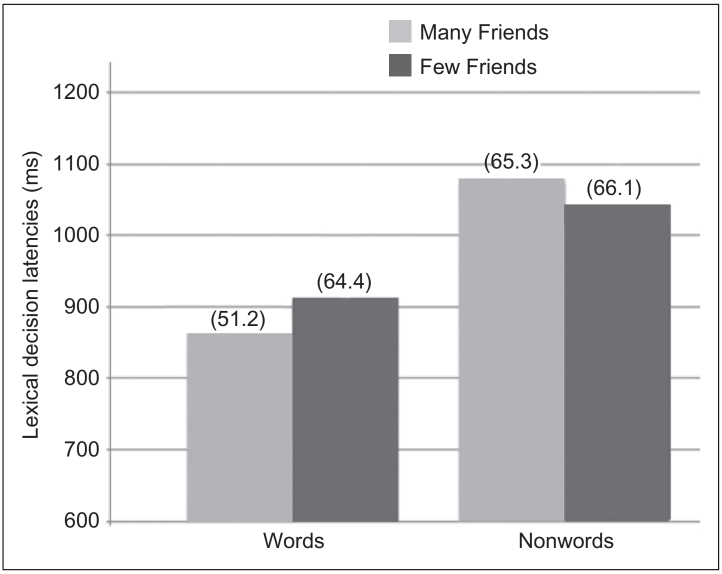

Figure 2. Lexical decision latencies and standard deviations (in parenthesis) for words and nonwords with many or few friends.

Nonwords with many phonological neighbors took more time to reject than nonwords with few, but the difference was significant on participants only, $F1(1, 30) = 13.97$, $MSE = 17054$, $p < .001$; $F2(2, 40) = 3.24$, $MSE = 13203$, $p > .05$. Importantly, words with many friends were identified significantly faster than words with few friends, $F1(1, 30) = 42.24$, $MSE = 35122.97$, $p < .001$; $F2(2, 40) = 5.46$, $MSE = 17150$, $p < .05$. We then computed a friends/enemies ratio, by type and by token, and introduced this as a covariate[1] in the by-item analysis. Importantly, the *friend facilitation effect* remained significant, $F(3,39) = 6.725$, $MSE = 23.136$, $p < .05$, and no effect of the ratio factor was found, $F < 1$.

Errors. Error rates did not differ significantly between words (3.8%) and nonwords (3.85%), *F*s > 1. Neither number of friends, nor the interaction between the two factors were reliable, all *F*s > 1.

[1] We computed the friends/enemies (F/E) ratio by *type*, but also by *token*, because in this latter case, the consistency of the items is weighted by their frequency. Since the friend facilitation effect remained significant when the F/E ratio by token was entered as a covariate, we only report the analyses run with the friends/enemies ratio *by type*.

DISCUSSION

A number of studies have shown that spoken word recognition is influenced by orthographic knowledge, based primarily on feedback consistency effects. One critical issue is to determine whether orthography influences spoken word recognition because of the on-line activation of orthographic units during speech processing (coactivation account) or because orthography modifies the organization of phonological representations during literacy acquisition (structural account). In the past, the structural account has received less empirical support. Adopting a definition of feedback consistency in terms of a friends/enemies ratio (Jared, 1997), we hypothesized that friends should have been more restructured during literacy acquisition, and should therefore be more accessible than enemies. When feedback consistency is controlled for, the coactivation account predicts an inhibitory effect of the number of friends, whereas the structural account predicts a facilitatory effect. The latter prediction was clearly confirmed. Words with many friends were recognized faster in auditory lexical decision than words with fewer friends, even when feedback consistency was controlled for. However, some other properties of orthographic neighborhood, like neighborhood frequency, might have a positive influence on the speech recognition process and be therefore responsible for our findings. To address this point, we ran an additional by-item analysis on RTs with the number of friends as an experimental factor and the cumulative frequency of orthographic neighbors as a covariate. Importantly, the number of friends was still significant, $F(1, 39) = 4.41$, $MSE = 3552$, $p = .042$, but the effect of cumulative frequency of friends was not, $F < 1$.

Could the *friend facilitation effect* be attributable to other subtle phonological properties? There are many reasons for thinking this is not the case. First, the phonotactic probabilities which have been found to boost speech perception (Ziegler et al., 2003), were controlled for. Second, even if the phonological neighborhood density is higher for words with many friends than for words with fewer, phonological neighborhood density effects in French have been found to be *inhibitory* (Ziegler et al., 2003).

Nonwords with many phonological neighbors led to slower decision latencies than nonwords with fewer. This effect remained significant when the diphone frequency was statistically factored out, thus ruling out the sublexical level as a possible locus. We assume that this effect occurred on nonword latencies due to the use of decision strategies (see Vitevitch & Luce, 1998). For *words*, importantly, a reliable friend facilitation effect was also found in a control shadowing task used to test for strategic factors. In effect, this task is generally assumed to be less sensitive to lexically-based strategies than lexical decision (e.g., Ventura, Morais, Pattamadilok, & Kolinsky, 2004). Thus, the friend facilitation effect cannot be due to decisional processes.

Overall, we provide further empirical evidence that spoken word recognition is influenced by orthographic knowledge -the number of friends- independently of feedback consistency. However, as we state below, we are aware that our data do not allow us to rule out the hypothesis of an on-line activation of orthographic codes in spoken word recognition. It is perhaps possible that previous reports of feedback consistency effects in spoken word recognition were due to the number of friends. A closer look at previous French studies reveals that the feedback consistency of words is strongly correlated with the number of friends. This was the case in both the Muneaux and Ziegler (2004), $r(72) = .376$, $p = .001$, and Ziegler et al. (2003) studies, $r(80) = .639$, $p < .001$. As a result, when Ziegler et al. (2003) entered feedback consistency as a covariate, they also statistically controlled for the number of friends. Thus, perhaps their orthographic effect was, at least in part, due to the number of friends.

We do not claim that our findings are not compatible with an on-line activation account of orthographic code activation in spoken word recognition. However, it is already clear that it will be necessary to identify in more detail how these effects take place in future studies. Nevertheless, it is possible to envisage the following functional scenario within an interactive framework. After hearing a target word (e.g., *barque*), the different types of orthographic neighbors - friends (e.g., *marque*), non-friend neighbors (e.g., *basque*) and enemies (e.g., *parc*) - become activated at the whole-word level. They then send activation to their corresponding graphemes which, in turn, reverberate to their connected orthographic word-forms. This positive feedback loop reinforces the activation of the target's orthographic word-form (e.g., *barque*). Finally, this additional activation strengthens the target's phonological word-form (e.g., */bark/*) against its lexical competitors (i.e., its phonological neighbors). As a result, the word recognition process is speeded up. Such a mechanism is possible because of the existence of bidirectional connections both between lexical and sublexical units and between phonological and orthographic word-form levels (Grainger & Ferrand, 1996). Within this framework, to account for the friend facilitation effect, one has to assume that the graphemes that are shared by friends (e.g., "A", "R", and "QUE"), and transcribe the same phonological rime, produce a stronger positive feedback loop than the graphemes that are shared by other neighbors, but which do not transcribe the same rime. Thus, the positive feedback loop created by friends reinforces the target's word-form (both orthographic and phonological) to a greater extent than the other types of neighbors do. As a result, the more friends a word has, the more additional activation its phonological word-form will receive, and the quicker it will be recognized. It is worth stressing that the coactivation account does not explicitly attribute any such role to friends.

To conclude, we suggest that the coactivation account is fundamentally flawed, in that it cannot be easily refuted. As illustrated above, even with our data it is still possible to preserve the coactivation account of orthographic effects in spoken word recognition. However, it is important to stress that the balance of evidence clearly favors the structural account (and interpretations of recent works on this issue generally also support the structural view, e.g., Montant, Schön, Anton, & Ziegler, 2011; Perre, Bertrand, & Ziegler, 2011; Petrova et al., 2011). Finally, our data suggest that friendly neighbors need to be taken into account when studying the role of orthographic neighbors in spoken word recognition.

Received September 18, 2012.
Revision accepted October 20, 2012.

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Appendix. List of the words (Approximate English translation in parenthesis)

Words with many Friends	Words with few Friends
bague (ring)	banque (bank)
berge (bank)	boucle (loop)
biche (doe)	bulbe (bulb)
boule (ball)	buste (bust)
brise (breeze)	boxe (boxing)
crise (crisis)	crampe (cramp)
digue (dyke)	drague (dredge)
mine (mine)	meute (pack)
grève (strike)	grade (rank)
frime (show off)	frange (fringe)
foire (fair)	fleur (flower)
foudre (lightning)	fougue (ardor)
figue (figue)	fugue (run away)
perte (loss)	parc (park)
poire (pear)	poigne (handle)
poudre (powder)	planque (stash)
peste (plague)	pompe (pump)
pitre (buffoon)	prose (prose)
riche (rich)	rampe (ramp)
ruse (trick)	ring (ring)
verbe (verb)	veuve (widow)