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Basic processes in reading: A critical review of pseudohomophone effects in reading aloud and a new computational account

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There are pervasive lexical influences on the time that it takes to read aloud novel letter strings that sound like real words (e.g., *brane* from *brain*). However, the literature presents a complicated picture, given that the time taken to read aloud such items is sometimes shorter and sometimes longer than a control string (e.g., *frane*) and that the time to read aloud is sometimes affected by the frequency of the base word and other times is not. In the present review, we first organize these data to show that there is considerably more consistency than has previously been acknowledged. We then consider six different accounts that have been proposed to explain various aspects of these data. Four of them immediately fail in one way or another. The remaining two accounts may be able to explain these findings, but they either make counterintuitive assumptions or invoke a novel mechanism solely to explain these findings. A new account is advanced that is able to explain all of the effects reviewed here and has none of the problems associated with the other accounts. According to this account, different types of lexical knowledge are used when pseudohomophones and nonword controls are read aloud in mixed and pure lists. This account is then implemented in Coltheart, Rastle, Perry, Langdon, and Ziegler's (2001) dual route cascaded model in order to provide an existence proof that it accommodates all of the effects, while retaining the ability to simulate three standard effects seen in nonword reading aloud.

A thorough understanding of the processes underlying the seemingly effortless act of reading a single letter string aloud would be a considerable achievement, in view of the fact that reading is a major cognitive skill. One contrast that has arisen in the study of reading aloud is the distinction between lexical and sublexical processes. Sublexical influences on word reading (e.g., reading words aloud) have been the topic of considerable research (e.g., the so called *regularity* effect; see Roberts, Rastle, Coltheart, & Besner, 2003, for a recent investigation that pits four different computational accounts against each other). Considerably less research has investigated lexical influences on novel word reading (e.g., reading nonwords aloud). Two lines of research have been pursued. One line concerns the effect of word neighbors (e.g., *crane*) on nonword reading aloud (e.g., *clane*) and has received little attention. The only three experimental papers on this topic with skilled readers of English are those by McCann and Besner (1987) and Reynolds and Besner (2004; see also Weekes, 1997). A related line of investigation concerns how nonwords that sound like words (e.g., *brane*) are influenced by the base word (*brain*) in reading aloud has received considerably more attention.

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Here, we address the simple act of reading pseudohomophones (nonwords that sound like words—e.g., *brane* from *brain*) and their controls (e.g., *frane*) aloud. A number of well-replicated effects have been reported since the first investigation of pseudohomophone reading aloud in intact skilled readers. Their interpretation, however, has been associated with considerable controversy. In addition, recent research has reported several counterintuitive findings. At present, there is no broadly accepted account of all these effects. In the present article, we briefly review six critical findings in this literature and six different accounts of these findings, and discuss their limitations. We also report a new experiment that replicates Borowsky, Owen, and Masson's (2002) novel demonstration of a pseudohomophone *disadvantage* and the modulation of this pseudohomophone disadvantage and base word frequency effect by list order. We then provide a new account of these six findings and report a successful computational instantiation of this account. We conclude that processing is considerably more dynamic than is widely believed and suggest several lines of investigation that merit further consideration.

THE FACTS

Currently, there are six effects that any successful account needs to explain. Three of these effects are well established in the literature (although not widely understood as such). These are (1) the pseudohomophone *advantage* and (2) the accompanying *absence* of a base word frequency effect when pseudohomophones and their controls are randomly intermixed (mixed list) and (3) the *presence* of a base word frequency effect in pure list reading aloud. The remaining three effects—(4) the conjunction of a pseudohomophone *disadvantage* and the *presence* of a base word frequency effect in a pure list when the pseudohomophones are read aloud *before* their nonword controls and the conjunction of (5) a reduced pseudohomophone disadvantage and (6) a reduced base word frequency effect when pseudohomophones are read aloud in a pure list *after* their nonword controls—have only recently been reported. We will discuss each of these effects in turn and will report a new experiment that replicates and extends our understanding of the latter three effects.

1. The Pseudohomophone Advantage in a Mixed List

McCann and Besner (1987) were the first to report that intact skilled readers read aloud pseudohomophones (e.g., *brane*) more quickly than they do control nonwords (e.g., *frane*) when the pseudohomophones and the controls are randomly mixed together in a single list. This pseudohomophone advantage has since been replicated a number of times (Borowsky et al., 2002 [two experiments]; Grainger, Spinelli, & Ferrand, 2000; Herdman, LeFevre, & Greenham, 1996 [two experiments]; Marmurek & Kwantes, 1996 [three experiments]; Taft & Russell, 1992).

2. The Absence of a Base Word Frequency Effect for Pseudohomophone Reading Aloud in a Mixed List

It is well known that the more frequently a word is encountered in print, the more quickly it is read aloud (e.g., Forster & Chambers, 1973). McCann and Besner (1987) also investigated whether the time it takes to read aloud a pseudohomophone (e.g., *brane*) is affected by how frequently their base words (e.g., *brain*) has been encountered in print. They reported a null base word frequency effect for pseudohomophones when these were randomly mixed with their nonword controls. That is, reading the pseudohomophones aloud was not affected by how frequently the base word had been encountered.[1]

This report of a null effect has been contested. Taft and Russell (1992) argued that McCann and Besner (1987) made a Type II error due to poor stimulus selection. They also reported an experiment of their own in which pseudohomophones produced a base word frequency effect in mixed lists. Subsequent research has suggested that McCann and Besner's results do not constitute a Type II error. Marmurek and Kwantes (1996) have reported three demonstrations of a null base word frequency effect for pseudohomophones in mixed lists (despite their use of Taft and Russell's items in one experiment). Furthermore, Herdman et al. (1996) noted that word frequency was confounded with other orthographic factors in Taft and Russell's stimuli, and they reported no base word frequency effect when these factors were properly controlled. Finally, two other laboratories have reported a null base word frequency effect with different stimulus sets (Borowsky et al., 2002; Grainger et al., 2000). In summary, the published data are most consistent with the conclusion that there is no base word frequency effect on reading aloud when pseudohomophones are randomly mixed with control nonwords.

3. The Presence of a Base Word Frequency Effect for Reading Aloud a Pure List

Marmurek and Kwantes (1996) assessed whether the null base word frequency effect observed with mixed lists was a consequence of list structure. They therefore investigated whether a base word frequency effect is observed when pseudohomophones are read aloud in a pure list. Indeed, this is what they found in three experiments. The presence of a pseudohomophone base word frequency effect on reading aloud a pure list has subsequently been replicated in other laboratories (Borowsky et al., 2002; Borowsky, Phillips, & Owen, 2003; Grainger et al., 2000).

4. The Pseudohomophone Disadvantage in Pure Lists

The remaining phenomena concern how pseudohomophones and nonword controls are read aloud in pure lists. Although Marmurek and Kwantes (1996) and Grainger et al. (2000) investigated pseudohomophone reading aloud in pure and mixed lists, they did not compare the time to read pseudohomophones aloud in a pure list with that for nonword controls in a pure list. In their Experiment 1, Marmurek and Kwantes had subjects read aloud both pseudohomophones in a pure list and nonwords (mixed with pseudohomophones). The pseudohomophones in the pure list were read aloud 77 msec more slowly than the nonword controls. Marmurek and Kwantes did not analyze this contrast, but our analysis shows it to be significant [$t(15) = 4.38$, $p < .001$, equal variance assumed]. With the exception of Borowsky et al. (2002), this effect has been ignored in the literature. It is difficult to draw any conclusions from Marmurek and Kwantes's remaining experiments, because list context was manipulated between subjects.

To date, Borowsky et al. (2002) are the only investigators to explicitly compare reading aloud performance for pseudohomophones and nonword controls when those are read aloud in pure lists. They used the stimulus sets from Herdman et al. (1996), McCann and Besner (1987), and Seidenberg, Peterson, MacDonald, and Plaut (1996) and one of their own. Three of the four lists produced a pseudohomophone *disadvantage* in which pseudohomophones took longer to read aloud than nonword controls. That is, unlike the mixed list situation, where it has been repeatedly demonstrated that pseudohomophones are read aloud *more quickly* than nonword controls, in a pure list pseudohomophones are read aloud *more slowly* than nonword controls. This is remarkable in that if the pseudohomophone disadvantage is strategic, it is an instance in which "strategy" hinders performance.

5. The Modulation of the Pseudohomophone Disadvantage by List Order

Borowsky et al. (2002) also manipulated the order in which subjects read aloud the pseudohomophones and nonword controls in pure lists. The pseudohomophone disadvantage was smaller for three of the four stimulus sets when the pseudohomophones were read aloud after the nonword controls. Seidenberg et al.'s (1996) items were the exception, yielding a larger disadvantage when the pseudohomophones were read aloud after the nonword controls. Thus, at least for three of the four lists, the data are consistent with a modulation of the size of the pseudohomophone disadvantage by list order, so that it is larger when pseudohomophones are read aloud before nonword controls.

6. The Modulation of the Base Word Frequency Effect by List Order

Borowsky et al. (2002) reported that for two of the four stimulus sets, the base word frequency effect was smaller when pseudohomophones were read aloud after nonword controls. In contrast, McCann and Besner's (1987) items yielded a larger base word frequency effect when pseudohomophones were read aloud after nonword controls, and Herdman et al.'s (1996) items yielded no base word frequency effect at all. Although it appears that list order affects the size of the base word frequency effect, more data are clearly needed to put this finding on a stronger footing.

A NEW EXPERIMENT

The importance of Borowsky et al.'s (2002) findings for accounts of pseudohomophone reading aloud cannot be overstated. At the time of publication, *there were no accounts of pseudohomophone reading aloud that explicitly predicted either a pseudohomophone disadvantage or its modulation by list order*. However, as was noted above, there is a substantial amount of variability in Borowsky et al.'s (2002) data across stimulus sets, especially with respect to the modulation of base word frequency effects by list order. Indeed, although the overall pattern of data reported by Borowsky et al. (2002) consists of a pseudohomophone disadvantage and base word frequency effect when pseudohomophones are read aloud before nonword controls and a reduced pseudohomophone disadvantage and a null base word frequency effect when pseudohomophones are read aloud after nonword controls, *no single stimulus set produces all of these effects*. It is not surprising, therefore, that the modulation of the pseudohomophone disadvantage and base word frequency effect has met with some skepticism.

It is unclear why there is so much variability in Borowsky et al.'s (2002) data. One possibility is that their experiments did not have sufficient power to demonstrate all four effects for each list (unfortunately, they did not report the error terms in any of their analyses). Another possible source of variability may be a consequence of how the data were analyzed. Borowsky et al. (2002) measured base word frequency effects by using linear regression. However, they did not report excluding any observations that were outliers with respect to the best-fitting line or those stimuli that had a disproportionately large influence on the regression coefficients (e.g., leverage; see Hoaglin & Welsch, 1978).

The purpose of the present experiment was to attempt to replicate and expand on Borowsky et al.'s (2002) report of the modulation of the pseudohomophone disadvantage and base word frequency effect as a function of list order. We improve upon Borowsky et al.'s (2002) design by including a delayed reading aloud condition. There are two reasons for including this condition. First, previous studies in which the pseudohomophone advantage has been examined have contrasted online and delayed reading aloud times, out of concern that part of the advantage may arise from differences in ease of articulation (McCann & Besner, 1987; Taft & Russell, 1992). Consistent with this possibility, virtually all of the studies in the literature have reported a reduced pseudohomophone advantage in the delayed reading aloud condition. If pseudohomophones have an articulatory advantage over nonword controls (as measured during delayed reading aloud), a null difference between pseudohomophones and nonword controls during online reading aloud would indicate that generating a pronunciation for the pseudohomophones is actually slowed, relative to the nonword controls. Therefore, the critical evidence for a lexically driven pseudohomophone disadvantage is a larger disadvantage during online reading aloud, as compared with delayed reading aloud. Similarly, the critical evidence for a lexically driven base word frequency effect is a larger frequency effect during online reading aloud, as compared with delayed reading aloud.

Second, the presence of a pseudohomophone disadvantage when pseudohomophones are read aloud first could be ascribed to nonspecific practice at nonword reading aloud. For example, it is possible that reading aloud time simply decreases over blocks. This can produce a lexicality $\times$ list order interaction. If the list order effects observed in online reading aloud are due simply to nonspecific practice effects, online reading aloud and delayed reading aloud should yield similar effects. Given this, the critical test for slowed pseudohomophone processing, relative to nonword controls, is the contrast between online and delayed reading aloud conditions. If the reduction in the size of the pseudohomophone disadvantage as a function of list order is due, in part, to a decrease in the use of lexical knowledge for the pseudohomophones, there ought to be an accompanying decrease in the size of the base word frequency effect for the pseudohomophones when they are read aloud second.

Method

Subjects

Thirty-two undergraduates from the University of Waterloo participated in the experiment; each was paid $4 for his or her participation. All the subjects reported normal or corrected-to-normal vision and were native English speakers.

Apparatus

Stimulus presentation was controlled by a Pentium IV 1.8-GHz computer running E-Prime 1.1. Vocal responses were collected using a Plantronics LS1 microphone headset and a voice key assembly. The stimuli were displayed on a 17-in. ADI Microscan monitor.

Stimuli

The stimuli consisted of 45 high-frequency and 45 low-frequency pseudohomophones and 90 matched nonword controls. Nonword controls were generated by rotating the onsets and rhymes of the pseudohomophones. High- and low-frequency items were matched on initial phoneme. Lists were equated on the number of orthographic neighbors and the number of body neighbors, including the number of body friends and the number of body enemies. Lists were also equated on position-specific and non–position-specific bigram and trigram frequencies, letter length, whammies (Rastle & Coltheart, 1998), and number of phonological neighbors. A summary of the stimulus characteristics can be seen in Table 1. The stimuli appear in Appendix A.

Procedure

The subjects read aloud pseudohomophones and nonword controls presented in pure lists, with list order counterbalanced across subjects. The subjects were told that in the pseudohomophone condition, items would sound like a word that they knew and that in the nonword control condition, items would not sound like a word that they knew. The subjects were instructed to read the strings aloud as quickly but as accurately as possible.

A trial began with a fixation marker (+) in the center of the screen for 1,000 msec, followed by a blank screen for 500 msec. The target was then presented at fixation until a vocal response was made. A blank screen then appeared for 800 msec, followed by a single dot presented immediately to the left of fixation. After 400 msec, a second dot appeared immediately to the right of the first, followed by a third dot after another 400 msec. After another 400 msec, the dots were replaced by a set of brackets that enclosed the fixation marker and remained on the screen until the subject read aloud the letter string a second time. The experimenter then coded the response as correct, incorrect (e.g., an extra or deleted phoneme or lexicalization), or spoiled (e.g., a cough, a stutter, or the voice key failed to activate). In addition, the experimenter transcribed the subject's pronunciation on incorrect trials when time permitted.

Each subject received 8 practice trials, followed by 90 experimental trials for each list condition. The stimuli in each list condition were presented in a different randomized order for each subject. All the stimuli were presented in a black 16-point Times Roman font in lowercase letters on a white background.

Results

Responses classified as incorrect pronunciations (11.4%) or voice key failures (6.9%) were removed from the reading aloud data prior to the response time (RT) analysis. An error was defined as an utterance that represented a clear mispronunciation (i.e., an extra or deleted phoneme or lexicalization of a nonword) or a pronunciation of a nonword that did not rhyme with the pronunciation required for a pseudohomophone with the same body.

RTs to correct responses were first subjected to a recursive trimming procedure in which the criterion cutoff for outlier removal was established independently for each condition for each subject, by reference to the sample size in that cell (Van Selst & Jolicœur, 1994). If an item was established as an outlier in either online or delayed reading aloud, this resulted in the removal of both scores. Analysis of the online reading aloud data resulted in the removal of 2.2% of the correct trials, and analysis of the delayed reading aloud data resulted in the removal of an additional 1.4% of the correct trials.[2] The RT and error data can be seen in Table 2.

Reaction Times

Lexicality effect: Online reading aloud. For the subject analysis, lexicality effects were assessed using a mixed model ANOVA with list order (pseudohomophones first/nonwords first) as a between-subjects factor and lexicality (pseudohomophone/nonword) as a repeated factor. For the item analysis, lexicality effects were assessed using a mixed model ANOVA with list order as a repeated factor and lexicality as a between-items factor. The analysis yielded a significant interaction between lexicality and list order [$F_1(1,30) = 11.3$, $MS_e = 5{,}603$, $p < .001$; $F_2(1,89) = 86.1$, $MS_e = 3{,}945$, $p < .001$]. When pseudohomophones were read aloud first, there was a significant pseudohomophone disadvantage [pseudohomophones read aloud in Block 1 were 128 msec slower than nonword controls read aloud in Block 2; $F_1(1,30) = 14.1$, $MS_e = 5{,}603$, $p < .001$; $F_2(1,89) = 155.2$, $MS_e = 3{,}945$, $p < .001$]. When nonword controls were read aloud first, the 2-msec pseudohomophone disadvantage was not significant (Fs < 1).

Lexicality effect: Delayed reading aloud. Analysis of the delayed reading aloud data yielded an interaction between stimulus order and lexicality [$F_1(1,30) = 11.3$, $MS_e = 1{,}433$, $p < .001$; $F_2(1,178) = 109.2$, $MS_e = 704$, $p < .001$]. One way this interaction can be understood is as a 31-msec pseudohomophone *disadvantage* when pseudohomophones were read aloud first [$F_1(1,30) = 5.2$, $MS_e = 1{,}433$, $p < .05$; $F_2(1,89) = 44.9$, $MS_e = 704$, $p < .001$] and a 33-msec pseudohomophone *advantage* when non-

Table 1
Summary Statistics for the Pseudohomophones and Nonword Controls

	Pseudohomophones		
Stimulus Characteristic	High Frequency	Low Frequency	Nonword Controls
Number of letters	4.6	4.5	4.5
Number of orthographic neighbors	4.2	4.6	4.7
Number of phonological neighbors	15.6	17.4	18.1
Number of body friends	4.5	5.1	5.0
Number of body enemies	0.5	0.7	0.6
Number of body neighbors	5.0	5.8	5.5
Type bigram frequency (position nonspecific)	616.2	576.6	590.4
Type trigram frequency (position nonspecific)	44.5	45.5	41.1
Type bigram frequency (position specific)	91.3	82.6	89.6
Type trigram frequency (position specific)	8.9	9.5	9.2
Base word frequency	296.6	1.2	–

Table 2
Mean Response Times (RTs, in Milliseconds) and Percentages of Error (%E) for High- and Low-Frequency Pseudohomophones and Nonword Controls as a Function of Online and Delayed Reading Aloud and List Order

	Online		Delayed		Difference	
	RT	%E	RT	%E	RT	%E
			Pseudohomophones Read Aloud First			
Lexicality effect						
Nonword controls (Block 2)	707	10.5	363	9.8	344	0.7
Pseudohomophones (Block 1)	835	12.6	394	11.8	442	0.9
Difference	−128	−2.1	−31	−2.0	−98	−0.2
Frequency effect						
Low frequency (Block 1)	876	13.1	399	12.3	477	0.8
High frequency (Block 1)	794	12.1	388	11.2	406	0.9
Difference	82	1.0	11	1.1	71	−0.1
			Nonwords Read Aloud First			
Lexicality effect						
Nonword controls (Block 1)	750	11.7	396	11.4	354	0.3
Pseudohomophones (Block 2)	752	11.5	364	11.2	388	0.3
Difference	−2	0.2	33	0.2	−35	0.0
Frequency effect						
Low frequency (Block 2)	767	11.4	373	11.2	394	0.2
High frequency (Block 2)	736	11.6	354	11.1	382	0.5
Difference	31	−0.2	19	0.1	12	−0.3

words were read aloud first [$F_1(1,30) = 6.1$, $MS_e = 1{,}433$, $p < .05$; $F_2(1,89) = 70.2$, $MS_e = 704$, $p < .001$]. An alternative interpretation is a main effect of block, where items read aloud in Block 2 were 32 msec faster than items read aloud in Block 1 [$F_1(1,30) = 11.3$, $MS_e = 1{,}433$, $p < .001$; $F_2(1,178) = 100.9$, $MS_e = 762$, $p < .001$].

Lexicality effect: Online versus delayed reading aloud. Earlier, we noted that a null difference between pseudohomophones and nonword controls in online reading aloud by itself is inconclusive. If pseudohomophones have an articulatory advantage over nonword controls (as measured during delayed reading aloud), a null difference between pseudohomophones and nonword controls during online reading aloud would indicate that generating a pronunciation for the pseudohomophones is slowed, relative to the nonword controls. We also noted that a lexicality × list order interaction could be interpreted as nonspecific practice at nonword reading aloud. If the list order effects observed in online reading aloud are due to a nonspecific practice effect, online reading aloud and delayed reading aloud should yield similar effects. Given these concerns, we argued that the critical evidence for a lexically driven pseudohomophone disadvantage is a larger disadvantage during online reading aloud, as compared with delayed reading aloud. Similarly, the critical evidence for a lexically driven base word frequency effect is a larger frequency effect during online reading aloud then during delayed reading aloud.

Analysis of the online reading aloud data revealed a pseudohomophone disadvantage when pseudohomophones were read aloud first and a null effect of pseudohomophony when nonwords were read aloud first. In contrast, analysis of the delayed reading aloud data revealed faster reading aloud in Block 2 than in Block 1. This takes the form of a pseudohomophone disadvantage when pseudohomophones are read aloud first and a pseudohomophone advantage when nonwords are read aloud first. It is, therefore, critical that online and delayed reading aloud data be directly compared, to assess whether there is a pseudohomophone disadvantage for both list orders.

A mixed model ANOVA was conducted with lexicality and reading aloud condition (online vs. delayed) as repeated factors and list order as an independent factor for the subject analysis. Lexicality was treated as an independent factor for the item analysis. The three-way interaction was significant [$F_1(1,30) = 3.9$, $MS_e = 1{,}984$, $p < .06$; $F_2(1,89) = 20.2$, $MS_e = 2{,}307$, $p < .001$]. When pseudohomophones were read aloud first, the 128-msec pseudohomophone disadvantage observed in online reading aloud was significantly different from the 31-msec pseudohomophone disadvantage observed during delayed reading aloud [$F_1(1,15) = 12.6$, $MS_e = 1{,}984$, $p < .001$; $F_2(1,89) = 81.3$, $MS_e = 2{,}307$, $p < .001$]. When nonwords were read aloud first, the null 2-msec pseudohomophone disadvantage observed in the online reading aloud condition was also significantly different from the 33-msec pseudohomophone advantage observed during delayed reading aloud [$F_1(1,15) = 4.9$, $MS_e = 1{,}984$, $p < .05$; $F_2(1,89) = 7.9$, $MS_e = 2{,}307$, $p < .05$].

Base word frequency effect: Online reading aloud. The subject data were analyzed using a mixed model ANOVA with frequency (high vs. low) as a repeated factor and list order as a between-subjects factor. Item data were analyzed with list order as a repeated factor and word frequency as a between-items factor. There was an interaction between base word frequency and list order [$F_1(1,30) = 4.7$, $MS_e = 3{,}364$, $p < .05$; $F_2(1,88) = 10.1$, $MS_e = 4{,}475$, $p < .001$]. There was a significant 82-msec frequency effect when pseudohomophones were read aloud first [$F_1(1,15) = 16.1$, $MS_e = 3{,}284$, $p < .001$;

$F_2(1,88) = 23.6$, $MS_e = 4{,}289$, $p < .001$]. When pseudohomophones were read aloud second, the 31-msec frequency effect was not reliable for subjects ($F_1 = 1$) but was for items [$F_2(1,88) = 4.6$, $MS_e = 4{,}289$, $p < .05$].

Base word frequency effect: Delayed reading aloud. There was a 15-msec main effect of base word frequency [$F_1(1,30) = 5.8$, $MS_e = 599$, $p < .05$; $F_2(1,88) = 5.6$, $MS_e = 1{,}806$, $p < .05$], and there was no interaction between base word frequency and list order (Fs < 1).

Base word frequency effect: Online versus delayed reading aloud. As was discussed earlier, the critical evidence for a lexically driven base word frequency effect in online reading aloud is a larger frequency effect than in delayed reading aloud. The three-way interaction was significant [$F_1(1,30) = 7.3$, $MS_e = 1{,}475$, $p < .001$; $F_2(1,178) = 10.9$, $MS_e = 2{,}689$, $p < .001$]. When pseudohomophones were read aloud first, the 82-msec base word frequency effect in the online reading aloud condition was significantly larger than the 11-msec effect in delayed reading aloud [$F_1(1,30) = 13.2$, $MS_e = 1{,}475$, $p < .001$; $F_2(1,178) = 28.4$, $MS_e = 2{,}689$, $p < .001$]. When pseudohomophones were read aloud second, the 31-msec base word frequency effect in the online reading aloud condition was not significantly different from the 19-msec effect in delayed reading aloud (Fs < 1).

Errors

Lexicality effect. The subject data were analyzed using a mixed model ANOVA with lexicality as a repeated factor and list order as a between-subjects factor. Item data were analyzed using a mixed model ANOVA with list order as a repeated factor and lexicality as a between-items factor. There was a marginal interaction between these factors for subjects [$F_1(1,30) = 3.1$, $MS_e = 7.1$, $p < .10$], but not for items ($F_2 < 1$). When pseudohomophones were read aloud first, 2.1% more errors were made to pseudohomophones (Block 1) than to nonword controls (Block 2) for subjects [$F_1(1,15) = 5.1$, $MS_e = 7.1$, $p < .05$], but not for items ($F_2 < 1$). When nonword controls were read aloud first, there was no difference between pseudohomophones in Block 2 and nonword controls in Block 1 (Fs < 1).

Base word frequency effect. Subject data were analyzed using a mixed model ANOVA with base word frequency (high vs. low) as a repeated factor and list order as a between-subjects factor. Item data were also analyzed using a mixed model ANOVA with list order as a repeated factor and base word frequency as a between-items factor. No effects approached significance (Fs < 1).

Discussion

The purpose of the present experiment was to replicate and extend Borowsky et al.'s (2002) novel observation of a pseudohomophone disadvantage and a base word frequency effect in pure lists and the modulation of these effects by list order. The inclusion of a delayed reading aloud condition makes it possible to assess whether lexical processing is slowed during online reading aloud despite the observation of a null pseudohomophone disadvantage. Base word frequency was dichotomized and the RTs trimmed so as to avoid the problems that we noted with Borowsky et al.'s (2002) analyses.

The data show that when pseudohomophones were read aloud first, there was a pseudohomophone disadvantage and a base word frequency effect. When pseudohomophones are read aloud after nonword controls, there was a pseudohomophone disadvantage but no base word frequency effect when delayed reading aloud is taken into account.

Nonspecific Practice

Responses in the delayed reading aloud task were approximately 32 msec faster in the second block. This effect was not modulated by list order or the base word frequency of the pseudohomophone. Thus, it appears as though practice with the delayed reading aloud task did not differentially affect any of the manipulations in the present experiment and the effect is, therefore, best characterized as a nonspecific practice effect. We infer that this nonspecific practice effect does not account for the modulation of the pseudohomophone disadvantage and the base word frequency effect by list order.

It has been argued that if subjects are prepared to make a pronunciation in delayed reading aloud, this condition measures only factors that affect articulation itself (e.g., phoneme onset and ease of articulation). If subjects are not prepared to make a pronunciation, other factors that affect the retrieval of the motor program may also be measured (see Balota & Chumbley, 1985, 1990; Monsell, Doyle, & Haggard, 1989). In the present experiment, the online and delayed reading aloud conditions occurred on the same trial. Furthermore, the response–stimulus interval between online and delayed reading aloud was constant throughout the experiment. Therefore, it seems likely that the subjects were completely prepared to make the articulation in the delayed reading aloud condition. However, the fact that the base word frequency effect for pseudohomophones read aloud after nonword controls in online reading aloud is statistically the same size as that in delayed reading aloud is inconsistent with this interpretation. If the subjects were not completely prepared in delayed reading aloud, the base word frequency effect could arise during output processes as early as retrieving the motor program for articulation. Thus, some component of the base word frequency effect in the present experiment arises from output processes occurring later than lexical activation.

In summary, when pseudohomophones are read aloud in pure lists before nonword controls, there is a pseudohomophone disadvantage that co-occurs with a base word frequency effect. When pseudohomophones are read aloud in pure lists after nonword controls, the pseudohomophone disadvantage that co-occurs with a null base word frequency effect is reduced (but still present).

THE ACCOUNTS

There are presently six empirical phenomena that need to be explained by any viable account of pseudohomophone reading aloud. In mixed list reading aloud, these are the conjunction of (1) a pseudohomophone advantage and (2) a null base word frequency effect. In pure list reading aloud, these are the conjunction of (3) a pseudohomophone disadvantage and (4) the presence of a base word frequency effect when pseudohomophones are read aloud before nonword controls, and the conjunction of (5) a reduced pseudohomophone disadvantage and (6) a reduced or null base word frequency effect when pseudohomophones are read aloud after nonword controls. We now will turn to six different accounts of pseudohomophone reading aloud and to a discussion of how well these accounts can explain these six findings.

Theory 1: Frequency-Insensitive Lexical Activation (FILA)

McCann and Besner (1987) have argued that nonwords are pronounced by the application of sublexical spelling–sound correspondences but that, in the case of a pseudohomophone, there is also activation of the base word's phonological (lexical) representation (see Figure 1). This provides an additional source of activation that affects phonemic-level processing and, hence, speeds up reading aloud. Nonword controls do not have such a base word representation; this advantage is, therefore, denied them. McCann and Besner's general account of the pseudohomophone advantage has been accepted by a number of researchers (Borowsky et al., 2002; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Grainger et al., 2000; Marmurek & Kwantes, 1996; Taft & Russell, 1992).

Besner and colleagues (Baluch & Besner, 1991; Besner, 1999; Besner & Smith, 1992; Borowsky & Besner, 1993; McCann & Besner, 1987) also argued that there is no base word frequency effect in mixed lists because lexical representations are not frequency sensitive. Indeed, they have argued that the concurrent presence of a pseudohomophone advantage and the absence of a base word frequency effect poses a problem for all accounts that assume that lexical representations are frequency sensitive. Besner and colleagues suggested instead that word frequency may affect lexical–lexical connections (between orthographic and phonological lexicons) and lexical–semantic connections, rather than lexical representations per se.

Besner (1999) proposed that the presence of a base word frequency effect in a pure list could be explained by appealing to the idea that additional knowledge sources are involved, as compared with mixed list presentation. For example, subjects could recruit additional semantic knowledge when reading aloud the pseudohomophones. This produces a base word frequency effect, because lexical–semantic connections that are now in play are frequency sensitive.

Besner and colleagues' frequency-insensitive lexical activation account does not explicitly predict a pseudohomophone disadvantage. However, it can account for this finding if the recruiting of semantics slows overall processing. Indeed, there is evidence that semantics can be involved in pseudohomophone reading aloud. Patterson, Suzuki, and Wydell (1996) reported the case of a Japanese patient (K.T.) suffering from phonological alexia (impaired nonword reading, but normal word reading). Although K.T. was very poor at reading nonwords aloud, he was much more accurate when reading pseudohomophones aloud. Patterson et al. also examined whether K.T.'s pseudohomophone reading performance was affected by imageability—a factor widely assumed to reflect the impact of semantic processing (e.g., Strain, Patterson, & Seidenberg, 1995). Critically, K.T. was more accurate at reading aloud pseudohomophones derived from high-imageability words than pseudohomophones derived from low-imageability words.

Given that semantics plays a role, at least sometimes, in reading pseudohomophones aloud, it is possible that such contact produces the pseudohomophone disadvantage. However, in order for this to occur, the utilization of such knowledge would have to increase the overall time to read aloud a pseudohomophone despite the fact that factors that index semantics (e.g., imageability) produce a facilitatory effect. This is not as strange as it may sound at first. For example, contact with semantics could initially add noise to the system that increases the overall time to read aloud (pseudohomophone disadvantage), but this noise could be cleaned up more quickly for pseudohomophones derived from high-imageability base words than for pseudohomophones derived from low-imageability base words (a facilitatory effect of imageability). Thus, if contact with semantic knowledge has greater costs than benefits, this account can explain the modulation of

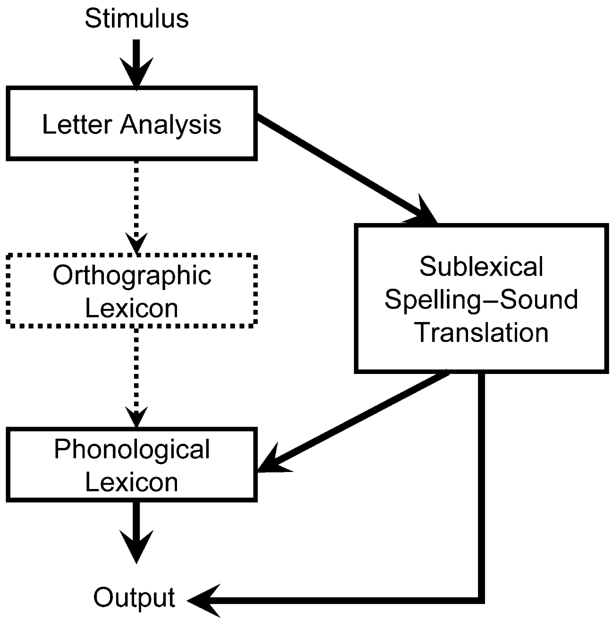

Figure 1. Besner and colleagues' frequency-insensitive lexical activation (FILA) account of pseudohomophone reading aloud.

the pseudohomophone disadvantage and the base word frequency effect by list order by appealing to the moderate application of these knowledge sources.

Theory 2: Orthographic Overlap

A quite different account of pseudohomophone reading aloud was proposed by Seidenberg and McClelland (1989), who examined whether their parallel distributed processing (PDP) model could simulate a pseudohomophone advantage, because in their model, "there does not seem to be a way for the spelling or pronunciation of BRAIN to directly influence BRANE because there is no lexical entry for BRAIN" (p. 555). Seidenberg and McClelland (1989) reported that their model produced a pseudohomophone advantage but that it was a consequence of more orthographic overlap with the base word than with the control items (as indexed by smaller orthographic error scores from the model). Seidenberg and McClelland (1989) therefore argued that the pseudohomophone advantage reported by McCann and Besner (1987) is not genuinely phonological.

Besner, Twilley, McCann, and Seergobin (1990) challenged Seidenberg and McClelland's (1989) account. They argued that if the orthographic overlap account is correct, controlling for this factor should eliminate the pseudohomophone advantage seen in skilled readers. Besner et al. therefore reanalyzed McCann and Besner's (1987) data by partialling out the orthographic error scores that are generated by running these items through Seidenberg and McClelland's (1989) model. Inconsistent with the purely orthographic overlap account, a pseudohomophone advantage persisted in McCann and Besner's data. (See Seidenberg & McClelland [1989, pp. 555–556; 1990, pp. 449–450], Besner et al. [1990, pp. 441–443], and Besner [1999] for these exchanges.)

A related problem is that Seidenberg and McClelland (1989) did not discuss the null base word frequency effect reported by McCann and Besner (1987). It is not easy to tell whether their orthographic overlap account would produce a base word frequency effect or not. Although distributed models lack distinct lexical representations, if the orthographic pattern of a pseudohomophone is similar enough to its base word, it is possible for the pseudohomophone to systematically benefit from this. As Seidenberg and McClelland (1989) noted, *cought* would receive a greater benefit from orthographic overlap with *caught* than would the pseudohomophone *cawt*. If this is true, the absence of a base word frequency effect in the model could be a consequence of confounding base word frequency and orthographic overlap. The only way to find out whether this PDP model produces a base word frequency effect would be to run simulations in which these factors are not confounded. Seidenberg and McClelland (1989) did not report any simulations that address the effect of base word frequency.

A second problem for the orthographic overlap account is that it does not provide a mechanism whereby a pseudohomophone advantage and a null base word frequency effect seen in a mixed list could change to a pseudohomophone disadvantage and the presence of a base word frequency effect in a pure list. Nor does this account provide a mechanism by which list order can modulate these effects.

Theory 3: Articulation

Yet another account of the pseudohomophone advantage in reading aloud supposes that it arises entirely in articulation. Seidenberg et al. (1996) argued that pseudohomophones have "familiar, over-learned articulatory trajectories" (p. 53), whereas control nonwords have novel articulatory trajectories. According to this account, a pseudohomophone advantage is genuinely phonological (rather than orthographic, as in Seidenberg & McClelland's, 1989, account) but arises later in processing.

Seidenberg et al. (1996) argued that if the pseudohomophone advantage arises entirely in articulation, it should be the same size in online and delayed reading aloud conditions. However, there are numerous delayed reading aloud methods, and the appropriateness of each method depends on what is being asked. For example, Balota and Chumbley (1985, 1990) advocated a delayed reading aloud condition in which subjects are not prepared to make the articulation, because some effects (e.g., word frequency) could arise, in part, through the retrieval of the motor program. In contrast, Monsell et al. (1989) advocated a delayed reading aloud procedure in which subjects are prepared to make the articulation, in order to assess whether effects occur during articulation itself. Seidenberg et al. (1996) used a delayed reading aloud procedure with two intervals for pronunciation: one that occurred two standard deviations after a subject's mean online RT and one that occurred four standard deviations after a subject's mean online RT. Given these deadlines, the subjects were likely prepared to make the articulation.

In accord with an articulation account, Seidenberg et al. (1996) reported an experiment with a 10-msec pseudohomophone advantage in the online reading aloud condition that persisted in the delayed reading aloud condition. The results from other experiments, however, are not consistent with a pure articulation account of the pseudohomophone advantage. For example, McCann and Besner (1987) included both online and delayed reading aloud conditions in their experiment. They reported a 36-msec pseudohomophone advantage in online reading aloud and a significantly smaller 11-msec pseudohomophone advantage in delayed reading aloud. Taft and Russell (1992) reported a 30-msec pseudohomophone advantage in online reading aloud and a 10-msec pseudohomophone advantage in delayed reading aloud (indeed, for fast subjects, they reported no pseudohomophone advantage at all). Furthermore, Besner (1999) reported a delayed reading aloud experiment, using Seidenberg et al.'s (1996) items and the procedure advocated by Monsell et al. (1989), in which the stimuli were read aloud twice in immediate succession. On the first *de-*

layed reading aloud presentation, there was a 28-msec pseudohomophone advantage, but on the second *delayed* reading aloud presentation, this was reduced to 2 msec. This reduction in the size of the pseudohomophone advantage in the delayed reading aloud condition to essentially zero is inconsistent with a purely articulation-based account. With the exception of Seidenberg et al. (1996), then, none of these data are consistent with an account in which the only source of the pseudohomophone advantage is in articulation.

Another problem for Seidenberg et al.'s (1996) articulation account is that it predicts the conjunction of a pseudohomophone advantage and a base word frequency effect. If familiar articulatory trajectories are developed through repeated pronunciation, these trajectories should surely be affected by word frequency. As was noted previously, however, the conjunction of a pseudohomophone advantage and a base word frequency effect is not seen in experiments with skilled readers. Finally, it is difficult to envision how articulatory effects could switch directions in pure and mixed list reading aloud conditions or be modified by list order.

Theory 4: Dual-Criterion Hypothesis

Grainger et al. (2000) have proposed an account in which pseudohomophones can be read aloud using two criteria, whereas nonword controls are afforded only one. The default *A* criterion is based on activation in articulatory units and can be used for both pseudohomophones and nonword controls. A second, *M*, criterion, based on activation in the phonological lexicon, acts as a fast-guess mechanism that facilitates pseudohomophone reading aloud time without affecting overall accuracy. To the extent that pseudohomophones are read aloud off the lexicon using the M criterion, there will be a pseudohomophone advantage. According to Grainger et al., if pseudohomophones are read using the M criterion a moderate amount, this will produce a pseudohomophone advantage and a null base word frequency effect, despite frequency-sensitive lexical processing. Grainger et al. also asserted that the base word frequency effect arises when pseudohomophones are read aloud in pure lists, because subjects use the M criterion more often. However, as the reader has likely anticipated, if reading off the lexicon facilitates pseudohomophone reading aloud, the dual-criterion account predicts a *larger* pseudohomophone advantage in the presence of a base word frequency effect, rather than the pseudohomophone disadvantage observed here and in Borowsky et al. (2002).

Theory 5: Verification and Scaling

Borowsky et al. (2002) have provided the most comprehensive account of pseudohomophone reading aloud. They proposed that subjects *verify* the phonological lexical status of the pseudohomophone in the pure block condition. The addition of this verification process *increases* the time it takes to read a pseudohomophone aloud, thus producing a pseudohomophone disadvantage. The verification process utilizes frequency-sensitive processes (lexical representations or the links between lexical and semantic representations). According to Borowsky et al. (2002), increasing the time that frequency-sensitive processes are active increases the size of the base word frequency effect. In mixed list conditions, there is a "moderate probability of invoking a lexical retrieval strategy, without preventing mean latency from crossing over to produce a pseudohomophone disadvantage" (p. 984). The problem here (to us, at least) is that it is unclear to us how this would actually work. A more detailed description of the process and/or a simulation would be useful.

That said, Borowsky et al.'s (2002) account resembles *lexical checking* (for more discussion of this point, see Kinoshita & Lupker, 2003; Lupker, Brown, & Colombo, 1997; Reynolds & Besner, 2005). The problem with lexical checking accounts is that they are usually post hoc and are typically underspecified (e.g., what happens if the verification process fails? Do subjects restart the reading process?). This makes these accounts difficult to assess.

Another problem with Borowsky et al.'s (2002) account is that it invokes a novel mechanism (*verification*) to explain the pseudohomophone disadvantage. In our view, it is premature to further complicate existing accounts. A better strategy is to assess whether existing accounts can be modified to explain the data. As we will demonstrate below, it is possible to explain all of these effects without invoking such a novel mechanism.

Theory 6: The Dual Route Cascaded Model

There is one other published account of pseudohomophone effects in reading aloud. This account is provided by Coltheart et al. (2001) and is nested in the context of their dual route cascaded (DRC) computational model of visual word recognition and reading aloud, which is considered to be "the most successful of current computational models of reading" (Coltheart et al., 2001, p. 204). As can be seen in Figure 2, the implemented version of the DRC model has two routes for translating print into sound.

The nonlexical route translates print into sound sublexically via a set of grapheme–phoneme correspondence rules applied left to right, one letter at a time. This route produces a correct pronunciation for words that follow typical spelling-to-sound rules (i.e., regular words) and is required to read nonwords (e.g., *frane*) aloud. The output from this route activates the phoneme system, where the activation of individual phonemes accumulates to some criterion. Reading aloud starts when all phonemes have reached criterion.

The lexical route consists of two lexicons. The orthographic lexicon contains a single node for each uniquely spelled word the model knows. The phonological lexicon contains a single node for each uniquely sounding word the model knows. Letter units activate words in the orthographic lexicon. Activation in the orthographic lexicon activates the letter units via feedback and the phonological lexicon via feedforward connections. Activation from the phonological lexicon feeds forward to the phoneme system and back to the orthographic lexicon. The lexical route can read aloud all the words it knows and is required to read aloud words that do not follow the typical spelling-to-sound rules (exception words such as *pint*). It cannot read nonwords correctly.

Coltheart et al. (2001) showed that the DRC model successfully simulates a pseudohomophone advantage. They argued that the pseudohomophone advantage produced by the DRC model arises through interactive activation between the phoneme system and the phonological lexicon. Consistent with this account, the pseudohomophone advantage is eliminated when the connections between the phonological lexicon and the phoneme system are *lesioned* by setting the connection weights to zero.

Coltheart et al.'s (2001) account differs from the account provided by McCann and Besner (1987; see also Besner, 1999; Besner & Smith, 1992) in that lexical representations in the DRC model are frequency sensitive. Perhaps not surprisingly, the DRC model produces a base word frequency effect (see Coltheart et al., 2001, p. 225). This would appear to be a problem for the DRC model given that it produces the conjunction of a pseudohomophone advantage and a base word frequency effect,

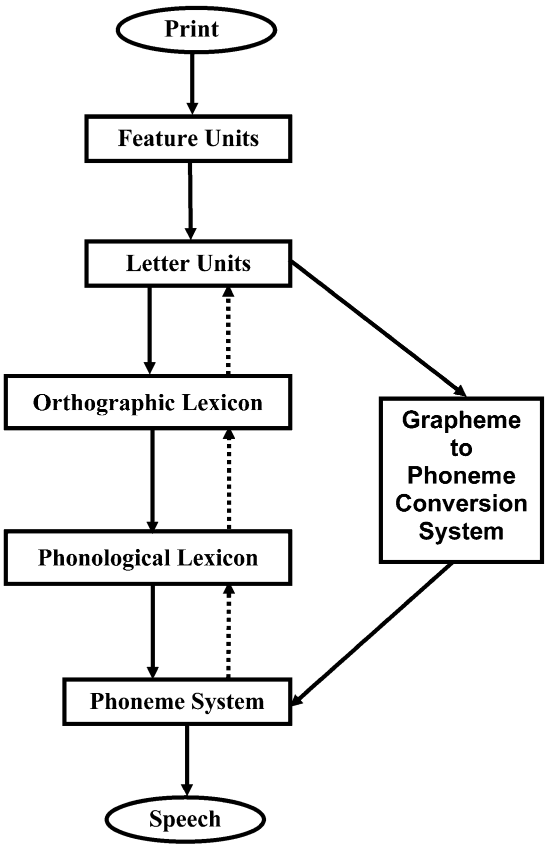

Figure 2. The dual route cascaded model's implemented architecture.

whereas skilled readers do not produce this conjunction when pseudohomophones and nonwords are mixed together. However, this conclusion might be premature. Coltheart et al. used Taft and Russell's (1992) items in their simulation, but Herdman et al. (1996) have claimed that word frequency is confounded with orthographic factors in the Taft and Russell stimulus set. Thus, it is an empirical question as to whether the DRC model successfully simulates the conjunction of a pseudohomophone advantage and a null base word frequency effect if the stimulus list is properly controlled.

Testing the DRC model. The first step in assessing the DRC model is to create a stimulus set. Many of the stimuli used in studies of pseudohomophone reading aloud are not pseudohomophones in the DRC model, which uses Australian English. To avoid issues that may arise from using only a part of a stimulus set (e.g., approximately 50% of the items used by Borowsky et al. [2002] are not pseudohomphones in the DRC model), we created a larger stimulus list by combining the items used by Borowsky et al. (2002), Herdman et al. (1996, Experiment 2), and McCann and Besner (1987). These items can be seen in Appendix B.

The DRC model read 99% of the pseudohomophones and 97% of the nonwords correctly. The correctly read aloud items produced a robust pseudohomophone advantage [$t(127) = 11.3$, $SEM = 1.2$, $p < .001$]. Two pseudohomophones (*helled* and *bocks*) were excluded from the analysis of base word frequency effects because they were over three standard deviations from the best-fitting line. As can be seen in Figure 3, the remaining items produced a robust base word frequency effect [$r = -.436$, $t(157) = 6.1$, $p < .001$].[3]

The DRC model thus produces a pseudohomophone advantage and a base word frequency effect. Skilled readers do not produce this pattern. Thus, the DRC model does not successfully simulate the conjunction of a pseudohomophone advantage and the absence of a base word frequency effect seen in skilled readers when pseudohomophones and controls are mixed in the same list. Nor does the DRC model successfully simulate the conjunction of a pseudohomophone disadvantage and the presence of a base word frequency effect seen in skilled readers when pseudohomophones are read aloud before controls in pure lists. Nor does the DRC model successfully simulate the conjunction of a pseudohomophone disadvantage and the absence of a base word frequency effect observed when pseudohomophones are read aloud after nonword controls in pure lists.

SUMMARY

We have reviewed six different empirical phenomena and six different theoretical accounts. How the six different theoretical accounts fare is summarized in Table 3. Of the accounts discussed so far, only Borowsky et al.'s (2002) post hoc verification/scaling account can accommodate the pattern of effects seen in both pure and mixed list pseudohomophone reading aloud. As was noted ear-

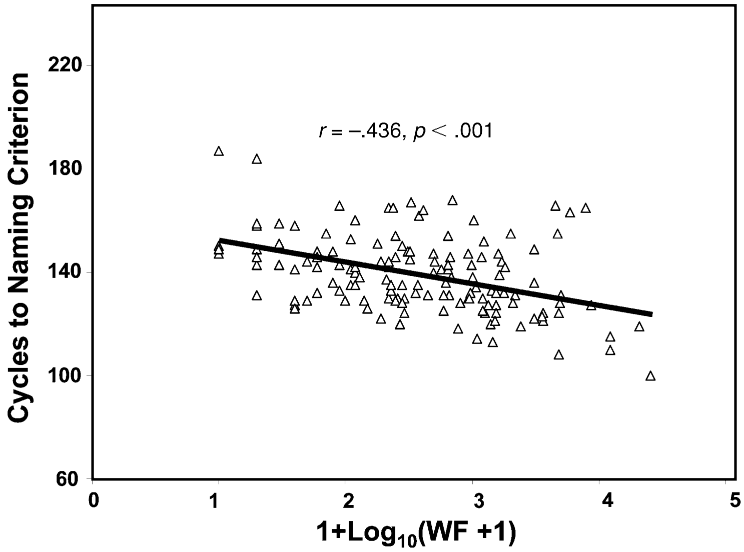

Figure 3. Cycles to reading aloud criterion in the dual route cascaded model (standard parameter set) for pseudohomophones as a function of base word frequency.

lier, this account is underspecified and invokes a novel mechanism to account for these data.

A NEW ACCOUNT

We now will propose a new account of pseudohomophone reading aloud that is able to account for all the pseudohomophone effects reviewed here. We then will implement this account in the DRC model, so as to provide an existence proof and to extend the range of effects that the DRC model can account for. In doing so, we also will demonstrate that it is possible to produce the conjunction of a pseudohomophone advantage and the absence of a base word frequency effect, *despite the use of frequency-sensitive lexical representations*. This is important because it undermines Besner and colleagues argument that the absence of a base word frequency effect in the presence of a pseudohomophone advantage is evidence that the lexical entries in the phonological lexicon are frequency insensitive. Finally, all these pseudohomophone effects can be produced without having to introduce a novel mechanism, such as the verification process that is central to Borowsky et al.'s (2002) account.

The basic premise of the account described here is that subjects can modulate how they use lexical knowledge. In pure list conditions, the base word dominates processing in the phonological output lexicon, whereas in mixed list conditions, many other lexical entries get ac-

Table 3
Success (✓) and Failure (×) at Producing the Six Pseudohomophone Reading Aloud Effects as a Function of Account Type

			Pure List			
	Mixed List		PHs First		PHs Second	
Account	PH Advantage	Absence of a BWFE	PH Disadvantage	Presence of a BWFE	Reduced PH Disadvantage	Absence of a BWFE
1. Besner and colleagues (Frequency-insensitive lexical activation)	✓	✓	?	✓	?	?
2. Seidenberg & McClelland (1989) (Orthographic overlap)	×	?	×	×	×	×
3. Seidenberg, Petersen, MacDonald, & Plaut (1996) (Articulation)	×	×	×	×	×	×
4. Grainger, Spinelli, & Ferrand (2000) (Dual-criterion hypothesis)	✓	✓	×	✓	×	×
5. Borowsky, Owen, & Masson (2002) (Verification)	✓	✓	✓	✓	✓	✓
6. Coltheart, Rastle, Perry, Langdon, & Ziegler (2001) (Dual route cascaded)	✓	×	×	✓	×	×

Note—PH, pseudohomophone; BWFE; base word frequency effect.

tivated as well. All of the six effects reviewed here fall out of this distinction.

This account makes the following assumptions about the reading of pseudohomophones and nonword controls: (1) Sublexical spelling–sound correspondences are used to generate a pronunciation for both pseudohomophones (e.g., *brane*) and nonword controls (e.g., *frane*); (2) general word knowledge (i.e., the activation of words that are similar in spelling and sound) facilitates the generation of a pronunciation for both pseudohomophones and nonword controls; (3) pseudohomophones and nonword controls differ in that pseudohomophones have an identical representation in the lexicon (*brane* → */brain/*), so pseudohomophones receive a greater benefit than do nonword controls from their base word (a specific lexical representation); (4) the default for the reading aloud of nonwords is to use (mostly) *general* word knowledge, and the default for the reading aloud of pseudohomophones is to use (mostly) base word specific knowledge; (5) the emphasis on general word knowledge versus specific word knowledge can be modulated by list context; and (6) in order to isolate the contribution of a specific lexical representation, other lexical representations must be inhibited.

The default set for reading nonwords aloud is to use general word knowledge. The absence of an identical representation in the phonological lexicon discourages the use of a strategy that promotes the rise of activation in a single specific lexical entry. This is likely because, given a nonword, a single entry cannot be isolated (process failure) and/or the isolation of a single lexical entry that does not match the nonword may adversely affect performance (relative to no contact with any lexical entries). Although pseudohomophones can be read aloud with assistance from specific word knowledge corresponding to their base word, they can easily be read aloud using general word knowledge, when mixed with nonword controls.

Mixed List Reading Aloud

We will refer to nonword reading aloud that makes reference to word knowledge in general as the general activation strategy (GAS). For the sake of simplicity, it is assumed here that this strategy is always employed when (1) nonwords are read aloud and (2) pseudohomophones mixed with nonwords are read aloud. This strategy yields a pseudohomophone advantage, because pseudohomophones activate their base words more strongly than do nonword controls. Relative to nonword controls, the base word facilitates pseudohomophone reading aloud directly because it is a perfect phonological match to the pseudohomophone and indirectly by increasing the activation of other lexical representations that overlap orthographically and phonologically with the pseudohomophone. Pseudohomophones do not produce a base word frequency effect in this condition because, although their base word is active, its impact is diluted by other active lexical representations.

Pure List Reading Aloud: Pseudohomophones First

When pseudohomophones are read aloud in a pure list format *before* nonword controls, they reference their base word by using specific word knowledge, rather than general word knowledge. We refer to this as the specific activation strategy (SAS). Nonword controls, which are read aloud second, are still read via the GAS. According to this account, a pseudohomophone *disadvantage* occurs because very few representations are activated in the phonological lexicon for pseudohomophones. In contrast, there are many active lexical representations for the nonword controls. The greater the activation in the lexicon, the more facilitation a reading aloud response receives. Thus, although pseudohomophones are benefited by activation of their base words, this benefit is smaller than the one conveyed to nonword controls by multiple active lexical representations.

The pseudohomophones produce a base word frequency effect in a pure list because the base words dominate processing in the phonological lexicon via the use of the specific lexical activation strategy. The rise of activation for a base word is sensitive to frequency. Thus, there will be more activation for a high-frequency base word than for a low-frequency base word. The time to read aloud a pseudohomophone is sensitive to this rise in activation because it is not diluted by other active lexical representations.

Pure List Reading Aloud: Pseudohomophones Second

There are two possible ways that the present account can explain the reduced pseudohomophone disadvantage and reduced base word frequency effect seen when pseudohomophones are read aloud in a pure list format *after* nonword controls. One possibility is that subjects adopt either the SAS or the GAS strategy for reading the pseudohomophones aloud. That is, one could imagine that subjects have only two processing alternatives available to them. They can use either specific or general word knowledge, but not both. A second possibility is that a less extreme SAS strategy is used to read the pseudohomophones aloud. According to this account, pseudohomophones are read aloud by reference to their base words, but there are an intermediate number of activated entries in the lexicon. This residual activation facilitates pseudohomophone processing, so that they are read aloud more quickly than when they are read aloud first but more slowly than when lexical activation is not constrained, as in the GAS strategy. There is no base word frequency effect because the residual activation in the lexicon dilutes the contribution from frequency-sensitive processing of the base word.

Why would subjects utilize different types of lexical knowledge in different list contexts? Here, we postulate that subjects do not know how to assess their reading aloud accuracy for items they have never seen before. When reading nonwords aloud, for example, how can they assess whether their pronunciation is correct? If they were to compare the pronunciation they are generating with a specific lexical representation, this would have only limited value. It would not convey enough information about how the *entire* string of letters should be combined. As a result, they activate many lexical representations and, through converging evidence from lexical and sublexical processes, calculate the appropriate pronunciation. As they gain experience balancing these two sources of knowledge, they learn that this will allow them to generate a correct pronunciation.

When pseudohomophones are read, however, it becomes apparent to the subjects that one source of knowledge that they can use to assess their accuracy is the base word. By using a lexical activation strategy that encourages the rise of activation of the base word, subjects can safely generate a correct pronunciation through converging evidence from lexical and sublexical processes. When pseudohomophones are read aloud first, subjects likely do not learn that there is an alternative lexical activation strategy (GAS) that also can generate a correct pronunciation and is more effective. When pseudohomophones are read aloud after nonword controls, subjects likely learn that the base word can be used to generate the correct pronunciation, but they also have the GAS strategy available to them.

SIMULATING GAS AND SAS

Although the strategy account outlined here is arguably plausible, the devil is in the details. An existence proof by simulation would be more convincing. This is accomplished here in the context of Coltheart et al.'s (2001) DRC model. The parameter sets used to simulate mixed and pure list pseudohomophone reading aloud can be seen in Table 4. These parameter sets are constrained by two factors, in addition to their ability to simulate the six pseudohomophone effects. One is that the parameter sets must allow the DRC model to simulate all of the nonword effects it currently simulates. The second is that parsimony suggests there should be as few parameter changes as possible. (We emphasize that it is not being claimed that these are the only parameter values that will produce these effects. Rather, it is simply an existence proof.) To avoid confusion, it is important to note that we are not claiming that subjects read words aloud, using Coltheart et al.'s parameter set, and then switch to reading nonwords aloud, using the GAS parameter set. It is entirely possible that words are read aloud using either the GAS or the SAS parameter set, depending on context. However, this is beyond the scope of the present article. The purpose of the present simulation exercise is simply to demonstrate that the distinction between general and specific word knowledge can capture the pattern of results observed in pseudohomophone reading aloud.

In its simplest form, the critical difference between mixed list pseudohomophone reading aloud and pure list pseudohomophone reading aloud is whether a number of lexical representations are active or only a specific lexical representation is activated. In mixed list conditions, the GAS strategy is in play: The activation of general word knowledge is encouraged. In pure list conditions, the SAS strategy is in play, and the activation of base word specific knowledge is encouraged. Hence, we use a parameter set that encourages the activation of general word knowledge in the mixed list condition and a parameter set that encourages the activation of a particular lexical entry in the pure list condition.

There are three sets of parameters that directly affect the amount of lexical activation: (1) facilitatory connections *into* the lexicons, (2) inhibitory connections *into* the lexicons, and (3) lateral inhibition *within* the lexicons. The facilitatory connections into the lexicons from the letter units and the phoneme system activate lexical representations that contain the same letter or phoneme in the same position. The inhibitory connections into the lexicons from the letter units and the phoneme system inhibit representations that do not contain a particular letter or phoneme in the same position. Lateral inhibition within in the lexicons causes active lexical representations to inhibit the rise of activation of all other lexical representations.

To simplify the search through the DRC model's parameter space, we attempted to simulate pseudohomophone reading aloud by changing only one parameter. Coltheart et al. (2001) have reported a simulation with words in which they increased the number of active lexical representations by reducing inhibition into the orthographic lexicon and setting lateral inhibition in the lexicons to zero. We chose this as our starting point. Unfortunately, "the DRC model needs to have a high value for letter-to-word inhibition, such as .435, to prevent lexical capture of nonwords in reading aloud" (Coltheart et al., 2001, p. 225). This problem arises because, as Coltheart et al. noted "the most delicate issue with the DRC model is to try to set an appropriate balance between the two routes in the model" (p. 219). To avoid lexical capture in the present simulations the facilitatory connections from the phonological lexicon to the phoneme system were reduced for all of the simulations.

Figure 4 provides an example of how varying the strength of inhibitory connections into the orthographic lexicon affects lexical activation. As can be seen there, the GAS parameter set resulted in more and earlier activation in the phonological lexicon than did the SAS parameter set, both for the base word and for other lexical representations. This is consistent with the distinction drawn between specific and general lexical knowledge.

Mixed List Reading Aloud

As we have already noted, numerous studies have demonstrated that in mixed lists, pseudohomophones are (1) read aloud more quickly than their nonword controls and (2) do not produce a base word frequency effect. Our argument here is that pseudohomophones are read aloud in mixed lists by reference to general word knowledge (GAS). Therefore, both pseudohomophones and nonword controls are read aloud using the GAS. The stimulus set consisted of the items used above to test the DRC model's account of pseudohomophone reading aloud,

Table 4
The Dual Route Cascaded Model's Default Parameter Values and the Parameter Values Used to Simulate the General Activation Strategy (GAS), Specific Activation Strategy (SAS), and Intermediate Activation Strategy (IAS)

			Pure List	
Parameter	Default Parameters	Mixed List (GAS)	PH First (SAS)	PH Second (IAS)
General				
Activation rate	.20			
Frequency scale	.050			
Reading-aloud criterion	.43			
Feature level				
Feature-to-letter excitation	.005			
Feature-to-letter inhibition	−.15			
Noise				
Letter level				
Letter-to-orthographic excitation	.07			
Letter-to-orthographic inhibition	−.435	−.250	−.435	−.385
Letter-to-letter inhibition				
Noise				
Decay				
Orthographic lexicon				
Orthographic-to-phonological excitation	.20			
Orthographic-to-letter excitation	.30			
Orthographic-to-letter inhibition				
Orthographic-to-orthographic inhibition	−.06	0	0	0
Noise				
Decay				
Phonological lexicon				
Phonological-to-phoneme excitation	.14	.014	.014	.014
Phonological-to-phoneme inhibition	0			
Phonological-to-orthographic excitation	.20			
Phonological-to-phonological inhibition	−.07	0	0	0
Noise				
Decay				
Phoneme level				
Phoneme-to-phonological excitation	.04			
Phoneme-to-phonological inhibition	−.16			
Phoneme-to-phoneme inhibition	−.15			
Noise				
Decay				
Grapheme-to-phoneme conversion (GPC) route				
GPC-to-phoneme excitation	.055			
Cycles before new route begins	10			
Cycles before next letter accessed	17			

Note—PH, pseudohomophone.

along with the items from our experiment that are pseudohomophones in the DRC model (see Appendix C).

The pseudohomophone advantage. The DRC model correctly read aloud 96.2% of the pseudohomophones and 97.5% of the nonwords correctly. The pseudohomophones were read aloud nine cycles faster than the nonword controls [$t(194) = 4.5$, $SEM = 2.0$, $p < .05$; see Table 5].

The absence of a base word frequency effect. Two of the correctly read aloud pseudohomophones (*plede* and *strete*) were excluded from the regression analysis because they were over three standard deviations from the best-fitting line. The remaining pseudohomophones did not produce a base word frequency effect [$r = -.043$; $t(222) < 1$; see Figure 5] (see note 3). It is clear that the DRC model is now successful in that it *does not* produce a pseudohomophone base word frequency effect when the general lexical activation parameter set is used. This finding is theoretically important because it demonstrates that it is possible to activate frequency-sensitive lexical representations but not have them produce a frequency effect, contrary to the interpretation advanced by Besner and colleagues (e.g., Baluch & Besner, 1991; Besner, 1999; Besner & Smith, 1992; Borowsky & Besner, 1993; McCann & Besner, 1987).

Pure List Reading Aloud: When Pseudohomophones Are Named First

As we have already noted, pseudohomophones read aloud in pure list presentation produce both a pseudohomophone disadvantage and a base word frequency effect when they are read aloud before nonword controls. According to the present account, when pseudohomo-

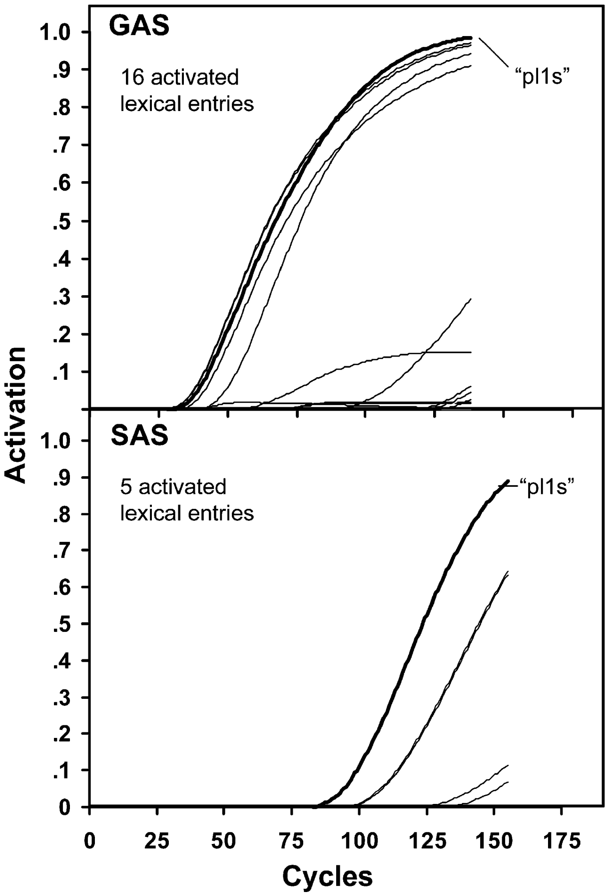

Figure 4. The rise of activation for entries in the phonological lexicon as a function of cycles to criterion for the general activation strategy (GAS) and the specific activation strategy (SAS) for the pseudohomophone *plase*.

phones are read aloud prior to nonword controls, subjects primarily activate only the base word in the lexicon. That is, pseudohomophones are primarily read aloud using the SAS (see Table 4).

The pseudohomophone disadvantage. Pseudohomophones read aloud using the SAS were compared with nonwords read aloud using the GAS (which is always used to read nonwords aloud). The DRC model made no pronunciation errors for the pseudohomophones. Critically, pseudohomophones took 17 cycles longer to read aloud than nonword controls [$t(200) = 9.38$, $SEM = 1.8$, $p < .01$; see Table 5].

The presence of a base word frequency effect. Three of the correctly read aloud pseudohomophones (*helled*, *thryve*, and *strete*) were excluded from regression analysis because they were over three standard deviations from the best-fitting line. The pseudohomophones produced a base word frequency effect [$r = -.16$; $t(230) = 2.45$, $p < .05$; see Figure 5] that was significantly larger than the one reported in the simulation of mixed list reading aloud [$t(222) = 16.0$, $SEM = 0.85$, $p < .001$].[4] The DRC model is now successful in that it *does* produce a pseudohomophone base word frequency effect when the specific lexical activation parameter set is used, consistent with what is observed with skilled readers when pseudohomophones are read aloud before nonword controls.

Pure List Reading Aloud: When Pseudohomophones Are Read Aloud Second

When pseudohomophones are read aloud in a pure list, but after nonword controls, they produce a *reduced* pseudohomophone disadvantage and a *null* base word frequency effect. Our suggestion here is that subjects use an intermediary strategy that has the properties of both SAS and GAS.

The pseudohomophone disadvantage. To simulate the reduced pseudohomophone disadvantage observed when pseudohomophones are read aloud second, we used a parameter set that sets inhibition to an intermediate value between the SAS and the GAS sets. We refer to this as the *intermediate activation strategy* (IAS). Pseudohomophones read aloud using the IAS were compared with the nonwords read aloud using the GAS (which is always used to read nonwords aloud). The model made no pronunciation errors for the pseudohomophones. The pseudohomophones took 3.7 cycles longer to read aloud than the nonword controls [$t(200) = 2.1$, $SEM = 1.8$, $p < .05$; see Table 5].

The absence of a base word frequency effect. The pseudohomophones were analyzed again to assess whether they produce a null base word frequency effect with this level of inhibition. Two of the pseudohomophones (*helled* and *strete*) were excluded from the regression analysis because they were over three standard deviations away from the best-fitting line. The pseudohomophones produced a null base word frequency effect [$r = -.108$; $t(231) = 1.65$, $p > .10$; see Figure 5]. It should also be noted that this null base word frequency effect is significantly smaller than the base word frequency effect observed when the SAS parameter set is used [$t(230) = 35.7$, $SEM = 0.43$, $p < .001$].

Table 5
Mean Number of Cycles to Reading Aloud Criterion in the Dual Route Cascaded Model for Pseudohomophones and Nonwords in Mixed and Pure List Conditions as a Function of Parameter Set

		Pseudohomophones		
	Nonwords GAS	Mixed List GAS	Pure List First SAS	Pure List Second IAS
Cycles to reading aloud criterion	132	123	149	136

Note—GAS, general activation strategy; SAS, specific activation strategy; IAS, intermediate activation strategy.

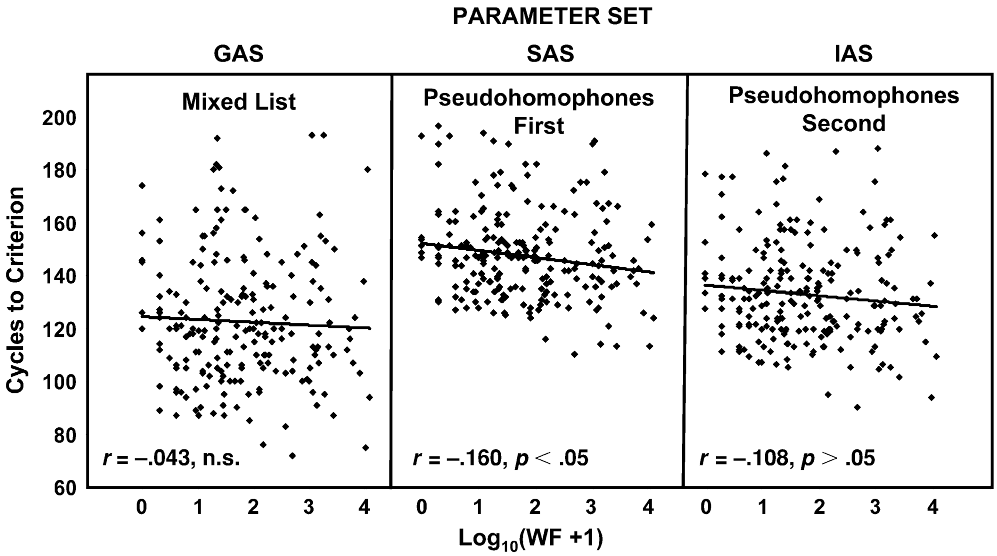

Figure 5. Cycles to reading aloud criterion in the dual route cascaded model for pseudohomophones as a function of base word frequency for the general activation strategy (GAS), specific activation strategy (SAS), and intermediate activation strategy (IAS) parameter sets.

Summary

The use of these three different parameter sets allows the DRC model to simulate the complex pattern of data observed in pseudohomophone reading aloud experiments. That is, the DRC model is now able to simulate (1) the conjunction of a pseudohomophone *advantage* and the *absence* of a base word frequency effect seen in mixed list reading aloud and (2) the conjunction of a pseudohomophone *disadvantage* and the *presence* of a base word frequency effect seen in pure list reading aloud when the pseudohomophones are read aloud first, and finally, (3) the conjunction of a pseudohomophone *disadvantage* and the *absence* of a base word frequency effect seen in pure lists when the pseudohomophones are read aloud after the nonword controls.

The lexical activation account described here differs from the verification account advocated by Borowsky et al. (2002). The verification account requires an additional *lexical checking* mechanism to account for the six effects reviewed here. In contrast, the lexical activation account appeals only to the inhibition of lexical representations to produce all of the pseudohomophone effects. In essence, the only difference between pseudohomophones read aloud in pure and mixed list conditions is the extent to which lexical representations are activated.

Reading nonwords aloud. If nonwords are always read aloud by using the GAS, it is essential that the DRC model be able to simulate known effects observed in nonword reading aloud by skilled readers when using this modified parameter set. Three critical effects in nonword reading aloud are (1) the letter length effect, (2) the whammy effect, and (3) the neighborhood density (N) effect.

The letter length effect. The time it takes to read a nonword aloud increases with the number of letters (e.g., Weekes, 1997). This nonword length effect has been used by Coltheart et al. (2001) to justify the use of a serial sublexical spelling-to-sound translation process. Use of the GAS parameter set does not prevent the DRC model from producing a robust length effect for Weekes's items [$r = .438$; $t(96) = 5.3, p < .001$] when controlling for N (see Table 6 and Appendix D).

The whammy effect. Rastle and Coltheart (1998) investigated how skilled readers' reading times to nonwords of a given length vary as a function of the number of phonemes. They found that it took longer to read aloud nonwords with fewer phonemes. This effect arises in the DRC model because the serial operation of the nonlexical route gives rise to spurious phoneme activation. For example, imagine that the grapheme *th* is submitted to the nonlexical route. Because each letter is entered serially, the DRC model will first generate the phoneme *t*; then when the *h* is submitted, it will have to overcome the activation of the phoneme *t* with the phoneme *T*. Rastle and Coltheart labeled this the *whammy effect*. To assess whether the GAS allows the DRC model to produce a whammy effect, the items from Rastle and Coltheart were run through the DRC model using the GAS parameter set (see Table 6 and Appendix E). These items produced a significant whammy effect [$t(21) = 2.6$, $SEM = 2.7$, $p < .05$].[5]

The N effect. A nonword's *neighborhood* is calculated by determining how many words differ from the item by only one letter and totaling them up. The more neighbors a nonword has, the more quickly it is read aloud (McCann & Besner, 1987; Reynolds & Besner, 2004). The ability of the GAS parameter set to produce an N effect for nonwords is assessed here by running Reynolds and Besner's (2004) items through the model. The data can

Table 6
Summary of the Nonword Reading Aloud Effects Simulated Using the GAS Parameter Set

Nonword Length	Length	
Weekes (1997) stimulus set	$r = .438$	
Whammies	Whammied	Nonwhammied
Rastle & Coltheart (1998) stimulus set	152	145
Neighborhood Density	High *N*	Low *N*
Reynolds & Besner (2004) stimulus set	85	115

Note—Latencies are in cycles to criterion.

be seen in Table 4, and the DRC model's latencies can be seen in Appendix F. The DRC model produces a significant *N* effect [$t(39) = 16.6$, $SEM = 1.8$, p. $< .001$].

GENERAL DISCUSSION

We have reviewed six effects from the pseudohomophone reading aloud literature and six accounts of these effects. We have illustrated how four of these accounts could not explain many of these effects and have identified a number of problems for the remaining accounts. A new account was proposed to explain all six of the observed effects. The central premise of this account is that subjects use lexical knowledge differently depending on the list context. When pseudohomophones and nonword controls are read aloud in a mixed list, they are read using general word knowledge (e.g., lexical representations that are orthographically and phonologically similar to the target). Pseudohomophones read aloud in a mixed list are processed using general word knowledge, because nonword controls lack a specific lexical representation. This is referred to as the *general activation strategy* (GAS). When pseudohomophones are read aloud prior to nonword controls in a pure list, they mainly activate their base words in the phonological lexicon, using the *specific activation strategy* (SAS). This strategy was simulated here by inhibiting the activation of lexical representations. Pseudohomophones read aloud after nonword controls in the pure list condition are read using an intermediate point on this continuum (as indexed by the IAS parameter set). This lexical activation strategy account was implemented in Coltheart and colleagues' DRC model and successfully produced all six effects. In addition, the GAS parameter set used for nonword reading aloud simulated three critical findings from the nonword reading aloud literature—that is, (1) as letter length increases, so does the time to read aloud; (2) whammies increase the time to read aloud; and (3) as the number of neighbors increases, the time to read aloud decreases.

Locus of the Word Frequency Effect

The present simulation exercise is also theoretically important because it demonstrates that frequency-sensitive representations need not give rise to a frequency effect. This undermines Besner and colleagues' (Baluch & Besner, 1991; Besner, 1999; Besner & Smith, 1992; Borowsky & Besner, 1993; McCann & Besner, 1987) inference that the joint finding of a pseudohomophone advantage and the absence of a base word frequency effect in reading aloud is inconsistent with lexical representations in the phonological lexicon being frequency sensitive. Relatedly, the present simulation exercise shows that it is possible to account for a range of effects without appealing to the operation of an (opaque) verification process (which in any case, does not play a role in the reading of words aloud).

Context Effects

There are numerous accounts of visual word recognition, where it has been argued that skilled readers can modulate the dynamics of the reading system (Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Reynolds & Besner, 2005; Zevin & Balota, 2000). However, these accounts have been concerned with how *different* routes for translating print into sound can be modulated (e.g., Baluch & Besner, 1991; Zevin & Balota, 2000) or how various levels of representation do or do not interact in different contexts (e.g., Brown & Besner, 2002; Smith & Besner, 2001; Stolz & Neely, 1995). The present work emphasizes a third alternative—namely, the *type* of information extracted from the lexicon: specific word knowledge from the activation of a particular lexical representation versus general word knowledge from the activation of many lexical representations.

Future Directions

Two issues that come easily to mind merit further investigation. One concerns the respective roles that orthographic neighbors (Grainger et al., 2000; McCann & Besner, 1987; Reynolds & Besner, 2004) and phonological neighbors (Mulatti, Besner, & Job, 2003; Reynolds, Mulatti, & Besner, 2004) play in pseudohomophone reading aloud. The point here is that orthographic and phonological neighbors are typically confounded. More analytic experiments are required to assess what respective roles they play in pseudohomophone (and nonword and word) reading aloud.

A second issue concerns the role that semantics may play in pseudohomophone reading aloud. Proponents of the PDP approach sometimes argue that pseudohomophone effects arise through the action of the semantic system. One way to investigate this is to examine whether there are pseudohomophone effects in reading aloud for patients with no ability to access semantics from print. For example, Bub, Cancelliere, and Kertesz (1985) report the case of M.P., who has an acute loss of language comprehension but uses lexical knowledge to read words and is also able to read nonwords. A demonstration that contact with semantics is not necessary to produce various pseudohomophone effects in reading aloud in such patients would presumably raise problems for the PDP account. Relatedly, one could jointly manipulate imageability and pseudohomophony in experiments with intact skilled readers. A failure to see an effect of imageability on the time to read aloud pseudohomophones would raise problems for the view that semantics standardly plays a role here[6] and would leave PDP models with the ongoing problem of how to produce these various pseudohomophone effects in intact readers.

Conclusion

The lexical activation strategy account provided here is currently the only implemented computational account that correctly simulates all six of the effects reported here. We reiterate a conclusion reached elsewhere (Reynolds & Besner, 2005): Processing in reading aloud appears to be considerably more dynamic than is generally acknowledged.

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NOTES

1. Herdman, LeFevre, and Greenham (1994) have reported a *reversed* base word frequency effect for pseudohomophones read aloud among nonwords and words, using a subset of McCann and Besner's (1987) stimulus set. Interpretation of their data is complicated by their use of only 20 of the original 80 pseudohomophones per subject for their analysis of a base word frequency effect. Although Herdman et al. (1994) reported data from a delayed reading aloud condition, it was collected from a different set of subjects. Furthermore, more errors were made in delayed reading aloud than in online reading aloud. Some data suit no theory.

2. The data were also analyzed excluding items that subjects did not recognize as sounding like words they knew. The pattern of results did not change.

3.The differences in degrees of freedom associated with lexicality and base word frequency effects are due to Herdman et al.'s (1996) items being matched in triplets. High- and low-frequency pseudohomophones are collapsed into a single score for the purposes of comparing pseudohomophones and nonword controls. Changes in the degrees of freedom for analyses across parameter sets are due to errors.

4. There is very little error variability in the item latencies between the different simulations.

5. The nonwhammy item *fruls* and its control *fooce* were excluded from the analyses because the former has a whammy in the final position (/s/→/z/).

6. To date, we have failed to observe an imageability effect in pseudohomophone reading aloud by university-level readers.

APPENDIX A
Pseudohomophones and Nonword Controls Used in the Experiment

Pseudohomophones							
Low Frequency		High Frequency		Nonword Controls			
bok	glene	bol	gud	baif	glae	binc	kud
bain	groap	berd	groop	baps	grok	blait	makt
basc	hoan	blak	hoap	bazed	haiv	boap	nol
blote	mame	bote	mete	blawnt	mawg	boart	phek
busc	noap	boath	noze	bont	nasc	bost	phlur
kalk	paiv	kamp	paje	kern	pene	chak	phunt
kelt	fazed	kase	fone	koez	fet	chilm	plawg
chaif	plede	chare	plase	chote	plinc	chite	poan
chyde	pron	chek	pryce	chawd	prich	cish	prud
chern	seap	cherch	saif	chail	sab	derd	serk
klaps	soke	kost	sed	klain	sair	drase	sheem
clawd	skab	coart	skeme	cloom	skoze	famp	shoath
dise	shean	dawg	shud	dont	shoap	fane	shyce
dawnt	shail	drinc	shoan	doan	shede	fett	skaje
finc	snair	fakt	smol	fusc	snue	flerch	smiew
fers	stich	feer	stait	fise	staip	fote	sone
flont	strue	fiew	strete	flers	stralk	frete	stete
flae	shoarn	philm	shur	flon	shype	gare	stred
flawg	tont	phish	teem	floke	teap	gat	tase
floom	thryve	phlat	threft	floap	thryde	grol	thraif
foze	trype	flite	trane	foarn	trean	haim	troze
phret	woez	frunt	werk	phryve	wame	keer	weme
gaip		gaim		gelt		koop	

APPENDIX B
Cycles to Reading Aloud Criterion for the Pseudohomophones and Nonword Controls Used to Assess Whether the DRC Model Produces the Conjunction of a Pseudohomophone Advantage and a Base Word Frequency Effect

Pseudohomophones								Nonword Controls					
furst	115	surve	138	hoald	147	gaim	132	gurst	149	furve	154	hoalt	156
hazz	119	roal	130	breaz	140	gole	148	nazz	142	zoal	138	brean	147
yung	166	nues	146	braiv	137	hed	108	nung	190	fues	149	brair	176
keap	123	wirth	138	boan	130	heet	125	feap	137	hirth	159	boam	137
wunce	163	gane	147	bern	135	hoam	131	tunce	181	hane	–	berv	143
wawl	120	groe	132	theem	150	keap	123	vawl	143	broe	152	theen	155
rong	155	waije	146	phlash	165	reech	143	mong	158	faije	156	phlast	171
grean	127	slite	162	swoar	166	weel	124	drean	143	klite	202	swoam	156
ferm	118	durt	130	coalt	141	tair	144	serm	137	jurt	136	coaft	147
reech	143	coad	130	stroal	148	flud	126	meech	165	doad	134	stroat	170
dait	131	fome	136	soke	143	focks	135	yait	138	yome	138	sofe	146
ment	113	taip	133	seaks	142	stane	155	nent	119	baip	139	seafs	148
choyce	160	keeze	151	burth	136	mair	144	phoyce	200	veeze	156	lurth	168
bote	141	berd	131	fayst	144	pait	129	wote	172	perd	130	nayst	156
dreem	131	sope	142	fownd	128	fleigh	187	breem	143	zope	156	nownd	156
gess	125	nerse	135	groope	149	laice	160	dess	127	merse	154	moope	156
pruve	154	bern	135	leest	121	daim	136	bruve	–	pern	131	deest	156
raize	140	trax	122	looz	128	fole	149	kaize	155	prax	141	gooz	133
shooze	168	leese	144	maik	127	sted	126	frooze	163	heese	155	daik	135
thret	131	glew	141	milc	114	bleet	146	shret	153	plew	149	filc	131
prufe	167	burth	136	proov	141	doam	135	trufe	194	turth	169	troov	155
golph	148	derth	143	shaip	146	weap	133	tolph	169	kerth	167	traip	143
boan	130	binje	184	tirn	119	peech	158	poan	137	jinje	184	nirn	143
waik	132	turse	146	trayd	139	neel	129	haik	135	burse	151	crayd	156
mait	129	wead	129	waije	146			pait	129	gead	132	laije	156
supe	165	hoest	143	gurth	159			zupe	177	hoert	156	sair	150
phocks	153	stait	136	layst	146			snocks	163	shait	154	brud	142
pirl	132	doun	110	hownd	143			birl	133	loun	139	vocks	140
coph	141	owt	100	soope	144			goph	153	ost	121	prane	175
perge	159	helled	*195	feest	138			berge	165	helked	207	gair	146
cheet	148	leest	121	booz	127			preet	156	leext	156	nait	138
lirch	158	gaim	132	caik	135			wirch	162	gair	146	teigh	176
fole	149	wyfe	131	silc	120			vole	83	vyfe	177	gaice	169
gool	131	fyne	133	groov	142			bool	131	fyce	–	raim	135
pirck	150	wawk	124	draip	147			virck	156	wawf	137	jole	154
hokes	151	bote	141	birn	128			lokes	170	boke	167	gled	133
yeer	124	layt	128	spayd	149			keer	155	payt	129	breet	154
groop	122	gyde	164	raije	145			croop	146	gyfe	177	goam	138
fownd	128	feeld	127	bair	143			yownd	156	teeld	156	meap	131
leest	121	flore	144	blud	121			heest	156	flove	197	feech	165
feal	124	woak	129	bocks	*77			beal	134	woaf	142	beel	–
hoap	132	hoap	132	brane	–			goap	138	hoaj	143		
peece	130	boarn	147	cair	142			deece	169	boarm	149		
blud	121	nyse	152	dait	131			clud	131	nyre	177		
cheef	134	cleen	130	deigh	165			bleef	156	cleem	156		
dowt	124	foart	154	faice	155			kowt	143	loart	162		

Note—There are unequal numbers of pseudohomophones and nonwords because Herdman et al. (1996) used twice as many pseudohomophones as nonword controls. Dashes indicate items read incorrectly by the DRC model. *Items excluded from the base word frequency analysis.

APPENDIX C
Cycles to Reading Aloud Criterion for Pseudohomophones (PHs) and Nonword Controls With the GAS, the SAS, and the IAS Parameter Sets

Pseudohomophones				Nonword Controls		Pseudohomophones				Nonword Controls	
Item	Mixed GAS	PH 2nd IAS	PH 1st SAS	Item	GAS	Item	Mixed GAS	PH 2nd IAS	PH 1st SAS	Item	GAS
furst	110	131	140	gurst	114	roal	96	115	132	zoal	105
hazz	113	126	137	nazz	121	nues	118	145	159	fues	127
yung	118	153	174	nung	131	wirth	115	139	152	hirth	117
keap	103	119	134	feap	101	gane	90	127	148	hane	102
wunce	148	168	177	tunce	159	groe	141	134	147	broe	134
wawl	105	120	134	vawl	113	waije	134	148	155	faije	156
rong	128	192	168	mong	124	slite	131	160	176	klite	202
grean	118	127	141	drean	153	durt	109	122	136	jurt	122
ferm	95	112	127	serm	101	coad	100	121	132	doad	100
reech	120	140	156	meech	133	fome	118	124	135	yome	113
dait	105	122	136	yait	108	taip	122	126	137	baip	116
ment	76	96	117	nent	80	keeze	156	156	156	veeze	156
choyce	162	173	184	phoyce	200	berd	100	121	137	perd	102
bote	100	131	154	wote	107	sope	105	149	150	zope	97
dreem	132	138	148	breem	124	nerse	111	132	148	merse	118
gess	106	116	130	dess	103	bern	91	110	127	pern	101
pruve	135	160	184	bruve	161	trax	–	126	135	prax	116
raize	121	136	150	kaize	128	leese	121	138	153	heese	136
shooze	165	164	170	frooze	170	glew	105	124	145	plew	111
thret	165	142	143	shret	139	burth	133	137	153	turth	169
prufe	146	161	192	trufe	162	derth	132	142	153	kerth	142
golph	165	165	165	tolph	169	binje	153	166	184	jinje	184
boan	95	116	133	poan	110	turse	114	130	149	burse	116
waik	100	115	136	haik	107	wead	87	109	129	gead	98
mait	98	113	131	pait	96	hoest	127	144	154	hoert	156
supe	192	153	165	zupe	145	stait	120	127	147	shait	169
phocks	138	152	166	snocks	123	doun	110	121	129	loun	98
pirl	108	123	136	birl	107	owt	87	103	114	ost	112
coph	–	140	149	goph	139	helled	120	*202	*226	helked	193
perge	120	141	162	berge	127	leest	124	136	143	leext	156
cheet	117	134	148	preet	129	gaim	110	122	138	gair	118
lirch	126	143	165	wirch	133	wyfe	136	147	159	vyfe	177
fole	98	120	146	vole	96	fyne	127	144	161	fyce	159
gool	89	113	131	bool	86	wawk	107	121	136	wawf	127
pirck	156	156	156	virck	156	bote	100	131	154	boke	105
hokes	109	134	157	lokes	119	layt	115	123	134	payt	110
yeer	104	122	144	keer	121	gyde	172	165	175	gyfe	153
groop	116	134	143	croop	114	feeld	122	126	140	teeld	156
fownd	132	137	146	yownd	156	flore	136	144	154	flove	172
leest	124	136	143	heest	156	woak	104	120	132	woaf	109
feal	83	107	129	beal	85	hoap	107	125	139	hoaj	132
hoap	107	125	139	goap	111	boarn	126	133	151	boarm	152
peece	133	137	149	deece	156	nyse	154	161	168	nyre	177
blud	110	122	135	clud	106	cleen	131	138	147	cleem	156
cheef	122	131	147	bleef	148	foart	161	161	161	loart	162
dowt	117	121	131	kowt	143	hoald	137	148	155	hoalt	156
surve	119	135	149	furve	129	breaz	150	142	146	brean	152
braiv	148	142	148	brair	216	bote	100	131	154	boart	134
boan	95	116	133	boam	98	boath	180	159	161	bost	83
bern	91	110	127	berv	113	kamp	96	106	128	chak	137
theem	130	145	154	theen	131	kase	124	128	144	chilm	154
phlash	181	181	181	phlast	171	chare	–	165	169	chite	140
swoar	165	168	177	swoam	156	chek	130	131	141	cish	103
coalt	121	129	147	coaft	134	cherch	150	158	168	derd	105
stroal	145	153	164	stroat	169	kost	95	107	122	drase	148
soke	111	136	149	sofe	160	coart	131	138	149	famp	90
seaks	103	126	147	seafs	116	drinc	135	140	152	fett	104
bain	88	108	127	baps	82	fakt	103	117	127	flerch	184
blote	–	175	192	blawnt	171	feer	122	132	143	fote	111
busc	124	123	132	bont	101	philm	144	141	151	gare	98
kelt	89	109	131	koez	143	phish	163	163	167	gat	66
chaif	127	135	148	chote	153	phlat	153	153	153	grol	117
chyde	161	182	199	chawd	125	flite	–	180	192	haim	106
chern	135	145	156	chail	153	frunt	112	134	141	keer	121

APPENDIX C (Continued)

Pseudohomophones				Nonword Controls		Pseudohomophones				Nonword Controls	
Item	Mixed GAS	PH 2nd IAS	PH 1st SAS	Item	GAS	Item	Mixed GAS	PH 2nd IAS	PH 1st SAS	Item	GAS
klaps	117	132	150	klain	126	gaim	110	122	138	koop	105
dise	120	142	161	dont	96	groop	116	134	143	makt	107
dawnt	126	136	150	doan	102	hoap	107	125	139	nol	87
finc	–	127	136	fusc	–	mete	193	151	162	phek	120
fers	119	138	159	fise	120	noze	112	122	145	phlur	169
floom	120	130	148	floap	149	paje	105	115	146	phunt	138
foze	144	150	172	foarn	161	fone	113	122	137	plawg	156
phret	155	155	155	phryve	226	plase	138	140	155	poan	110
gaip	111	122	138	gelt	88	pryce	155	165	181	prud	115
glene	–	182	195	glae	–	saif	113	124	133	serk	105
groap	119	131	148	grok	134	sed	75	95	114	sheem	155
hoan	105	124	139	haiv	133	skeme	193	193	193	shoath	155
mame	87	123	137	mawg	131	shoan	118	133	147	skaje	162
noap	116	129	140	nasc	130	stait	120	127	147	sone	108
paiv	133	130	133	pene	161	strete	*211	*211	*211	stete	–
plede	*225	191	196	plinc	169	teem	91	108	115	tase	107
seap	94	111	129	sab	76	thrett	145	150	158	thraif	171
soke	111	136	149	sair	118	trane	138	148	169	troze	144
skab	102	118	139	skoze	202	werk	94	111	125	weme	159
shean	117	137	154	shoap	146	burth	133	137	153	lurth	158
shail	145	139	150	shede	–	fayst	130	147	154	nayst	132
snair	158	161	176	snue	–	fownd	132	137	146	nownd	156
stich	182	163	163	staip	135	groope	145	153	166	moope	135
strue	–	161	166	stralk	171	leest	124	136	143	deest	156
shoarn	180	180	180	shype	185	looz	120	122	129	gooz	135
thryve	173	186	*213	thryde	226	maik	101	113	131	daik	118
trype	156	171	193	trean	152	milc	110	119	128	filc	123
woez	120	126	141	wame	89	proov	147	142	151	troov	147
berd	100	121	137	blait	144	shaip	146	145	151	traip	137
blak	107	125	138	boap	112	tirn	104	114	130	nirn	143
trayd	148	141	149	crayd	156						
waije	134	148	155	laije	156						
gurth	140	150	166								
layst	130	145	154								
hownd	134	142	153								
soope	165	145	151								
feest	124	136	149								
booz	106	115	128								
caik	125	132	142								
silc	–	122	134								
groov	124	137	153								
draip	146	142	153								
birn	102	116	133								
spayd	145	144	155								
raije	132	142	153								
bair	113	128	144	sair	118						
blud	110	122	135	brud	120						
bocks	85	113	125	vocks	105						
brane	132	155	180	prane	169						
cair	110	125	144	gair	118						
dait	105	122	136	nait	105						
deigh	151	162	177	teigh	151						
faice	140	152	165	gaice	169						
gaim	110	122	138	raim	114						
gole	106	133	150	jole	96						
hed	72	91	111	gled	96						
heet	97	115	130	breet	127						
hoam	108	124	140	goam	102						
keap	103	119	134	meap	100						
reech	120	140	156	feech	127						
weel	87	107	126	beel	92						
tair	115	125	144								
flud	106	122	139								
focks	90	115	142								
stane	118	130	152								
mair	126	134	145								

APPENDIX C (Continued)

	Pseudohomophones			Nonword Controls			Pseudohomophones			Nonword Controls	
Item	Mixed GAS	PH 2nd IAS	PH 1st SAS	Item	GAS	Item	Mixed GAS	PH 2nd IAS	PH 1st SAS	Item	GAS
pait	96	113	128								
fleigh	174	183	195								
laice	155	157	167								
daim	120	135	142								
fole	98	120	146								
sted	97	114	133								
bleet	112	134	152								
doam	104	123	140								
weap	97	117	135								
peech	120	142	162								
neel	96	114	132								

Note—There are unequal numbers of pseudohomophones and nonwords because Herdman, LeFevre, and Greenham (1996) used twice as many pseudohomophones as nonword controls. Dashes indicate items read incorrectly by the DRC model. *Items excluded from the base word frequency analysis.

APPENDIX D
Cycles to Reading Aloud Criterion for Weekes's (1997) Items With the GAS Parameter Set

seb	84	shub	109	skown	142	slanch	149
sep	81	sket	108	slort	120	snutch	168
som	81	sneg	120	sorch	133	spants	133
ped	74	pand	86	plown	126	pretch	189
pob	73	prib	111	prish	146	pruise	142
sab	76	sarn	99	shart	107	shrain	177
tha	166	thun	93	thurn	130	threwn	140
tob	72	tord	91	trabe	146	tranks	119
wid	75	wilk	97	whurf	141	whetch	199
sov	–	spuk	134	spont	125	squate	248
spo	141	stul	117	steck	101	stetch	171
sut	71	sush	92	swonk	142	sworve	148
lud	83	leck	86	lorge	116	loaked	116
cag	72	cade	95	carge	117	clants	122
cas	80	clet	110	cland	122	clitch	175
cif	131	colm	116	crand	114	clotch	168
bam	75	blog	102	betch	113	branks	118
bez	94	blug	105	blent	122	brants	128
bot	66	bram	92	brant	110	breeth	150
gid	78	gand	91	grink	146	granks	137
gop	74	gend	84	grite	176	grewth	151
hin	70	hant	86	horch	128	hupped	153
cug	75	crum	109	crish	126	crants	123
fot	69	frip	103	frosh	146	flanch	146
fud	83	fune	154	frund	127	fretch	233

Note—A dash indicates items read incorrectly by the DRC model.

APPENDIX E
Cycles to Reading Aloud Criterion for Rastle and Coltheart's (1998) Items With the GAS Parameter Set

Whammies		Nonwhammies	
barch	116	breps	126
bersh	158	bulsk	156
boace	156	blusp	148
soach	125	steld	138
foush	157	fenks	131
keesh	168	kelst	156
doath	132	delst	134
doaph	169	dalst	156
doish	169	drusp	156
feech	127	freps	122
gaiff	156	glect	156
fooce	138	fruls	–
gaich	169	glupt	156
fooph	169	frolp	156
serce	–	strik	119
gauch	156	glesp	156
verck	156	vulsk	156
darch	126	dreps	110
tawsh	167	twenk	169
taive	137	trusp	125
goich	169	glosp	148
paish	169	prenk	131
ghoan	154	grusk	156
kirch	144	krelm	156

Note—A dash indicates items read incorrectly by the DRC models. The item *fruls* was excluded from the present analysis because it has a late position whammy in the DRC model.

(*Continued on next page*)

APPENDIX F
Cycles to Reading Aloud Criterion for Reynolds and Besner's (2004) Items With the GAS Parameter Set

High N		Low N	
bant	94	bapt	112
dast	83	dakt	120
dend	84	demf	120
dest	76	demk	121
dind	87	dild	104
dunt	85	dund	110
fant	88	fapt	104
fent	76	femp	115
fest	77	fenf	134
fint	87	fimk	122
fost	85	fomp	114
fust	83	fuld	107
hant	86	hamf	118
hend	79	hemk	118
hest	79	hept	105
hust	81	himp	100
kest	85	kect	113
kint	88	kimp	113
lant	90	lamf	107
lind	84	limf	121
lond	93	lomk	121
lont	92	lonf	122
mant	92	mamk	110
nast	86	nald	125
nent	80	nant	102
pont	93	pomk	115
pust	80	pumk	107
rast	81	ramf	135
rint	87	rild	102
sant	92	samf	–
sast	83	samk	108
sest	78	semp	111
sint	85	simk	121
sunt	93	suld	113
sust	88	sumf	111
tant	90	tamf	–
tast	81	timp	99
tind	87	timk	128
tunt	89	tuld	119
tust	83	tunf	117
wint	83	wimf	143
wust	85	wund	99

Note—Dashes indicate items read incorrectly by the DRC model.

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