Cross-modal repetition priming with homophones provides clues about representation in the word recognition system

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In three experiments, we assessed the impact of auditory homophone primes (/swi:t/) on lexical decisions to visually presented low-frequency (*suite*) and high-frequency (*sweet*) homophone spellings. In Experiment 1 we investigated the time course of these cross-modal repetition priming effects. Results suggested that low-frequency homophone spellings do not reach the same activation level as nonhomophones, even at long SOAs. There were no differences in priming between high-frequency homophones and nonhomophones. In Experiments 2 and 3 we attempted to eliminate the impact of strategies with lower proportions of repetition primes. Results showed smaller priming effects for both low- and high-frequency homophones than for nonhomophones, suggesting that neither homophone spelling is fully activated. Implications for local and distributed models of word recognition are discussed.

Keywords: cross-modal priming, repetition priming, homophones, lexical decision, word recognition, blend state, phonology, semantic, orthography

The process by which people recognize words has long been a central topic in cognitive psychology. Many different types of models have been proposed to describe this process, however, one basic distinction between types of models concerns how words are represented in memory. In some models, the representational units correspond to identifiable lexical information, including letters, words, phonemes, and concepts. These types of models are said to incorporate *local* representations. In contrast, in *distributed* models, the representational units do not correspond to identifiable pieces of information. Instead, lexical knowledge is represented by patterns of activation across sets of units (i.e., the coordinated activity of many units) and each of these units can be involved in the representations for a number of different words. Both types of models have enjoyed reasonable success. Thus, there are now localist models of both visual word recognition (e.g., Coltheart,

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Rastle, Perry, Langdon, & Ziegler, 2001; Grainger & Jacobs, 1996; Jacobs, Rey, Ziegler, & Grainger, 1998) and spoken word recognition (e.g., Marslen-Wilson, 1987; Marslen-Wilson, Moss, & Halen, 1996; McClelland & Elman, 1986; Norris, 1994) and also distributed models of both visual word recognition (e.g., Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Van Orden & Goldinger, 1994) and spoken word recognition (e.g., Gaskell & Marslen-Wilson, 1997, 1999).

One way to try to test between these different types of representational schemes is to examine how the different models explain ambiguity effects. Words can be ambiguous in a number of ways (e.g., semantically, phonologically, orthographically) with localist and distributed models of word recognition offering different accounts of how this ambiguity is represented. It has been proposed that in a localist model, representation of ambiguity is achieved by activation of multiple representations at the level of the model that characterizes the nature of the ambiguity (e.g., multiple semantic representations in the case of semantic ambiguity). For most localist models the assumption is that there are lateral inhibitory links between representations and, although all representations would initially be activated, the dominant (more frequently encountered) representation would deactivate subordinate (less frequently encountered) representations via those inhibitory links. That is, it is assumed that, within a level of representation, the activity of one unit reduces the activity of other activated units. By this process the dominant representation could eventually reach full activation, whereas the subordinate representations would be deactivated.

By contrast, simulations have shown that in most parallel distributed processing (PDP) models the typical result when processing an ambiguous word is a blend state, where the pattern of activation is partially appropriate for each candidate but not fully appropriate for either candidate (e.g., Borowsky & Masson, 1996; Harm & Seidenberg, 2004; cf. Rodd, Gaskell, & Marslen-Wilson, 2004). In such a situation, both candidates would remain partially (although not necessarily equivalently) activated unless context was available to allow the intended meaning to ultimately be selected.

When it comes to processing ambiguous stimuli, therefore, the basic difference between localist and distributed models is that, in the former, it is assumed that processing resolves the ambiguity (by suppressing the subordinate meaning), while, in the latter, ambiguity can remain unresolved unless an appropriate context is available. As will be discussed below, Grainger, Van Kang, and Segui (2001) exploited these ideas in order to evaluate the lateral inhibition assumption of localist models, using homophones in a cross-modal repetition priming task. Homophones are words like *maid* and *made*, which have a single pronunciation but multiple spellings and multiple meanings. When presented as auditory stimuli, homophones are semantically ambiguous *and* orthographically ambiguous. The purpose of the present research was to re-examine and expand on Grainger et al.'s conclusions about the nature of lexical representations, using those authors' experimental paradigm.

In the previous literature, homophones have almost always been presented as visual stimuli. It is now well established that in the visual lexical decision task (LDT), latencies for homophones are longer than those for nonhomophones (e.g., Edwards, Pexman, & Hudson, 2004; Ferrand & Grainger, 2003; Pexman, Lupker, & Jared, 2001; Pexman, Lupker, & Reggin, 2002; Rubenstein, Lewis, & Rubenstein, 1971). This homophone effect can be readily explained in terms of feedback activation from phonology to orthography (e.g., Pexman et al., 2001). The idea is that, when a homophone is presented, there would initially be activation of the word's orthographic representation followed by activation of the word's phonological and semantic representations. Once they become activated, these phonological and semantic representations then feed activation back to the orthographic level. Because, for homophones, one pronunciation corresponds to multiple spellings, the feedback activation from phonology would provide activation to orthographic representations for both homophone spellings. It is typically assumed that visual LDT responses are made based primarily on activation in the orthographic units (Balota & Chumbley, 1984; Balota, Paul, & Spieler, 1999). With multiple orthographic representations activated via this feedback activation process, responding would be expected to be slower for homophones than for nonhomophones in visual LDT. What is also typically reported is that the homophone effect is more pronounced when the low-frequency members of homophone pairs (*maid* is lower frequency than its homophone mate *made*) are presented (e.g., Pexman et al., 2001). The explanation for this result is that high-frequency spellings are presumed to be more rapidly activated and, hence, they can both more easily avoid the competition when they are presented and become strong competitors when their low-frequency mates are presented.

In Grainger et al.'s (2001) experiments the targets were also visually-presented low- and high-frequency French homophones and nonhomophones and participants were asked to make lexical decisions to the targets. Prior to each visual target stimulus, however, participants were presented with an auditory prime. These primes were either repetition primes for the targets or unrelated to the targets. That is, on a repetition trial, participants heard a word pronounced and then saw the same word, as in the English example /meId/ – *made*. On an unrelated trial, participants heard a word pronounced and then saw a different word, as in /hi:p/ – *made*. Previous research had suggested that spelling information is activated in the process of auditory word recognition (Seidenberg & Tanenhaus, 1979; Tanenhaus, Flanigan, & Seidenberg, 1980; Zecker, 1990; Ziegler & Ferrand, 1998).

Hence, Grainger et al. assumed that when an auditory homophone prime was presented, both candidate meanings and spellings would be activated. For the auditory nonhomophone primes, in contrast, only one meaning and one spelling would be activated.

In this cross-modal repetition priming situation, Grainger et al. (2001) made the following predictions, based on the notion of lateral inhibition: the auditory homophone primes would, at least early on in processing, activate both their dominant and subordinate meanings and spellings. Due to the existence of lateral inhibitory links, however, there would be rapid deactivation of the subordinate meanings and spellings, "given sufficient processing time, only the dominant orthographic and semantic representations should remain activated." (p. 54). The result will be a small or nonexistent priming effect for low-frequency homophones. In contrast, the activation for representations of high-frequency homophones should grow quickly and be maintained. Thus, there should be no cost incurred in the processing of dominant homophone meanings and spellings, and so these words should show just as much priming as would nonhomophones of comparable frequency.

In Grainger et al.'s (2001) Experiment 1 the nonword targets were all pronounceable pseudowords (e.g., *prane*) and in Experiment 2 half of the nonword targets were pseudohomophones (e.g., *brane*). The results of both experiments were consistent with Grainger et al.'s predictions based on localist models containing an inhibition mechanism. Considering first the low-frequency (subordinate) targets, in both experiments, there was less repetition priming for homophone targets than for nonhomophone targets. In Experiment 2, in fact, there was a trend toward inhibitory repetition priming for low-frequency homophone targets yet robust facilitory repetition priming for low-frequency nonhomophone targets. The authors argued that these results are best explained in terms of lateral inhibition. The high-frequency homophone spelling dominates and, ultimately, eliminates the activation of the low-frequency spelling.

In contrast, for high-frequency (dominant) homophone targets there was facilitory repetition priming in both experiments, and the magnitude of repetition priming for these targets was equivalent to that for high-frequency nonhomophone targets. Grainger et al. (2001) argued that these results indicate that homophones are not represented in terms of activation that is shared between representations (e.g., the blend state situation in which multiple candidates are partially activated in distributed representational models). That is, if the system had been in something like a blend state for homophones, there should have been less priming for homophones than for nonhomophones because the pattern of activation generated by the prime would only be a partial match for both homophone spellings, whereas the pattern of activation generated by the nonhomophone prime would correspond fully to the spelling of the nonhomophonic target word. The fact that high-frequency homophones appear to be activated without such a cost seems more consistent with Grainger et al.'s localist model.

In evaluating Grainger et al.'s (2001) conclusions, a point to note is that although their results are consistent with predictions derived from a localist system, those same predictions could also be made by any distributed model that had a way of escaping from blend states. For example, Rodd et al. (2004) described a model that incorporated distributed semantic representations but, unlike other PDP models, it was able to escape the blend state incurred for semantically ambiguous words due to the way it made weight adjustments on connections among the semantic units. Like other PDP models, the different meanings of ambiguous words corresponded to different regions of the model's semantic space. Simulations showed that the representations of those meanings essentially competed with each other for activation and that, most of the time, one of those representations would become fully active. As such, it does appear that this particular distributed model would also be consistent with Grainger et al.'s results.

Nonetheless, simulations with most distributed models show that they do not seem capable of escaping blend states for ambiguous stimuli and, thus, Grainger et al.'s (2001) results would not be consistent with those models (e.g., Joordens & Besner, 1994). The predictions of these distributed models for auditory homophone stimuli were demonstrated in simulations reported by Harm and Seidenberg (2004). Harm and Seidenberg reported results of a number of simulations using their distributed model and the most relevant for our purposes are those that focus on the mappings from phonology to semantics, since the issue here is what happens when an auditory stimulus is presented. Harm and Seidenberg included 1,125 homophones in their 6,103 word training corpus and found that, after extensive training, the phonological codes of the homophone stimuli produced the semantic pattern for a single meaning only 26% of the time. More often, the model tended to produce patterns that involved some of each of the homophones' meanings (i.e., a blend state). For the item *ale* (which has the homophone mate *ail*), for instance, the model's semantic pattern included an activity level of 0.70 for the *beverage* feature and an activity level of 0.61 for the *be* feature (ailing as a state of being). In general, the model did tend to produce slightly more activity in the representation of the more frequent (dominant) homophone meaning, however, there was normally some activation of the less frequent homophone's meaning features and, equally importantly, there was only incomplete activation of the more frequent homophone's features. As Harm and Seidenberg noted "…the network is "on the fence" as to which interpretation is correct" (p. 679).

What also needs to be kept in mind when analyzing these models is that participants make *visual* lexical decisions to the target stimuli in Grainger et al.'s (2001) cross-modal repetition priming paradigm. Thus, orthographic activation should be their primary basis for responding. Nonetheless, Grainger et al.'s analysis of these models' predictions would still appear to be correct. That is, in distributed models, the blend state arising in the semantic units would be expected to lead to only partial activation of each of a homophone's orthographic representations (via feedback from the semantic units to the orthographic units). As a result, the orthographic representations for homophones, both low- and high-frequency, would be activated to a lesser degree than those for nonhomophones, which should therefore lead to smaller priming effects for homophones. A secondary result is that orthographic representations for homophones may also be activated more slowly than those for nonhomophones.

Experiment 1

To summarize, according to predictions derived from localist models with lateral inhibition (e.g., Grainger et al., 2001), in a cross-modal repetition priming paradigm with homophone stimuli there may initially be activation of both low-frequency and high-frequency homophone spellings but at longer prime-target asynchronies (SOAs) only the high-frequency spellings should remain activated. Further, the size of cross-modal repetition priming effects for high-frequency homophones should always be comparable to priming effects for high-frequency nonhomophones. In contrast, predictions derived from most distributed models for the same paradigm are that both low- and high-frequency homophone spellings should show less priming than low- and high-frequency nonhomophone spellings, and that priming for homophone spellings may be relatively slow to emerge.

In the present research, we tested these predictions by specifically examining the time course of cross-modal repetition priming effects for homophone targets (Experiment 1). In Grainger et al. (2001) the visual targets were always presented at the offset of auditory primes and, as such, the effect of different SOAs was not evaluated. In our Experiment 1, we presented primes and targets at four different SOAs, with our shortest SOA roughly corresponding to that used by Grainger et al. In Grainger et al.'s experiments the auditory primes were of different durations so the SOA ranged from 280 to 750 ms. Here we used auditory primes of consistent duration (785 ms) and then systematically manipulated the prime-target SOA in order to examine the time course of activation for the different homophone spellings. The SOA conditions in Experiment 1 were 750 ms (essentially no interval between prime offset and target onset), 1000 ms (215 ms interval between prime offset and target onset), 1250 ms (465 ms interval between prime offset and target onset), and 1500 ms (715 ms interval between prime offset and target onset). In all cases, foils were pseudohomophones, since Grainger et al. argued that effects of lateral inhibition should be most evident with these types of foils.

Method

Participants

Participants in Experiment 1 were undergraduates at the University of Calgary who received bonus course credit for participation: there were 40 participants in the 750 ms SOA condition, 40 in the 1000 ms SOA condition, 44 in the 1250 ms SOA condition, and 36 in the 1500 ms SOA condition. All participants reported that English was their first language and had normal hearing and normal or corrected-to-normal vision.

Stimuli

Words. The word stimuli for this experiment were 18 high-frequency homophones (> 35 per million, Kučera & Francis, 1967), 18 high-frequency nonhomophonic control words, 18 low-frequency homophone mates of the high-frequency homophones (< 32 per million, Kučera & Francis, 1967) and 18 low-frequency nonhomophonic control words. All word stimuli were monosyllabic. The homophones, of course, all had phonological rimes that could be spelled in more than one way (as classified in the norms of Ziegler, Stone, & Jacobs, 1997). The nonhomophonic control words all had phonological rimes that could legally be spelled in only one way. In addition, we ensured that all of the words in this experiment had word

Table 1. Mean Characteristics (Standard Deviations in Parentheses) for Target Word Stimuli

Word type	Example	Print frequency	Print length	Orthgraphic N	Phonological N	Number of phonemes
High-frequency homophone	*sweet*	176.22 (156.57)	4.28 (0.46)	10.06 (4.86)	20.39 (8.33)	3.11 (0.58)
High-frequency nonhomophone	*sound*	174.89 (124.77)	4.28 (0.58)	11.61 (7.30)	17.50 (5.44)	3.17 (0.51)
Difference test		$t < 1$	$t < 1$	$t < 1$	$t(34) = 1.23, p = .23$	$t < 1$
Low-frequency homophone	*suite*	16.06 (19.04)	4.22 (0.43)	10.56 (6.19)	20.39 (8.33)	3.11 (0.58)
Low-frequency nonhomophone	*sing*	15.67 (9.70)	4.22 (0.43)	9.78 (3.53)	19.39 (4.39)	3.33 (0.59)
Difference test		$t < 1$	$t < 1$	$t < 1$	$t < 1$	$t(34) = 1.13, p = .27$

bodies that could only be pronounced in one way (usually termed feedforward consistency in the visual word recognition literature, e.g., Stone et al., 1997). We matched the homophones with the nonhomophonic control words for printed frequency (Kučera & Francis, 1967), number of letters, phonological neighborhood size (Buchanan & Westbury, 2000), orthographic neighborhood size (Coltheart, Davelaar, Jonasson, & Besner, 1977) and number of phonemes. Mean characteristics for the four word groups are presented in Table 1. These words are listed in the Appendix.

Nonwords. The nonwords in this experiment were 36 pseudohomophones. These were taken from sets of pseudohomophones used in previous studies (Edwards et al., 2004; Pexman et al., 2001). These stimuli are also listed in the Appendix.

In this experiment, each word was presented following a repetition prime to half of the participants and following an unrelated prime to the other half. In addition, only one member of each homophone pair was presented to a given participant; we did not want a participant to see both *sweet* and *suite*, for instance. In order to meet these constraints, four versions of the experiment were created. Thus, across participants, both the low and high-frequency members of each homophone pair were presented as visual targets with both repetition and unrelated auditory primes.

Because the same priming and frequency manipulations were used with the nonhomophones, there were eight conditions in total: (1) high-frequency homophone target, repetition prime (e.g., /swi:t/ – *sweet*), (2) high-frequency homophone target, unrelated prime (e.g., /kIŋ/ – *sweet*), (3) high-frequency nonhomophone target, repetition prime (e.g., /saʊnd/ – *sound*), (4) high-frequency nonhomophone target, unrelated prime (e.g., /hɛ:/ – *sound*), (5) low-frequency homophone target, repetition prime (e.g., /swi:t/ – *suite*), (6) low-frequency homophone target, unrelated prime (e.g., /dΛk/ – *suite*), (7) low-frequency nonhomophone target, repetition prime (e.g., /sIŋ/ – *sing*), (8) low-frequency nonhomophone target, unrelated prime (e.g., /geIt/ – *sing*). Each participant was presented with nine items of each of the four basic stimulus types (i.e., low- versus high-frequency, homophones versus nonhomophones). Of these nine items, four or five (depending on which version of the experiment they received) were presented following repetition primes and four or five (again, depending on the version of the experiment they received) were presented following unrelated primes. In each version of the experiment there were nine high-frequency nonhomophones and nine low-frequency nonhomophones that were not presented as targets. These unused targets were used as the unrelated primes. That is, of the nine high-frequency nonhomophones that did not appear as targets in a particular version of the experiment, four of these would be used as unrelated primes for the high-frequency nonhomophone targets in that list and five of these would be used as unrelated primes for the high-frequency homophone targets in that list. Similarly, of the nine low-frequency nonhomophones that did not appear as targets in a particular version of the experiment, five of these would be used as unrelated primes for the low-frequency nonhomophone targets in that list and four of these would be used as unrelated primes for the low-frequency homophone targets in that list.

Each pseudohomophone target (nonword trials) was also paired with either a repetition prime or an unrelated prime. Thus, across participants, each pseudohomophone appeared as a visual target in both the repetition (e.g., /breIn/ – *brane*) and unrelated (e.g., /klΛb/ – *brane*) conditions.

Auditory stimuli were recorded as digital sound files using SoundMaker software. Individual stimulus files were then edited to ensure that all files were of comparable duration. The resulting stimulus files ranged from 770 ms to 800 ms in duration. Mean auditory prime durations across the four word groups ranged from 784 to 786 ms. Mean auditory prime duration for pseudohomophone targets was 786 ms. After editing, we presented the sound files to five additional participants in order to ensure that, in an untimed recognition task, participants could correctly identify the word presented in every sound file. This was indeed the case.

Procedure

Participants were told that on each trial they would first hear a word pronounced (via headphones) and then would see a word on the computer screen. Their task was to listen to the auditory word, and then decide whether the visual target was a real word or a nonword. They were asked to make this decision as quickly and as accurately as possible. Lexical decision responses were made by pressing either the left button (labeled NO) or the right button (labeled YES) on a PsyScope response box.

Participants first completed 16 practice trials and were given verbal feedback if they responded incorrectly to any of the practice items. Participants were told to respond as quickly and as accurately as possible to both practice and experimental items. The intertrial interval was 2000 ms. The stimuli were presented in a different random order for each participant. There were four SOA conditions: 750 ms (i.e., visual targets appeared 750 ms after the onset of the auditory prime), 1000 ms, 1250 ms, and 1500 ms.

Results

In this experiment, a trial was considered an error and was removed from the latency analysis if the decision latency was longer than 2000 ms or shorter than 250 ms (less than 1% of trials), or if participants made an incorrect response (7.08% of trials in the 750 ms SOA condition, 7.21% of trials in the 1000 ms SOA condition, 8.08% of trials in the 1250 ms SOA condition, and 6.56% of trials in the 1500 ms SOA condition). Error percentages observed in this experiment for each stimulus type are very similar to those reported by Grainger et al. (2001). Mean decision latencies and error percentages are presented in Table 2. In all experiments reported in this paper, data were analyzed with subjects (F_1 or t_1) and, separately, items (F_2 or t_2) treated as random factors.

Word Responses

Decision latencies and errors for word responses were analyzed with 2 (Prime repetition: repetition prime, unrelated prime) by 2 (Homophony: homophone, nonhomophone) by 2 (Frequency: low-frequency, high-frequency) by 4 (SOA: 750 ms, 1000 ms, 1250 ms, 1500 ms) ANOVAs. Prime repetition, homophony, and frequency were within-subject factors and SOA was a between-subject factor. Results included a significant 3-way interaction of prime repetition, homophony, and frequency in the latency analysis ($F_1(1, 156) = 30.82$, $p < .001$, $MSE = 4591.99$; $F_2(1, 68) = 5.97$, $p < .05$, $MSE = 9144.85$) and also in the error analysis ($F_1(1, 156) = 7.98$, $p < .005$, $MSE = 160.30$; $F_2(1, 68) = 4.67$, $p < .05$, $MSE = 157.83$). As illustrated in Table 2, the nature of this interaction was that at each SOA, low-frequency homophones showed smaller repetition priming effects than did low-frequency nonhomophones, while high-frequency homophones and high-frequency nonhomophones showed equivalent repetition priming effects.

The interaction of prime repetition and homophony was significant in the latency analysis ($F_1(1, 156) = 27.93$, $p < .001$, $MSE = 5326.13$; $F_2(1, 68) = 7.08$, $p < .01$, $MSE = 9144.85$) and also in the error analysis ($F_1(1, 156) = 8.60$, $p < .005$, $MSE = 152.01$; $F_2(1, 68) = 4.54$, $p < .05$, $MSE = 157.83$). The interaction of homophony and frequency was also significant in the latency analysis ($F_1(1, 156) = 53.29$, $p < .001$, $MSE = 6462.90$; $F_2(1, 68) = 11.33$, $p < .001$, $MSE = 22840.87$) and in the error analysis ($F_1(1, 156) = 184.33$, $p < .001$, $MSE = 204.44$; $F_2(1, 68) = 15.05$, $p < .001$, $MSE = 1050.74$). There were no significant interactions with SOA but there was a significant main effect of SOA in the latency analysis ($F_1(3, 156) = 3.92$, $p < .01$, $MSE = 77518.06$; $F_2(3, 204) = 32.16$, $p < .001$, $MSE = 4186.16$) although not in the error analysis ($F_1 < 1$; $F_2 < 1$). Decision latencies tended to be somewhat faster overall at the 1500 ms SOA, likely because of the longer interval between primes and targets.

Results also included a significant main effect of repetition in the latency analysis ($F_1(1, 156) = 221.81$, $p < .001$, $MSE = 9395.60$; $F_2(1, 68) = 119.66$, $p < .001$, $MSE = 9144.85$) and the error analysis ($F_1(1, 156) = 13.49$, $p < .001$, $MSE = 188.38$; $F_2(1, 68) = 6.48$, $p < .05$, $MSE = 157.83$), a significant main effect of homophony in

Table 2. Mean Decision Latencies, Error Percentages, and Priming Effects for Experiment 1 (Standard Deviations in Parentheses)

Stimulus type	750 ms SOA				1000 ms SOA				1250 ms SOA				1500 ms SOA			
	RT	Error	RT effect	Error effect	RT	Error	RT effect	Error effect	RT	Error	RT effect	Error effect	RT	Error	RT effect	Error effect
LF homophone																
Repetition	683	27.78			695	32.87			659	28.78			601	29.01		
	(254)	(44.92)			(232)	(47.06)			(227)	(45.39)			(160)	(45.52)		
Unrelated	686	21.67	3	-6.11	730	27.00	35	-5.87	722	30.30	63* **	1.52	670	28.40	69* **	-0.61
	(236)	(41.31)			(223)	(44.62)			(239)	(46.07)			(192)	(45.23)		
LF nonhomophone																
Repetition	515	3.33			555	2.99			504	2.02			479	1.85		
	(158)	(18.00)			(201)	(16.52)			(135)	(14.10)			(126)	(13.52)		
Unrelated	626	8.90	111* **	5.57* **	688	8.11	133* **	5.12* **	646	10.10	142* **	8.08* **	594	6.17	115* **	4.32*
	(151)	(28.54)			(227)	(27.66)			(200)	(30.21)			(150)	(24.14)		
HF homophone																
Repetition	520	2.22			549	2.34			535	3.54			489	1.23		
	(147)	(14.78)			(172)	(12.78)			(150)	(18.51)			(116)	(11.08)		
Unrelated	613	5.56	93* **	3.34	658	6.82	109* **	4.48* **	593	5.56	58* **	2.02	559	6.79	70* **	5.56* **
	(186)	(22.97)			(205)	(25.04)			(152)	(22.96)			(122)	(25.23)		
HF nonhomophone																
Repetition	486	1.67			508	0.78			502	0.00			461	0.00		
	(161)	(12.84)			(134)	(7.46)			(164)	(0.00)			(119)	(0.00)		
Unrelated	582	4.44	96* **	2.77	605	3.90	97* **	3.12* **	586	4.04	84* **	4.04* **	528 (96)	4.94	67* **	4.94* **
	(184)	(20.67)			(151)	(20.71)			(182)	(19.74)				(21.73)		
Pseudohomophone																
Repetition	637	4.31			661	3.24			674	6.19			598	2.62		
	(157)	(20.31)			(165)	(18.01)			(193)	(24.11)			(134)	(15.99)		
Unrelated	670	5.14	33* **	0.83	716	5.21	55* **	1.97	714	5.05	40* **	-1.14	635	4.01	37* **	1.39
	(211)	(22.09)			(210)	(20.85)			(230)	(21.91)			(168)	(19.64)		

Note. HF = high frequency; LF = low frequency. * $p < .05$ by subjects, ** $p < .05$ by items the latency analysis ($F_1(1, 156) = 169.94$, $p < .001$, $MSE = 6732.04$; $F_2(1, 68) = 35.96$, $p < .001$, $MSE = 22840.87$) and in the error analysis ($F_1(1, 156) = 215.70$, $p < .001$, $MSE = 223.62$; $F_2(1, 68) = 20.13$, $p < .001$, $MSE = 1050.74$), and a significant main effect of frequency in the latency analysis ($F_1(1, 156) = 221.30$, $p < .001$, $MSE = 7950.91$; $F_2(1, 68) = 48.34$, $p < .001$, $MSE = 22840.87$) and in the error analysis ($F_1(1, 156) = 317.65$, $p < .001$, $MSE = 187.95$; $F_2(1, 68) = 24.62$, $p < .001$, $MSE = 1050.74$).

In addition, at each SOA, priming effects for each word type were evaluated with planned comparisons and the significance levels of these effects are indicated with asterisks in Table 2.

Pseudohomophone Responses

Decision latencies and errors for pseudohomophone responses were analyzed with 2 (Prime repetition: repetition prime, unrelated prime) by 4 (SOA: 750 ms, 1000 ms, 1250 ms, 1500 ms) ANOVAs. Results included a significant main effect of prime repetition in the latency analysis ($F_1(1, 156) = 68.61$, $p < .001$, $MSE = 2260.48$; $F_2(1, 35) = 27.29$, $p < .001$, $MSE = 4422.75$) but not in the error analysis ($F_1 < 1$; $F_2 < 1$): as illustrated in Table 2, responses to pseudohomophones were faster following repetition primes than following unrelated primes. The main effect of SOA was significant in the latency analysis ($F_1(3, 156) = 4.02$, $p < .01$, $MSE = 25921.97$; $F_2(3, 105) = 56.95$, $p < .001$, $MSE = 1639.33$) and was significant by items in the error analysis ($F_1(3, 156) = 1.57$, $p = .20$, $MSE = 48.61$; $F_2(3, 105) = 4.32$, $p < .01$, $MSE = 16.28$). As with word responses, the nature of this main effect was that pseudohomophone responses tended to be faster at the 1500 ms SOA. The interaction of prime repetition and SOA was not significant in the latency analysis ($F_1 < 1$; $F_2 < 1$) or in the error analysis ($F_1(3, 156) = 1.36$, $p = .26$, $MSE = 21.22$; $F_2(3, 105) = 1.20$, $p = .31$, $MSE = 20.38$).

Discussion

Notably, the results we observed in the 750 ms SOA condition of Experiment 1 were very similar to those reported in Grainger et al.'s (2001) Experiment 2. Essentially, the present results for the 750 ms SOA condition provide a nice replication of their results, although here with English stimuli. The results for the longer SOA conditions, conditions that were not included in Grainger et al.'s experiments, paint a different picture, however. Given a localist framework with lateral inhibition it might, in theory, be possible at short SOAs to observe automatic facilitory priming for low-frequency homophones, however, as the SOA increases, evidence for deactivation of these words' meanings and spellings should be obvious. This is not what we observed here. Although SOA was not involved in any significant interactions, planned comparisons for low-frequency homophones showed a null repetition priming effect only at the shortest SOA, and significant facilitory repetition priming at the longer SOAs. Although an increase in priming for low-frequency homophones at longer SOAs may be somewhat inconsistent with predictions derived from localist models, it is not at all inconsistent with expectations based on distributed models. As the semantic units compete with one another (the process that ultimately leads to a blend state), their ability to provide rapid feedback to the orthographic units would, presumably, be somewhat limited. Thus, it would be expected that the activation of the orthographic representations, particularly for the low-frequency homophone spelling, would take some time. Eventually, however, this orthographic representation would become partially activated due to the fact that, in the absence of context, its semantic representation would become partially activated (e.g., Harm & Seidenberg, 2004) and, hence, capable of providing feedback to its orthographic representation.

An explanation of this sort does run into problems, however, because it predicts a similar result for high-frequency homophones. That is, if blend states at the semantic level have the effect of slowing the activation rate at the orthographic level, high-frequency homophones should have shown less priming than high-frequency nonhomophones, at least at the short SOAs. Instead, high-frequency homophones showed equivalent priming to high-frequency nonhomophones, suggesting that the high-frequency homophone spelling is activated without cost.

Before interpreting these results any further, however, one should consider the possibility that participants in Experiment 1 may have been strategically using the information conveyed by the prime and, thus, the obtained priming effects may not have been faithful representations of the typical semantic/orthographic activation process. One aspect of the data, in particular, raises concerns about participant strategies. In the analyses of nonword latencies, there was a significant facilitory repetition priming effect for pseudohomophone targets in every SOA condition of Experiment 1. That is, responses were faster to pseudohomophone targets like *brane* when they were preceded by repetition primes than when they were preceded by unrelated primes. Given that these targets must be rejected as words (i.e., they require a nonword response), it is somewhat surprising that the response process was facilitated by first hearing the base word. One might expect that hearing those words would make the pseudohomophone targets seem more like words and hence delay responding. Yet we observed the opposite effect, as did Grainger et al. (2001) who also reported that there was a facilitory repetition priming effect for pseudohomophone targets. This result raises the possibility that what participants might have been doing in this task was using prime information to generate an expected spelling pattern for the target. When that expectation was accurate, participants could readily make a word response. When that expectation was not accurate, participants would have been biased toward making a nonword response. Thus, when the target actually was a pseudohomophone (e.g., *brane*), participants would have detected this spelling mismatch quite quickly, allowing them to make a rapid decision that the target is a nonword.

If participants adopted this type of strategy, an additional effect would have been to exaggerate the priming effect for the high-frequency homophone targets. That is, upon hearing the auditory homophone prime (e.g., /swi:t/), the spelling that participants would most likely expect for the target would correspond to the high-frequency homophone (*sweet*), not the low-frequency homophone (*suite*). This expectancy would produce larger priming effects for high-frequency homophone targets, compared to the effect sizes that would be produced for the same targets in the absence of such a strategy. A further effect of this strategy may have been to reduce the priming effect for the low-frequency homophones because they do not match the expected spelling and, hence, the participant would have been biased toward a negative response.

Experiment 2

If an anticipation strategy was being used in Experiment 1, the main factor motivating it was, likely, the high repetition proportion in that experiment (50% repetition trials). In the remaining experiments in this paper, we reduced the repetition proportion to 14% in order to discourage strategic use of the prime information. In order to achieve this lower repetition proportion we presented the low-frequency homophones and nonhomophones in a separate experiment from the high-frequency homophones and nonhomophones. In Experiment 2 we examined the consequences of the lower repetition proportion for low-frequency homophones and low-frequency nonhomophones. In Experiment 3 we examined the consequences of the lower repetition proportion for high-frequency homophones and high-frequency nonhomophones. In both experiments, only SOAs of 750 ms and 1250 ms were used.

Method

Participants

Participants in Experiment 2 were undergraduates at the University of Calgary who received bonus course credit for participation; there were 38 participants in the 750 ms SOA condition and 36 participants in the 1250 ms SOA condition. All participants reported that English was their first language and had normal hearing and normal or corrected-to-normal vision.

Stimuli

Words. The critical word stimuli for this experiment were the same 18 low-frequency homophones and 18 low-frequency nonhomophones selected for Experiment 1. In addition, we included 90 filler words in this experiment. These fillers included both low- and high-frequency words (mean frequency = 37.57 per million, mean length = 4.68 letters). All of these stimuli are listed in the Appendix.

Nonwords. The nonwords in this experiment were the 36 pseudohomophones selected for Experiment 1, as well as 90 pseudowords. The pseudowords were taken from previous studies (Edwards et al., 2004; Pexman et al., 2001). These stimuli are also listed in the Appendix.

Each critical target word was presented following both a repetition prime and an unrelated prime, however, each participant saw each target only once. In order to achieve this, two versions of the experiment were created. There were four conditions in total: (1) low-frequency homophone target, repetition prime (e.g., /swi:t/ – *suite*), (2) low-frequency homophone target, unrelated prime (e.g., /dΛk/ – *suite*), (3) low-frequency nonhomophone target, repetition prime (e.g., /sIŋ/ – *sing*), (4) low-frequency nonhomophone target, unrelated prime (e.g., /geIt/ – *sing*). Each participant was presented with 18 low-frequency homophone targets and 18 low-frequency nonhomophone targets. Of these 18 items, nine were presented with repetition primes and nine were presented with unrelated primes. For both the low-frequency homophone and the low-frequency nonhomophone targets, unrelated primes were selected from the set of 18 high-frequency nonhomophones that had been presented in Experiment 1 (none of which appeared as targets in Experiment 2). The repetition proportion was 14%.

We also included pseudohomophone targets on some of the nonword trials in this experiment, in order to evaluate the impact of the lower repetition proportion on repetition priming for pseudohomophones. Each pseudohomophone target was paired with a repetition prime and an unrelated prime, however, each participant saw each pseudohomophone target only once. All filler word targets and all pseudoword targets appeared with unrelated word primes.

Sound files for auditory primes were recorded as in Experiment 1.

Procedure

The procedure was the same as that used in Experiment 1, except here the prime-target SOA was either 750 ms or 1250 ms.

Results

In this experiment, a trial was considered an error and was removed from the latency analysis if the decision latency was longer than 2000 ms or shorter than 250 ms (less than 1% of trials), or if participants made an incorrect response (6.39% of trials in the 750 ms SOA condition, 7.58% of trials in the 1250 ms SOA condition). Mean decision latencies and error percentages are presented in Table 3.

Table 3. Mean Decision Latencies, Error Percentages, and Priming Effects for Experiment 2 (Standard Deviations in Parentheses)

Stimulus type	**750 ms SOA**				**1250 ms SOA**			
	RT	**Errors**	**RT effect**	**Error effect**	**RT**	**Errors**	**RT effect**	**Error effect**
Low-frequency homophone								
Repetition	640 (231)	17.84 (38.33)			647 (224)	18.67 (39.16)		
Unrelated	649 (208)	18.13 (38.58)	9	0.29	692 (239)	21.50 (41.21)	45*	2.83
Low-frequency nonhomophone								
Repetition	513 (160)	2.34 (15.14)			532 (152)	2.14 (14.56)		
Unrelated	594 (168)	3.80 (19.15)	81* **	1.46	621 (176)	3.67 (18.88)	89* **	1.53
Filler words								
Unrelated	593 (177)	4.80 (21.37)			623 (194)	8.77 (28.46)		
Pseudohomophone								
Repetition	699 (170)	8.77 (28.31)			731 (207)	8.67 (28.10)		
Unrelated	680 (203)	9.50 (29.35)	−19	0.73	733 (250)	8.58 (27.90)	2	−0.09
Filler pseudowords								
Unrelated	658 (176)	5.23 (22.27)			678 (206)	5.87 (22.87)		

* $p < .05$ by subjects, ** $p < .05$ by items

Word Responses

Decision latencies and errors for word responses were analyzed with 2 (Prime repetition: repetition prime, unrelated prime) by 2 (Homophony: low-frequency homophone, low-frequency nonhomophone) by 2 (SOA: 750 ms, 1250 ms) ANOVAs. Results included a significant 2-way interaction of prime repetition and homophony in the latency analysis ($F_1(1, 72) = 16.32$, $p < .001$, $MSE = 4433.84$; $F_2(1, 34) = 5.23$, $p < .05$, $MSE = 5833.31$) but not in the error analysis ($F_1 < 1$; $F_2 < 1$). As illustrated in Table 3, the nature of this interaction was that at both SOAs, low-frequency homophones showed smaller repetition priming effects than did low-frequency nonhomophones.

The main effect of repetition was significant in the latency analysis ($F_1(1, 72) = 60.47$, $p < .001$, $MSE = 3859.36$; $F_2(1, 34) = 19.70$, $p < .001$, $MSE = 5833.31$) but not in the error analysis ($F_1(1, 72) = 1.24$, $p = .27$, $MSE = 139.21$; $F_2(1, 68) = 14.75$, $p < .001$, $MSE = 1066.36$). The main effect of homophony was significant in the latency analysis ($F_1(1, 72) = 167.53$, $p < .001$, $MSE = 4015.22$; $F_2(1, 34) = 26.76$, $p < .001$, $MSE = 14898.97$) and also in the error analysis ($F_1(1, 72) = 224.15$, $p < .001$, $MSE = 84.94$; $F_2(1, 34) = 18.22$, $p < .001$, $MSE = 523.03$). The only other significant effect was a main effect of SOA, significant only by items in the latency analysis ($F_1 < 1$; $F_2(1, 34) = 8.93$, $p < .005$, $MSE = 2597.95$).

In addition, at each SOA, priming effects for each word type were evaluated with planned comparisons and the significance levels of these effects are indicated with asterisks in Table 3. As in Experiment 1, the repetition priming effect for low-frequency homophones was only significant at the longer SOA.

Pseudohomophone Responses

Decision latencies and errors for pseudohomophones were analyzed with 2 (Prime repetition: repetition prime, unrelated prime) by 2 (SOA: 750 ms, 1250 ms) ANOVAs. The only significant effect was a main effect of SOA, significant by items in the latency analysis ($F_1(1, 72) = 1.94$, $p = .17$, $MSE = 29450.38$; $F_2(1, 35) = 38.01$, $p < .001$, $MSE = 2040.44$).

Discussion

With a lower repetition proportion (14%) and fewer pseudohomophones in this experiment, we did not observe the facilitory repetition priming for pseudohomophone targets that was observed in Experiment 1 and also in Grainger et al.'s (2001) experiment. We interpreted the facilitory repetition priming effect for pseudohomophones in Experiment 1 as an indication that the participants may have adopted the strategy of anticipating target spellings in that experiment. The lack of an effect here suggests that they were not adopting such a strategy in this experiment. Nonetheless, we observed the same pattern of priming effects that was obtained in Experiment 1 for low-frequency homophone and nonhomophone word targets: larger repetition priming for low-frequency nonhomophone targets than for low-frequency homophone targets with the difference narrowing at the longer SOA. Thus, this pattern does not appear to be the result of the use of an anticipation strategy. The remaining question was what consequence this lower repetition proportion has on responding to high-frequency homophone and nonhomophone targets. This question was addressed in Experiment 3.

Experiment 3

Method

Participants

Participants in Experiment 3 were undergraduates at the University of Calgary who received bonus course credit for participation; there were 38 participants in the 750 ms SOA condition and 38 participants in the 1250 ms SOA condition. All participants reported that English was their first language and had normal hearing and normal or corrected-to-normal vision.

Stimuli

Words. The critical word stimuli for this experiment were the same 18 high-frequency homophones and 18 high-frequency nonhomophones selected for Experiment 1. In addition, as in Experiment 2, we included 90 filler words in this experiment. All of these stimuli are listed in the Appendix.

Nonwords. The nonwords in this experiment were the same 36 pseudohomophones and 90 pseudowords used in Experiment 2.

As in Experiment 2, two versions of the experiment were created. Thus, across participants, the critical words were presented as visual targets following both repetition and unrelated auditory primes. There were four conditions in total: (1) high-frequency homophone target, repetition prime (e.g., /swi:t/ – *sweet*), (2) high-frequency homophone target, unrelated prime (e.g., /kIŋ/ – *sweet*), (3) high-frequency nonhomophone target, repetition prime (e.g., /saʊnd/ – *sound*), and (4) high-frequency nonhomophone target, unrelated prime (e.g., /hɛ:/ – *sound*). Each participant was presented with 18 high-frequency homophone targets and 18 high-frequency nonhomophone targets. Of these 18 items, nine were presented with repetition primes and nine were presented with unrelated primes. For both the high-frequency homophone and the high-frequency nonhomophone targets, unrelated primes were selected from the set of 18 low-frequency nonhomophones

Table 4. Mean Decision Latencies, Error Percentages, and Priming Effects for Experiment 3 (Standard Deviations in Parentheses)

Stimulus type	750 ms SOA				1250 ms SOA			
	RT	Errors	RT effect	Error effect	RT	Errors	RT effect	Error effect
High-frequency homophone								
Repetition	505 (135)	4.34 (20.39)			538 (154)	5.79 (23.49)		
Unrelated	525 (124)	4.34 (20.40)	20*	0.00	562 (150)	4.05 (19.80)	24*	−1.74
High-frequency nonhomophone								
Repetition	461 (101)	0.28 (5.36)			495 (141)	0.87 (9.32)		
Unrelated	524 (124)	2.60 (15.80)	63* **	2.32* **	555 (139)	1.74 (13.07)	60* **	0.87
Filler words								
Unrelated	569 (152)	7.65 (27.15)			622 (200)	8.90 (28.77)		
Pseudohomophone								
Repetition	638 (143)	10.92 (30.82)			697 (198)	7.50 (26.03)		
Unrelated	642 (180)	6.42 (24.26)	4	−4.50* **	675 (211)	4.79 (21.08)	−22	−2.71* **
Filler pseudowords								
Unrelated	616 (163)	4.41 (18.89)			660 (200)	2.99 (17.57)		

* $p < .05$ by subjects, ** $p < .05$ by items

that had been presented in Experiments 1 and 2 (none of which appeared as targets in Experiment 3). The repetition proportion was again 14%.

Procedure

The procedure was the same as that used in Experiment 2.

Results

In this experiment, a trial was considered an error and was removed from the latency analysis if the decision latency was longer than 2000 ms or shorter than 250 ms (less than 1% of trials), or if participants made an incorrect response (6.27% of trials in the 750 ms SOA condition, 5.79% of trials in the 1250 ms SOA condition). Mean decision latencies and error percentages are presented in Table 4.

Word Responses

Decision latencies and errors for word responses were analyzed with 2 (Prime repetition: repetition prime, unrelated prime) by 2 (Homophony: high-frequency homophone, high-frequency nonhomophone) by 2 (SOA: 750 ms, 1250 ms) ANOVAs. Results included a significant 2-way interaction of prime repetition and homophony in the latency analysis ($F_1(1, 74) = 13.95$, $p < .001$, $MSE = 1678.47$; $F_2(1, 34) = 10.79$, $p < .005$, $MSE = 1195.32$) but not in the error analysis ($F_1(1, 74) = 3.55$, $p = .06$, $MSE = 32.37$; $F_2(1, 34) = 1.73$, $p = .20$, $MSE = 39.26$). As illustrated in Table 4, the nature of this interaction was that at both SOAs, high-frequency homophones showed smaller repetition priming effects than did high-frequency nonhomophones.

The main effect of repetition was significant in the latency analysis ($F_1(1, 74) = 79.93$, $p < .001$, $MSE = 1787.96$; $F_2(1, 34) = 46.44$, $p < .001$, $MSE = 1195.32$) but not in the error analysis ($F_1 < 1$; $F_2 < 1$). The main effect of homophony was significant in the latency analysis ($F_1(1, 74) = 32.24$, $p < .001$, $MSE = 1398.69$; $F_2(1, 34) = 9.66$, $p < .005$, $MSE = 2531.02$) and also in the error analysis ($F_1(1, 74) = 24.64$, $p < .001$, $MSE = 32.71$; $F_2(1, 34) = 7.43$, $p < .01$, $MSE = 54.30$). The only other significant effect was a main effect of SOA, significant in the latency analysis ($F_1(1, 74) = 4.47$, $p < .05$, $MSE = 20260.59$; $F_2(1, 34) = 49.28$, $p < .001$, $MSE = 808.80$) but not in the error analysis ($F_1 < 1$; $F_2 < 1$).

In addition, at each SOA, priming effects for each word type were evaluated with planned comparisons and the significance levels of these effects are indicated with asterisks in Table 4. The priming effect for high-frequency homophones was significant in the subject analysis at both SOAs.

Pseudohomophone Responses

Decision latencies and errors for pseudohomophones were analyzed with 2 (Prime repetition: repetition prime, unrelated prime) by 2 (SOA: 750 ms, 1250 ms) ANOVAs. The main effect of repetition was not significant in the latency analysis ($F_1 < 1$; $F_2 < 1$) but was significant in the error analysis ($F_1(1, 74) = 11.77$, $p < .001$, $MSE = 41.98$; $F_2(1, 35) = 11.20$, $p < .005$, $MSE = 46.53$), such that participants tended to make more errors to pseudohomophone targets in the repetition condition than in the unrelated condition at both SOAs. In addition, there was a main effect of SOA that was significant by items in the latency analysis ($F_1(1, 74) = 3.88$, $p = .05$, $MSE = 25541.07$; $F_2(1, 35) = 41.04$, $p < .001$, $MSE = 1579.99$) and was also significant by items in the error analysis ($F_1(1, 74) = 2.84$, $p = .10$, $MSE = 85.29$; $F_2(1, 35) = 5.23$, $p < .05$, $MSE = 43.97$).

Discussion

The lack of a facilitory priming effect for pseudohomophones in Experiment 3 in latencies and the inhibitory priming effects in error rates show that, as in Experiment 2, the lower repetition proportion reduced reliance on the strategy of using primes to anticipate target spellings. Equally importantly, with reliance on this strategy reduced, we observed in Experiment 3 a different pattern of priming effects for high-frequency homophone targets than was observed either in Experiment 1 or in Grainger et al.'s (2001) experiments. That is, in Experiment 3 there was less priming for high-frequency homophone targets than for high-frequency nonhomophone targets. The pattern of priming effects observed suggests: (1) that a large share of the priming effect observed for high-frequency homophones in Experiment 1 (and, likely, that observed by Grainger et al.) was due to the use of an anticipation strategy and (2) that there is a cost incurred for high-frequency homophone spellings when such a strategy is not used. These spellings are not activated by auditory primes to the same degree as high-frequency nonhomophone spellings. Presumably, this cost is incurred because, following auditory presentation of a homophone prime, the representational system cannot fully represent either the low-frequency or the high-frequency homophone meanings or spellings. As discussed further below, the fact that the high-frequency homophone spellings are not as strongly activated as are high-frequency nonhomophone spellings is more consistent with the kind of representational system incorporated in distributed models of word recognition.

General Discussion

The purpose of the present research was to investigate cross-modal priming effects for homophones and to evaluate the implications of those effects for models of word recognition. In Experiment 1 we assessed the time course of cross-modal priming effects for low- and high-frequency homophone targets. The predictions derived from localist models of word recognition were: (1) although early in processing there might be evidence for automatic activation of the representations of low-frequency homophones, over time, those representations should be fully inhibited and (2) for high-frequency homophones, activation levels should grow quickly and be maintained (Grainger et al., 2001). In contrast, the predictions of most distributed models were: (1) both low- and high-frequency homophones should show less priming than nonhomophones (Harm & Seidenberg, 2004) and (2) homophones may show more priming at longer SOAs than at shorter SOAs.

At our shortest SOA of 750 ms, there was a null repetition priming effect for low-frequency homophone targets and significant facilitory repetition priming for low-frequency nonhomophone targets. In addition, there was significant facilitory repetition priming for high-frequency homophone targets equal in size to the priming effect for nonhomophones. These results essentially replicate the results reported by Grainger et al. In localist terms, the complete lack of priming for low-frequency homophones at this short SOA suggests that the activation/inhibition process had been completed by that point in time.

Extending the SOA up to 1500 ms allowed more time for processing of the primes. The pattern of priming effects observed for high-frequency homophone and nonhomophone targets (equivalent facilitory repetition priming) was maintained over this interval, a result consistent with localist assumptions. The unexpected result from a localist perspective was that significant facilitory repetition priming emerged for low-frequency homophone targets at the longer SOAs. This type of result is inconsistent with the idea that the continued activation of the high-frequency spelling keeps the activation of the low-frequency homophone spelling inhibited, as would be predicted by localist models based on strong lateral inhibition processes or by PDP models that regularly escape the blend state (e.g., Rodd et al., 2004).

Given the fact that there was also facilitory priming for pseudohomophone targets in Experiment 1 (and in Grainger et al., 2001) it seemed probable that the effects observed in Experiment 1 were at least partly attributable to participants using prime information strategically in order to generate expectancies about target spelling. This strategy was likely encouraged by the high repetition proportion (50%) used in Experiment 1. In Experiments 2 and 3 the repetition proportion was decreased to 14%. In Experiment 2, the pattern for low-frequency homophones replicated that in Experiment 1; the priming for low-frequency homophone targets was significantly smaller than the priming for low-frequency nonhomophone targets but increased with SOA. As such, the use of this spelling expectancy strategy (or other possible strategies) appears to have had little impact on the processing of low-frequency homophones. In Experiment 3, a different pattern emerged for high-frequency homophones than in Experiment 1. In Experiment 3 the priming for high-frequency homophone targets was significantly smaller than the priming for high-frequency nonhomophone targets, a result more similar to that for low-frequency words. This overall pattern suggests that auditory homophone primes did not strongly pre-activate either low-frequency or high-frequency homophone spellings. Rather, it appears that the orthographic representation of both remained in a state of limited activation, due presumably to the fact that there is no context available to push the semantic/orthographic system toward either of the two possibilities.

These results are reasonably consistent with assumptions characteristic of distributed models of word recognition (e.g., Harm & Seidenberg, 2004; Plaut et al., 1996; Van Orden & Goldinger, 1994). Following auditory presentation of a homophone, the word recognition system does not seem to be able to fully represent either the low-frequency or the high-frequency meaning/spelling, instead, settling into a blend state, that is, a state in which the homophone's different representations are both partially activated. In everyday speech, of course, one would assume that this situation would be rapidly resolved, and representations for the correct homophone would be fully activated, by contextual information (e.g., Gernsbacher & Faust, 1991; Harm & Seidenberg, 2004).The one aspect of our results that is not entirely consistent with this explanation is that, in Experiment 3, the facilitory priming effect for high-frequency homophones did not increase with SOA in the same manner that the facilitory priming effect for low-frequency homophones did in Experiment 2. If auditory homophones created a blend state as described above, one might expect that the high-frequency homophone spellings would show at least as much priming as the low-frequency spellings. Further, since low-frequency homophones showed more repetition priming at the 1250 ms SOA than the 750 ms SOA, one would expect the same result for high-frequency homophones. Numerically, of course, there was more priming for high-frequency homophones in the long (24 ms) versus the short (20 ms) SOA conditions in Experiment 3. Nonetheless, one might have expected a somewhat larger increase in the size of the priming effect.

What should also be kept in mind, however, is that more rapidly processed high-frequency targets generally show smaller priming effects than more slowly processed low-frequency targets. Consider, for instance, the priming observed for nonhomophone targets in Experiment 1. Averaged across SOA conditions, low-frequency nonhomophone targets showed 39 ms more repetition priming than did high-frequency nonhomophone targets. Across SOA conditions in Experiments 2 and 3 low-frequency nonhomophone targets showed an average of 24 ms more repetition priming than did high-frequency nonhomophone targets. Similarly, in Grainger et al.'s (2001) Experiment 1 (no pseudohomophone foils) low-frequency nonhomophone targets showed 47 ms more repetition priming than did high-frequency nonhomophone targets. In their Experiment 2 (with pseudohomophone foils) low-frequency nonhomophone targets showed 18 ms more repetition priming than did high-frequency nonhomophone targets. This pattern is most likely due to the fact that low-frequency targets are more difficult (slower) to process and can therefore obtain more benefit from priming. If such is the case, it may not be reasonable to expect high-frequency homophone targets to show priming that is of the same magnitude (numerically) as low-frequency homophone targets or to show as obvious an increase in the size of the priming effect as SOA is increased.

In addition to reducing the repetition proportion in Experiments 2 and 3 we also reduced the proportion of pseudohomophones presented. In Experiment 1 the nonwords were 100% pseudohomophones. In Experiments 2 and 3 the nonwords were 29% pseudohomophones and 71% pseudowords. This change in the nature of the nonwords likely made the lexical decisions slightly easier in Experiments 2 and 3. It seems unlikely, however, that this change would explain why the repetition priming for high-frequency homophone targets was less than that for high-frequency nonhomophone targets in Experiment 3. In Grainger et al.'s (2001) Experiment 1, the nonwords were 100% pseudowords (i.e., 0% pseudohomophones), and in their Experiment 2 the nonwords were 50% pseudohomophones and 50% pseudowords. In both of Grainger et al.'s experiments, high-frequency homophone targets and high-frequency nonhomophone targets showed equivalent priming. That is, Grainger et al.'s manipulation of pseudohomophone proportion did not change the pattern of priming effects for high-frequency homophones and high-frequency nonhomophones. As such, our change in pseudohomophone proportion between Experiment 1 and Experiments 2 and 3 is likely not the reason we observed a different pattern of repetition priming effects for high-frequency targets in those experiments. Instead, the different pattern of results appears to be due to the manipulation of repetition proportion and resulting changes in participant strategies for the task.

There are two additional points on which we should comment. First, although our homophone and nonhomophone stimuli were matched for printed frequency, it was not possible to match the low-frequency stimuli for spoken (phonological) frequency. The phonological frequency of a homophone is, by definition, the sum frequency of the dominant (high-frequency) and subordinate (low-frequency) forms. That is, the frequency of the spoken /swi:t/ combines the instances where *sweet* was intended with the instances where *suite* was intended. As such, although the phonological frequencies of the high-frequency homophones are only minimally affected by the existence of their low-frequency mates, the phonological frequencies of our low-frequency homophone primes inevitably had to be higher than the phonological frequencies of the low-frequency nonhomophone primes if these two stimulus sets were to be matched on printed frequency. Could this difference in phonological frequency have played a role in producing the results for low-frequency targets?

The most likely implication of the phonological frequency advantage for low-frequency homophone primes is that they might cause the other (i.e., orthographic, semantic) representations of these words to reach a higher level of activation more rapidly than the similar representations for low-frequency nonhomophone primes (e.g., Lee, Binder, Kim, Pollatsek, & Rayner, 1999). If so, the most likely consequence would be a larger and/or faster emerging repetition priming effect for low-frequency homophone targets than for low-frequency nonhomophone targets. This result, of course, is exactly the opposite of what was observed. As such, it seems unlikely that the phonological frequency of the prime stimuli played much of a role in producing the pattern of results for the low-frequency targets.

The second point that should be commented on is that, in the unrelated conditions in each of the experiments, response latencies tended to be longer, and error rates higher, for homophones than for nonhomophones, particularly when considering the low-frequency targets. These results are the standard results that are observed in LDT: despite frequency matching, responses are slower and more error-prone for low-frequency homophones than for low-frequency nonhomophones (Edwards et al., 2004; Ferrand & Grainger, 2003; Pexman et al., 2001; Pexman et al., 2002; Rubenstein et al., 1971). The fact that these effects appeared in the present data is evidence that the set of homophone and nonhomophone stimuli in these experiments are representative of the stimuli normally used in the literature.

The fact that the latency data showed a low-frequency homophone disadvantage in the unrelated conditions also means, of course, that the low-frequency homophone and low-frequency nonhomphones had different "baseline" latencies from which to establish priming effects. Is this fact a cause for concern? It seems unlikely. According to the literature, the most likely result of different baselines is that slower unrelated baseline conditions produce larger priming effects (e.g., Burt, 2002). (See also the above discussion about the size of the priming effects for high- versus low-frequency targets.) What we observed in the present data, of course, is the opposite pattern: smaller priming effects in the slower baseline condition. As such, the smaller priming effects for low-frequency homophones would not appear to be due to differences in baseline latencies.

"The Problem of Blend States"

Since at least Joordens and Besner's (1994) paper, distributed models have been criticized for having what is referred to as "the problem of blend states" (Rodd et al., 2004, p. 94). That is, when a semantically ambiguous word is presented to a distributed model of visual word recognition most of these models regularly produce a blend state in the semantic units; a pattern of activation that is a partial match for both meanings of the ambiguous word (Besner & Joordens, 1995; Borowsky & Masson, 1996; Joordens & Besner, 1994; Kawamoto, Ferrar, & Kello, 1994; Rueckl, 1995). The main reason that this is regarded as a problem is that it predicts that there should be a processing delay for ambiguous words, a prediction that is not supported by the available evidence. Instead, in lexical decision and naming tasks, the bulk of the evidence suggests that semantically ambiguous words are typically processed faster than unambiguous words (Borowsky & Masson, 1996; Hino &

Lupker, 1996; Hino, Lupker, & Pexman, 2002; Jastrzembski, 1981; Jastrzembski & Stanners, 1975; Kellas, Ferraro, & Simpson, 1988; Millis & Button, 1989; Pexman & Lupker, 1999; Rubenstein, Garfield, & Millikan, 1970). When considering tasks that are potentially more likely to show this expected processing delay, tasks that require participants to tap into semantic knowledge, an ambiguity disadvantage (slower processing for ambiguous words than for unambiguous words) is also typically not observed (Hino, Pexman, & Lupker, 2006; Pexman, Hino, & Lupker, 2004; Siakaluk, Pexman, Sears, & Owen, 2007). In fact, it appears that an ambiguity disadvantage is only observed in semantic tasks when the multiple meanings create response competition (e.g., one meaning suggests a "yes" response while the other suggests a "no" response, Pexman et al., 2004). If response competition is not created then a null ambiguity effect is observed. As such, there is little evidence for the ambiguity disadvantage that is predicted by the blend state scenario.

A second reason that blend states tend to be viewed as not being realistic is that, intuitively, it appears that readers/listeners are typically able to settle quite readily on one meaning when presented with ambiguous words (Rodd et al., 2004). Thus, the blend state does not appear to be supported by either intuition or empirical work. The implication seems to be that models that produce blend states could not possibly be correct.

Nonetheless, the present data suggest that, at least for auditory homophones, a blend state representation does mirror the situation that is actually produced (independent of context). To what extent this conclusion can be generalized to other types of ambiguity and other paradigms are questions for future research. Notably, however, ours is not the only recent work to suggest that blend states may be a consequence of ambiguity; see, for example, Gaskell and Marslen-Wilson's (2002) experiments demonstrating that, when primes are auditory word fragments, there is a cost associated with activation of multiple candidates. These results suggest that it may not be appropriate to assume that there actually is a "problem of blend states". That is, models that produce blend states may not be incorrect simply by definition. Rather, we would argue that the issue of how ambiguity should be represented in the word recognition system is far from being understood. We anticipate that, in future work on this topic, the question of when blend states actually do arise in readers'/listeners' mental representations will come to be an issue of central concern.

Conclusion

The results of the present research suggest that, although low-frequency spellings of auditory homophones are not activated early in processing, they do become activated as processing continues. These results are not particularly compatible with localist models, especially ones in which inhibitory processes play a major role. The results of our final experiment also suggest that the high-frequency spellings of homophones are activated to a lesser degree than the spellings of frequency-matched nonhomophones. This is the case even at longer SOAs, when, through inhibitory processes, their dominance over their low-frequency mates should be fully evident. This result is also inconsistent with localist models in which inhibitory processes play a large role. In general, these results would appear to be better explained by distributed models that assume that a blend state is the usual consequence of this type of ambiguity.

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Appendix

Target Word Stimuli

HF homophone	HF nonhomophone	LF homophone	LF nonhomophone
feet	tell	feat	bell
blue	cook	blew	boil
sweet	king	suite	duck
fair	held	fare	coil
main	sound	mane	hang
sale	edge	sail	kick
meet	book	meat	foil
week	hell	weak	colt
plane	sick	plain	rust
beach	luck	beech	sing
gate	march	gait	tuck
sight	fell	site	gang
loan	large	lone	bench

hair	look	hare	coin
might	charge	mite	lift
real	took	reel	mound
need	wife	knead	barge
seem	join	seam	carve

Pseudohomophone Stimuli

ake	blaid
boks	brane
byke	cleen
cort	crait
creem	dait
deel	flaim
fraim	froot
frunt	gole
grean	gurl
heet	jale
kee	laik
lern	nale
noze	perse
poam	rait
ritch	rong
rore	shurt
skool	teer
tutch	vurse

Filler Target Words Presented in Experiments 2 and 3

apt	ask	badge	bid
bill	black	boat	boost
bounce	brag	brick	bulb
bulk	bunch	cab	choice
church	dish	dodge	dog
drab	draft	draw	dusk
else	fast	fetch	field
fig	flag	globe	grab
grass	grudge	gulp	harsh
health	hedge	hook	hulk
joint	joy	jump	ledge
length	lens	lodge	lymph
marsh	midst	mosque	noise
ounce	pact	pig	plague
poise	probe	prompt	pulp

pulse	ridge	scrub	siege
self	shaft	shelf	shield
shook	shrug	slab	slug
slump	smug	song	sprang
stab	stealth	strife	suave
swift	tempt	text	thing
thrust	tribe	tub	vague
vogue	wealth		

Pseudoword Targets Presented in Experiments 2 and 3

baip	balce	blaie	blain
blayl	blurse	bort	brate
brax	broal	broze	cade
ched	clane	clave	cleep
darr	dawlt	dawp	deef
dirm	drale	drave	dunch
feap	feen	fet	fleek
foast	foun	froar	funt
furt	gair	geel	geet
gree	greel	haik	harl
jair	jeek	jite	kaks
kirm	klor	lale	lasp
loak	loast	lurge	marn
meap	meef	murt	nace
naff	nait	nande	neem
noak	paik	ped	pife
pilm	prore	reet	rimp
rutch	sern	shet	shong
shung	slahr	spail	swait
taige	taize	tane	thipe
treal	troar	turge	turl
varck	vayk	vock	weech
yock	zeer		