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## Homophone Interference Effects in Visual Word Recognition

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## ABSTRACT

In three lexical decision experiments and one progressive demasking experiment, performance to low-frequency heterographic homophones having a high-frequency mate was compared with performance on non-homophone target words with or without high-frequency orthographic neighbours. Robust homophone interference effects were observed in all experiments, as well as inhibitory effects of neighbourhood frequency. When speed-accuracy trade-offs were reduced, the homophone interference effects were found to be additive with effects of high-frequency orthographic neighbours. Furthermore, the size of homophone interference effects increased when pseudohomophone stimuli were presented among the nonwords. These results are tentatively interpreted within the framework of a bi-modal interactive activation model.

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Much recent work on how people recognise written and spoken words has focused on the competitive nature of the underlying processes (e.g., Grainger & Jacobs, 1996; Norris, McQueen, & Cutler, 1995). It is assumed that bottom-up information provides an initial partial match to a multiplicity of whole-word representations in long-term memory (representations coding orthographic and/or phonological descriptions, for example). This multiple partial matching generates competitive processes inasmuch as only one word can be recognised at a time. The term competition is used here to convey the hypothesis that the processing of a given word is always influenced by the existence of other partially matching words. Although a competition-free, best-match algorithm (whether parallel or serial) would guarantee that the correct word is indeed identified in idealised noise-free conditions, the experimental data at present suggest that competitive processes are an integral part of how we recognise words.

These hypothetical competitive processes operating during visual word recognition are triggered by the initial partial match established between sensory information extracted from the printed stimulus and whole-word representations in long-term memory. There is a growing consensus that this initial mapping concerns both orthographic information (letter identity and position) and phonological information (sounds corresponding to specific letters or letter combinations). Although not necessary for response generation in certain experimental tasks (e.g., visual lexical decision), there is now abundant evidence that phonological codes are automatically generated from printed words (e.g., Ferrand & Grainger, 1996; Frost, 1998; Grainger & Ferrand, 1994; Jacobs, Rey, Ziegler, & Grainger, 1998; Lukatela & Turvey, 1994; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988; Ziegler, Ferrand, Jacobs, Rey, & Grainger, 2000). Given the evidence for early phonological influences in visual word recognition, and given the evidence for the competitive nature of the recognition process, the present study examines one situation where phonological coding ought to hinder visual word recognition. The specific situation we examine

concerns heterographic homophones (e.g., MAID-MADE), for which the whole-word phonology is compatible with two (or more) whole-word orthographic descriptions. Shared phonology should lead to competition between incompatible orthographic representations. These homophone interference effects will be compared to interference observed with low-frequency non-homophonic words with a high-frequency orthographic neighbour.

Interference effects on the low-frequency member of heterographic homophone pairs were first reported by Rubenstein, Lewis, and Rubenstein (1971). In a lexical decision task, correct positive responses to these stimuli were significantly slowed compared to non-homophone controls. Coltheart, Davelaar, Jonasson, and Besner (1977) failed to replicate this result using stimuli that were better controlled for word frequency. However, the absence of a homophone effect in the Coltheart et al. study was shown to be due to the presence of pseudohomophones (nonwords that can be pronounced like a real word, e.g., ROZE) as stimuli eliciting negative lexical decision responses (Davelaar, Coltheart, Besner, & Jonasson, 1978). In the absence of such pseudohomophone stimuli, the low-frequency members of a heterographic homophone pair produced longer response times (RTs) than non-homophone control words. Davelaar et al. concluded that their participants abandoned use of an "optional phonological encoding strategy" in the presence of pseudohomophone stimuli, hence the absence of a homophone disadvantage in this situation.

Pexman, Lupker, and Jared (2001), replicated the homophone disadvantage observed by Davelaar et al. (1978) in a lexical decision task with regular nonwords. However, these authors failed to replicate the absence of a homophone disadvantage when all the nonwords are pseudohomophones. Indeed, the homophone disadvantage even increased in this situation compared to the regular nonword condition, with effects appearing for both the high and the low-frequency members of the homophone pair. With regular nonwords, Pexman et al. (2001) found that homophone interference effects are only reliable for the low-frequency member of

polarized homophone pairs (i.e., when there is a notable difference in frequency of occurrence in the two words, such as maid-made).

Homophone disadvantages have also been reported in a perceptual identification task (Hawkins, Reicher, Rogers, & Peterson, 1976), a semantic categorization task (Van Orden, 1987), and a letter search task (Ziegler, Van Orden, & Jacobs, 1997). Hawkins et al. reported that participants performed worse with homophone than non-homophone stimuli in the Reicher-Wheeler task (Reicher, 1969; Wheeler, 1970). Participants had to choose which of two orthographically similar words (e.g., WORD-WORK) had been presented, and were often at chance level performance when these were homophones (e.g., SENT-CENT). In a semantic categorisation task, Van Orden (1987) reported that participants made significantly more false positive errors when the homophone mate of the target word was a member of the pre-specified category (e.g., is ROWS a FLOWER?), compared to orthographic controls (is ROBS a FLOWER?). Finally, in the letter search task, Ziegler et al. (1997) reported that with low-frequency homophone stimuli, participants made more false positive errors in the target absent condition (e.g., A in LEEK) when the target letter was present in the homophone mate of the test word (A in LEAK). Also, more false negative errors were made in the target present condition, when the target letter did not figure in the homophone mate of the test word (e.g., A in SEAM is not present in SEEM).

The homophone disadvantage observed in these different tasks is subject to certain restrictions. Hawkins et al. (1976) reported that increasing the percentage of homophone stimuli removed the homophone disadvantage. This suggests that, on becoming aware of the presence of homophone pairs, participants could modify their response strategy, placing more reliance on orthographic information (see Verstaen, Humphreys, Olson, & d'Ydewalle, 1995, for a similar result using a backward masking paradigm). In the letter search task, the homophone disadvantage is strongest for the low-frequency printed forms of homophones (Ziegler et al., 1997), as is generally the case for the homophone disadvantage in

lexical decision (Pexman et al., 2001). Finally, it has been shown that the homophone disadvantage in semantic categorisation is significantly larger when homophone pairs have high orthographic similarity (Coltheart, Patterson, and Leahy, 1994; Jared & Seidenberg, 1991; Van Orden, 1987). It is the influence of orthographic overlap between homophone pairs that will be one central point of the present investigation.

Although non-homophone control stimuli are generally selected to match homophone words in terms of orthographic overlap with one other word, none of the prior studies investigating the homophone disadvantage in lexical decision have controlled for the printed frequency of orthographic neighbours (Pexman et al., 2001, controlled for number of orthographic neighbours). This is problematic in that homophone mates are often also orthographic neighbours (e.g., BAWL-BALL). An orthographic neighbour of a given word is another word that has maximum orthographic overlap with the former. Typically, this is operationally defined as a word sharing all but one letter while respecting letter position (e.g., WORD-WORK, Coltheart et al., 1977)<sup>1</sup>. Now, given that it has been reported that low-frequency words with high-frequency orthographic neighbours are harder to identify than low-frequency words with no such high-frequency orthographic neighbour (Carreiras, Perea, & Grainger, 1997; Grainger, 1990; Grainger, O'Regan, Jacobs, & Segui, 1989; 1992; Grainger & Jacobs, 1996; but see Sears, Hino, & Lupker, 1995 and Forster & Shen, 1996, for two failures to replicate), it seems critical to control for potential interference from high-frequency neighbours when measuring homophone interference effects. This is the main objective of the present study.

At a more general level of analysis, the present experiments are designed to clarify how early phonological coding influences later competitive processes in visual word recognition. The experiments are motivated by the need to move one step further from simply stating that phonology does influence visual word recognition, to specifying exactly how it does so. Establishing the precise nature of homophone interference effects in visual word recognition should provide critical constraints on the type of architecture that can account for competitive and



cooperative interactions between orthographic and phonological codes in alphabetic writing systems. One critical point concerns the interactive or additive nature of homophone interference and interference generated by high-frequency orthographic neighbours.

In light of the prior work of Pexman et al. (2001), the present study only tests the low-frequency members of highly polarised heterographic homophones. As an improvement over prior research, the present study controls for the degree of orthographic overlap across homophone pairs and for the influence of high-frequency orthographic neighbours. These effects are examined using the lexical decision task and the progressive demasking paradigm (a variant of Feustel, Shiffrin, & Salasoo's, 1983, continuous threshold identification technique) introduced by Grainger and Segui (1990). In extensive pilot work before proceeding with the present study, we manipulated the degree of orthographic overlap across homophone mates and measured homophone interference effects relative to effects of high-frequency orthographic neighbours. Orthographically dissimilar homophones in French (e.g., cent-sans) generated significantly longer RTs compared to non-homophonic words with no high frequency orthographic neighbours, in both the lexical decision and progressive demasking tasks. On the other hand, no homophone interference was observed when homophones with orthographically similar mates (e.g., tare-tard) were compared to non-homophonic words with high frequency orthographic neighbours. Constraints in stimulus selection had, however, led to some uncontrolled variability in printed frequency and neighbourhood density (number of orthographic neighbours) across stimulus conditions. The experiments to be reported here show that with stricter controls, homophone interference effects are observed irrespective of the degree of orthographic overlap across homophone mates.

## EXPERIMENT 1

### Method

*Participants.* Fifty-two psychology students served as participants for course credit, thirty-two from the University of Provence and twenty from René Descartes University. Thirty-two participated in the lexical decision task, and twenty in the progressive demasking task. All were native speakers of French, with normal or corrected-to-normal vision.

*Stimuli.* A set of five-letter French words were selected for the purposes of the present experiment. Orthographic neighbourhood (at least one high frequency neighbour vs. no high frequency neighbour) was crossed with Homophone status (homophone vs. non-homophone) in a 2X2 factorial design. Two types of homophone target were required for this design: 1) homophones whose high frequency mate is also an orthographic neighbour and which has no other high frequency orthographic neighbour (e.g., ANCRE-ENCRE); and 2) homophones with an orthographically dissimilar high frequency mate and with no high frequency orthographic neighbour (e.g., AUTEL-HOTEL). Only the less frequent member of the homophone pairs served as stimuli. These homophones were matched in frequency as closely as possible to the other two categories. A full description of the 4 item categories is given in Table 1. Ten words were chosen per category giving a total of forty stimulus words. Forty orthographically legal, pronounceable nonwords were also included in the experimental lists for the purposes of the lexical decision task.

<Insert Table 1 about here>

*Procedure for the lexical decision task: Experiment 1A.* Stimuli were presented individually on the centre of the display screen of a personal computer with a 60-Hz refresh rate. The items appeared on the screen as white characters on dark background. A central fixation point was presented for 500 msec followed by a 500 msec delay after which the stimulus item was presented centred on the fixation point. The stimulus remained on the screen until the subject pressed one of the two response buttons to indicate if the stimulus was a word (using the index finger of the preferred hand) or not a word (using the index finger of the non-preferred hand). Participants were instructed to respond as rapidly and accurately as possible. Each subject was given a list of twenty practice trials containing ten 5-letter words and ten 5-letter nonwords, none of which appeared in the experimental trials. Stimulus presentation was randomised with a different order for each subject. The next trial followed after a 2 second delay.

*Procedure for the progressive demasking task: Experiment 1B.* The procedure used by Grainger and Segui (1990) was adopted here. Word stimuli were presented in alternation with a pattern mask (a row of hash marks). Each presentation cycle was composed of a given stimulus word followed immediately by a pattern mask of 5 hash marks. On each successive cycle the exposure duration of the stimulus was increased by 17 msec and the duration of the mask decreased by 17 msec (1 screen refresh at a frequency of 60 Hz lasts 16.66 msec). The total duration of each cycle remained constant at 336 msec. Each trial consisted of a succession of cycles where stimulus duration increased and mask duration decreased. On the first cycle of each

trial, stimuli were presented for 17 msec and the mask for 333 msec. On the second cycle, stimuli were presented for 33 msec and the mask for 317 msec etc. There was no interval between cycles. This succession of cycles continued until the participant pressed a response key on the computer key-board to indicate that he or she had recognised the stimulus word. Response latencies were measured from the beginning of the first cycle until the participant's response. Participants were instructed to focus their attention on the centre of the visual display and to press the response key with the forefinger of their preferred hand as soon as they had recognised the word. They then typed in the word they had recognised and pressed the return key to initiate the following trial, which followed after a 2 second delay. Participants were asked to carefully check that they had correctly typed the word they had identified before initiating the following trial.

## Results

*Experiment 1A: Lexical decision.* Means of the lexical decision latencies and percent errors in the different stimulus categories are given in Table 2. An ANOVA was performed on the reaction time data with Orthographic Neighbourhood (no high frequency neighbours vs. one high frequency neighbour) and Homophone Status entered as main factors. The F values are given by participants (F1) and items (F2).

<Insert Table 2 about here>

The main effect of Orthographic Neighbourhood was significant by participants,  $F(1,31)=8.93$ ,  $p<.01$ , but not by items,  $F(1,36)=2.84$ , and there was a

main effect of Homophone Status,  $F(1,31)=34.96$ ,  $p<.001$  and  $F(1,36)=15.93$ ,  $p<.001$ . The interaction between these two factors was of borderline significance by participants,  $F(1,31)=3.99$ ,  $p=.05$ , but not by items,  $F(1,36)=1.78$ . An analysis of the error data showed main effects of Orthographic Neighbourhood,  $F(1,31)=20.81$ ,  $p<.001$  and  $F(1,36)=7.21$ ,  $p<.01$ , and Homophone Status,  $F(1,31)=65.36$ ,  $p<.001$  and  $F(1,36)=17.54$ ,  $p<.001$ , and again the interaction was marginally significant,  $F(1,31)=3.78$ ,  $p=0.06$  and  $F(1,36)=2.59$ .

Mean RT for correctly rejected nonwords was 748 msec and percent error rate was 14.9%.

*Experiment 1B: Progressive demasking.* Means of the latencies for correctly identified words and percent errors in the different stimulus categories are given in Table 2. An ANOVA was performed on the reaction time data in the same way as for Experiment 1A.

There was a main effect of Orthographic Neighbourhood,  $F(1,19)=5.54$ ,  $p<.03$  and  $F(1,36)=5.92$ ,  $p<.05$ , and a main effect of Homophone Status,  $F(1,19)=7.15$ ,  $p<.02$  and  $F(1,36)=6.73$ ,  $p<.02$ . The interaction between these two factors was significant by participants,  $F(1,19)=8.08$ ,  $p<.01$  but not by items,  $F(1,36)=3.52$ . An analysis of the error data showed a main effect of Homophone Status,  $F(1,19)=5.51$ ,  $p<.02$  and  $F(1,36)=5.97$ ,  $p<.02$ , but no effect of Orthographic Neighbourhood,  $F(1,19)=3.06$  and  $F(1,36)=2.15$ . The interaction was not significant,  $F(1,19)=2.40$  and  $F(1,36)=1.98$ .

## Discussion

Experiment 1 provides clear evidence for homophone interference effects in visual word recognition while providing a strict control over effects of orthographic neighbourhood. The low-frequency member of heterographic homophone pairs were harder to recognise (longer RTs and more errors) than non-homophonic words matched in terms of the number and frequency of their orthographic neighbours.

One interesting aspect of the results of Experiment 1 concerns the patterns of interactivity in the RT and error data. There is a marginally significant under-additive interaction between homophone status and orthographic neighbourhood in the RT data, and a trend to an over-additive interaction in the error data. This suggests that speed-accuracy trade-offs might be hiding additive effects of these two variables. In the lexical decision task this would arise if a temporal deadline for negative responding, as implemented in the multiple read-out model (Grainger & Jacobs, 1996), were set too low. In the progressive demasking task these trade-offs could arise via a fast-guess strategy, whereby responses to the most difficult stimuli would be generated prematurely (i.e., before complete stimulus identification). Both of these mechanisms would result in the truncation of long RTs while causing error rate to increase for the most difficult words.

Experiment 2 examines whether increasing the difficulty of the nonword stimuli would change the pattern of results obtained in the lexical decision task of Experiment 1A. Prior research has shown that adding pseudohomophones (nonwords that can be pronounced like real words, such as brane) among the nonword stimuli caused a global increase in response times, and an increase in

homophone interference effects (Pexman et al., 2001). Apart from attempting a replication of the Pexman et al. pattern, Experiment 2 investigates whether any additional time allotted for word responses will allow neighbourhood frequency effects to emerge (in RTs) over and above effects of homophony for the orthographically similar homophone targets.

## EXPERIMENT 2

### Method

*Participants.* Twenty-two psychology students at René Descartes University, Paris, served as participants for course credit. All were native speakers of French, with normal or corrected-to-normal vision and had not participated in the previous experiment.

*Stimuli and Design.* The design was identical to Experiment 1A, and the stimuli were the same as in Experiment 1A. However, 75% of pseudohomophones were introduced in the experimental lists as nonword targets. Forty orthographically legal, pronounceable nonwords were used. Thirty of them were orthographically similar pseudohomophones (e.g., AVYON, derived from the real word AVION in French). The other nonwords were not homophonic with any real word.

*Procedure.* This was identical to Experiment 1A using the lexical decision task. Participants first saw a set of twenty practice trials including ten word and ten nonwords, 7 of which were pseudohomophones. None of these stimuli were used in the experimental trials.

## Results

Means of the lexical decision latencies and percent errors in the different stimulus categories are given in Table 3. An ANOVA was performed on the reaction time data to word targets with Orthographic Neighbourhood (no high frequency neighbours vs. one high frequency neighbour) and Homophone Status entered as main factors. The F values are given by participants (F1) and items (F2).

<Insert Table 3 about here>

There was a main effect of Orthographic Neighbourhood,  $F(1,21)=4.94$ ,  $p<.05$  and  $F(1,36)=6.72$ ,  $p<.01$ , and a main effect of Homophone Status,  $F(1,21)=34.48$ ,  $p<.001$  and  $F(1,36)=12.36$ ,  $p<.01$ . The interaction between these two factors was significant,  $F(1,21)=9.07$ ,  $p<.001$  and  $F(1,36)=8.45$ ,  $p<.01$ . An analysis of the error data showed main effects of Orthographic Neighbourhood,  $F(1,21)=7.65$ ,  $p<.02$  and  $F(1,36)=8.33$ ,  $p<.01$ , and Homophone Status,  $F(1,21)=26.65$ ,  $p<.001$  and  $F(1,36)=20.75$ ,  $p<.01$ . The interaction was significant,  $F(1,21)=14.49$ ,  $p<.001$  and  $F(1,36)=9.02$ ,  $p<.005$ .

An ANOVA run on the correct RTs to nonword targets showed that pseudohomophones were responded to more slowly than non-homophonic nonwords,  $F(1,21)=11.27$ ,  $p<.005$  and  $F(1,38)=5.23$ ,  $p<.05$ . Pseudohomophones also produced more errors than non-homophonic nonwords,  $F(1,21)=8.56$ ,  $p<.01$  and  $F(1,38)=5.77$ ,  $p<.05$ .

## Discussion

The results of Experiment 2 show that adding pseudohomophones among the nonword stimuli causes a global increase in RTs (with relatively stable error rates)



compared to the lexical decision results of Experiment 1A. Homophone interference effects also increased in size in the presence of pseudohomophone stimuli (from 62 msec in Experiment 1A to 93 msec in Experiment 2), thus confirming the prior work of Pexman et al. (2001). Neighbourhood frequency effects also increased in size (from 31 msec to 61 msec). However, as with the previous experiment, a pattern of underadditivity in the RTs and overadditivity in the errors remains in the present study. Thus increasing RTs by making word / nonword discrimination harder did not solve the speed-accuracy trade-off problem. In a further attempt to remove these opposing effects in RT and errors, we decided to replace two words (forer and fumet) that contributed most to the high error rates in the orthographically similar homophone category. We also decreased the percentage of pseudohomophones to 50%.

### EXPERIMENT 3

#### Method

*Participants.* Eighty psychology students at René Descartes University, Paris, served as participants for course credit. All were native speakers of French, with normal or corrected-to-normal vision and had not participated in the previous experiments.

*Stimuli.* Two of the 5-letter stimuli tested in the previous experiment were removed from each category (8 words removed) and replaced with 4-letter words since no other 5-letter homophones could be found for these conditions given the constraints on stimulus selection applied here. The summary statistics of the new set of stimuli are given in Table 4. Eight of the 5-letter nonwords tested in Experiment 1A were

replaced by 4-letter nonwords. A complete list of the stimuli is presented in the Appendix. The design was the same as the previous experiments except that the presence versus absence of pseudohomophones was introduced as a between-participant factor in this experiment. Half of the participants were tested with regular nonwords, and half tested with 50% of these nonwords replaced by pseudohomophones previously tested in Experiment 2.

*Procedure.* This was identical to the previous lexical decision experiments.

<Insert Table 4 about here>

## **Results**

Means of the lexical decision latencies and percent errors in the different stimulus categories are given in Table 5. An ANOVA was performed on the correct RTs to word targets with Orthographic Neighbourhood (no high frequency neighbours vs. one high frequency neighbour), Homophone Status, and Type of Nonword entered as main factors. The F values are given by participants (F1) and items (F2).

<Insert Table 5 about here>

The ANOVA showed a main effect of adding pseudohomophones among the nonwords,  $F_1(1,78)=33.15$ ,  $p<.001$  and  $F_2(1,72)=20.8$ ,  $p<.001$ , a main effect of Homophone Status,  $F_1(1,78)=17.5$ ,  $p<.005$  and  $F_2(1,72)=23.32$ ,  $p<.001$ , and a main effect of Orthographic Neighbourhood,  $F_1(1,78)=32.45$ ,  $p<.001$  and  $F_2(1,72)=40.34$ ,  $p<.001$ . The triple interaction was not significant (both  $F_s<1$ ), and the two-way

interactions between Orthographic Neighbourhood and Type of Nonword, and between Orthographic Neighbourhood and Homophone Status were not significant (all  $F_s < 1$ ). However, the two-way interaction between Homophone Status and Type of Nonword was significant in the analysis by participants,  $F_1(1,78)=7.84$ ,  $p < .01$  and  $F_2 < 1$ .

Concerning percent errors, the ANOVA showed a main effect of adding pseudohomophones,  $F_1(1,78)=86.0$ ,  $p < .001$  and  $F_2(1,72)=4.10$ ,  $p < .05$ , and main effects of Homophone Status,  $F_1(1,78)=16.46$ ,  $p < .005$  and  $F_2(1,72)=17.25$ ,  $p < .005$ , and Orthographic Neighbourhood,  $F_1(1,78)=137.58$ ,  $p < .001$  and  $F_2(1,72) < 1$ . The triple interaction was significant in the analysis by participants,  $F_1(1,78)=10.77$ ,  $p < .005$ , and  $F_2 < 1$ , as well as the two-way interactions between Homophone Status and Type of Nonword,  $F_1(1,78)=20.95$ ,  $p < .001$ , and  $F_2 < 1$ . The two-way interactions between Orthographic Neighbourhood and Type of Nonword, and between Orthographic Neighbourhood and Homophone Status were not significant (all  $F_s < 1$ ).

An ANOVA run on the correct RTs to nonword targets showed that pseudohomophones were responded to more slowly than non-homophonic nonwords,  $F_1(1,39)=32.47$ ,  $p < .001$  and  $F_2(1,38)=7.95$ ,  $p < .01$ . Pseudohomophones also produced more errors than non-homophonic nonwords,  $F_1(1,39)=82.62$ ,  $p < .001$ , and  $F_2(1,38)=4.81$ ,  $p < .05$ .

## **Discussion**

Experiment 3 demonstrates that additive effects of homophone interference and orthographic neighbourhood frequency are obtained when speed-accuracy trade-offs are

absent. This is most clear in the condition with regular nonword stimuli, where it can be seen in Table 5 that interference from high frequency orthographic neighbours adds an average of 43 msec to RTs on top of the 48 msec homophone interference effect. Mean RT in each experimental condition is predicted from the linear combination of these two interference effects plus a baseline RT.

Experiment 3 once again demonstrates that homophone interference effects increase in the presence of pseudohomophone distracters. Furthermore, the data show an interesting dissociation in the influence of pseudohomophone stimuli on the homophone disadvantage and the neighbourhood frequency effect. Homophone interference effects practically tripled in the presence of pseudohomophone targets (48 msec to 142 msec), while the increase in effects of high frequency orthographic neighbours was much less pronounced (41 msec to 61 msec). This pattern is reflected by the significant interaction (in the by-participant analysis) between homophone status and type of nonword, while effects of orthographic neighbourhood did not interact with type of nonword. However, given the absence of a triple interaction in the RT data, this particular result requires further confirmation.

## GENERAL DISCUSSION

The present experiments show interference effects in the recognition of visually presented low-frequency heterographic homophones in the lexical decision and progressive demasking tasks. Homophone interference effects were obtained when comparing performance to heterographic homophones with orthographically dissimilar mates (e.g., AUTEL-HOTEL) and having no high frequency orthographic neighbours, with performance to non-homophone stimuli with no high frequency

orthographic neighbours. RTs to these homophone stimuli in both the lexical decision and progressive demasking tasks were longer than RTs to words with no high frequency neighbours. This is the first demonstration of a “pure” homophone disadvantage that cannot be explained by uncontrolled effects of orthographic neighbourhood (at least when applying current definitions of this variable).

In the same experiments it was shown that non-homophonic words with high frequency orthographic neighbours were responded to more slowly and less accurately than non-homophonic words with no high frequency neighbours. This neighbourhood frequency effect, as observed in prior studies (e.g., Grainger, 1990; Grainger & Jacobs, 1996) is an important comparison point for the homophone disadvantage effect. This is particularly true for the situation tested in the present study where target words in the high frequency neighbour condition had only a single high frequency orthographic neighbour. In this situation, a direct comparison can be made between competition arising from these unique high frequency neighbours and competition generated by the unique high frequency homophone mate of homophone target words.

Another important finding of the present study concerns the very similar data patterns obtained in the two tasks that were used: lexical decision and progressive demasking. Within the theoretical framework proposed by Grainger and Jacobs (1996), this suggests that homophone status and orthographic neighbourhood are influencing the rate of rise in activation of whole-word representations in memory. Positive responses in the lexical decision and progressive demasking tasks can be triggered when a single whole-word orthographic or phonological representation reaches a criterion level of activation. High frequency orthographic neighbours slow the rate of rise in activation of a given target word representation via within-level inhibition following the general principles of the interactive activation model of McClelland and Rumelhart (1981). In a bi-modal variant of the interactive activation model (Grainger & Ferrand, 1994) homophone interference effects can also be explained by lateral inhibition operating across whole-word representations that

compete for identification. We will examine this particular account of the homophone disadvantage effect in what follows.

<Insert Figure 1 about here>

Figure 1 describes the cooperative and competitive interactions that occur in a bi-modal interactive activation network on presentation of a heterographic homophone (e.g., FOIE which is the French word for “liver”). Sublexical connections from orthography to phonology rapidly allow the phonological representation of the homophone (/fwa/) to become activated. Activation of this phonological representation then leads to an increase in activation of both orthographic representations that correspond to that phonology (FOIS, which means “time” as in “number of times” in French, and FOIE). Assuming that connection strengths are greatest between the phonological representation and the most frequent orthographic form, then FOIS will receive an activation boost that will increase its inhibitory capacity relative to FOIE.

According to this account of the homophone disadvantage effect, there is a common underlying mechanism generating orthographic and homophonic interference. Both effects are generated via a boost in activation in a word competing for identification with the target, that results in increased inhibitory input to the target word representation. The boost in activation is a function of word frequency as well as orthographic and/or phonological similarity with the target word. Within this theoretical framework, one would expect to observe additive effects of homophone interference and neighbourhood frequency. The degree of competition is a function of the activation level of the competing representation, which is a function of its frequency and the amount of bottom-up support it receives during processing of the target word. Very approximately, if one assumes similar levels of activation input from shared orthography (O+) and shared phonology (H+) in the particular stimuli tested here, then the level of competition (as measured relative to the O-H- condition) will be approximately equal for the O+H- and O-H+ stimuli, while the O+H+ stimuli should generate about twice as much competition. In

support of this analysis, preliminary simulation work on an implementation of a bimodal interactive activation model (van Heuven, 2000) has indeed produced the additive pattern of effects obtained in Experiment 3.

An alternative means of expressing the competitive processes that are assumed to underlie the homophone disadvantage effect appeals to the notion of feedback inconsistency (Stone, Vanhoy, & Van Orden, 1997). This refers to the possibility that a given sound in a given language can be written in more than one way (e.g., /eid/ → ADE, AID). According to this account, competition arises as a result of incompatible feedback from activated phonological representations back to orthographic representations (Pexman et al., 2001). Thus, no lateral inhibition is necessary in order to account for homophone interference effects. If one were to remove the lateral inhibitory connections in the model presented in Figure 1, homophone interference could be captured by the mismatch across top-down and bottom-up information generated by homophone stimuli. The target word FOIE activates its phonological representation /fwa/ which in turn activates the alternative orthographic representation FOIE, which then feeds back inconsistent information to letter representations. In this account, the competition lies at the interface between sublexical and lexical representations. In this case, however, one might expect even stronger interference with orthographically dissimilar homophone pairs, since the degree of inconsistency (as measured by the number of incorrect letters that receive feedback) will be much higher with these stimuli. This was not observed in the present study.

This does not imply that feedback inconsistency is not playing any role in printed word perception, as attested by the work of Stone et al. (1997) and Ziegler, Montant, and Jacobs (1997). These studies have shown that visual lexical decision RTs are sensitive to the sound-to-spelling consistency of the rimes of monosyllabic non-homophone target words. Thus, when target words are consistent in the direction of spelling-to-sound (i.e., the orthographic rime has a unique pronunciation), RTs are significantly slower to words that had rimes that could be

spelled in several ways (e.g., HEAP, with the inconsistent spelling EEP), compared to consistently spelled rimes (e.g., COIN).

Heterographic homophones are words that, by definition, have inconsistent sound-to-spelling mappings. Using the tables of bi-directional inconsistency for French provided in Ziegler, Jacobs, and Stone (1996), we calculated the average spelling-to-sound and sound-to-spelling conditional probabilities of the rimes of target words in the present study. Practically all the words tested had consistent body pronunciations (conditional probability equal to 1), with no significant variation across stimulus categories. On the other hand, sound-to-spelling consistency varied essentially as a function of homophone status. For example, the average conditional probabilities of the monosyllabic stimuli tested in Experiment 3 are O-H- (0.70), O+H- (0.61), O-H+ (0.16), and O+H+ (0.09).<sup>2</sup> Thus feedback inconsistency might explain part of the homophone disadvantage effect, but it cannot capture the difference in performance between orthographically similar homophones and orthographically dissimilar homophones observed in Experiment 3.

The bi-modal interactive activation framework also provides a means of explaining how type of nonword influences the size of the homophone disadvantage effect. In the present study we found that adding pseudohomophone stimuli among the nonwords caused the effects of homophone status and orthographic neighbourhood to increase. Separating out whole-word orthographic and phonological representations in the architecture presented in Figure 1 allows one to apply a response read-out strategy from one or the other (or both) of these functionally separable lexicons. In a visual word recognition task it is assumed that response read-out will be mainly determined by activity in whole-word orthographic representations. However, in situations where inhibition across orthographic representations is excessively high (as is assumed to be the case with homophone stimuli and words with high frequency orthographic neighbours),<sup>3</sup> then read-out based on activity in whole-word phonological representations provides a



means of partially alleviating the inhibition. Adding pseudohomophone stimuli among the nonwords in a lexical decision task forces participants to abandon such a phonological response strategy, thus leading to an increase in observed levels of orthographic inhibition.

Exactly the same logic was applied to explain the masked homophone priming data of Grainger and Ferrand (1994) and more recently the cross-modal homophone priming results of Grainger, Van Kang, and Segui (2001). In the first study, masked primes that were the high-frequency homophone mate of low frequency target words facilitated target word recognition in the presence of regular nonword distracters, and inhibited the recognition of these same target word stimuli when pseudohomophones were included among the nonwords. Similarly, Grainger et al. (2001) found that auditorily presented homophone primes facilitated the recognition of both the low and the high frequency printed forms as targets in a visual lexical decision task with regular nonwords. However, when pseudohomophones were added to the nonword stimuli, then only the high frequency printed form of homophone primes continued to be facilitated, while a trend to inhibition was observed with the low frequency targets. These two sets of results fit with the general idea that participants can use a phonological response strategy in a visual lexical decision task in order to reduce effects of orthographic inhibition. The presence of pseudohomophones as distracters forces participants to abandon such a phonological response strategy. In line with this reasoning, the presence of pseudohomophones caused an increase in the size of the homophone disadvantage observed in Experiment 3. As can be seen in Figure 1, inhibitory effects across heterographic homophones will be strongest when responses in a given task are read-out from whole-word orthographic representations.<sup>4</sup>

Concluding, it appears that evidence is accumulating in favour of strong interactivity between orthographic and phonological codes during the perception of written words. Some critical evidence along these lines has been drawn from the manipulation of the orthographic (and semantic) ambiguities found in heterographic

homophones. These stimuli provide a means of examining the consequences of ambiguity in the mapping from phonology to orthography at the whole-word level. What is critical with this particular class of stimulus is that effects of ambiguity, when observed, can only be explained if it is assumed that some form of phonological representation of the stimulus has been generated. The present research provides further evidence concerning the functional architecture that links these different types of code, thus explaining how such ambiguities affect performance. Future research should help specify the precise nature of the orthographic and phonological codes involved.

**APPENDIX.** List of the word stimuli tested in Experiment 3. H+/H- refers to homophone status and O+/O- indicates whether the word has a high frequency orthographic neighbour or not. A target word's high frequency homophone mate and/or orthographic neighbour are given when applicable.

<u>H+O+</u>	<u>H+O-</u>	<u>H-O+</u>	<u>H-O-</u>
ANCRE (ENCRE)	AUTEL (HOTEL)	ASTRE (AUTRE)	ASILE
CHAUX (CHAUD)	CLERC (CLAIR)	GLAND (GRAND)	ORAGE
DENSE (DANSE)	CYGNE (SIGNE)	RUINE (REINE)	CRAIE
HEURT (HEURE)	LAQUE (LAC)	SUEUR (SŒUR)	PHASE
PANSE (PENSE)	METRE (MAITRE)	CHOPE (CHOSE)	CULTE
POING (POINT)	PALET (PALAIS)	GRADE (GRACE)	ACIER
RENNE (REINE)	SCEAU (SAUT)	FIBRE (LIBRE)	BOMBE
TENTE (TANTE)	CHÊNE (CHAINE)	POMPE (POMME)	SOLDE
BOUE (BOUT)	AILE (ELLE)	QUAI (QUOI)	ANGE
SANG (SANS)	CAMP (QUAND)	NIER (HIER)	FLOT

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## FOOTNOTES

1. We immediately acknowledge that this measure of orthographic neighbourhood is confounded with phonological neighbourhood (e.g., WORD and WORK share two out of three phonemes). For simplicity we will use the term orthographic neighborhood as defined, in contrast to homophonic neighbourhood that involves 100% phonological overlap.
2. A conditional probability greater than 0.5 arises when the summed frequency of words having the same body pronunciation and the same body spelling as the target is greater than the summed frequency of words with the same body pronunciation associated with a different body spelling.
3. In a lateral-inhibitory interactive-activation network (McClelland & Rumelhart, 1981), the amount of inhibition received by a given stimulus word representation is a function of the activation of all other word representations in the network. Inhibition is maximal when a low frequency stimulus shares bottom-up information with other high frequency words.
4. Following Pexman et al. (2001), this provides a further failure to replicate the original pattern reported by Davelaar et al. (1978), where the homophone disadvantage was found to disappear in the presence of pseudhomophone distracters.



**TABLE 1**

Description of the different words tested in Experiment 1, defined according to whether or not they have high frequency orthographic neighbours (O+/O-), and whether or not they are heterographic homophones (H+/H-). The frequencies are expressed as number of occurrences per million (Imbs, 1971).

Item Category	H-O-	H-O+	H+O-	H+O+
Example stimulus word	ASILE	ASTRE	AUTEL	ANCRE
Examples of high frequency orthographic (O) and homophonic (H) neighbours	---	Autre(O)	Hôtel(H)	Encre(O+H)
Frequency	18	18	18	18
Average number of neighbours	1.4	1.9	1.4	2.6
Average number of high frequency neighbours	0	1	0	1

**TABLE 2**

Mean Lexical Decision Latencies and Progressive Demasking Latencies (RT) in Milliseconds and Corresponding Standard Errors (SE), and Percent Errors (PE) in Response to the Different Stimulus Categories in Experiment 1A (Lexical Decision) and Experiment 1B (Progressive Demasking).

Homophone Status	Orthographic Neighbourhood Frequency					
	No High Frequency Neighbours			With High Frequency Neighbours		
	RT	SE	PE	RT	SE	PE
<u>Lexical Decision</u>						
Non-homophone	615	13	3.1	666	15	8.4
Homophone	697	17	14.9	707	20	26.7
<u>Progressive Demasking</u>						
Non-homophone	1171	51	1.5	1272	60	1.5
Homophone	1268	59	2.5	1273	56	5.5

**TABLE 3**

Mean Lexical Decision Latencies (RT) in Milliseconds and Corresponding Standard Errors (SE), and Percent Errors (PE) in Response to the Different Stimulus Categories Tested in Experiment 2 (Lexical Decision with Pseudohomophone Distracters).

Homophone Status	Orthographic Neighbourhood					
	No High Frequency Neighbours			With High Frequency Neighbours		
	RT	SE	PE	RT	SE	PE
<u>Word Trials</u>						
Non-Homophone	694	25	5.0	783	30	6.8
Homophone	815	24	14.5	847	34	22.5
<u>Nonword Trials</u>						
	RT	SE	PE			
Legal	816	31	11.3			
Pseudohomophone	880	39	22.0			

**TABLE 4**

Description of the different words tested in Experiment 3 defined according to whether or not they have high frequency orthographic neighbours (O+/O-), and whether or not they are heterographic homophones (H+/H-). The frequencies are expressed as number of occurrences per million (Imbs, 1971).

Item Category	H-O-	H-O+	H+O-	H+O+
Example stimulus word	ASILE	ASTRE	AUTEL	ANCRE
Examples of high frequency orthographic (O) and homophonic (H) neighbours	----	Autre(O)	Hôtel(H)	Encre(O+H)
Frequency	27	24	28	32
Average number of neighbours	2.1	2.1	1.9	3.8
Average number of high frequency neighbours	0	1	0	1
Average length in letters	4.8	4.8	4.8	4.8

**TABLE 5**

Mean Lexical Decision Latencies (RT) in Milliseconds and Corresponding Standard Errors (SE), and Percent Errors (PE) in Response to the Different Stimulus Categories Tested in Experiment 3 (Lexical Decision with Legal Nonwords Only vs. Lexical Decision with Pseudohomophones Distracters).

<b>Legal Nonwords Only</b>		Orthographic Neighbourhood Frequency					
Homophone Status	No High Frequency Neighbours			With High Frequency Neighbours			
	RT	SE	PE	RT	SE	PE	
Non-homophone	603	11	1.75	645	14	4.5	
Homophone	650	14	9.75	694	17	9.0	
<b>Pseudohomophone Distracters (50%)</b>		Orthographic Neighbourhood Frequency					
Homophone Status	No High Frequency Neighbours			With High Frequency Neighbours			
	RT	SE	PE	RT	SE	PE	
<u>Word Trials</u>							
Non-Homophone	754	27	13.25	804	36	15.25	
Homophone	885	43	24.5	956	49	32.5	
<u>Nonword Trials</u>							
Legal nonword	771	20	6.37				
Pseudohomophone	852	22	13.0				

## FIGURE LEGEND

Figure 1. Processing an example heterographic homophone (FOIE) in a bi-modal interactive-activation model of visual word recognition. Letter units activated by a printed stimulus (F, O, I, E) simultaneously send activation to whole-word orthographic units and sublexical phonological units. Whole-word phonological units (/fwa/) receive activation from both whole-word orthographic units (e.g., FOIE, FOIS) and sublexical phonology. Lines with arrows represent excitatory connections and lines with dots represent inhibitory connections, as in an interactive activation network (McClelland & Rumelhart, 1981). The relative amount of activation flowing from one unit to another is depicted by the thickness of lines.

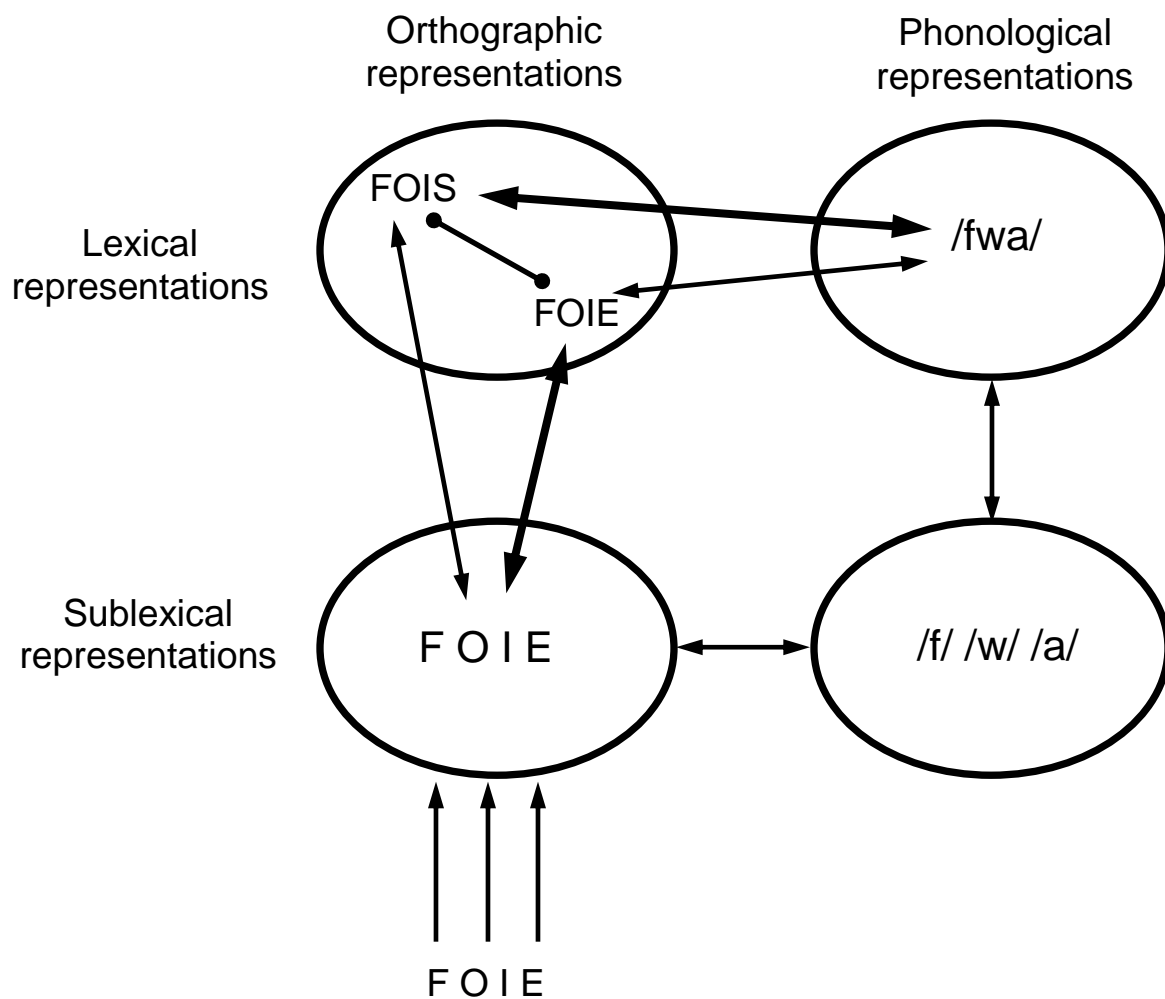


Figure 1