Ambiguity and Visual Word Recognition: Can Feedback Explain Both Homophone and Polysemy Effects?

PENNY M. PEXMAN, *University of Calgary*
STEPHEN J. LUPKER, *The University of Western Ontario*

Abstract In a lexical-decision task (LDT), Hino and Lupker (1996) reported a polysemy effect (faster response times for polysemous words [e.g., BANK]), and attributed this effect to *enhanced* feedback from the semantic system to orthographic units, for polysemous words. Using the same task, Pexman, Lupker, and Jared (in review) reported a homophone effect (slower response times for homophonic words [e.g., MAID]) and attributed this effect to *inconsistent* feedback from the phonological system to orthographic units, for homophones. In the present paper we test two predictions derived from this feedback explanation: Polysemy and homophone effects should (a) co-occur in a standard LDT (with pseudoword foils) and (b) both be larger with pseudohomophones (e.g., BRANE) as foils in LDT. The results supported both predictions.

Language has many different ambiguities. For instance, some words have one spelling (orthography) but have multiple meanings (e.g., BANK). These words are referred to as polysemous words. Similarly, some words have one sound (phonology) and multiple spellings, and have different meanings for each spelling (e.g., MAID/MADE). These words are referred to as homophones. Both types of words have the potential to create confusion in the mind of readers or listeners, confusion that needs to be resolved before the intended meaning of the message can be fully comprehended.

In fact, in the literature examining how readers access meaning from print, both homophones and, separately, polysemous[1] words have received special attention. The purpose of the present paper was to investigate an apparent paradox in this literature. The paradox is that, when a lexical-decision task is used, homophones produce slower response times than nonhomophones (e.g., Pexman, Lupker, & Jared, in review; Rubenstein, Lewis, & Rubenstein, 1971a), whereas polysemous words generally produce faster response times than nonpolysemous words (e.g., Borowsky & Masson, 1996; Hino & Lupker, 1996; Jastrzembski, 1981; Jastrzembski & Stanners, 1975; Kellas, Ferraro, & Simpson, 1988; Millis & Button, 1989; Rubenstein, Garfield, & Millikan, 1970; Rubenstein, Lewis, & Rubenstein, 1971b). The puzzle is how it could be possible that the ambiguity inherent in homophones could create a processing *disadvantage,* while the ambiguity inherent in polysemous words could create a processing *advantage.* In this paper we will address this issue, and, in doing so, investigate the way in which semantic, phonological, and orthographic codes interact in the word recognition system.

HOMOPHONE EFFECTS

In an early investigation of homophone effects, Rubenstein, Lewis, and Rubenstein (1971a) found that lexical-decision latencies were longer for the lower-frequency members of homophone pairs relative to frequency-matched nonhomophonic control words (although the same was not true for the higher-frequency members of homophone pairs). Based on this result, Rubenstein et al. concluded that phonology mediated lexical access. This homophone effect came under serious scrutiny in the next several years. Clark (1973), for example, pointed out that the homophone effect was not significant in analyses where both subjects and items were treated as random factors (cf. Cohen, 1976; Keppel, 1976; Smith, 1976; Wike & Church, 1976) and suggested that homophone effects were artifactual.

Attempts to replicate the homophone effect were subsequently reported by Coltheart and colleagues (Coltheart, Davelaar, Jonasson, & Besner, 1977; Davelaar, Coltheart, Besner, & Jonasson, 1978). Coltheart et al. failed to find a homophone effect in a lexical-decision experiment. Davelaar et al., however, found a significant low-frequency homophone effect in a lexical-decision task when the foils were standard pseudowords (e.g., SLINT). Equally important, Davelaar et al. also reported that the homophone effect disappeared when the foils were pseudohomophones (e.g.,

[1] Words like BANK, which have multiple meanings, are often referred to as "ambiguous." For the present purposes, however, we will call these words "polysemous" to avoid confusion with homophones, which could also be considered ambiguous.

GRONE). Pseudohomophones are nonwords that, when pronounced, sound like real words. Davelaar et al. argued that with pseudohomophones as foils, readers strategically de-emphasized phonological processing in order to avoid processing the real-word phonology of the foils. That de-emphasis of phonological processing eliminates the homophone effect because the homophone effect is generated by phonology. Thus, Davelaar et al. concluded that *sometimes* phonology mediates access to word meaning, but that it is also possible to access meaning directly from orthography.

Upon close examination, however, it became apparent that Davelaar et al.'s (1978) study had several methodological flaws. In order to provide a more thorough evaluation of homophone effects in lexical-decision tasks, Pexman, Lupker, and Jared (in review; also Pexman, Lupker, Jared, Toplak, & Rouibah, 1996) conducted an improved version of Davelaar et al.'s experiment. Their results showed a significant low-frequency homophone effect in the pseudoword foil condition. In the pseudohomophone foil condition not only were response times slower, but, more importantly, the low-frequency homophone effect was *larger*, and there was a significant high-frequency homophone effect. This general pattern of results (i.e., larger homophone effects when the task was more difficult) was replicated in several additional experiments. Pexman et al. concluded that (a) homophone effects in the lexical-decision task were genuine and were due to the impact of phonological processing and (b) it did not seem possible to strategically de-emphasize phonological processing in response to the inclusion of pseudohomophone foils in the lexical decision task.

Pexman et al. (in review) argued that the basic impact of using pseudohomophone foils was to make the lexical-decision task more difficult, which then increased the chances that the existence of a homophonic mate would interfere with the processing of a homophone target. The account Pexman et al. offered was based on a parallel distributed processing (PDP) type of model (e.g., Plaut, McClelland, Seidenberg, & Patterson, 1996) with interactive sets of processing units representing orthography, phonology, and semantics. In this type of model, the processing of all types of homophones (regardless of frequency) can be slowed by their homophone mates because the homophone mates have the ability to create competition. If the lexical decision is relatively difficult (as when pseudohomophones are used as foils), the chances of observing the effects of such competition would increase.

In PDP-type models there are numerous places at which such competition could take place. For example, one could certainly propose that these competition effects arise at the semantic level. That is, if a phonological code played a primary role in early processing, homophones would activate multiple semantic representations (e.g., for both MAID [servant] and MADE [created]). The result could be competition, delaying the settling of the semantic units and, hence, delaying processing, at least for low-frequency words. Pexman et al. (in review), however, rejected this idea based on what is known about polysemy effects. As noted, polysemous words are words with one spelling and multiple meanings. These types of words would seem to be candidates for producing competition effects at the semantic level, if, indeed, there are effects of competition at the semantic level. Yet quite the opposite is observed. As noted, polysemous words (e.g., BANK) lead to *faster* lexical-decision and naming latencies than words with only one meaning (e.g., COVE). Thus, semantic ambiguity appears to have a facilitatory effect, rather than an inhibitory effect, when processing individual words.

Based on the full pattern of their results and on this analysis, Pexman et al. (in review) concluded that homophone effects must be phonologically based and specifically are due to the fact that homophones generate inconsistent feedback from phonology to orthography. The result is that homophones create competition among orthographic units. The idea that inconsistent feedback from phonology to orthography can affect processing time was first suggested by Stone, Vanhoy, and Van Orden (1997; see also Ziegler, Montant, & Jacobs, 1997; but see Peereman, Content, & Bonin, 1998, for criticisms of Stone et al.'s findings). Although Stone et al. did not propose that feedback inconsistency is the explanation for homophone effects, they did suggest that if the phonology of a word *body* could be spelled in more than one way (e.g., -AIT, -ATE, -EIGHT) then processing would be slowed. Homophones, by their nature, are examples of these types of words.

Stone et al.'s (1997) notion is that initial orthographic processing of a letter string feeds forward to create a pattern of activation in phonological units, which, in a fully interactive model, in turn feeds back to the orthographic units. Consistent feedback (i.e., when there is a one-to-one mapping between phonology and orthography) strengthens orthographic activation and speeds processing. On the other hand, inconsistent feedback, where there is a one-to-many mapping between phonology and orthography (such as for a homophone as well as many nonhomophonic words) creates competition in the orthographic units which generally must be resolved before a response is made.

In order to account for homophone effects in terms of this inconsistent feedback explanation, Pexman et al. (in review) concluded, further, that lexical decisions must be made primarily on the basis of patterns of activation in the orthographic units. More specifically, since the model Pexman et al. described is fully interactive,[2] the decision

[2] Although our account was presented within the PDP framework, Max Coltheart (personal communication, November 1998) suggested that the Dual-Route Cascaded (DRC; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart & Rastle, 1994) model would account for homo-

would actually be made on the basis of some kind of global coherence (e.g., Gibbs & Van Orden, 1998; Stone & Van Orden, 1993) with an emphasis on activity in the orthographic units.

POLYSEMY EFFECTS

Like homophone effects, the existence of polysemy effects has been somewhat controversial (Borowsky & Masson, 1996; Clark, 1973; Forster & Bednall, 1976; Gernsbacher, 1984; Hino & Lupker, 1996; Jastrzembski, 1981; Jastrzembski & Stanners, 1975; Kellas et al., 1988; Millis & Button, 1989; Rubenstein et al., 1970; Rubenstein et al., 1971b). Despite mixed results in studies using polysemous words, Joordens and Besner (1994) concluded that polysemy effects were genuine, and attempted to simulate these effects using two existing PDP models. They assumed that lexical-decision performance was directly related to the settling of activity in the semantic units of such models and suggested that a:

> potential problem arises when the same orthographic pattern is associated with two different meanings (e.g., BANK) because these meanings vie for dominance over the semantic nodes. This competition may work against producing an ambiguity effect in the time it takes to achieve a stable representation. (p. 1051)

As they suspected, Joordens and Besner found that neither Hinton and Shallice's (1991) model, nor Masson's (1991) model effectively simulated the polysemy effect that can be observed in human data.

Although Joordens and Besner's (1994) simulations did not produce a facilitory polysemy effect, Kawamoto, Farrar, and Kello (1994) reported a successful simulation of this effect with their own model. There are two main reasons for the difference. First, Kawamoto et al. made a very different assumption about lexical-decision performance. Kawamoto et al. assumed that lexical-decision performance is best captured by activation of the orthographic, rather than the semantic, units. Second, as a result of the algorithm they used, a model was created in which the weights for connections between orthographic units were enacted differently for polysemous and nonpolysemous words, leading to simulation performance that showed a processing advantage for polysemous words.

Kawamoto et al. (1994) also argued that the nature of the polysemy effect would depend on task demands. If performance in a task depended on orthography (e.g., a standard lexical-decision task), there would be a processing advantage for polysemous words. In contrast, if performance in a task depended on semantics (presumably, for instance, a semantic categorization task), there would be a processing disadvantage for polysemous words.

Borowsky and Masson (1996) examined Kawamoto et al.'s (1994) hypotheses about the locus of polysemy effects and the impact of task demands by using two different foil conditions in a lexical-decision task. Borowsky and Masson noted that it is unclear whether semantic information is involved in making lexical decisions when the foils are orthographically legal. However, with consonant strings as foils, lexical decisions would certainly be based on orthographic, and not semantic, information. Thus, they argued that Kawamoto et al.'s account would definitely predict a polysemy effect with consonant string foils. They also argued that, if anything, the model would predict a smaller polysemy effect with orthographically legal foils. Borowsky and Masson's findings did not support these predictions because they found polysemy effects only with orthographically legal foils.

In simulations with a version of Masson's (1991, 1995) distributed memory model, Borowsky and Masson (1996) found that the model did generate polysemy effects in the lexical-decision task. According to the model's assumptions, lexical decisions are made on the basis of the "familiarity for a letter string's orthography and meaning" (p. 76). Specifically, a familiarity value is calculated based on the summed *energy* within the orthographic and meaning modules. Energy in this sense is a feature of Hopfield networks and it measures the extent to which the network has progressed into a basin of attraction. Borowsky and Masson found an energy advantage for polysemous words, due to faster settling of meaning units into attractor basins for those words. They argue that this happens because of the *proximity* effect, a term introduced by Joordens and Besner (1994). This term describes the notion that the random starting state for the meaning units is more likely to be more similar to one of the many meanings of a polysemous word than it would be to the single meaning of a nonpolysemous word.

A somewhat different account of polysemy effects was offered by Hino and Lupker (1996). Based on Balota, Ferraro, and Connor's (1991) account of polysemy effects, Hino and Lupker suggested that semantic units could feed activation back to the orthographic units. Polysemous words create more semantic activation which would provide stronger feedback to the orthographic units than would nonpolysemous words. This would lead to higher levels of activation in the orthographic units for polysemous words. If the lexical-decision response was based primarily on activation in the orthographic units, responses should be faster for polysemous words. Note that the processing assumptions made by Hino and Lupker are similar to those proposed by Kawamoto et al. (1994). The major difference is that, in Hino and Lupker's feedback account, the differ-

phone effects in a similar fashion. Specifically, homophone effects would be due to feedback from the phonological output lexicon to the visual input lexicon, and lexical decisions in that model would be based on activity in the visual input lexicon.

ence between polysemous and nonpolysemous words is in terms of the nature of the connections from orthographic to semantic units. Kawamoto et al.'s account, in contrast, is based on the idea that, through experience, readers have come to represent polysemous and nonpolysemous words differently at the orthographic level.

THE FEEDBACK ACCOUNTS

Hino and Lupker's (1996) explanation of polysemy effects is based on the notion that the nature of feedback to the orthographic units can influence lexical-decision performance, and in that and many other ways, it is very similar to the account proposed by Pexman et al. (in review) to explain homophone effects. While Pexman et al. proposed that homophone effects are caused by *inconsistent* feedback from phonological units to the orthographic units for homophonic words, Hino and Lupker proposed that polysemy effects are caused by *enhanced* feedback from semantic units to the orthographic units for polysemous words. For homophones, one phonological code feeds back to multiple orthographic codes, while for polysemous words, multiple semantic codes feed back to one orthographic code. The result is a processing disadvantage for homophones and a processing advantage for polysemous words.

If one merges these two accounts, there are two predictions that can be derived. The first prediction arises from the fact that both polysemy and homophone effects are due to the structure of the system and not to the use of particular response strategies. It has been suggested, for instance, that homophone effects arise when phonology is emphasized (Davelaar et al., 1978). It has also been suggested by Kawamoto et al. (1994) that polysemy effects arise only when tasks depend on orthographic processing, and not semantic processing. We argue, instead, that homophone and polysemy effects arise whenever there is sufficiently extensive processing to allow phonological activation and semantic activation to provide feedback to, and influence activation of, the orthographic units. Since we argue that both homophone and polysemy effects are caused by similar feedback processes, and we argue that these effects are not strategic, the first prediction would be that the homophone and polysemy effects should co-occur in a lexical-decision task (i.e., if the conditions are right for one, they should be right for the other).

Although the prediction that these effects would co-occur might seem like an obvious one, it is actually not. The reason it is not is that very different effects can arise for word stimuli when the word-likeness of nonword foils is manipulated. For example, as the results of Pexman et al. (in review) show, the existence of a homophone effect with pseudoword foils is highly dependent on how word-like those foils are. If they are quite word-like, then a homophone effect arises (at least for low-frequency words). If they are not as word-like, homophone effects tend to be small and nonsignificant. Although Pexman et al. controlled the word-likeness of foils, the word-likeness of foils in the literature on polysemy effects has not been explicitly controlled. If, in the literature reporting polysemy effects, the pseudoword foils were not very word-like, then it is possible that the polysemy effect may only arise in conditions where shallow processing is sufficient and might disappear if substantially deeper processing were required (as Kawamoto et al., 1994, seemed to suggest). If the polysemy effect arises only when processing is relatively shallow, and yet the homophone effect arises only when processing is more extensive, then only one effect or the other would be expected in the present experiments. In contrast, if, as we suggest, polysemy effects arise because of feedback, then they should occur under the same circumstances as homophone effects do. This issue can only be resolved by examining the homophone and polysemy effects together, so that word-likeness of pseudowords can be controlled.

The second prediction stems from our assertion that pseudohomophones make a lexical-decision task more difficult by requiring more complete processing at the orthographic level. If this assertion is true, then the prediction is that with pseudohomophone foils there will be larger effects of feedback from phonology and from semantics to the orthographic units. As a result, both the homophone effect and the polysemy effect should be *larger* when pseudohomophones rather than pseudowords are used as foils.

It is unclear whether this second prediction could be derived from other accounts of polysemy effects. As noted, Kawamoto et al. (1994) suggested that polysemy effects arise in tasks that emphasize orthographic processing. In tasks where responding is based on semantic activity, there should actually be a processing disadvantage for polysemous words since their semantic activation should settle more slowly than that of nonpolysemous words. It is unclear whether Kawamoto et al. wish to assume that using pseudohomophones in lexical-decision tasks would increase the use of semantic processing or not. Certainly, there is evidence that semantic factors do have more impact when pseudohomophones are used as foils in a lexical-decision task. For example, James (1975) found larger concreteness effects (faster response times for concrete words [DRUM] compared to abstract words [HALT]) with pseudohomophones as foils in a lexical-decision task than with pseudowords as foils. According to our account, these results were due to increased impact of semantic feedback in the pseudohomophone foil condition. It would seem that Kawamoto et al. would also be compelled to invoke an explanation based on use of orthographic processing in order to explain James's effects rather than arguing that the impact of pseudohomophones is to increase the reliance on semantic units.

Another point that should be made is that the Kawamoto et al. (1994) account does not have a mechanism for explaining homophone effects. Similarly, the Borowsky and Masson (1996) model was not designed to explain homophone effects. It should also be noted that while the Borowsky and Masson model does predict larger polysemy effects with orthographically legal foils than with consonant string foils, it does not appear that it would predict even larger polysemy effects with pseudohomophone foils. In this model, the amount of processing necessary to respond accurately to the target (in terms of cycles) may in fact be greater when pseudohomophones are used than when orthographically legal nonwords are used. However, Figure 2 and Table 9 in Borowsky and Masson's paper appear to indicate that the size of the polysemy effect asymptotes by about 115 cycles which is the point where a "WORD" response can be made when the foils are orthographically legal nonwords. Thus, the model would seem to predict that the extra processing cycles required to respond "WORD" when the pseudohomophones are used would not increase the polysemy effect. Alternatively, it is possible that the parameter values could be re-selected in such a way that the model could account for a larger polysemy effect with pseudohomophone foils. It is not clear, however, that this would work and further simulations would be required to evaluate this possibility.

Experiment 1

In the present paper, we tested the two predictions of the feedback account of homophone and polysemy effects. We examined two empirical questions: (a) Do homophone and polysemy effects co-occur in a standard lexical-decision task (with pseudoword foils)? (b) Are homophone and polysemy effects both larger when pseudohomophones are presented as foils in a lexical-decision task? In Experiment 1, low- and high-frequency homophonic and polysemous words were presented, along with their respective controls, and the foils were orthographically legal pseudowords. In Experiment 2, the same word stimuli were presented but the foils were pseudohomophones.

METHOD

Participants. The participants in these experiments were undergraduate students at the University of Calgary who received bonus credit in a psychology course in exchange for their participation. There were 28 participants in Experiment 1 and 30 in Experiment 2. All participants had normal or corrected-to-normal vision and considered English to be their first language. Two groups of participants were required for each experiment because there were two stimulus list conditions (described below). Participants were assigned to a list condition by their order of participation in an experiment, such that the first participant was assigned to List A, the second to List B, and so on.

Stimuli. Words. The word stimuli for these experiments included low- and high-frequency polysemous and non-polysemous words, and low- and high-frequency homophones and nonhomophones. The polysemous and non-polysemous words were the stimuli used by Hino and Lupker (1996; see that paper for a description of how number of meanings was determined). We chose these stimuli because the polysemous and nonpolysemous words were equated, as much as possible, for subjective familiarity, positional bigram frequency, neighbourhood size, and word length. In this set there were 15 low-frequency polysemous words (mean frequency = 14.20, SD = 7.82, all frequencies from Kucera & Francis, 1967), 15 low-frequency non-polysemous words (mean frequency = 14.40, SD = 8.21), 15 high-frequency polysemous words (mean frequency = 226.67, SD = 234.47), and 15 high-frequency nonpolysemous words (mean frequency = 231.13, SD = 265.78).

The word stimuli for these experiments also included low- and high-frequency homophones and nonhomophones. These were a subset of the stimuli used by Pexman et al. (in review). There were 18 pairs of homophones used in the present experiments. Most of these pairs were selected from pairs listed by Kreuz (1987). One member of each pair was a low-frequency word (frequency less than 32 per million) and the other member of the pair was a high-frequency word (frequency greater than 40 per million). A non-homophone was chosen to match each of the 36 homophones used in this experiment. Homophones and non-homophones were matched as closely as possible for frequency, length, neighbourhood size, and first letter. In this set there were 18 low-frequency homophones (mean frequency = 8.67, SD = 7.86), 18 low-frequency non-homophones (mean frequency = 8.33, SD = 5.96), 18 high frequency homophones (mean frequency = 246.89, SD = 240.34), and 18 high-frequency nonhomophones (mean frequency = 238.44, SD = 210.60).

Each participant was to be presented with only one member of each homophone pair, so two lists of word stimuli were created. One list contained the high-frequency members of nine homophone pairs (and their matched non-homophones) and the low-frequency members of the nine other homophone pairs (and their matched nonhomophones). The other list contained the remaining 36 words. The polysemous and nonpolysemous words were similarly divided between the two lists.

Foils. There were 70 orthographically legal pseudowords used as foils in Experiment 1. These were selected from the 80 pseudowords used by Hino and Lupker (1996) in their lexical-decision tasks. The foils for Experiment 2 were 60 pseudohomophones. These were the same pseudohomophones used by Pexman et al. (in review). Pexman et al. created these pseudohomophones by using only real English word bodies. The base words for the pseudohomophones (i.e., the words that the pseudohomophones sounded like)

TABLE 1
Mean Lexical Decision Response Times (in ms), Error Percentages, Polysemy Effects, and Homophone Effects for Experiments 1 and 2

	Experiment 1 (pseudoword foils)			Experiment 2 (pseudohomophone foils)		
Stimulus Type	RT	Error %	RT Effect	RT	Error %	RT Effect
Low frequency						
Polysemous						
M	571	2.4		614	4.4	
SD	121	15.3		155	20.6	
Nonpolysemous						
M	591	10.0	-20	647	10.7	-33*
SD	143	30.1		186	30.9	
High frequency						
Polysemous						
M	516	0.5		548	2.2	
SD	119	6.9		111	14.4	
Nonpolysemous						
M	526	0.9	-10	570	2.7	-22*
SD	115	9.7		148	16.1	
Low frequency						
Homophone						
M	600	8.3		652	12.2	
SD	177	27.7		206	32.8	
Nonhomophone						
M	586	6.7	+14	621	7.4	+31*
SD	171	25.1		176	26.2	
High frequency						
Homophone						
M	532	2.4		575	3.7	
SD	147	15.3		164	18.9	
Nonhomophone						
M	520	4.0	+12	554	2.2	+21*
SD	107	6.3		126	14.8	
Foil						
M	656	6.1		738	8.8	
SD	183	23.9		218	28.4	

Note. RT = response time.
$^* p < .05$

all had frequencies of more than 10 per million. Also, Pexman et al. pilot-tested the pseudohomophones to ensure that participants recognized that each of these foils would sound like a real word if pronounced. All of the stimuli used in these experiments are listed in the Appendix.

Procedure. On each trial, a letter string was presented in the centre of a 17-inch Sony Trinitron monitor controlled by a Macintosh G3 and presented using PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). Letters were approximately 0.50 cm high and at eye level for the participants. The distance between each participant and the monitor screen was approximately 40 cm. Lexical-decision responses were made by pressing either the left button (labeled NONWORD) or the right button (labeled WORD) on a response box.

Participants first completed 20 practice trials and were given verbal feedback if they responded incorrectly to any of the practice items. On each trial, the target was presented until the participant responded, and the intertrial interval was 1,000 msec. The stimuli were presented in a different random order for each participant.

RESULTS AND DISCUSSION

A trial was excluded from the analysis of response times if an incorrect response was made on that trial (5.09% of trials) or if the response time was faster than 250 ms or slower than 1,750 ms (0.31% of trials). Mean response times and response error rates for Experiment 1 are presented in Table 1.

In both experiments, the response times and response error data were examined with analyses in which subjects and items were separately treated as random factors.[3] In the analyses of response times by items, a z-score transformation was used to remove subject variability from item means (Bush, Hess, & Wolford, 1993).

Response times and error rates for the first four word types (the factorial combination of polysemy and frequency) were analyzed with a 2 (polysemous vs. nonpolysemous word) × 2 (low frequency vs. high frequency word) × 2 (word list A vs. word list B) analysis of variance (ANOVA). The main effect of Frequency was significant for response times ($Fs(1,26) = 47.52$, $p < .001$, $MSE = 2{,}065.39$; $Fi(1,52) = 12.90$, $p < .001$, $MSE = 0.29$) and for errors ($Fs(1,26) = 23.44$, $p < .001$, $MSE = 38.94$; $Fi(1,52) = 5.43$, $p < .05$, $MSE = 89.59$), since decisions were faster and also more accurate for high-frequency words. There were also main effects of Polysemy for response times ($Fs(1,26) = 3.76$, $p = .07$, $MSE = 1{,}429.56$; $Fi(1,52) = 2.86$, $p = .10$, $MSE = 0.29$) and for errors ($Fs(1,26) = 10.55$, $p < .005$, $MSE = 44.92$; $Fi(1,52) = 2.82$, $p = .09$, $MSE = 89.59$), although these polysemy effects were not significant in the items analyses. The polysemy effect was due to the fact that polysemous words were responded to more quickly and more accurately than nonpolysemous words. Although the interaction of Frequency and Polysemy was not significant in the analysis of response times ($Fs < 1.5$; $Fi < 1.5$), that interaction was significant by subjects in the analysis of response errors ($Fs(1,26) = 10.14$, $p < .005$, $MSE = 38.45$; $Fi(1,52) = 2.32$, $p = .13$, $MSE = 89.59$). Using the same stimuli, Hino and Lupker (1996) also reported this interaction in their error data, and attributed it to the high error percentage (54%) for a particular word in the low-frequency nonpolysemous word condition (VETO). In the present experiment, the error percentage for "VETO" was 71% and the significant Frequency by Polysemy interaction in the error data once again seems to have been due to this particular word.[4]

The remaining four word types (the factorial combination of homophony and frequency) were analyzed with a 2 (homophone vs. nonhomophone) × 2 (low-frequency vs. high-frequency word) × 2 (word list A vs. word list B) analysis of variance (ANOVA). The only significant effects were the main effects of Frequency for response times ($Fs(1,26) = 54.71$, $p < .001$, $MSE = 2{,}273.14$; $Fi(1,64) = 18.21$, $p < .001$, $MSE = 0.20$) and for errors ($Fs(1,26) = 26.41$, $p < .001$, $MSE = 40.09$; $Fi(1,64) = 10.56$, $p < .005$, $MSE = 64.49$). Again, the nature of this effect was that responses were faster and more accurate for high-frequency words. There was also a main effect of Homophony for response times ($Fs(1,26) = 3.86$, $p = .06$, $MSE = 1756.09$; $Fi(1,64) = 2.19$, $p = .14$, $MSE = 0.20$) although the homophone effect for response times was not significant in the items analysis, and the effect was not significant for errors ($Fs(1,26) = 2.36$, $p = .14$, $MSE = 39.42$; $Fi < 1.5$). The nature of the homophone effect was that response times were slower for homophones than for nonhomophones. The interaction of Frequency and Homophony was not significant for response times or for errors ($Fs < 1.5$; $Fi < 1.5$).

Pexman et al. (in review) did find that frequency and homophony interacted in a lexical-decision task with pseudoword foils, but only if the foils were word-like (spelled with bodies that occurred in real English words). When the foils were spelled with bodies that did not occur in any real English words the interaction was nonsignificant, but in the direction of a larger homophone effect for low frequency words. The foils in the present experiment were from the Hino and Lupker (1996) experiment, where word-likeness of foils was not controlled. The Hino and Lupker foils included some pseudowords spelled with real bodies and some pseudowords spelled with nonreal bodies. Thus, it is not surprising that the Frequency by Homophony interaction in the present experiment was not as marked as in Pexman et al.

The main purpose of the present experiment was to determine whether polysemy and homophone effects co-occurred when orthographically legal pseudowords were used as foils in a lexical-decision task. The effects did indeed co-occur. That is, there was a polysemy effect that was very similar to the effect reported by Hino and Lupker (1996) and there was a homophone effect as in Pexman et al. (in review). Thus, in the same experiment, polysemous words were processed more quickly than nonpolysemous words while homophones were processed more slowly than nonhomophonic words.

As noted, the possibility existed that the type of

[3] Because the items in this experiment were not selected randomly, the implication is that items really should not be treated as a random factor in these analyses since to do so would be to violate a number of assumptions underlying the ANOVA model (see Wike & Church, 1976). Further, the effect of these violations is to create a bias in the items analysis and, hence, severely limit its power. Nonetheless, we will be carrying out and reporting these items analyses for the interested reader. We will, however, be basing our conclusions only on the results of the subjects analyses.

[4] The analyses in this experiment were also conducted with the word VETO removed. In these analyses, the Polysemy effect was slightly smaller for both response times ($Fs(1,26) = 2.98$, $p = .10$, $MSE = 1{,}289.92$; $Fi(1,51) = 1.79$, $p = .19$, $MSE = 0.12$) and for errors ($Fs(1,26) = 3.78$, $p = .08$, $MSE = 36.32$; $Fi < 1.5$). The interaction of Frequency and Polysemy was not significant in these analyses for either response times ($Fs < 1.5$; $Fi < 1.5$) or errors ($Fs(1,26) = 2.16$, $p = .15$, $MSE = 36.32$; $Fi < 1.5$).

pseudowords used in studies of homophone effects and the type of pseudowords used in studies of polysemy effects might have been very different. Pexman et al. (in review) demonstrated that the homophone effect was observed only when the pseudoword foils were relatively word-like, but the issue of word-likeness of foils had never been investigated for polysemy effects. Thus, it was possible that the polysemy effect might arise only with pseudoword foils that were not very word-like (i.e., when shallow processing was sufficient for responding), while homophone effects would arise only when processing was more extensive. Since, in Experiment 1, the homophone and polysemy effects occurred together, the findings do not support the possibility that polysemy effects arise under different conditions than homophone effects do.

On the other hand, one could argue that the pseudoword foils used in Experiment 1 actually represented sort of a happy medium in that they may have been word-like enough to generate a homophone effect but not word-like enough to eliminate the polysemy effect. That is, these pseudowords might be ones that, by chance, lead to processing that was extensive enough to generate a homophone effect but not too extensive to prevent a polysemy effect from being observed (at least a small one such as that observed in Experiment 1). The way to address this issue would be to use foils that are even more word-like. This was the approach taken in Experiment 2 in which the foils were pseudohomophones. If the homophone and polysemy effects really do arise under different task conditions, then the effects should diverge in Experiment 2. If the effects are due, instead, to feedback then the effects should both be larger in Experiment 2.

Experiment 2

RESULTS AND DISCUSSION

A trial was excluded from the analysis of response times if an incorrect response was made on that trial (7.22% of trials) or if the response time was faster than 250 ms or slower than 1,750 ms (0.40% of trials). Mean response times and response error rates for Experiment 2 are presented in Table 1.

In the analyses of responses for the first four word types (the factorial combination of polysemy and frequency), there were significant main effects of Frequency for response times ($Fs(1,28) = 56.45$, $p < .001$, $MSE = 2{,}684.59$; $Fi(1,52) = 18.93$, $p < .001$, $MSE = 0.14$) and for errors ($Fs(1,28) = 10.58$, $p < .005$, $MSE = 77.81$; $Fi(1,52) = 4.43$, $p < .05$, $MSE = 92.58$), since responses were faster and more accurate for high-frequency words. There were also main effects of Polysemy for response times ($Fs(1,28) = 11.18$, $p < .005$, $MSE = 2{,}192.60$; $Fi(1,52) = 3.94$, $p = .06$, $MSE = 0.14$) and for errors ($Fs(1,28) = 10.96$, $p < .005$, $MSE = 31.52$; $Fi(1,52) = 1.86$, $p = .17$, $MSE = 92.58$). As in Experiment 1, polysemous words were responded to more quickly than nonpolysemous words. Although the interaction of Frequency and Polysemy was not significant in the analysis of response times ($Fs < 1.5$; $Fi < 1.5$), that interaction was, as in Experiment 1, significant by subjects in the analysis of response errors ($Fs(1,28) = 4.55$, $p < .05$, $MSE = 56.12$; $Fi < 1.5$). Again, the source of this interaction was the high error percentage (53%) for the word VETO.[5]

In the analyses of responses for the remaining four word types (the factorial combination of homophony and frequency), there were significant main effects of Frequency for response times ($Fs(1,28) = 39.32$, $p < .001$, $MSE = 3{,}580.29$; $Fi(1,64) = 23.03$, $p < .001$, $MSE = 4{,}873.59$) and for errors ($Fs(1,28) = 38.31$, $p < .001$, $MSE = 40.42$; $Fi(1,64) = 5.98$, $p < .05$, $MSE = 80.39$). Again, responses were faster and more accurate for high-frequency words. There were also significant main effects of Homophony for response times ($Fs(1,28) = 12.27$, $p < .005$, $MSE = 2{,}115.51$; $Fi(1,64) = 2.62$, $p = .10$, $MSE = 4{,}873.59$) and for errors ($Fs(1,28) = 5.45$, $p < .05$, $MSE = 43.59$; $Fi(1,64) = 2.21$, $p = .13$, $MSE = 80.93$) although these homophone effects were not significant in the items analysis. As in Experiment 1, responses were slower and less accurate for homophones than nonhomophones. There was also a main effect of List for response times only ($Fs(1,28) = 5.88$, $p < .05$, $MSE = 8{,}469.10$; $Fi < 1.5$) although this effect was not significant by items. The nature of the list effect was that response times were faster for List A than List B. Again, the Frequency by Homophony interaction was not significant for response times or for errors ($Fs < 1.5$; $Fi < 1.5$).

As illustrated in Table 1, the response times and error rates for Experiment 2 suggest that the lexical decisions in this experiment were more difficult than those in Experiment 1. Our expectation was that, with a more difficult decision, requiring more extensive processing, larger effects would be observed. In planned comparisons, the present results showed that both the polysemy effect ($ts(56) = 1.68$, $p < .05$; $ti(58) = 1.34$, $p = .09$, both one-tailed) and the homophone effect ($ts(56) = 1.72$, $p < .05$; $ti(70) = 1.25$, $p = .10$, both one-tailed) were significantly larger in Experiment 2 than in Experiment 1.

As illustrated in Table 1, the polysemy effects in Experiment 2 were almost identical, numerically, to the homophone effects in that same experiment.[6] Nonetheless, as in

[5] As in Experiment 1, the analyses in this experiment were also conducted with the word VETO removed. In these analyses, the Polysemy effect was slightly smaller for both response times ($Fs(1,26) = 8.05$, $p < .01$, $MSE = 2{,}331.18$; $Fi(1,51) = 1.64$, $p = .21$, $MSE = 0.13$) and for errors ($Fs(1,26) = 3.90$, $p = .06$, $MSE = 25.89$; $Fi < 1.5$). The interaction of Frequency and Polysemy was not significant in these analyses for either response times ($Fs < 1.5$; $Fi < 1.5$) or errors ($Fs < 1.5$; $Fi < 1.5$).

[6] We investigated whether individual participants showed both effects. In order to determine this, we collapsed the homophone effects and polysemy effects across frequency and tallied the number of partici-

Experiment 1, the homophone and polysemy effects went in opposite directions. There was an advantage for polysemous words in terms of both response times and error rates and a disadvantage for homophones. These findings support the feedback explanation of homophone and polysemy effects.

General Discussion

The purpose of the present paper was to investigate whether a feedback account could provide an adequate explanation for both homophone effects and polysemy effects. We tested this account by examining two empirical questions: (a) Do homophone and polysemy effects co-occur in a standard lexical-decision task? (b) Are homophone and polysemy effects both larger when pseudohomophones are used as foils in a lexical-decision task?

The answer to both questions was "yes". Key assumptions of this account are that both the semantic and phonological units generate feedback to the orthographic units, and that lexical decisions are based primarily on activation in the orthographic units. According to this explanation both homophone and polysemy effects arise because of the type of feedback they provide to the orthographic units. When words are processed, there is initially a certain amount of phonological activation and this in turn creates feedback to the orthographic units. Since homophones involve one phonological code and multiple spellings, this feedback to orthography will be inconsistent, generating problems at the level of the orthographic units and producing a homophone effect. The polysemy effect arises because polysemous words initially create strong semantic activation and this in turn creates strong feedback to the orthographic units. That is, since polysemous words involve multiple semantic codes and one orthographic code, this feedback to orthography will be much stronger than for words that have only one semantic code. The result is very rapid settling in the orthographic units.

According to this feedback account, it is assumed that lexical decisions are made primarily on the basis of activity in the orthographic units. When decisions are more difficult, then processing is more extensive (i.e., more settling is required before a decision can be made) and there is the opportunity for feedback to have more influence. When decisions are easier, processing is more shallow and this feedback should have less influence.

This feedback mechanism is not part of other accounts of polysemy effects. The Kawamoto et al. (1994) account is similar to the feedback account in its suggestion that lexical decisions are performed on the basis of orthographic activity, but the Kawamoto et al. account explains polysemy effects in terms of learned weights on orthographic units. That account could potentially explain larger polysemy effects with pseudohomophone foils by assuming, as we have, that the use of pseudohomophones requires additional settling of orthographic units. Such an assumption, however, is not currently part of the model. Additionally, the Kawamoto et al. account offers no explanation for homophone effects.

Borowsky and Masson (1996) provide an account of polysemy effects based on Masson's (1991, 1995) distributed memory model. It remains to be seen whether the model could account for either homophone effects or the increase in the size of both effects when pseudohomophone foils are used.

There is one additional issue to clarify. According to our account, polysemous words activate multiple semantic representations and, thus, the potential exists for these representations to provide feedback to multiple orthographic representations. If so, polysemous words, like homophones, would create competition at the orthographic level. For example, the polysemous word "BANK" would activate the semantic representation for "BANK" and would also activate concepts such as "RIVER" and "MONEY". If all these semantic representations provided feedback to their separate orthographic representations (i.e., for the letter patterns "BANK," "RIVER" and, "MONEY") considerable competition would be created at the orthographic level which, in theory, should slow processing of polysemous words.

In response, we would like to make the following two points. First, nonpolysemous words would produce a similar effect (although on average to a lesser degree). For example, the semantic representations activated by the nonpolysemous word "LADY" would presumably also allow activation to feed back orthographic representations for "GIRL", "WOMAN", "FEMININE", etc., creating similar competition. Second, in all cases, the majority of the feedback would converge on the correct set of orthographic units. In other words, there would be vastly more feedback to the orthographic representation for "BANK" than to the orthographic representations for "RIVER" or "MONEY" (and more feedback to the orthographic representation for "LADY" than to the orthographic representations for "GIRL" or "WOMAN"). Thus, the net effect for a polysemous word like "BANK" should still be facilitory.

The main empirical point that the present data make is that although polysemy and homophony produce effects that go in opposite directions, those effects appear to be influenced by many of the same factors. This fact implies that a successful model of either of these effects will be one which can simultaneously account for the other effect. The

pants who showed a polysemy advantage (faster mean response time for polysemous words than for nonpolysemous words) and a homophone disadvantage (slower mean response time for homophones than for nonhomophones). In Experiment 1, 14 of the 28 participants showed both the polysemy and homophone effects. In Experiment 2, 16 of the 30 participants showed both effects.

feedback mechanism proposed here is one such example. It is a mechanism based on the idea that processing is affected by the nature of the feedback from both phonology and semantics. This feedback affects the activation and settling of orthographic units and, hence, affects not only lexical-decision performance but, presumably, also reading processes in general.

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Correspondence concerning this article should be addressed to Penny M. Pexman, Department of Psychology, University of Calgary, 2500 University Drive NW, Calgary, Alberta T2N 1N4 (E-mail: pexman@ucalgary.ca).

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Appendix

Word Stimuli — Experiments 1 and 2

Low Frequency Polysemous	Low Frequency Nonpolysemous	High Frequency Polysemous	High Frequency Nonpolysemous
perch	evade	watch	event
rash	fern	post	nine
punch	badge	pass	lady
hail	veto	base	loss
spade	sewer	date	news
shed	wool	mass	lack
limp	cult	shot	clay
drag	lung	march	green
seal	lamp	club	paid
lean	tent	range	river
pupil	solve	fine	food
beam	mode	miss	half
bowl	gang	order	often
sink	pond	right	small
draft	beard	well	also
Low Frequency Homophone	**Low Frequency Nonhomophone**	**High Frequency Homophone**	**High Frequency Nonhomophone**
blew	boil	blue	bill
bored	baked	board	black
brake	bleed	break	broad
coarse	cheese	course	church
deer	deed	dear	draw
feat	flip	feet	five
hare	hack	hair	hard

haul	hoop	hall	hope
hire	heap	higher	having
ladder	locate	latter	larger
leased	loomed	least	large
maid	mess	made	must
mane	maze	main	more
mourning	mounting	morning	million
reed	rail	read	rest
reel	rude	real	rate
seam	seep	seem	soon
sighs	skids	size	step

Foil Stimuli

Pseudowords — Experiment 1

vit	glock	gound	dast	kell	chep
dosh	sair	crace	iton	coint	natch
nold	jelt	plit	strim	smallow	troce
clow	bix	kug	soat	frosk	kas
tabit	lig	het	mage	tace	sacket
scake	scrop	smate	ked	choone	fity
grouk	mape	misk	koney	maint	tark
blan	proom	polse	reace	sace	kingle
thonk	wist	whike	doy	yat	fost
crep	dictant	dount	tirst	korest	gep
foy	lian	sile	fow	morth	pamer
rask	kobbin	wobot	skock		

Pseudohomophones — Experiment 2

chace	rade	laff	scail	sain	shair
squair	hait	mait	jale	trale	brane
rane	wate	trax	wheal	sleap	keap
ded	hed	plee	teech	greef	cheef
bleek	speek	deel	meel	creem	cleen
leep	heer	heet	neet	lern	kerse
swet	thret	nife	tipe	tite	joak
smoak	roal	floar	scoar	koast	goast
rong	bor	rore	cort	noze	yung
murge	gurl	vurse	shurt	durt	tutch

Sommaire

Dans une tâche de décision lexicale (TDL), Hino et Lupker (1996) ont signalé un effet de polysémie (réponse plus rapide pour les mots polysémiques [p. ex., bank]), et ont attribué cet effet à une rétroaction améliorée du système sémantique par rapport aux unités orthographiques, pour les mots polysémiques. Utilisant la même tâche, Pexman, Lupker et Jared (dans un examen) ont signalé un effet d'homophonie (réponse plus lente pour les mots homophoniques [p. ex., maid]) et ont attribué cet effet à une rétroaction irrégulière du système phonologique par rapport aux unités orthographiques, pour les homophones. Dans notre document, nous mettons à l'épreuve deux prédictions dérivées de cette explication par la rétroactivité: les effets de polysémie et d'homophonie devraient (a) se produire simultanément dans une TDL standard (avec des leurres de pseudo-mots) et (b) être tous deux plus intenses avec les «pseudo-homophones» (p. ex., brane) servant de leurres dans la TDL. Les résultats corroborent les deux prédictions.