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► **To cite this version:**

Jonathan Grainger, Elsa Spinelli, Ludovic Ferrand. Effects of Baseword Frequency and Orthographic Neighborhood in Pseudohomophone Naming.. *Journal of Memory and Language*, 2000, pp.88-102. 10.1006/jmla.1999.2675 . hal-00859160

**HAL Id: hal-00859160**

**<https://hal.science/hal-00859160>**

Submitted on 28 Mar 2024

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# Effects of Baseword Frequency and Orthographic Neighborhood in Pseudohomophone Naming

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*Journal of Memory and Language* (2000). <https://doi.org/10.1006/jmla.1999.2675>

Short title: Pseudohomophone naming.

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## ABSTRACT

Three experiments tested for effects of baseword frequency and orthographic neighborhood with French pseudohomophone stimuli that were orthographic neighbors of the corresponding baseword. Speeded naming of pure lists of pseudohomophones gave a pattern of results that mirrored performance to the basewords themselves: effects of frequency and orthographic neighborhood that significantly interacted. When non-homophonic nonwords were mixed with the pseudohomophones, the pattern of results now mirrored that obtained to the nonwords: an effect of orthographic neighborhood, no effect of frequency, and no interaction. When participants were asked to classify the same set of nonwords as sounding like a real word or not, baseword frequency significantly affected correct positive responses to pseudohomophones, but orthographic neighborhood had no effect. Capturing these variations in the processing of pseudohomophone stimuli remains a challenge for any comprehensive model of reading.

Key words: reading, naming task, pseudohomophone, word frequency, orthographic neighborhood

Much current research in low-level psycholinguistics is aimed at specifying the mechanisms that allow skilled adult readers to generate the appropriate articulatory response on presentation of a pronounceable string of letters. The preferred paradigm for research in this field is the speeded naming task where participants are requested to read aloud the target word (or pronounceable nonword) as rapidly as possible. One key result in this area, with important theoretical consequences, was reported by McCann and Besner (1987). These authors measured speeded naming latencies to pseudohomophone stimuli, that is, strings of letters that do not form real words but can be pronounced like a real word (e.g., BRANE). They observed an important dissociation: pseudohomophones were named faster than orthographic controls (e.g., BLANE), but the printed frequency of the corresponding baseword (i.e., BRAIN in the above example) did not influence pseudohomophone naming times. In other words, a pseudohomophone advantage was obtained in the absence of a baseword frequency effect. Since McCann and Besner (1987) did observe significant word frequency effects in the naming latencies to the basewords of the pseudohomophone stimuli, they argued that the effects of word frequency cannot be located at the level of word representations (as assumed by frequency-sensitive word detector models such as the logogen model of Morton, 1969, and the interactive activation model of McClelland & Rumelhart, 1981), since this is the likely locus of the pseudohomophone naming advantage. If word frequency effects were located at the level of whole-word representations (in terms of resting level activation for example, McClelland & Rumelhart, 1981), and the pseudohomophone advantage reflects access to such whole-word representations, then one should observe baseword frequency effects in pseudohomophone naming.

These conclusions have been called into question by two more recent papers on pseudohomophone naming. Seidenberg, Petersen, MacDonald, and Plaut (1996) have shown that the pseudohomophone advantage can also be observed in delayed naming, thus implying that this mainly reflects ease of computation of an

articulatory code rather than access to any whole-word orthographic or phonological representation. Note that Seidenberg et al. (1996) also failed to observe a baseword frequency effect in naming latencies to pseudohomophones. However, a number of recent studies have found baseword frequency effects in pseudohomophone naming, thus undermining the conclusions drawn by McCann and Besner (1987) and Seidenberg et al. (1996). The present study provides a further demonstration of the pseudohomophone advantage in nonword naming, and a baseword frequency effect in pseudohomophone naming, while showing that both effects disappear in delayed naming.

An examination of prior studies of pseudohomophone naming (Borowsky & Masson, 1999; Herdman, LeFevre, & Greenham, 1994; Lukatela & Turvey, 1993; Marmurek & Kwantes, 1996; Seidenberg et al., 1996; Taft & Russell, 1992) helps isolate the specific conditions in which baseword frequency effects can be obtained. These specific conditions fall into two categories. The first is purely methodological and concerns the choice of pseudohomophone stimuli. Only pseudohomophones which are considered as such by the majority of participants, and for which the basewords themselves elicit a reliable word frequency effect, should be used as stimuli (Borowsky & Masson, 1996, 1999). The second is more theoretically interesting and concerns strategic influences on baseword frequency effects caused by manipulations of list-context. Marmurek and Kwantes (1996) demonstrated that a reliable baseword frequency effect can be observed with McCann and Besner's (1987) pseudohomophones when all the non-homophonic nonwords are removed from the stimulus list. The present study provides a further examination of such strategic influences on baseword frequency effects in pseudohomophone naming.

While manipulating list composition, the present study also provides a further examination of the influence of orthographic neighbors on nonword naming latencies. McCann and Besner (1987) performed regression analyses on nonword naming latencies and failed to find any influence of number of orthographic

neighbors on naming latencies to pseudohomophone stimuli, while demonstrating a facilitatory effect of this factor on naming latencies to non-homophonic nonwords. Contradictory results were later reported by Laxon, Masterson, Pool, and Keating (1992). These authors observed a significant facilitatory influence of number of orthographic neighbors on naming latencies to both pseudohomophones and nonword controls. Since both word naming latencies and nonword naming latencies are facilitated by increasing the neighborhood size of stimuli (Andrews, 1989; 1992; Peereman & Content, 1995; but see Peereman & Content, 1997, for possible confounding variables<sup>1</sup>), it would indeed be a surprising result that pseudohomophone naming were not affected by this variable. The present study tests for effects of orthographic neighborhood in pure lists of pseudohomophones and lists of pseudohomophones mixed with non-homophonic nonwords.

The conjoint manipulation of baseword frequency, orthographic neighborhood, and list composition, aims to provide stronger constraints on possible interpretations of the pseudohomophone advantage and baseword frequency effects. Furthermore, the systematic use of a delayed naming condition allows us to examine the extent to which any of these effects can be attributed to differences in the ease with which an articulatory response can be output once it has been computed. Finally, in an attempt to provide optimal control of orthographic influences, all the pseudohomophone stimuli were orthographic neighbors of their basewords<sup>2</sup>, and all the non-homophonic nonwords differed from the same baseword as the matched pseudohomophone by the same letter (e.g., *sujet-suget-sunet*, where *sujet* is a French word, *suget* a pseudohomophone of this word, and *sunet* a pronounceable nonword in French, see Appendix for a complete list of the stimuli).

The experiments are organized as follows. We first test all the basewords of the pseudohomophone stimuli in a word naming experiment with no nonwords present. The pseudohomophones derived from these basewords are then tested in a

naming experiment with only pseudohomophones present (pure lists). In Experiment 2, these pseudohomophones are mixed with an equal number of non-homophonic nonwords and tested in a mixed pseudohomophone - nonword naming experiment (mixed lists). Finally, in Experiment 3, the same set of pseudohomophones and nonwords are tested in a phonological lexical decision task (say "yes" if the stimulus sounds like a word). The present study therefore provides a further example of an ideal strategy manipulation (Stone & Van Orden, 1993) where the same stimuli are tested in different list-contexts and different tasks.

## EXPERIMENT 1: PURE LISTS

### Method

Participants. 40 psychology students at René Descartes University, Paris, participated in the experiment for course credit, 20 in the word naming task and 20 in the pseudohomophone naming task. In this and the following experiments all participants reported normal or corrected-to-normal vision and were native speakers of French.

Stimuli and Design. Using the lexical database Brulex (Content, Mousty, & Radeau, 1990), six categories of 5-letter words were selected as a function of word frequency (very low, low, and high) and neighborhood size (zero vs. several). There were 20 words in each category. Neighborhood size is defined as the number of words of the same length that can be obtained by single letter substitution (Coltheart, Davelaar, Jonasson, & Besner, 1977). Descriptive statistics of stimulus sets are given in Table 1. Note that only words that could generate a pseudohomophone by changing a single letter were selected. This is possible in French with letter pairs such as C/K, I/Y, G/J, S/C, S/Z. Thus, one hundred and twenty 5-letter pseudohomophones were derived from these words, such that each

pseudohomophone differed from its baseword by a single letter. The neighborhood characteristics of the pseudohomophones were very similar to the corresponding basewords. Thus, the pseudohomophones derived from hermit basewords (N=0) had only one orthographic neighbor, the baseword itself, while the pseudohomophones derived from words with more than four orthographic neighbors had similar numbers of orthographic neighbors. One group of participants was tested with the word stimuli and one group of participants with the corresponding pseudohomophones.

<Insert Table 1 about here>

Procedure. The stimuli appeared singly, in lower-case, on a video screen. Presentation and timing were controlled by a 386 PC computer. Participants were asked to pronounce each letter string as quickly as possible, and were informed about the nature of the pseudohomophone stimuli with the help of some examples that were not tested in the main experiment. The vocal response activated a voice key connected to the computer. Each trial began with a warning signal (a + sign) presented for 300 ms. It was immediately followed by the target letter string. The target remained on the screen until a vocal response was made. The intertrial interval was 1 sec.

Following the immediate pronunciation task, participants performed a delayed naming task with the same stimuli. The delayed naming task was identical to the immediate naming task except that participants waited until the appearance of a response cue (a row of five stars) before pronouncing the letter string as quickly as possible. The response cue was displayed 1 sec after the disappearance of the to-be-named stimulus. Response times (RTs) in this case were measured from the appearance of the response cue until the triggering of the voice key. The experimenter sat in the same room as the participant in order to check and note



responses. Stimulus presentation was randomized, with a different order for each participant.

## Results

Response latencies above 1500 msec or below 200 msec were excluded from the analysis. This led to the rejection of 1% of the word data and 2% of the pseudohomophone data in the immediate naming task. The condition means are given in Table 2. Analyses of variance (ANOVAs) by participant (F1) and by item (F2) were performed on the naming latencies and the percentage of errors, with target frequency (high-frequency, low-frequency, very-low frequency) and neighborhood size (zero/one vs. several) as within-participant variables, and type of target as a between-participant variable.

<Insert Table 2 about here>

Immediate naming task. There were main effects of frequency ( $F(2,76)=43.51$ ,  $MSe = 32231$ ,  $p<.001$  and  $F(2,108)=18.88$ ,  $MSe = 13638$ ,  $p<.001$ ), neighborhood size ( $F(1,38)=6.61$ ,  $MSe = 11165$ ,  $p<.02$  and  $F(1,108)=9.32$ ,  $MSe = 6735$ ,  $p<.005$ ), and target type ( $F(1,38)=18.29$ ,  $MSe = 575162$ ,  $p<.001$  and  $F(1,108)=328.43$ ,  $MSe = 237185$ ,  $p<.001$ ). There was a significant Frequency X Neighborhood size interaction ( $F(2,76)=5.31$ ,  $MSe = 3349$ ,  $p<.01$  and  $F(2,108)=3.05$ ,  $MSe = 2151$ ,  $p<.05$ ), reflecting the disappearance of neighborhood effects in high frequency stimuli (words or pseudohomophones with high frequency basewords). None of the other interactions were significant (all  $F_s<1$ ). An ANOVA conducted on the error data showed no main or interaction effects (all  $F_s<1$ ).

Delayed naming task. An ANOVA conducted on RTs and error data showed no main or interaction effects (all  $F_s<1$ ).

## Discussion

The results of Experiment 1 provide a replication of some standard effects in word naming: an effect of word frequency, neighborhood density, and an interaction between these two factors (Andrews, 1989; 1992). These effects completely disappear in delayed naming. Experiment 1 also shows that the effects of word frequency are of similar size in the naming latencies to pseudohomophones derived from these same words. The pseudohomophone stimuli show an almost identical pattern of results to the word stimuli. This is confirmed by an absence of interaction between the type of target factor and the other main factors. Furthermore, a linear regression using the six condition means (Frequency X Neighborhood) for each type of target shows that the RTs to pseudohomophones can be derived from the RTs to the corresponding basewords by the following equation:  $RT(\text{pseudohomophone}) = 0.95 RT(\text{word}) + 124$  ( $r^2 = .98$ ).

These results suggest that very similar mechanisms are used to name blocked lists of word stimuli, and pseudohomophones that are derived from these words by changing a single letter. The only major difference is that pseudohomophone naming latencies are slower than word naming latencies. The difference was 98 ms in this experiment (not identical to the intercept of the linear regression since the slope is not equal to one) compared to the 92 ms difference observed by Marmurek and Kwantes (1996) in similar conditions. This word advantage is also observed when pseudohomophones are mixed with their basewords in the same list (Marmurek & Kwantes, 1996; McRae, Jared, & Seidenberg, 1990).

The question to be examined in Experiment 2 is whether mixing the same set of pseudohomophones with non-homophonic nonwords will generate a different pattern of results in the pseudohomophone naming latencies. The prior work of Marmurek and Kwantes (1996) suggests that this will be the case. As noted in the introduction, these authors observed that intermixing non-homophonic nonwords

with the pseudohomophone stimuli in a speeded naming task, caused the baseword frequency effect to disappear.

## EXPERIMENT 2: MIXED LISTS

### Method

Participants. 32 psychology students at René Descartes University, Paris, who had not participated in Experiment 1, participated in Experiment 2 for course credit.

Stimuli and Design. Orthographically regular, pronounceable nonwords that are not homophonic with any real French word were created by changing the specific letter in the pseudohomophones tested in Experiment 1 that distinguished the pseudohomophone from its baseword (e.g., suget derived from the French word sujet becomes sunet). In this way the non-homophonic nonwords were orthographic neighbors of the same basewords as the pseudohomophone stimuli. Thus, pseudohomophones and nonword controls were matched in terms of length in letters, orthographic baseword frequency, and had similar numbers of orthographic neighbors. This resulted in twelve categories of 5-letter pseudowords formed from the factorial combination of baseword frequency (very low, low, and high), neighborhood size (one vs. several) and type of nonword (pseudohomophone vs. control). There were 20 nonwords in each category. All participants received the complete list of 240 stimuli in a single block.

Procedure. This was the same as Experiment 1.

### Results

Response latencies above 1500 msec or below 200 msec were excluded from the analysis. This led to the rejection of 2% of the pseudoword data in the

immediate naming task. Condition means are given in Table 3. Analyses of variance (ANOVAs) including the variables target frequency (high-frequency, low-frequency, very-low frequency), neighborhood size (one vs. several) and type of nonword (pseudohomophones vs. non-homophonic nonwords) were conducted on the naming latencies and percentage of errors.

<Insert Table 3 about here>

Immediate naming task. As Table 3 shows, there were main effects of type of nonword ( $F(1,31)=65.57$ ,  $MSe = 66333$ ,  $p<.001$  and  $F(1,108)=29.35$ ,  $MSe = 14366$ ,  $p<.001$ ), neighborhood size ( $F(1,31)=4.93$ ,  $MSe = 46486$ ,  $p<.03$  and  $F(1,108)=12.15$ ,  $MSe = 5950$ ,  $p<.001$ ), but no effect of baseword frequency ( $F_1<1$  and  $F_2<1$ ). All interactions failed to reach significance (all  $F_s<1$ ). An ANOVA conducted on the error data showed no main or interaction effects (all  $F_s<1$ ).

Delayed naming task. An ANOVA conducted on RTs and error data showed no main or interaction effects (all  $F_s<1$ ).

## Discussion

The results of Experiment 2 replicate the standard pseudohomophone advantage effect in nonword naming latencies. The results also show a strong facilitatory effect of neighborhood density in nonword naming that appears independently of whether the nonword is a pseudohomophone or not. On the other hand, baseword frequency had no effect on nonword naming latencies in this experiment, and there were no interaction effects. Since all the pseudohomophones were orthographic neighbors of the corresponding basewords, one can dismiss the possibility that previous failures to obtain baseword frequency effects were due to the use of pseudohomophones having lower levels of orthographic overlap with the basewords. Furthermore, the fact that the control nonwords differed from the same basewords as the pseudohomophones, by changing the same letter, suggests that the pseudohomophone advantage observed in this experiment cannot be ascribed to

uncontrolled differences in orthographic similarity with a real word (Marmurek & Kwantes, 1994).

The pattern of results obtained with the pseudohomophone stimuli in Experiment 2 contrasts sharply with the pattern obtained in Experiment 1. Indeed there is a non-significant correlation between the two sets of 6 condition means ( $r = 0.32, p > .10$ ). On the other hand, there is a significant correlation between the condition means for the pseudohomophones and the control nonwords tested in Experiment 2 ( $r = 0.90, p < .05$ ). The significant correlation arises mainly because number of orthographic neighbors has a similar influence on RTs to the control nonwords and the pseudohomophones.

The results of Experiments 1 and 2 suggest that when pseudohomophones are presented in pure blocks, and participants are informed of the nature of the stimuli, then the pseudohomophones are processed like real words. On the other hand, when the pseudohomophones are mixed with an equal number of non-homophonic nonwords, then they are processed like nonwords. However, the homophonic status of these stimuli confers them a processing advantage compared to non-homophonic nonwords, and a processing disadvantage compared to their basewords. Finally, it is important to note that in Experiments 1 and 2, none of the effects obtained with the word, pseudohomophone, or nonword stimuli, showed up in delayed naming.

In Experiment 3, participants are instructed to determine as rapidly as possible whether the pseudohomophone and control nonwords that were tested in Experiment 2 sound like a real word or not. Here we expect to reinstate the baseword frequency effect for pseudohomophone stimuli, since the corresponding whole-word phonological form must be used in some way to perform this specific task. Taft and Russell (1992) have previously demonstrated strong effects of baseword frequency in this task. Indeed, these authors used the phonological lexical decision task as a pilot study for selecting pseudohomophone stimuli that ought to be maximally sensitive to baseword frequency effects in a subsequent naming task.

## EXPERIMENT 3: PHONOLOGICAL LEXICAL DECISION

### Method

Participants. 22 psychology students at René Descartes University, Paris, who had not participated in Experiments 1 and 2, participated in this experiment for course credit.

Stimuli and Design. Exactly the same stimuli as in Experiment 2 were used here.

Procedure. Participants were told that they would see a series of nonwords, some of which could be pronounced like real French words and some which could not. Their task was to classify the items in this way by means of a button press, YES this sounds like a real word, or NO this does not sound like a real word. Both speed and accuracy in responding were emphasized. Participants responded YES with the index finger of their preferred hand and NO with the index finger of the other hand.

### Results

RTs above 1500 msec or below 200 msec were excluded from the analysis (about 4% of the data). ANOVAs by participant and by item were performed on the correct RTs after removing outliers, with baseword frequency (high, low, or very-low), neighborhood size (one vs. several) and type of nonword (pseudohomophones vs. controls) as within-participant factors. Condition means are given in Table 4.

<Insert Table 4 about here>

There was a main effect of type of nonword ( $F(1,21)=16.54$ ,  $MSe = 817966$ ,  $p<.001$  and  $F(1,108)=17.52$ ,  $MSe = 53218$ ,  $p<.001$ ), frequency ( $F(2,42)=10.54$ ,  $MSe = 33677$ ,  $p<.001$  and  $F(2,108)=35.93$ ,  $MSe = 41263$ ,  $p<.001$ ) but no effect of

neighborhood size ( $F_1 < 1$  and  $F_2 < 1$ ). Only the Type of nonword X Frequency interaction was significant ( $F_1(2,42)=9.46$ ,  $MSe = 28652$ ,  $p < .01$ ;  $F_2(2,108)=4.28$ ,  $MSe = 9596$ ,  $p < .02$ ). There was a significant effect of frequency on RTs to the pseudohomophone targets ( $F_1(2,42)=11.39$ ,  $MSe = 62146$ ,  $p < .005$  and  $F_2(2,108)=3.11$ ,  $MSe = 13427$ ,  $p < .05$ ) but no effect for the control nonwords ( $F_1 < 1$  and  $F_2 < 1$ ). An ANOVA conducted on the error data showed no main or interaction effects (all  $F_s < 1$ ).

### Discussion

When participants have to classify nonwords as sounding like real words or not, then strong effects of baseword frequency are obtained in the RTs to pseudohomophone stimuli. The number of orthographic neighbors of the nonword stimuli did not significantly influence classification times, and this factor did not modulate the effects of baseword frequency obtained with pseudohomophones. It appears that the time to match a letter string to a whole-word phonological representation in memory is strongly influenced by the printed frequency of the word, but not by its orthographic neighborhood.

### GENERAL DISCUSSION

The present experiments provide further confirmation that the baseword frequency of pseudohomophone stimuli influences the speed with which such stimuli are read aloud. Following Borowsky and Masson's (1999) advice, we demonstrated significant effects of word frequency in the naming latencies to the basewords themselves while demonstrating significant effects of baseword frequency in pseudohomophone naming in pure lists of pseudohomophones. No baseword frequency effects were obtained with the same stimuli tested in a mixed list of pseudohomophones and nonword controls. However, when participants had to classify the same set of nonwords as pseudohomophones or not (phonological lexical decision), the baseword frequency effect re-emerged.

Concurrently with baseword frequency, the present study also investigated the effects of number of orthographic neighbors on the processing of pseudohomophone stimuli. In pure lists, pseudohomophones with several orthographic neighbors were named more rapidly than pseudohomophones whose only word neighbor was the corresponding baseword. Furthermore, this facilitatory effect of neighborhood density interacted with baseword frequency in a manner identical to that observed with the basewords themselves: the facilitation disappears in pseudohomophones with high frequency basewords. In mixed lists of pseudohomophones and control nonwords, neighborhood density facilitated both types of stimuli to approximately the same extent, and these effects did not interact with baseword frequency. No effect of neighborhood density was observed in the phonological lexical decision task.

While replicating two theoretically important results concerning the processing of pseudohomophones, the baseword frequency effect and the pseudohomophone advantage, the present study confirms the pervasive influence of list-context on pseudohomophone naming. In pure lists, pseudohomophones are named as if they were real words, albeit more slowly. In mixed lists, pseudohomophones are named as if they were standard nonwords, just more rapidly. In what follows, we examine some different ways of capturing the flexibility in processing that gives rise to effects of list-context. The precise pattern of effects obtained to the same set of pseudohomophone targets presented in different contexts provides considerable constraints for the development of a comprehensive model of word and pseudoword naming.

#### List-context effects in pseudohomophone naming.

The simplest possible interpretation of the influence of list-context on baseword frequency effects can be expressed within the framework of a generic dual-route or two-process model of naming (see e.g., Baluch & Besner, 1991;



Herdman et al., 1994; Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Paap & Noel, 1991). The basic idea is that list-context modifies the relative involvement of the lexical and non-lexical routes in the naming process. Depending on the precise version of the model, the lexical route can either be a means of retrieving a whole-word pronunciation once a word has been recognized (e.g., Paap & Noel, 1991), or it can simply refer to the contribution of whole-word phonology to the final articulatory output that is synthesized from both lexical and sublexical information sources (e.g., Monsell et al., 1992). In the latter type of two-process model, list-context modifies the relative contribution of the lexical and non-lexical routes to the resulting articulatory output. Thus, in pure lists of pseudohomophones the lexical route dominates, and baseword frequency effects are observed. When non-homophonic nonwords are added, then the non-lexical route dominates, and baseword frequency effects disappear.

A dual-route model can also accommodate the variation in effects of orthographic neighborhood observed in the present study, by assuming that these effects are the result of the non-lexical route (e.g., McCann & Besner, 1987).<sup>3</sup> Stimuli with several orthographic neighbors generally have more frequent sublexical spelling-to-sound correspondences than stimuli with just one orthographic neighbor. According to this account of neighborhood effects within the dual-route framework, the effects should be greatest in the presence of non-homophonic nonwords. In the present study, the pseudohomophones with high frequency basewords showed no effect of orthographic neighborhood in the pure list condition, and a significant facilitatory effect when mixed with non-homophonic nonwords. In the mixed list condition, participants will apply the non-lexical route to all stimuli, hence the appearance of orthographic neighborhood effects for all stimulus categories.

One puzzle remains: Why are pseudohomophones read aloud faster than the non-homophonic nonwords in the mixed list condition where the non-lexical

route is hypothesized to dominate? One could argue that pseudohomophones contain more frequent spelling-to-sound correspondences than the non-homophonic nonwords, hence a pseudohomophone advantage could arise in conditions where the nonlexical route is used. However, Seidenberg et al. (1996) showed a robust pseudohomophone advantage when pseudohomophones and nonword controls were composed of exactly the same onsets and rimes (e.g., hoap and joak matched with hoak and joap), in a mixed list of pseudohomophones and nonword controls, as in Experiment 2 of the present study. This appears to be a critically damaging result for the above dual-route account of the present data. Although this line of argument is somewhat weakened by the fact that the pseudohomophone advantage in Seidenberg et al.'s study was also present in delayed naming latencies, in what follows we examine an alternative account of these phenomena.

#### Variable response criteria and nonword naming.

One possible way out of this dilemma is to assume that speeded naming RTs are triggered by response criteria that flexibly adjust with variations in list-context. These criteria are used by participants to determine the earliest possible moment that a naming response can be triggered with minimum risk of making an error. Criterion models have been proposed in many different areas of cognitive psychology in order to capture list-context effects. Lupker, Brown, and Colombo (1997) proposed a time criterion model of speeded naming (see also Jared, 1997a). According to these authors, the average difficulty in naming the stimuli in a given list will modify the setting of a time criterion that participants use to initiate their articulatory response. Here we argue that the combined use of two different response criteria offers one solution to the observed dissociation between effects of baseword frequency and the pseudohomophone advantage in nonword naming. Although a full exposition of these ideas is beyond the scope of the present article,

we will provide a brief outline here to enable a preliminary evaluation of this proposal.

<Insert Figure 1 about here>

The architecture presented in Figure 1 is a proposal for extending the model described by Jacobs, Rey, Ziegler, and Grainger (1998) to the task of reading aloud. The architecture is very similar to the recent connectionist two-process model of Zorzi, Houghton, and Butterworth (1998). In the complete version of the model presented by Zorzi et al., the phonological decision system (i.e., articulatory output units) receives activation from a system that stores whole-word phonology (i.e., the phonological lexicon) and a system that computes assembled phonology from the stored associations between sublexical orthographic representations and sublexical phonology. Within this general framework, it is hypothesized that speeded naming responses are mostly generated using a response criterion set on activity in articulatory output units (cf. Grainger & Ferrand, 1996; Kawamoto, Kello, Jones, & Bame, 1998; Monsell et al., 1992; Zorzi et al., 1998). We refer to this default criterion for speeded word naming as the A criterion. In addition to the A criterion, it is hypothesized that in certain conditions (to be specified below), a response can be triggered on the basis of unit activity in the phonological lexicon (the phonological equivalent of the M criterion set on whole-word orthographic representations in the Multiple Read-Out Model, Grainger & Jacobs, 1996, see also Ferrand & Grainger, 1996). This secondary criterion for response initiation in speeded word naming is only applied when a gain in RT can be achieved with no cost in accuracy.

The M criterion can therefore be seen as a fast-guess mechanism for speeded naming to the extent that participants risk initiating a response in the absence of totally reliable information concerning how they can actually formulate that response. The M criterion will be used to initiate an articulatory response on a given trial as a function of a) the processing involved on that specific trial, and b) adjustments of response criteria over the entire experiment. More precisely, the

likelihood of a response being generated by the M criterion is maximal when: 1) build up in activation in word units is relatively fast, and build up in activation in articulatory units is relatively slow on that specific trial (e.g., the high frequency words with no orthographic neighbors in the present study); 2) the majority of stimuli in the experiment have a whole-word phonological representation.

Responses based on the A criterion are sensitive to the number of activated word units that have pronunciations that are compatible with the target pronunciation, and to the frequency and consistency of the target's sublexical spelling-to-sound correspondences (Glushko, 1979; Jared, McRae, & Seidenberg, 1990; Peereman & Content, 1997). These influences are reduced in the case of high frequency words via involvement of the M criterion (high frequency words reach this criterion faster than low frequency words), thus capturing the well-known interaction between effects of word frequency and effects of regularity / consistency or number of orthographic neighbors (as in Experiment 1 of the present study). However, effects of spelling-to-sound consistency can be observed with high frequency words (Jared, 1997b) when the degree of inconsistency forces participants to abandon use of the M criterion (i.e., when the M criterion generates too many premature responses). Furthermore, responses triggered by the M criterion would also be sensitive to manipulations of spelling-to-sound consistency that affect performance in word recognition tasks such as lexical decision.

As concerns effects of list-context, on every trial that the M criterion leads to a fast accurate naming response, the placement of the criterion is lowered. Thus, in the present study the presence of word stimuli will increase the use made of the M criterion (by lowering it), while the presence of non-homophonic nonwords will minimize involvement of the M criterion. In other words, criterion shifts replace the relative involvement of processing routes as an explanation of list-context effects (see also Stone & Van Orden, 1993). Thus, in pure lists of pseudohomophones, the M criterion will generate fast responses to stimuli with high-frequency basewords. On

the other hand, when pseudohomophones are mixed with non-homophonic nonwords, only the A criterion remains operational, giving rise to facilitatory effects of orthographic neighborhood and the presence of a pseudohomophone advantage in the absence of a baseword frequency effect. It is the fact that articulatory output units pool information from all whole-word and sublexical phonological representations that will hide any influence of baseword frequency, while maintaining a pseudohomophone advantage. The whole-word phonological representation that is activated by a pseudohomophone stimulus generates a significant increase in activation sent to appropriate articulatory output units. The difference in activation level between the whole-word representation of a high frequency baseword and the representation corresponding to a low frequency baseword will significantly influence the time to reach the M criterion, but will have little influence on the activation that arrives at articulatory output units.<sup>4</sup> Finally, phonological lexical decision is performed using the M criterion (with the possible addition of a criterion based on summed activity in the phonological lexicon, Grainger & Jacobs, 1996), thus giving rise to the baseword frequency effects observed in this task.

The criterion adjustment account of list-context effects is independent of any specific model architecture, as long as the architecture contains some form of whole-word representation of phonology. It will be therefore interesting to examine applications of these response criteria in other computational models of word naming such as the dual-route cascaded model of Coltheart et al. (1993), and the recent two-process connectionist model proposed by Zorzi et al. (1998). The critical point here is that this general account of list-context effects offers one possible solution to a problem raised over a decade ago by McCann and Besner (1987) with respect to speeded nonword naming: How to explain a pseudohomophone advantage over non-homophonic nonwords in the absence of any effect of baseword frequency? McCann and Besner suggested that baseword frequency effects are

mediated by differences in the strength of connections between whole-word orthographic representations and output phonology, while the pseudohomophone advantage arises from such stimuli contacting frequency-insensitive whole-word phonological representations in memory. No baseword frequency effect is observed because pseudohomophones do not have a representation in the orthographic input lexicon. In order to account for the effects of baseword frequency observed in pure lists of pseudohomophones in the present study (see also Marmurek & Kwantes, 1996), one would have to assume that a rather complicated sublexical orthography-to-whole-word phonology-to-whole-word orthography-to-output phonology route is used in these specific conditions. We believe that the criterion adjustment account offers a more parsimonious alternative.

However, although one can challenge the interpretation that McCann and Besner (1987) proposed for their results, this particular pattern of data still remains a serious challenge to modelers of word naming. Clearly, more research is required on this issue. One promising avenue involves contrasting performance in the speeded naming task with performance to the same stimuli in other tasks used to study how skilled readers process printed strings of letters (e.g., letter search: Ziegler, Van Orden, & Jacobs, 1997). Within the criterion adjustment approach described in the present work (see also Grainger & Jacobs, 1996; Jacobs et al., 1998), one must specify which response criteria are necessary for performing task A and are not necessary for performing task B, and specify how experimental variables have different influences on performance as a function of the response criteria being applied. In this way task manipulations as well as manipulations of list-context, can be used to improve our understanding of the basic mechanisms involved in reading printed words.

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APPENDIX: Stimuli tested in the present experiments.

**High Frequency Stimuli**

<b>Zero / One neighbor</b>			<b>Several Neighbors</b>		
<b>Baseword</b>	<b>Pseudo-homophone</b>	<b>Control</b>	<b>Baseword</b>	<b>Pseudo-homophone</b>	<b>Control</b>
abime	abyme	abame	boire	boyre	botre
crâne	krâne	vrâne	ligne	lygne	lagne
avril	avryl	avrol	large	larje	larce
céder	séder	géder	force	forse	forve
chéri	chéry	chéra	tirer	tyrer	torer
cruel	kruel	pruel	étage	étaje	étade
envie	anvie	invie	canon	kanon	ranon
sujet	suget	sunet	crise	crize	crite
génie	jénie	fénie	corde	korde	sorde
trois	troie	troil	dépit	dépie	dépir
actif	aktif	antif	crier	krier	frier
civil	sivil	nivil	titre	tytre	tatre
avion	avyon	avron	geste	jeste	meste
merci	mercy	merca	livre	lyvre	luvre
ennui	ennuy	ennur	riche	ryche	rache
exact	exakt	exapt	cadre	kadre	sadre
genou	jenou	menou	prise	prize	prire
froid	froie	froir	carte	karte	varte
genre	jenre	benre	pente	pante	punte
objet	obget	oblet	douze	douse	doule

**Low Frequency Stimuli**

<b>Zero / One neighbor</b>			<b>Several Neighbors</b>		
<b>Baseword</b>	<b>Pseudo-homophone</b>	<b>Control</b>	<b>Baseword</b>	<b>Pseudo-homophone</b>	<b>Control</b>
usure	uzure	umure	berge	berje	berve
bijou	byjou	bojou	biche	byche	boche
cycle	cicle	cucle	brise	brize	bripe
écume	ékume	érume	prose	proze	prome
frein	frain	froin	débit	débie	débin
idôle	ydôle	édôle	forge	forje	forne
impôt	impôts	impôt	ligue	lygue	lague
lilas	lylas	lulas	local	lokal	lobal
outil	outie	outir	raser	razer	raver
talut	talue	talur	vider	vyder	voder
duvet	duvey	duvel	virer	vyrer	vorer
éloge	éloje	éloce	fente	fante	funte

bazar	basar	bacar	germe	jerme	lerme
exclu	exklu	exflu	laine	leine	loine
gifle	jifle	difle	fiche	fyché	fuche
rival	ryval	roval	fusée	fuzée	fulée
osier	ozier	omier	marge	marje	marpe
myope	miope	maope	loger	lojer	loder
seize	saize	soize	torse	torce	torne
tribu	trybu	trubu	coupe	koupe	toupe

### Very Low Frequency Stimuli

#### Zero / One neighbor

Baseword	Pseudo-homophone	Control
bidet	bydet	budet
écrou	ékrou	éprou
cobra	kobra	lobra
cumin	kumin	bumin
tibia	tybia	tobia
déjel	déjel	dérel
oxyde	oxide	oxade
poney	ponet	poneu
hamac	hamak	hamal
hibou	hybou	hebou
micro	mikro	mibro
câpre	kâpre	dâpre
frigo	frygo	frago
nylon	nilon	nolon
rugby	rugbi	rugbo
icône	ikône	ilône
nocif	nocyf	nocaf
cabri	kabri	fabri
obèse	obèze	obère
virus	vyrus	vorus

#### Several Neighbors

Baseword	Pseudo-homophone	Control
bison	bizon	bilon
carie	karie	darie
frire	fryre	frore
jaser	jazer	janer
cirer	sirer	lirer
doser	dozer	domer
carpe	karpe	marpe
frise	frize	frile
piler	pyler	poler
limer	lymer	lumer
frime	fryme	frume
morse	morce	morge
rider	ryder	rader
miser	mizer	miper
pince	pinse	pinde
filon	fylon	falon
sacre	sakre	sapre
caler	kaler	naler
baser	bazer	baper
rager	rajer	rader

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The authors thank Ron Borowsky, Greg Stone, and one anonymous reviewer for their helpful comments on an earlier version of this work. Correspondence can be addressed to Jonathan Grainger: [grainger@up.univ-mrs.fr](mailto:grainger@up.univ-mrs.fr)

## FOOTNOTES

1. We fully acknowledge the partial confound between orthographic neighborhood and what Peereman and Content (1997) have called phonographic neighbors. We continue to manipulate orthographic neighborhood size to facilitate comparison with other studies of pseudohomophone naming. For the same reason a neighborhood size manipulation was preferred to a neighborhood frequency manipulation (Grainger, 1990).
2. Marmurek and Kwantes (1994) and Spinelli (1994) have shown that the greater the orthographic similarity between pseudohomophone and baseword, the faster the pseudohomophone is named. Whether this interacts with effects of baseword frequency and list context is an important question for future research.
3. This is not, however, true for Coltheart, Curtis, Atkins, and Haller's (1993) DRC model, since in this particular version of dual route theory, effects of orthographic neighborhood can only be generated via the lexical route.
4. Alternatively, articulatory output units could be structured in such a way as to speed the processing of real words. One possibility is the whole-word criterion discussed by Kawamoto et al. (1998), set on articulatory motor programs for the entire word. These whole-word articulatory programs should not be sensitive to word frequency (otherwise the pseudohomophone advantage would always be accompanied by effects of baseword frequency), and would therefore not dispense with the need for another whole-word mechanism in order to capture baseword frequency effects.

TABLE 1. Descriptive Statistics for the Word Stimuli Tested in Experiment 1.

	High Frequency		Low Frequency		Very Low Frequency	
	N=0	N>4	N=0	N>4	N=0	N>4
Word frequency	118	139	12	15	1.3	1.5
Frequency range	44-543	43-527	6-25	5-29	0.1-3.2	0.2-3.5
Average N size	0	5.6	0	5.8	0	5.8

Note. The letter N stands for number of orthographic neighbors according to the definition proposed by Coltheart et al. (1977). Frequencies are expressed in occurrences per million (Content et al., 1990).

TABLE 2. Mean naming latencies and percentage errors (in parentheses) for the word and pseudohomophone stimuli tested in the immediate and delayed naming conditions of Experiment 1 (pure lists) as a function of word frequency and number of orthographic neighbors.

<b>WORDS</b>	<b>zero neighbors</b>		<b>several neighbors</b>	
	Immediate	Delayed	Immediate	Delayed
High Frequency	471 (1.5)	330 (3.0)	475 (0.5)	331 (1.5)
Low Frequency	518 (3.0)	328 (3.5)	495 (1.0)	335 (1.5)
Very Low Frequency	521 (2.0)	332 (3.5)	498 (2.0)	330 (1.5)
Means	<b>503</b> <b>(2.1)</b>	<b>330</b> <b>(3.3)</b>	<b>489</b> <b>(1.1)</b>	<b>332</b> <b>(1.5)</b>
<b>PSEUDOHOMOPHONES</b>				
	<b>one neighbor</b>		<b>several neighbors</b>	
	Immediate	Delayed	Immediate	Delayed
High Frequency	572 (2.0)	380 (2.5)	570 (2.0)	384 (2.5)
Low Frequency	612 (4.0)	386 (4.5)	592 (4.0)	380 (3.5)
Very Low Frequency	618 (5.0)	382 (4.0)	600 (4.0)	385 (5.5)
Means	<b>601</b> <b>(3.6)</b>	<b>383</b> <b>(3.6)</b>	<b>587</b> <b>(3.3)</b>	<b>383</b> <b>(3.8)</b>



TABLE 3. Mean naming latencies and percentage errors (in parentheses) for the pseudohomophone and non-homophonic (control) nonwords tested in the immediate and delayed naming conditions of Experiment 2 (mixed lists) as a function of word frequency and number of orthographic neighbors.

	<b>one neighbor</b>		<b>several neighbors</b>	
	Immediate	Delayed	Immediate	Delayed
High Frequency Pseudohomophone	593 (3.0)	410 (4.0)	571 (3.0)	408 (4.5)
High Frequency Control	615 (3.5)	413 (5.0)	596 (4.0)	414 (4.5)
Low Frequency Pseudohomophone	587 (3.5)	417 (5.5)	571 (5.5)	409 (4.5)
Low Frequency Control	618 (3.5)	410 (6.0)	593 (5.5)	408 (4.0)
Very Low Frequency Pseudohomophone	591 (5.0)	409 (6.0)	577 (4.5)	413 (4.0)
Very Low Frequency Control	630 (5.5)	412 (6.0)	595 (5.0)	411 (5.0)
<b>Means</b>	<b>606</b> <b>(4.0)</b>	<b>412</b> <b>(5.4)</b>	<b>584</b> <b>(4.6)</b>	<b>411</b> <b>(4.4)</b>

TABLE 4. Mean RTs and percentage errors (in parentheses) for the pseudohomophones and non-homophonic (control) nonwords tested in the phonological lexical decision task of Experiment 3 as a function of word frequency and number of orthographic neighbors.

	<b>one neighbor</b>	<b>several neighbors</b>
High Frequency Pseudohomophone	870 (9.0)	883 (10.0)
High Frequency Control	1030 (10.0)	1020 (10.0)
Low Frequency Pseudohomophone	927 (9.5)	905 (9.0)
Low Frequency Control	1030 (11.5)	1020 (10.5)
Very Low Frequency Pseudohomophone	950 (12.0)	953 (13.0)
Very Low Frequency Control	1034 (13.0)	1023 (14.5)
Means	<b>973</b> <b>(10.9)</b>	<b>967</b> <b>(11.2)</b>

Figure Caption.

Figure 1. Extended architecture of the Multiple Read-Out Model with phonology (Jacobs et al., 1998) including a pool of articulatory output units. Criteria used for triggering a speeded naming response are set on activity in whole-word phonological representations (M criterion) and activity in articulatory output units (A criterion).

FIGURE 1

