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Jonathan Grainger, Ludovic Ferrand

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JONATHAN GRAINGER AND LUDOVIC FERRAND

Laboratoire de Psychologie Expérimentale, C.N.R.S. and René Descartes University, Paris, France

Three lexical decision experiments and one perceptual identification experiment investigated the effects of briefly presented forward-masked homophone primes on target recognition. When primes are the more frequent homophone of target words (e.g., real–REEL) then facilitation is observed relative to unrelated controls. This contrasts sharply with the inhibitory effects of more frequent orthographic primes (e.g., ride–RITE) observed in the same experimental conditions. However, the facilitation obtained with homophone primes turns to inhibition in the presence of pseudohomophone foils in the lexical decision task. Some tentative interpretations of these results are discussed.

The role of phonological information in the processing of written words has been an important point of debate among psycholinguists since the earliest psychological studies of reading. Although it is clear that reading written words aloud necessarily involves the use of phonological information, silent reading could be performed without phonological mediation. The debate is further complicated by the fact that phonological information may be available to the visual word recognition[1] process during silent reading but simply does not affect performance in laboratory tasks such as lexical decision. Nevertheless, evidence is accumulating in favor of the general hypothesis that phonological information is generated automatically and extremely rapidly during the processing of written words (Ferrand & Grainger, 1992, 1993, 1994; Humphreys, Evett, & Taylor, 1982; Lukatela & Turvey, 1990a, 1990b; Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988). The present experiments represent a further test of this general hypothesis while also examining how such rapidly generated phonological information could influence the visual word recognition process as reflected in the lexical decision and perceptual identification tasks.

There are two ways phonological information could be generated from the printed word. Either the word can be recognized as a particular orthographic pattern and then its pronunciation retrieved from memory (addressed phonology) or phonological information concerning the word can be generated during the recognition process before identification is complete (assembled phonology; see Patterson & Coltheart (1987) for a more detailed discussion of this distinction). Models of word naming must describe which of these sources provide input to the generation of an articulatory response, and if both are used, then how they are combined.

In visual word recognition, on the other hand, the major question concerns how assembled phonology could combine with orthographic information in the process of isolating a particular orthographic representation of a word in memory from among the thousands of other possibilities. This assembled phonology could be generated by two possible mechanisms: (1) prelexically, via spelling-to-sound correspondences that are by definition sublexical; (2)

[1] Here we use the term visual word recognition to refer to the process of word form identification as opposed to meaning retrieval. In doing so we assume that words are represented as whole-word orthographic and phonological forms in memory and that these formal representations mediate access to semantic information.

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lexically, by whole-word orthographic units that are activated by the stimulus sending on activation to corresponding whole-word phonological units. Prelexically generated phonology could combine with sublexical orthographic information as input to word units thus influencing the word recognition process by an excitatory feed-forward mechanism (see Ferrand & Grainger, 1992). This prelexical generation of phonology is typically described in terms of a grapheme–phoneme conversion process (Coltheart, 1978) or via larger spelling-to-sound correspondences (Kay, 1987). On the other hand, lexically generated phonology could provide positive feedback from activated whole-word phonological units to whole-word orthographic units. This mechanism represents an extension of analogy models of word naming (Glushko, 1979; Kay & Marcel, 1981) to the problem of word recognition.

Masked Phonological Priming

Perhaps the clearest evidence that phonology is rapidly generated from printed strings of letters and does influence the word recognition process comes from priming studies using very briefly presented pattern-masked primes. The fact that subjects are typically unable to correctly identify primes in such presentation conditions allows one to reject interpretations of any priming effects observed in terms of the strategic use of prime-target relations to predict target stimuli after identifying the prime. In such extreme priming conditions Humphreys et al. (1982) found that percentage correct identification of target words was significantly higher when preceded by a homophonic prime (e.g., maid–MADE) than when preceded by an orthographic control (e.g., mark–MADE). However, they failed to observe a facilitative effect compared to orthographic controls when the primes were pseudohomophones (e.g., bloo–BLUE). This latter result suggests that the automatic generation of phonological information in visual word recognition proceeds via whole-word representations rather than a sublexical spelling-to-sound conversion.

However, contradictory evidence has been provided more recently by Perfetti and colleagues (Perfetti & Bell, 1991; Perfetti et al., 1988) and Ferrand and Grainger (1992). Using a primed perceptual identification task Perfetti et al. (1988) and Perfetti and Bell (1991) observed that correct identification of targets primed by pseudohomophone primes (e.g., mayd–MADE) was significantly higher than that obtained with orthographic controls (e.g., mard–MADE) with slightly longer prime exposures than those used by Humphreys et al. (1982). This effect is explained in terms of a rapid activation of phonetic units by the corresponding graphemic units, these phonetic units in turn increasing the activation level of any word units that contain them. Ferrand and Grainger (1992) have observed the same pattern of effects using RT as the dependent measure in a primed lexical decision task, and Lukatela and his colleagues have reported phonological priming effects in Serbo-Croatian in similar conditions with both the perceptual identification and lexical decision tasks (Lukatela, Carello, and Turvey, 1990; Lukatela & Turvey, 1990a, 1990b). These results therefore strongly suggest that phonological information is rapidly generated during the processing of pronounceable strings of letters and that this information can be used to facilitate performance in visual word recognition tasks. It also appears likely that this rapid generation of phonological information occurs sublexically.

Phonological Facilitation and Orthographic Inhibition in the Masked Priming Paradigm

In the first experiment reported here we use the lexical decision task combined with the masked priming paradigm as a tool to investigate the hypothesized early generation of phonological information in visual word recognition. This particular experi-

mental paradigm has already proved useful in the investigation of orthographic priming. Clear facilitative effects of repetition priming are observed for both low and high frequency words (Forster & Davis, 1984; Segui & Grainger, 1990). When primes are orthographically related to the target there is some evidence that facilitation effects can be obtained, particularly with long words (Forster, Davis, Schoknecht, & Carter, 1987; Sereno, 1991). On the other hand, with short words, orthographically related primes have been shown to inhibit target recognition when primes are more frequent than targets (Segui & Grainger, 1990).

In experimental conditions (64 ms prime exposures) identical to those used in the study of Segui and Grainger (1990), Ferrand and Grainger (1992) observed facilitative effects of phonologically related nonword primes compared to orthographic controls but no effect of orthography compared to unrelated controls. The fact that orthographically related nonword primes did not affect lexical decision performance relative to unrelated controls suggests that the inhibitory effects of higher frequency orthographically related word primes (Segui & Grainger, 1990) are within-level effects (between lexical representations competing for identification) to be clearly distinguished from between-level excitatory effects (i.e., from the sublexical to the lexical level). This distinction is explicitly made in the interactive activation model of word recognition (McClelland & Rumelhart, 1981). In this model the representational nodes of words that share letters with the stimulus receive excitatory input from the letter level and these simultaneously activated word units mutually inhibit each other. In simulation work using a semistochastic version of the interactive activation model, Jacobs and Grainger (1992) have recently shown that the model successfully stimulates the inhibitory effects of orthographically related primes that are more frequent than the target, plus the absence of an effect when primes are less frequent than the target (Segui & Grainger, 1990).

Thus the present experiments were motivated by the combination of three different types of masked priming effect observed with 64-ms prime exposures: the inhibitory effect of more frequent orthographically related primes (Segui & Grainger, 1990), the facilitative effect of pseudohomophone primes, and the absence of an effect of orthographically related nonword primes (Ferrand & Grainger, 1992).

Experiment 1

In Experiment 1 related primes were either more frequent or less frequent homophones of French target words and could be orthographic neighbors (e.g., fois–FOIE) or not (e.g., sans–CENT). The results of Segui and Grainger (1990) suggest that on purely orthographic grounds the first case (fois–FOIE) should provide inhibitory effects compared to unrelated controls. If phonological overlap provides facilitative effects then one should predict reduced interference for "fois–FOIE" and facilitative effects for "sans–CENT."

Method

Stimuli and design. Two categories of French homophone pairs were selected from a computerized list of four- and five-letter French words and their printed frequencies (*Trésor de la langue française*, 1971). The first category contained homophone pairs that are also orthographic neighbors (i.e., that differed only by one letter in the same position, as defined by Coltheart, Davelaar, Jonasson, and Besner (1977); e.g., fois–FOIE). The second category contained orthographically distinct homophone pairs sharing none, one, or maximally two letters in the same position (e.g., sans–CENT). All pairs had contrasting frequencies, for example, FOIS occurs much more frequently than FOIE). Average printed frequency of the stimuli was 1432 occurrences per million for the high frequency group and 36 occurrences per million for the low frequency group. Twenty such pairs were selected for each

category (all were four to five letters long, average length = 4.4). Relative prime–target frequency was manipulated such that in one condition (high–low) the prime was the high frequency member of the pair and the target the low frequency member, and in another condition (low–high) the opposite was true. For each of the 80 prime–target pairs a control prime word was chosen that shared no letters in the same position with the corresponding target word and that was approximately the same frequency as the experimental prime word. The two categories of stimuli represent the factor Type of Relation. This factor was crossed with the Relatedness factor and Relative prime–target frequency in a 2 × 2 × 2 factorial design. Relatedness and Type of Relation factors were within-subjects factors and Relative prime–target frequency a between-subjects factor. Within each of the Relative prime–target frequency conditions two groups of subjects were used such that no subject saw any single prime or test word more than once but each subject received all experimental conditions. None of the prime–target pairs were semantically related in any obvious way. Eighty pairs of four- to five-letter word–nonword pairs were constructed for the purposes of the lexical decision task. Nonwords were orthographically legal, pronounceable, meaningless letter strings and were not homophonic with any French word. Twenty pairs were composed of nonwords that were orthographically related to the prime word (e.g., faim–CAIM), and 20 other pairs were nonwords that shared some letters with the prime word (e.g., taire–SARE). This manipulation led to two sets of nonwords that differed in terms of their orthographic similarity with real words. Forty other orthographically unrelated word–nonword pairs were also included.

Procedure. Stimuli were presented in isolation on the center of the display screen (60 Hz) of an Olivetti M24 personal computer. The items appeared on the screen as green characters on dark background. Each character (in uppercase) covered approximately 0.38° of visual angle from the viewing distance of 60 cm, so the largest words (five letters) subtended about 1.9° of visual angle. The masked priming procedure with the lexical decision task used in the experiments of Forster et al. (1987) and Segui and Grainger (1990) was adopted here. Each trial consisted of the following sequence of three stimuli presented on the same screen location. First a forward mask consisting of a row of four or five hash marks (#) was presented for 500 ms, this was immediately followed by presentation of the prime word for 64 ms, and this was in turn immediately followed by presentation of the target item, which remained on the screen until the subjects responded. Primes were always presented in lowercase and targets in uppercase. Subjects were instructed to indicate as rapidly and as accurately as possible if the letter string in uppercase that remained on the screen was a French word or not. The presence of a prime word was not mentioned. Subjects responded "yes" by pressing one of two response buttons with the forefinger of their preferred hand and "no" by pressing the other response button with the forefinger of the nonpreferred hand. The next sequence followed after a 1-s delay. Stimulus presentation was randomized, with a different order for each subject. Reaction times, measured from target onset until the subject's response, were accurate to the nearest millisecond. Subjects were presented with 20 practice trials before doing the experiment proper. These consisted of 10 word–word and 10 word–nonword pairs none of which appeared in the experimental trials, all four to five letters long and selected from the same frequency range as the experimental stimuli.

Subjects. Forty psychology students at René Descartes University, Paris, participated in the experiment for course credit. All were native speakers of French, with normal or corrected-to-normal vision.

Results

All reaction times exceeding 1 s (1.5% of the data) were excluded from the analysis of the correct responses to word stimuli. Means of the lexical decision latencies for correct responses and percentages of errors to word targets in each stimulus category are given in Table 1.

The reaction time data were submitted to an analysis of variance, with Relatedness (prime related or unrelated to the target), Type of Relation (orthographically related and homophonic versus orthographically distinct and homophonic), and Relative Frequency as principal factors. F values are reported by subject ($F1$) and by item ($F2$).

There is a significant two-way interaction between Frequency and Relatedness ($F1(1,36) = 5.38, p < .05$; $F2(1,38) = 5.75$, $p < .05$). When primes are more frequent than targets there is a 24-ms facilitative priming effect, whereas when primes are less frequent than targets there is a 14-ms inhibitory effect. It is clear from Table 1, however, that the facilitative effects of more frequent homophone primes are much stronger when primes and targets are orthographically similar ($F(1,18) = 5.32, p < .05$; $F2(1,18) = 5.53$, $p < .05$) than when they are orthographically dissimilar (both Fs < 1). More frequent targets were responded to more rapidly than less frequent targets ($F1(1,36) = 15.13$, $p < .001$; $F2(1,38) = 34.0$, $p < .001$). None of the other main or interaction effects are significant (all Fs < 1). In an analysis of the error data only the main effect of Frequency reaches significance ($F(1,36) = 8.36$, $p < .01$).

TABLE 1
MEAN LEXICAL DECISION LATENCIES (MILLISECONDS) FOR CORRECT RESPONSES AND PERCENTAGE ERRORS (IN PARENTHESES) TO LOW FREQUENCY TARGETS PRECEDED BY HIGH FREQUENCY PRIMES (HIGH–LOW) OR HIGH FREQUENCY TARGETS PRECEDED BY LOW FREQUENCY PRIMES (LOW–HIGH) IN EXPERIMENT 1

	Related	Unrelated	Effect
High–low			
Orthographically similar homophone prime	626 (7.5)	663 (6.5)	+37
Orthographically dissimilar homophone prime	639 (6.0)	649 (7.0)	+10
Low–high			
Orthographically similar homophone prime	631 (9.5)	618 (4.0)	−13
Orthographically dissimilar homophone prime	625 (3.5)	611 (5.0)	−14

Note. Primes were related (orthographically similar homophone or orthographically dissimilar homophone) or unrelated to targets.

Response times to nonword targets were not affected by prime relatedness (797 ms in the related condition compared to 798 ms in the unrelated condition, $F < 1$). On the other hand, nonwords that were orthographically more similar to real words were responded to more slowly (819 ms) than orthographically dissimilar nonwords (777 ms, $F(1,36) = 7.79$, $p < .01$). None of the other effects in the nonword RT analysis reach statistical significance, nor do any of the effects in the nonword error data (all Fs < 1).

Discussion

Perhaps the most striking result of Experiment 1 is that exactly the opposite interaction between relative prime–target frequency and priming effects was observed compared to Segui and Grainger's (1990) results. Adding homophony to an orthographic relation apparently produces a marked qualitative change in the pattern of effects. When primes are more frequent than targets, rather than producing inhibitory effects of relatedness, the present experiments show facilitative effects. Moreover, the fact that high frequency targets were slightly inhibited by less frequent orthographically related homophone primes suggests that subjects are not just giving fast positive responses as soon as they detect a phonological match between prime and target.

The results of Experiment 1 therefore suggest that masked homophone priming

does not reflect the simple combination of phonological facilitation and orthographic inhibition. The strong facilitative effect of homophonic orthographically similar primes observed in Experiment 1 cannot be uniquely attributed to assembled phonology increasing the activation level of word units (within the framework presented by Ferrand & Grainger, 1992), since this would lead us to predict even greater facilitation with orthographically dissimilar homophone primes, whereas exactly the opposite is observed. In other words, orthographically unrelated homophones primes should be providing facilitative phonological input to word units in the absence of orthographic inhibition, thus leading to stronger facilitation.

It is possible, however, to explain this facilitative effect of orthographically similar homophone primes in terms of the information used by subjects to give their response in the lexical decision task. It is hypothesized that subjects can make a positive lexical decision response **before** the target word has been recognized (reached a critical activation level). This could occur if it is the prime representation rather than the target representation that reaches a criterion level of activation necessary for triggering a positive response in the lexical decision task. The probability of this occurring will increase with increasing prime–target similarity. With maximum prime–target overlap (which occurs with orthographically similar homophones, excluding the case of identity) maximum levels of activation will be reached by prime word representations during target processing. This therefore increases the probability that a prime word representation will reach threshold and trigger a fast lexical decision response.

This hypothesis explains the facilitative effect of orthographically related homophone primes as a result of the prime word representation reaching a high level of activation during target processing. This is consistent with the fact that the effects of phonological priming tend to become inhibitory when primes are less frequent than targets. In this situation the prime word representation does not reach a sufficiently high enough activation level to trigger a response before target identification.

Experiment 2

It has been previously reported that introducing pseudohomophones as distractors in a lexical decision task causes a rise in overall RT (Davelaar, Coltheart, Besner, & Jonasson, 1978). One means of accommodating this result is in terms of subjects applying a spelling check before responding in the lexical decision task. Once a lexical representation has reached threshold, stored information about spelling can be checked against available letter-level information. This minimizes errors to pseudohomophone targets since the spelling check will allow them to be identified as nonwords. This explanation of pseudohomophone influences on lexical decision performance predicts that if prime stimuli were indeed provoking fast positive responses to homophonic targets in Experiment 1 then these should be eliminated in the presence of pseudohomophones, since subjects will detect a mismatch between prime and target orthography when applying a spelling check.

While manipulating the presence or absence of pseudohomophones, Experiment 2 was also designed to demonstrate inhibitory effects of higher frequency nonhomophonic orthographically related primes (e.g., blue–BLUR) in conditions where facilitative effects of higher frequency orthographically similar homophonic primes (e.g., real–REEL) are observed.

Method

Stimuli and design. From a computerized list of four-letter and five-letter French words with their printed frequencies (*Trésor de la langue française,* 1971), two

categories of French word pairs were selected. The first category contained homophone pairs that are orthographically similar (e.g., fois–FOIE) and with contrasting frequencies. The second category contained nonhomophone pairs that differed only by one letter in the same position (e.g., chat–CHAR) also with contrasting frequencies. The high frequency member of each pair served as the prime word and the low frequency member as the target word. Average prime frequency was 737 occurrences per million and average target frequency was 17 occurrences per million. Twenty pairs were selected for each category (all were four to five letters long) and for each pair a control prime word was chosen that shared no letters in the same position with the corresponding test word and that was approximately of the same frequency as the experimental prime word. These two categories of stimuli represent the factor Type of Relation. Two independent groups of subjects were used such that no subject saw any single prime or test word more than once but each subject received all experimental conditions. Thus each subject saw all the experimental stimuli once only in either the related or unrelated conditions. The presence or absence of pseudohomophone distractors was manipulated between subjects. For both groups of subjects the word–word pairs remained identical. In the pseudohomophone condition there were 20 pseudohomophone targets and 20 nonhomophonic nonwords. Half of the pseudohomophones were preceded by the homophonically related prime word of high frequency (e.g., joie–JOIS) and half preceded by an unrelated control prime word of approximately the same frequency as the experimental prime word (e.g., vrai–JOIS). Half of the nonhomophonic nonword targets were preceded by high frequency orthographically related prime words (e.g., bien–NIEN) and half by unrelated word primes (e.g., huit–NIEN). In the no-pseudohomophone condition subjects received 40 nonhomophonic nonwords half preceded by orthographically related high frequency prime words (e.g., deux–DEUL), and the other half by unrelated control prime words of approximately the same frequency as the experimental prime (e.g., coin–DEUL). Thus, in the pseudohomophone group half of the nonword targets were pseudohomophones and in the no-pseudohomophone group no pseudohomophones were present. These characteristics of the nonword targets were respected in the practice trials for each group.

Procedure. This was identical to the previous experiment.

Subjects. Thirty-two psychology students at René Descartes University, Paris, served as subjects for course credit. All had normal or corrected-to-normal vision. None of these subjects had participated in the previous experiments.

Results

All reaction times exceeding 1 s (2.8% of the data) were excluded from the analysis of the correct responses to word stimuli. Means of the latencies and percentage of errors to target words are given in Table 2. The reaction time data were submitted to an analysis of variance, with Relatedness, Type of Relation, and Type of Nonword as principal factors.

There is a significant Relatedness × Type of Relation × Type of Nonword interaction ($F1(1,30) = 4.99, p < .05$; $F2(1,38) = 4.74$, $p < .05$). This triple interaction reflects the fact that the Type of Relation × Relatedness interaction (of main interest here) is only significant in the absence of pseudohomophones ($F1(1,15) = 17.19, p < .01$; $F2(1,38) = 4.13, p < .05$). This pattern of interaction effects is evident in Table 2 where we can see clear facilitative effects of homophonic primes in the absence of pseudohomophones which become inhibitory effects when pseudohomophones are

TABLE 2
MEAN LEXICAL DECISION LATENCIES (MILLISECONDS) FOR CORRECT RESPONSES AND PERCENTAGE ERRORS (IN PARENTHESES) TO WORD TARGETS PRECEDED BY RELATED (HOMOPHONIC AND ORTHOGRAPHIC OR UNIQUELY ORTHOGRAPHIC) AND UNRELATED PRIMES IN EXPERIMENT 2

	Related	Unrelated	Effect
Without pseudohomophones			
Homophonic prime	624 (12.3)	651 (10.1)	+27
Orthographic prime	671 (11.3)	640 (6.9)	−31
With pseudohomophones			
Homophonic prime	746 (8.4)	718 (8.4)	−28
Orthographic prime	748 (10.6)	717 (6.3)	−31

Note. The same set of target words were tested with and without pseudohomophones in the experimental lists.

present. On the other hand, the inhibitory effect of nonhomophonic orthographically related primes are unaffected by the presence of pseudohomophones. There is also a main effect of Type of Nonword ($F1(1,30) = 15.32, p < .001$; $F2(1,38) = 117.85, p < .001$) since the presence of pseudohomophones as distractors caused an 86-ms rise in average RT. In the error analysis word targets preceded by related primes systematically gave rise to more errors ($F(1,30) = 7.18, p < .05$). Also homophone targets gave rise to more errors than nonhomophones ($F(1,30) = 10.61, p < .01$). The main effect of Type of Nonword is not significant, neither are any of the interaction effects.

Response times to nonword targets were significantly longer in the pseudohomophone condition (854 ms) compared to when no pseudohomophones were present (712 ms, $F(1,14) = 7.34, p < .05$). In the absence of pseudohomophones there is a nonsignificant 15-ms inhibitory effect of Relatedness ($F1(1,14) = 2.41$), whereas in the pseudohomophone present condition there is a significant 58-ms inhibitory effect of Relatedness ($F(1,14) = 6.19, p < .05$). In the latter condition, pseudohomophone targets were responded to more slowly than nonpseudohomophone targets ($F(1,14) = 8.53, p < .05$) but this factor does not interact with the effects of Relatedness ($F < 1$). None of the other main or interaction effects are significant. An analysis of the errors to nonword stimuli showed that pseudohomophone targets provoked more errors than nonpseudohomophones ($F(1,14) = 6.46, p < .05$). All the other effects fail to reach statistical significance (all $Fs < 1$).

Discussion

The results of Experiment 2 confirm that more frequent homophonic, orthographically similar primes (e.g., fois–FOIE) do facilitate target processing in the lexical decision task when no pseudohomophones are present as targets in the experiment. Moreover, in the same experiment higher frequency orthographically similar primes (e.g., avec–AVEU) inhibited target processing, thus confirming the observations of Segui and Grainger (1990). This orthographic inhibition remained unaffected by the presence of pseudohomophone distractors in the lexical decision task whereas the homophone facilitation effect was transformed into an inhibitory effect.

The effect of pseudohomophone distractors caused a global increase in RT to both the word and nonword targets. According to the explanation proposed above, the overall increase in RT with the presence of pseudohomophones is explained by subjects applying a spelling check before responding in the lexical decision task. The spelling check will enable subjects to detect mismatches between a lexical representation that has been accessed and available letter-level information. Thus, prime words that were triggering fast positive responses in Experiment 1 are now detected as not corresponding to the target. Subjects therefore respond only after the target representation itself has reached threshold. This therefore explains why the facilitative effects of orthographically related homo-

phone primes become inhibitory in the presence of pseudohomophone distractors. Within the interactive activation framework (McClelland & Rumelhart, 1981) this inhibition results from the mutually inhibitory connections between word units. The high level of activation attained by a related prime inhibits the rise in activation of the target word thus slowing recognition (Jacobs & Grainger, 1992). This high activation level provoked by related prime stimuli can also explain the inhibitory effects of related primes on nonword responses observed in Experiment 2. Within the framework of a deadline model of nonword decision making (Coltheart et al., 1977; Jacobs & Grainger, 1992), nonword response times are a function of overall lexical activity. A high level of overall lexical activity simply encourages subjects to set a longer time limit before responding "no." This will be exaggerated when pseudohomophones are present in the experimental lists since subjects will tend to set longer deadlines in order to reduce the false alarm rate to such stimuli.

This same deadline mechanism explains the negative effects of nonword wordlikeness on negative decision latencies, since the more wordlike a nonword is the more lexical activity it will generate. Moreover, this decision mechanism can also explain the small (nonsignificant) trend to an increase in error rate accompanying the facilitative effects on RT of homophone primes in Experiments 1 and 2. In this situation it is argued that if a fast positive response is not triggered (by prime stimuli reaching threshold) then the inhibition on the target word is strong enough to prevent it reaching a critical activation level before the deadline has been reached, thus resulting in a false negative response. This interpretation of the speed–accuracy tradeoff observed in this particular condition correctly predicts that false negative reaction times are (93 ms) longer in the related than those in the unrelated condition (for homophone primes in the absence of pseudohomophone foils).

Experiment 3

Because of the theoretical importance of these results, Experiment 3 was designed as a replication of the finding in Experiment 2 that more frequent homophonic primes facilitate target processing whereas more frequent orthographic primes inhibit target processing in the absence of pseudohomophones. Experiment 3 was run in English in order to provide a replication with different stimuli. A set of English words were selected all of which were homophones such that the effects of orthographically similar homophone primes (e.g., real–REEL) could be compared against the orthographic priming of homophone targets (e.g., ride–RITE). This tests the possibility that some of the differences observed between the homophone and nonhomophone priming conditions in Experiment 2 are not just due to targets being homophones in one condition.

Method

Design and stimuli. Twenty English homophones with low printed frequencies (average seven per million, Kucera & Francis, 1967) were selected whose homophone partners were orthographically similar (differing by only one letter) and had higher printed frequencies. Twenty other homophones were selected that were matched for length and frequency to the first set. The homophone stimuli were of length three to six letters (average 4.3). Forty nonhomophone words were added as filler items, half of which were preceded by orthographically related primes. Eighty orthographically legal, pronounceable nonword targets (three to six letters long) were created for the purposes of the lexical decision task. These were preceded by English word primes, half of which were orthographically related to the target.

Procedure. This was identical to the previous experiments except that prime exposure duration was slightly less (57 ms) due to the use of a 70 Hz screen.

Subjects. Eighteen students at the University of Birmingham were paid for their participation in the experiment. All had normal or corrected-to-normal vision and were native speakers of English.

Results and Discussion

All reaction times exceeding 1 s (1.8% of the data) were excluded from the analysis of the correct responses to word stimuli. Means of the latencies and percentage of errors to target words are given in Table 3. The reaction time data were submitted to an analysis of variance with Relatedness and Type of Relation as main factors.

There is a significant interaction between Relatedness and Type of Prime ($F1(1,17) = 5.44$, $p < .05$; $F2(1,19) = 6.78$, $p < .05$). Orthographically related homophone primes facilitated target recognition by 32 ms whereas orthographically related nonhomophone primes inhibited target recognition by 23 ms. None of the main effects are significant in the RT analysis (all Fs < 1) and no significant effects are obtained in an analysis of the error data nor in an analysis of the nonword latencies and errors (all Fs < 1).

Experiment 3 provides a perfect replication of the results obtained in the absence of pseudohomophones in Experiment 2 while controlling for the homophone status of target words. Using a different set of stimuli from a different language (English as opposed to French) the mean RTs and error rates in each condition are remarkably similar across experiments. It is therefore clear that this interaction between the effects of orthographic priming and whether primes are homophones of the target or not is a particularly robust phenomenon which requires an adequate explanation.

TABLE 3
MEAN LEXICAL DECISION LATENCIES (MILLISECONDS) FOR CORRECT RESPONSES AND PERCENTAGE ERRORS (IN PARENTHESES) TO HOMOPHONE WORD TARGETS PRECEDED BY RELATED (HOMOPHONIC AND ORTHOGRAPHIC OR UNIQUELY ORTHOGRAPHIC) AND UNRELATED PRIMES IN EXPERIMENT 3 IN THE ABSENCE OF PSEUDOHOMOPHONE DISTRACTORS

	Related	Unrelated	Effect
Homophonic prime	617 (13.9)	649 (12.2)	+32
Orthographic prime	670 (12.8)	647 (8.3)	−23

From facilitation to inhibition: Two possible explanations. The explanation for this surprising contrast in effects that has been proposed up to now is in terms of the strategies subjects adopt to optimize performance in the lexical decision task. More specifically it is hypothesized that subjects can respond positively in this task before the target word has been identified. This arises in the masked priming paradigm when maximum prime-target overlap causes prime representations to reach excessively high activation levels thus leading to primes reaching an activation threshold before targets. This explanation is couched in terms of a single-lexicon interactive activation type model of visual word recognition (McClelland & Rumelhart, 1981; Ferrand & Grainger, 1992; Jacobs & Grainger, 1992). According to this type of model a positive lexical decision response is made to visual stimuli when a unit corresponding to the orthographic description of a word reaches a critical activation level.

An alternative interpretation of this pattern of results can, however, be formulated within the general hypothesis that a visual lexical decision can be made on the basis of either orthographic or phonological whole-word units. This could be introduced into the interactive activation framework by simply adding a new set of word units that are directly connected to sublexical phonological units (see Fig. 1). This corresponds to the distinction, popular among neuropsychologists (Allport, 1983; Ellis & Young, 1988; Morton & Patterson, 1980), between a visual input lexicon and an auditory input lexicon. Within each of these lexicons connections are inhibitory whereas between lexicons the connections are primarily ex-

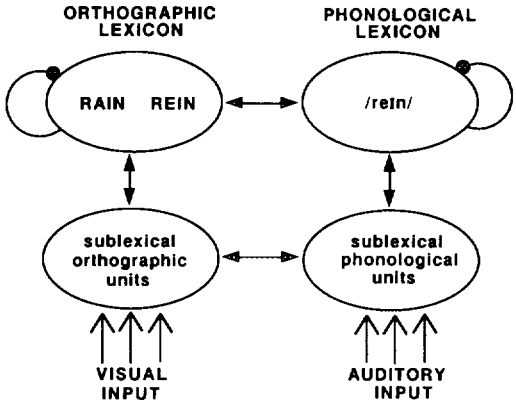

FIG. 1. A dual-lexicon interactive activation model in which the sublexical orthographic units activated by a visual input and the sublexical phonological units activated by an auditory input mutually facilitate each other and send activation on to their respective orthographic and phonological lexicons. These lexicons contain mutually inhibitory within-lexicon connections and excitatory between-lexicon connections.

citatory (inhibitory between-level connections have been left out for simplification). This is basically an interactive activation version of a dual-route theory of print-to-sound translation in reading. Addressed phonology is obtained by mapping sublexical orthographic units onto whole-word phonological units via the orthographic lexicon, whereas assembled phonology is obtained by mapping sublexical orthographic units directly onto sublexical phonological units [see Dijkstra, Frauenfelder, & Schreuder (1993) for evidence in favor of bidirectional excitatory connections at this level].

Within this framework it is hypothesized that a positive lexical decision response can be triggered when any lexical representation (orthographic or phonological) reaches a critical activation level. Generally speaking, when the stimulus is a written word it is the orthographic representation that reaches threshold first. This is simply because arrival of information at the phonological lexicon lags behind the arrival of information at the orthographic lexicon due to the extra processing involved (see Fig. 1). However, when the orthographic representation is suffering strong within-level inhibition (as is hypothesized in the case of masked priming with a higher frequency orthographic neighbor) and the corresponding phonological representation is not (as is the case when the prime and target are homophonic and therefore share the same phonological representation, e.g., rain–REIN) then it is the phonological representation that reaches threshold first, giving rise to facilitation.

Now, it has been proposed above that in the presence of pseudohomophone targets, subjects use a spelling check procedure in order to avoid too many false positive responses to these stimuli. However, a spelling check can operate on information derived from an orthographic representation but not from a phonological representation. Subjects must therefore wait for the orthographic representation to reach threshold when pseudohomophones are included in the experiment. This explains why inhibitory effects of homophone primes, of a size comparable to the effects of orthographic primes, are observed in the presence of pseudohomophone distractors.

This alternative explanation differs from the initial hypothesis in that it appeals to mechanisms that are not specific to the lexical decision task. Thus according to this explanation one should observe similar effects in other word recognition tasks such as perceptual identification. On the other hand, according to the initial hypothesis, the observed effects of homophone primes are particular to the lexical decision task and arise when subjects respond when the prime rather than the target representation has reached a critical activation level. The probability of subjects making such undetected "errors" increases with prime-target similarity, maximum likelihood occurring with orthographically similar homophonic prime–target pairs. In particular, the undetected errors that are hypothetically producing this facilitation in the lexical decision task should produce detectable errors in the perceptual identification task. Exper-

iment 4 tests this prediction using the same prime–target word pairs of Experiment 2 in a primed perceptual identification task.

Experiment 4

Method

Design and stimuli. Exactly the same prime–target word pairs of Experiment 2 were used here. Apart from the absence of nonword stimuli, the design was identical to Experiment 2.

Procedure. Stimuli were presented on the display screen of an AT286 personal computer. The four-field masking technique of Evett and Humphreys (1981) was adapted for the purposes of the present experiment. Field duration was held constant at 43 ms (three frame durations of a 70 Hz screen) for the prime and target stimuli. The forward and backward masks (a row of nine hash marks) were presented for 500 ms. Pilot work indicated that response accuracy was on average about 60% in these conditions. On each trial subjects saw a central fixation point followed by the forward mask, the prime word in lowercase, the target word in uppercase, and finally the backward mask, all centered on the fixation point and presented on the same screen location. Subjects were instructed to report the word in uppercase letters by typing in their response with the computer keyboard. After checking their answer subjects initiated the next trial with the enter key. Subjects were given a set of 10 practice trials before doing the experiment proper.

Subjects. Twenty-four psychology students at René Descartes University, Paris, volunteered as subjects. All had normal or corrected-to-normal vision. None of these subjects had participated in the previous experiments.

Results and Discussion

Means of the percentage correct whole-word report are given in Table 4. The data were submitted to an analysis of variance, with Relatedness and Type of Relation as principal factors.

TABLE 4
PERCENTAGE CORRECT IDENTIFICATIONS OF WORD TARGETS PRECEDED BY RELATED (HOMOPHONIC AND ORTHOGRAPHIC OR UNIQUELY ORTHOGRAPHIC) AND UNRELATED PRIMES IN THE PERCEPTUAL IDENTIFICATION TASK OF EXPERIMENT 4

	Related	Unrelated	Effect
Homophonic prime	80.5	59.5	+21
Orthographic prime	60.5	72.5	−12

The main effect of Relatedness is significant in the subject analysis ($F1(1,22) = 5.38$, $p < .05$; $F2 < 1$) and significantly interacts with Type of Relation ($F1(1,22) = 23.78$, $p < .001$; $F2(1,18) = 8.98$, $p < .01$). This interaction reflects the fact that the homophone primes facilitated target recognition ($F1(1,22) = 35.81$, $p < .001$; $F2(1,9) = 12.31$, $p < .01$) whereas the orthographic primes produced an inhibitory effect that failed to reach significance in the item analysis ($F1(1,22) = 7.87$, $p < .05$; $F2(1,9) = 1.87$).

The results of Experiment 4 therefore contradict the hypothesis according to which homophone facilitation observed in the lexical decision task is the result of subjects responding on the basis of prime representations reaching threshold. According to this hypothesis, homophone primes should have inhibited target identification in the perceptual identification task since the prime words would be incorrectly reported instead of target words. This hypothesis also predicts that homophone primes will be given as errors on a greater percentage of trials than orthographic primes in the related priming condition. An analysis of the type of errors made by subjects in Experiment 4 showed, on the contrary, that 58.3% of the errors in the homophone condition corresponded to the prime word compared to 59.3% in the orthographic condition.

The dual-lexicon hypothesis, on the other hand, correctly predicted a pattern of

effects similar to that obtained in the lexical decision task. According to this hypothesis, in the homophone priming condition subjects recognize a word on the basis of its phonological representation and as such the recognition process benefits from identity priming (e.g., FOIS–FOIE becomes /fwa/–/fwa/). Subjects then use available letter-level information to report the correct orthographic form (i.e., FOIE and not FOIS). One could of course argue, with respect to the original hypothesis, that such letter-level information would be used to correct responses when the prime representation reaches threshold before the target. However, when an orthographic representation reaches threshold, then all letters are fully specified and subjects need not consult letter-level information to complete their response. Such information is necessary, on the other hand, when an orthographically ambiguous phonological representation reaches threshold. Nevertheless, one means of saving the original account of these results would be to devise some method of combining stored information derived from the prime representation after reaching threshold with letter-level information derived from the target.

General Discussion

The main results of the present experiments can be summarized as follows. Contrasting effects of more frequent orthographically related primes are obtained in the masked priming paradigm as a function of the homophonic or nonhomophonic relation between prime and target (see Fig. 2). When primes are not homophones of the target (e.g., ride–RITE) there are consistent inhibitory effects, thus replicating the results of Segui and Grainger (1990). When primes are homophones of the target (e.g., real–REEL) then facilitative effects are obtained in the absence of pseudohomophone distractors in the lexical decision task, whereas inhibitory effects are obtained when pseudohomophones are present. The interaction between type of effect and prime–target homophony was also observed in a primed perceptual identification task.

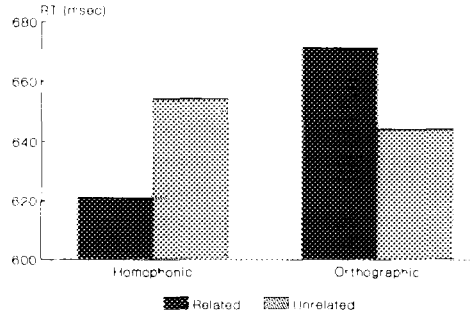

FIG. 2. Interaction of priming effects (RT in milliseconds) obtained with more frequent orthographically related primes compared to unrelated controls as a function of the homophonic relation between prime and target, averaging reaction times for the appropriate conditions across Experiments 1, 2, and 3.

Phonology and Orthography in Visual Word Recognition

The general hypothesis that phonological information is automatically and extremely rapidly encoded during the processing of written words receives further support from the present experiments. The fact that higher frequency homophonic, orthographically related primes (e.g., real–REEL) facilitated target recognition in conditions where orthographically related nonhomophonic primes (e.g., ride–RITE) inhibited target recognition clearly indicates that phonological prime–target overlap is influencing the processing of target words. This therefore corroborates the studies showing phonological influences on visual word recognition from masked nonword primes (Ferrand and Grainger, 1992, 1993, 1994; Perfetti et al., 1988; Perfetti and Bell, 1991). In these experiments masked primes that are pseudohomophones of the target (e.g., mayd–MADE) facilitated target recognition compared to orthographic controls.

The effects of briefly presented, masked primes are readily accommodated within the framework of the interactive activation model (McClelland & Rumelhart, 1981). In

this framework within-level effects are inhibitory and between-level effects primarily excitatory. Thus, if the prime stimulus activates sublexical information (either orthographic or phonological) shared by the target word then target processing will be facilitated. At the same time, prime stimuli that share sublexical information with the target will also activate lexical representations similar to the target thus leading to within level inhibition during target processing. Within-level inhibition will tend to dominate when primes are words, whereas between-level facilitation will tend to dominate when primes are nonwords. According to this theoretical position facilitative effects should develop with shorter prime presentation durations, whereas inhibitory effects will tend to develop as prime presentation duration increases.

This general conception of the form priming process therefore allows us to explain why orthographically related word primes tend to produce inhibition (Grainger, Colé, & Segui, 1991; Segui & Grainger, 1990) and that this inhibition develops as prime duration is increased (Grainger, 1992), whereas orthographically related nonword primes tend to produce facilitative effects (Ferrand & Grainger, 1992, 1993, 1994; Forster et al., 1987; Grainger & Jacobs, 1993) which appear to be reinforced with shorter prime presentation durations (Evett & Humphreys, 1981; Ferrand & Grainger, 1992, 1993, 1994; Humphreys et al., 1982; Humphreys, Evett, Quinlan, & Besner, 1987; Perfetti et al., 1988; Perfetti & Bell, 1991). Nevertheless, this general conception of form priming effects cannot explain why larger facilitation effects were obtained with orthographically similar homophone primes (e.g., FOIS–FOIE) than with orthographically dissimilar homophone primes (e.g., QUAND–CAMP) in Experiment 1. Indeed, exactly the opposite prediction was made.

A Tentative Attempt at an Interpretation

In our initial attempt at interpreting the present results within the interactive activation framework, it was hypothesized that fast positive responses can be generated in primed lexical decisions when subjects respond on the basis of the prime rather than the target representation. Within this framework it is the high level of activation of the prime representation during target processing that inhibits the rise in activation level of the target representation, thus provoking slower identification latencies. If, however, the prime representation actually reaches threshold before the target representation then a response will be triggered earlier than in the neutral condition and facilitation will result. However, according to this hypothesis the facilitative effects of homophone primes observed in lexical decision should have given rise to inhibitory effects in the perceptual identification task of Experiment 4. If the effects in lexical decision were being produced by prime words reaching threshold then these same prime words should have been incorrectly reported in the perceptual identification task giving rise to inhibitory effects of homophone primes.

An alternative explanation was proposed that incorporates the hypothesis that a visual lexical decision response can be made when either a whole-word orthographic or phonological representation reaches a critical activation level. The facilitative effects of homophone primes are interpreted within this framework as an identity priming effect when subjects respond on the basis of a phonological representation. In this situation response times will reflect the equivalent of a true identity priming facilitation minus the hypothetical delay between input to the orthographic lexicon and the phonological lexicon from a visual stimulus. Orthographically dissimilar homophone primes provide less facilitation as a result of incompatibility at the level of sublexical orthographic units.

The neuropsychological literature is rich with cases where the dual input lexicon hypothesis provides the only viable interpretation (Allport, 1983; Ellis & Young, 1988). Perhaps the most striking examples are pro-

vided in Funnell and Allport (1987) where two dysphasic patients are described. These patients had intact intramodal language abilities (e.g., repeating heard words, writing written words) but made many errors when asked to transcode from one modality to the other (e.g., reading aloud, writing to dictation). The authors conclude, after extensive testing of these patients, that they have intact phonological and orthographic input lexicons, but that direct mediation between the two is eliminated and can only be performed via amodal conceptual/semantic units.

The present experiments provide data from normal subjects that support this distinction between an orthographic and a phonological input lexicon and suggest that information from both input lexicons is available for making a visual lexical decision response. The use made of whole-word phonological codes would appear, however, to be under strategic control. Either subjects could verify the validity of such codes by applying a spelling check before responding, or information available from the phonological input lexicon could be voluntarily suppressed in the presence of pseudohomophone foils. Only a full implementation of the model outlined in Fig. 1 will allow a precise analysis of the appropriate form(s) that such strategic control should take.

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