

Phonological and Orthographic Priming Effects in Auditory and Visual Word Recognition*

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Four experiments investigated the effects of orthographic and phonological similarity on word recognition latencies using either auditory or visual presentations. All experiments exploited a priming methodology, with subjects participating in a lexical decision and a pronunciation task. In all experiments, target stimuli were preceded by primes which were related either orthographically, phonologically, or both orthographically and phonologically. The same stimuli were used for all experiments. For the experiments in the auditory modality, both lexical decision and naming data show robust priming effects relative to unrelated controls for experimental conditions in which there was both orthographic and phonological overlap as well as for conditions in which there is only phonological similarity. In the visual modality, the orthographically related condition showed significant inhibitory effects while phonologically related conditions show no priming effects. The data were analyzed in terms of modality of presentation, task requirements, and nature of the priming relationship. The results are interpreted in terms of the role of orthographic and auditory information in word recognition and implications for models of lexical organization.

1 Introduction

A major issue in psycholinguistics is the structure and organization of lexical information in memory. Recent research has emphasized the possible role of both phonological and orthographic codes in word recognition. In reading, it has been proposed that readers use phonological information in word recognition (e.g., Hillinger 1980; Meyer, Schvaneveldt and Ruddy 1974). Conversely, it has been suggested that orthographic information is used in auditory word recognition (Jakimik, Cole and Rudnicky 1985). However, because models of auditory and visual word recognition have developed rather separately, it is often difficult to interpret how studies suggesting the use of sound in reading and the use of spelling in speech processing relate to a more general model of the lexicon. Frequently, these studies use different methodologies, contrast different experimental conditions, and address radically different issues in the word recognition process.

The purpose of the present series of experiments was to systematically investigate phonological and orthographic effects in auditory word recognition and to compare these effects, using identical stimuli and similar testing procedures, to those obtained for visual word recognition. Moreover, these issues were explored using both a lexical decision and

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a naming task. The study of the interaction of phonological and orthographic information in word recognition is not an uncontroversial area of research as evidenced by Rayner and Pollatsek's remark that "at present, reasonable people can hold almost diametrically opposite views on the subject" (Rayner and Pollatsek 1989). The present series of experiments attempts to lend relevant data to this acrimonious debate.

Studies of word recognition have only recently focused on the spoken word. In one of the few studies on spoken word recognition, Jakimik, Cole and Rudnicky (1985) found that lexical decision latencies are significantly faster for words such as MESS when it was preceded by a word that is both orthographically and phonologically similar such as MESSAGE, compared to when MESS was preceded by an unrelated word such as LETTER. In contrast, when words were preceded by words that were related either only phonologically such as DEFINITE-DEAF or orthographically as in LEGISLATE-LEG, no facilitation was found. Thus, Jakimik et al. conclude that spelling plays a role in spoken word recognition since both overlap of phonological and orthographic information is required to produce priming.

However, there were a number of methodological factors which make it difficult to interpret their results. First, stimuli were both recorded and presented in a single list, resulting in variable and sizable intervals between primes and targets. Jakimik et al. reported that the stimuli were about two seconds apart, which given the speed of word recognition processes is a long interstimulus interval (ISI), allowing time for post-access as well as access processes to take place (e.g., Balota and Lorch 1986). Second, repetition of target items and unequal numbers of words and nonwords in the lists may also have biased the results. And finally, similarity was based on an overlap of the entire target word with the first syllable of the preceding word. This is an unusual manipulation and makes it difficult to compare these results to others. In most priming studies of word recognition, portions of the prime and target words overlap rather than the entire target word with part of the prime. These factors may have contributed to subjects developing strategies in anticipation of words that were orthographically and/or phonologically related, possibly exaggerating the role of spelling information in an auditory word recognition task.

A more recent study has reexamined the interaction of phonology and orthography in spoken word recognition, using a paired presentation with a shorter ISI (100 ms) in a lexical decision and shadowing task. Again, however, the domain of orthographic and phonological overlap was the first syllable of multisyllabic primes and targets. Soltano and Slowiaczek (1994) tested pairs of words that overlapped in sound (FERTILE- FURNISH), spelling (BUGLE-BUGGY) or both sound and spelling (PICKLE-PICTURE). In

addition, there were unrelated pairs (PENGUIN-FELLOW). Their results showed that the spelling condition was facilitated relative to the sound and to the both sound and spelling conditions in the two tasks. It is unclear, however, how these prime conditions compared to the unrelated pairs (These analyses were not provided). Additionally, Soltano and Slowiaczek showed that the lexical status of the overlapping syllable interacted with prime condition, suggesting that different processes may be involved for words and nonwords. Soltano and Slowiaczek's results contrast with those of Jakimik et al., which showed facilitation for only word pairs in which both phonological and orthographic information overlapped. Nevertheless, Soltano's and Slowiaczek's results also support a model of auditory word recognition in which there is significant influence of orthographic information.

Although these studies suggest a role for orthographic information in auditory word recognition, it is difficult to draw conclusions because of the conflicting results and differing methodologies. In order to address these drawbacks, the present series of experiments systematically investigated phonological and orthographic effects by manipulating phonological and orthographic similarity between prime-target pairs. All prime-target pairs were monosyllables in which most of the phonological or orthographic information overlapped. For this reason, these priming conditions are similar to conditions used to investigate phonological and orthographic effects in visual word recognition experiments.

Three experimental conditions were created. In the first condition, targets were preceded by orthographically similar rhymes (PITCH-DITCH), with primes and targets overlapping in both sound and spelling. In a second condition, targets were preceded by orthographically dissimilar rhymes (CUFF-ROUGH). In this case, the prime and target only overlapped in terms of sound, not spelling. In a third condition, targets are preceded by orthographically similar nonrhymes (DOLL-TOLL). The prime and target only overlap in terms of spelling. For each of the conditions, control pairs are included which consist of pairs of unrelated words. In this way, facilitatory and inhibitory effects were evaluated.

Often, the results of such priming experiments depend in part on the paradigm used. To assess this possible contribution, two tasks were employed. Subjects were asked to perform either a lexical decision (Experiment 1) or a naming task (Experiment 2). For both experiments, the same sets of stimuli were used. If orthographic information plays a role in auditory word recognition, then there should be facilitation for pairs which overlap visually, such as the orthographically similar nonrhymes (as in Soltano and Slowiaczek 1994) and the orthographically similar rhymes (as in Jakimik et al. 1985). However, if

sound rather than spelling information is important in auditory word recognition, then pairs with phonological overlap (the orthographically dissimilar rhymes and the orthographically similar rhymes) should both show priming effects.

2 Experiment 1

2.1 Method

2.1.1 Participants

Twenty subjects from an introductory psychology course at the Pennsylvania State University received extra credit for their participation. All were native speakers of American English and reported no hearing impairments.

2.1.2 Materials

The stimuli consisted of monosyllabic prime-target pairs. All primes were words; half of the targets were words and half were nonwords. All prime and target word stimuli were low-frequency words (less than 50 occurrences per million) (Francis and Kucera 1982).

For the word targets, primes and targets were combined such that three different related conditions were created. In the Both condition, pairs overlapped in both sound and spelling (e.g., PITCH - DITCH); in the Sound condition, pairs overlapped in sound only (e.g., CUFF - ROUGH); and in the Spelling condition, pairs overlapped in spelling only (e.g., TOLL - DOLL). Each related condition consisted of 20 word pairs. The stimuli were controlled for amount of phonological and orthographic overlap. The mean amount of phonological and orthographic overlap, respectively, was 2.75 and 3.60 for the Both condition, 2.20 and 1.85 for the Sound condition, and 1.35 and 3.05 for the Spelling condition.

In addition to these three related conditions, unrelated conditions were created. Since some of the related pairs of words had unusual characteristics (e.g., in terms of their neighborhoods), unrelated pairs were created from the related pairs by 're-pairing' each stimulus target with an unrelated stimulus prime, resulting in an unrelated condition matched to each of the related conditions. Both the related and unrelated conditions consisted of 20 word pairs.

Each target stimulus, therefore, was presented with either a related prime word or an unrelated prime word. To ensure that subjects were presented with targets only once, pairs with word targets were pseudorandomly divided into two lists. An equal number of related and unrelated pairs were included in each list. The stimuli were checked to ensure that the pairs in both lists had a similar amount of phonological and orthographic overlap and a

similar number of rhyming neighbors. Each subject was presented with only one list. Subjects were presented with all targets, each preceded by either a related or unrelated prime. No prime or target appeared more than once in any of the lists.

Finally, there were 60 stimulus pairs with word primes and nonword targets; half of these pairs rhymed and half were unrelated. The nonwords were all phonotactically legal, created by changing one or two sounds of a word. Both lists had the same nonword target pairs.

Thus, each subject was presented with 120 stimulus pairs (30 related word targets, 30 unrelated word targets, and 60 nonword targets). There were 60 word target pairs (List 1 or List 2) and 60 nonword target pairs. For the word targets, half were related pairs and the other half were unrelated pairs, divided evenly among the three priming conditions (Both, Sound, Spelling).

Stimuli were recorded by a female native speaker of American English on a DAT recorder (Sony 75 ES) using a Sennheiser ME-80 microphone. Stimuli were digitized on a PC (Swan 386/25) running BLISS software (Mertus 1989), at a sampling rate of 10 kHz with a low-pass filter setting of 4.5 kHz and 12-bit quantization. Stimuli were excised using both auditory and visual criteria. Mean duration for primes was 556 ms, and that for targets was 576 ms.

2.1.3 Procedure

All stimuli (primes and targets) were presented auditorily. Subjects were tested individually. Their task was to make a lexical decision for each trial. Subjects were asked to press with the index finger of their dominant hand buttons labeled "word" or "nonword" to indicate whether the second member of each trial pair was or was not a word in English. Between trials, the subjects rested their index finger in a neutral position between the two buttons. The position of the word and nonword buttons was counterbalanced across subjects. Subjects were further instructed to perform the task as quickly and accurately as possible.

Prior to the experiment, subjects were provided with ten practice trials. The practice trials contained examples of unrelated pairs with either word or nonword targets. None of the practice trial stimuli appeared among the test stimuli. For the experiment, ten subjects were randomly assigned to each list.

Stimulus timing was controlled by a PC (Swan 386/25), running BLISS software (Mertus 1989). Each subject was presented with the stimuli in random order over Sony MDR-V2 headphones. Stimuli were presented at a fixed rate, with an ISI of 50 ms.

Reaction time was measured from the onset of the target stimulus until a response was made. Responses and reaction times were recorded. This sequence was repeated for every stimulus prime-target pair. The entire experiment lasted approximately 15 minutes.

2.2 Results

ANOVAs were conducted for subjects (F1) and items (F2) for both the reaction time and error data. No errors or reaction times below 200 ms and above 2000 ms are included in the analyses. In addition, data from all target words with error rates greater than 25% were eliminated. In this experiment, three targets were not included in further analyses (LOON 60% error rate, VICE 50%, and MAIM 30%). The total error rate was 4.2%.

Subject and item analyses were calculated for the reaction time data to the word targets. Subject means were calculated by collapsing across exemplars in each priming condition. Overall item means were computed by collapsing across subjects. In all analyses, analysis of variance with repeated measures were used; Newman-Keuls post-hoc tests were conducted where appropriate. All means presented are taken from the subject analyses. Mean lexical decision latencies and errors for all conditions are reported in Table 1.

	Related	Unrelated	Unr-Rel
Both (orthographically similar rhymes)	817 (3.7)	989 (4.2)	+172
Sound (orthographically dissimilar rhymes)	870 (3.3)	961 (5.0)	+91
Spelling (orthographically similar nonrhymes)	963 (5.0)	999 (4.0)	+36

Table 1. Mean lexical decision latencies (msec) for correct responses and percentage errors (in parentheses) to targets preceded by related (orthographically similar rhymes, orthographically dissimilar rhymes, and orthographically similar nonrhymes) and unrelated primes in Experiment 1.

A two-way repeated measures analysis of variance (ANOVA) was conducted: Priming Condition (Both vs. Sound vs. Spelling) X Relatedness (related vs. unrelated). Both subject and item analyses showed main effects of Priming Condition [$F(2,38) = 22.62$, $p < .01$, $MSe = 3074$; $F(2,54) = 3.67$, $p < .05$, $MSe = 21162$]. A Newman-Keuls post-hoc test revealed that subjects responded significantly slower to the Spelling condition (980 ms) than to the Both condition (903 ms) or the Sound condition (915 ms).

In addition, there was a main effect of Relatedness [$F(1,19) = 31.89$, $p < .01$, $MSe = 9359$; $F(1,54) = 63.72$, $p < .01$, $MSe = 4752$], such that response latencies to related pairs (883 ms) were 100 ms faster than to unrelated pairs (983 ms).

The critical interaction between Priming Condition and Relatedness was significant [$F(2,38) = 14.34$, $p < .01$, $MSe = 3251$; $F(2,54) = 9.23$, $p < .001$, $MSe = 4752$]. A Newman-Keuls post-hoc test showed that the interaction was due to significant differences between unrelated and related pairs in the Both (172 ms) and Sound conditions (91 ms), but not in the Spelling condition (36 ms) (See Table 1). There were significant priming effects when there was either phonological overlap between prime and target or when there was both phonological and orthographic overlap. However, there was no significant priming when there was only orthographic overlap.

Both subject and item analyses were also conducted for the error data. No significant main effects or interactions were observed.

2.3 Discussion

Experiment 1 investigated phonological and orthographic priming effects in an auditory lexical decision task. The amount of priming was not equal across all experimental conditions. Phonological overlap, either by itself or in combination with orthographic overlap, produced consistent facilitatory effects relative to unrelated controls. However, orthographic relatedness did not show such facilitation, with overlap in spelling showing no significant facilitation of related compared to unrelated conditions.

The facilitation of words preceded by phonologically related primes does not replicate earlier findings. Jakimik et al. found facilitation only for orthographically similar rhymes, and not for orthographically dissimilar rhymes or for orthographically similar nonrhymes. Soltano and Slowiaczek's data show the opposite, with orthographic information alone (when overlap is a lexical item) and phonological information alone (when overlap is a nonword) exhibiting facilitatory effects relative to conditions in which there is both orthographic and phonological overlap. Both groups of researchers interpret their data as suggesting that orthographic information does play a role, albeit minor, in auditory processing. The present data, however, do not support such a conclusion. Our results show facilitation for orthographically similar rhymes and for orthographically dissimilar rhymes, suggesting little influence of overlapping or conflicting orthographic information in an auditory lexical decision task.

3 Experiment 2

3.1 Method

3.1.1 Participants

Eighteen subjects attending the Pennsylvania State University received extra credit in an

introductory psychology course for their participation. All were native speakers of American English and reported no hearing impairments. No subjects had participated in the previous experiment.

3.1.2 Materials

The stimuli consisted of the 60 prime-target word pairs from Experiment 1. Nonword target trials were not included in Experiment 2.

3.1.3 Procedure

All stimuli (primes and targets) were presented auditorily. Subjects participated in a naming (shadowing) task in which they were asked to repeat the target word as quickly and accurately as possible. Subjects' vocal responses were fed via a Realistic Stereo Electret (33-1065) microphone to a voice-activated relay (Lafayette Model 18010). The relay triggered a signal which was sent to the computer (Swan 386/25) controlling the experiment. The subjects' responses were measured from the onset of the target stimulus to the onset signal from the voice activated relay. Subjects' responses were also recorded on a cassette tape deck (Sanyo M S540) to insure that subjects were pronouncing the target word correctly. All other procedures were the same as in Experiment 1. The entire experiment lasted approximately 10 minutes.

3.2 Results

ANOVAs were conducted for subjects (F1) and items (F2) for both the reaction time and error data. In the shadowing task, errors occurred because the subject mispronounced the target or the reaction timer was not triggered by the subject's voice. No errors or reaction times below 200 ms and above 2000 ms are included in the analyses. Three items with high error rates were eliminated: BLOT (39%), THIEF (39%), and LEAF (44%). The total error rate in the experiment was 5.8%. All means presented are taken from the subject analyses. Mean shadowing latencies and errors for all conditions are presented in Table 2.

	Related	Unrelated	Unr-Rel
Both (orthographically similar rhymes)	801 (4.7)	846 (4.1)	+45
Sound (orthographically dissimilar rhymes)	781 (5.6)	842 (6.8)	+61
Spelling (orthographically similar nonrhymes)	857 (4.5)	875 (4.5)	+18

Table 2. Mean lexical decision latencies (msec) for correct responses and percentage errors (in parentheses) to targets preceded by related (orthographically similar rhymes, orthographically dissimilar rhymes, and orthographically similar nonrhymes) and unrelated primes in Experiment 2.

A two-way repeated measures analysis of variance (ANOVA) was conducted: Priming Condition (Both vs. Sound vs. Spelling) X Relatedness (related vs. unrelated). There was a significant main effect for Priming Condition in the subject analysis [$F(2,34) = 41.29$, $p < .01$, $MSe = 722$]. However, it was not significant by items [$F(2,54) = 1.78$, $p > .10$, $MSe = 17994$]. A Newman-Keuls post-hoc test showed that response latencies to the Spelling condition (866 ms) were slower than to either the Both (824 ms) or the Sound (812 ms) conditions.

The main effect of Relatedness was significant both by subjects and by items [$F(1, 17) = 38.33$, $p < .001$, $MSe = 1233$; $F(1,54) = 15.02$, $p < .001$, $MSe = 3878$]. Naming latencies to related pairs (813 ms) were 41 ms faster than to unrelated pairs (854 ms).

Finally, the interaction of Priming Condition by Relatedness was significant by subjects [$F(2,34) = 4.91$, $p = .01$, $MSe = 878$], but did not reach significance by items [$F(2,54) = 2.09$, $p = .13$, $MSe = 3878$]. A Newman-Keuls post-hoc test revealed that the differences between the related and unrelated pairs were larger in the Both and Sound conditions (45 ms and 61 ms, respectively) than in the Spelling condition (18 ms) (See Table 2). There was priming when there was either phonological overlap between prime and target or when there was both phonological and orthographic overlap. However, there was no priming when there was only orthographic overlap.

Both subject and item analyses were also conducted for the error data. No significant main effects or interactions were observed.

3.3 Discussion

Experiment 2 investigated phonological and orthographic priming effects in an auditory shadowing task. The amount of priming was not equal across all experimental conditions. Phonological overlap, either by itself or in combination with orthographic overlap, produced facilitatory effects relative to unrelated controls. Orthographic relatedness, on the

other hand, did not show such facilitation, with overlap in spelling showing no significant facilitation of related compared to unrelated conditions.

The shadowing results were similar to the lexical decision results (Experiment 1) in that phonologically-related pairs (Sound and Both) showed facilitation relative to unrelated controls, whereas the orthographically-related pair (Spelling) did not. However, it should be noted that the interaction in shadowing did not reach significance by items.

The facilitation of words preceded by phonologically related primes does not replicate earlier findings. Soltano and Slowiaczek's naming data show that orthographic information alone (when overlap is a lexical item) and phonological information alone (when overlap is a nonword) exhibit facilitatory effects relative to conditions in which there is both orthographic and phonological overlap. The present data, however, do not support such a conclusion. Our results show facilitation for orthographically similar rhymes and for orthographically dissimilar rhymes, suggesting little influence of overlapping or conflicting orthographic information in an auditory shadowing task.

4 Experiment 3

Orthographic and phonological effects have been investigated to a much greater extent in the visual modality. Meyer, Schvaneveldt and Ruddy (1974) found some facilitation (although not significant) for both orthographically and phonologically similar prime-target pairs such as BRIBE-TRIBE compared to unrelated controls such as FENCE-TRIBE. Furthermore, they found significant inhibition for orthographically similar but phonologically dissimilar pairs such as FREAK-BREAK compared to unrelated controls, such as COUCH-BREAK. Meyer et al. interpreted these results in terms of an "encoding bias," arguing that subjects encoded the first word of the pair by using a grapheme-to-phoneme conversion process and that subjects were then biased to using the same set of conversion rules for the second orthographically similar word. In the case of orthographically similar but phonologically dissimilar word pairs such as FREAK-BREAK, the same set of grapheme-to-phoneme rules cannot be appropriately used for both words. An additional attempt at phonological coding of the target is necessary, thus resulting in longer reaction times.

Subsequent research questioned the encoding bias hypothesis. Hillinger (1980) argued that due to the application of grapheme-to-phoneme conversion rules there should be a difference in processing between orthographically similar rhyming pairs such as HATE-FATE compared to orthographically dissimilar rhyming pairs such as BAIT-FATE. However, Hillinger found no difference in the magnitude of the facilitation for such pairs.

Hillinger therefore argued against an encoding bias hypothesis and opted instead for a spreading activation explanation. Hillinger claimed that phonological information was automatically accessed in visual word recognition and that activation then spread from prime words to phonologically related target items. However, in a series of experiments, Martin and Jensen (1988) did not replicate Hillinger's results. Martin and Jensen found no evidence of phonological mediation for visual lexical decisions. Both orthographically similar rhymes and orthographically dissimilar rhymes showed no facilitation relative to control conditions. The Martin and Jensen results refute the claim that automatic spreading activation occurs on the basis of phonological similarity during visual word recognition.

In an attempt to retrieve some rhyming effects in visual word recognition, Peter, Lukatela and Turvey (1990) used a naming task rather than lexical decision. Since naming is more dependent on phonological information, rhyming effects should be evident in this task. However, similar to Martin and Jensen's results in lexical decision, Peter et al. observed no facilitation for either orthographically similar rhymes or for orthographically dissimilar rhymes.

The purpose of the present series of experiments (Experiments 3 and 4) was to systematically investigate phonological and orthographic effects in visual word recognition and to compare these effects, using identical stimuli and similar testing procedures, to those obtained for auditory word recognition (Experiments 1 and 2). Again, two paradigms were used to assess task contributions — a lexical decision task (Experiment 3) and a naming task (Experiment 4). As stated earlier, three experimental conditions were created. In the first condition, targets were preceded by orthographically similar rhymes (PITCH-DITCH), with primes and targets overlapping in both sound and spelling. In a second condition, targets were preceded by orthographically dissimilar rhymes (CUFF-ROUGH). In this case, the prime and target only overlapped in terms of sound, not spelling. In a third condition, targets were preceded by orthographically similar nonrhymes (DOLL-TOLL). The prime and target only overlapped in terms of spelling. For each of the conditions, control pairs were included which consist of pairs of unrelated words. In this way, facilitatory and inhibitory effects were assessed.

If phonological information plays a role in visual word recognition, then there should be facilitation for pairs which overlap auditorily, such as the orthographically similar rhymes or orthographically dissimilar rhymes. However, if spelling rather than sound information is relevant to visual word recognition, then pairs with orthographic overlap (the orthographically similar rhymes and the orthographically similar nonrhymes) should both show priming effects.

4.1 Method

4.1.1 Participants

Eighteen subjects attending the Pennsylvania State University received extra credit in an introductory psychology course for their participation. All were native speakers of American English and reported no hearing impairments. No subjects had participated in any of the other experiments.

4.1.2 Materials

The stimuli were the same as those used in Experiment 1.

4.1.3 Procedure

All stimuli (primes and targets) were presented visually. Subjects participated in a lexical decision task in which they were asked to decide as quickly and accurately as possible whether the target was either a word or nonword. The experiment was controlled by a Swan 386/25 computer running MEL software (Schneider 1990). Subjects were seated in front of a video monitor (Swan VGA Color Monitor). At the beginning of a trial the word "READY" appeared on the screen for 800 ms. Then the prime was presented for 500 ms, which was similar to the mean duration of the auditory primes. There was a 50 ms ISI and then the target appeared on the screen until the subject responded. Subjects were asked to press a key on the keyboard in front of them. The position of the keys was counterbalanced across subjects. All other procedures were the same as in Experiment 1. The entire experiment lasted approximately 15 minutes.

4.2 Results

ANOVAs were conducted for subjects (F1) and items (F2) for both the reaction time and error data. No errors or reaction times below 200 ms and above 2000 ms are included in the analyses. Four items had high error rates and were deleted: loon (33%), MAIM (56%), CLOVE (44%) and WAD (56%). The error rate for the experiment was 3.7%. All means presented are taken from the subject analyses. Mean lexical decision latencies and errors for all conditions are presented in Table 3.

	Related	Unrelated	Unr-Rel
Both (orthographically similar rhymes)	643 (5.0)	691 (2.5)	+48
Sound (orthographically dissimilar rhymes)	633 (2.5)	654 (1.2)	+21
Spelling (orthographically similar nonrhymes)	704 (6.1)	646 (3.7)	-58

Table 3. Mean lexical decision latencies (msec) for correct responses and percentage errors (in parentheses) to targets preceded by related (orthographically similar rhymes, orthographically dissimilar rhymes, and orthographically similar nonrhymes) and unrelated primes in Experiment 3.

A two-way repeated measures analysis of variance (ANOVA) was conducted: Priming Condition (Both vs. Sound vs. Spelling) X Relatedness (related vs. unrelated). None of the main effects was significant: Priming Condition [$F(2,34) = 2.54$, $p > .10$, $MSe = 3768$; $F_2 < 1$]; Relatedness [$F_1 < 1$; $F_2 < 1$].

Only the interaction between Priming Condition and Relatedness was significant in both the subject and the item analyses [$F(2,34) = 6.06$, $p < .01$, $MSe = 4387$; $F(2,53) = 6.91$, $p < .01$, $MSe = 4067$]. A Newman-Keuls post-hoc test showed that the Spelling condition showed a significant 58 ms inhibitory effect. Response latencies to orthographically related targets were significantly slower than to unrelated controls. Differences between related and unrelated pairs in the Both (48 ms) and Sound (21 ms) conditions were not significant (See Table 3).

Both subject and item analyses were also conducted for the error data. Although a significant main effect of Priming Condition was observed in the subject analysis [$F(2,34) = 3.75$, $p = .0339$, $MSe = .84$], it did not reach significance in the item analysis [$F(2,53) = 2.03$, $p = .141$, $MSe = .372$].

4.3 Discussion

Experiment 3 investigated phonological and orthographic priming effects in a visual lexical decision task. The amount of priming was not equal across all experimental conditions. Orthographic overlap alone produced significant inhibitory effects relative to unrelated controls. Phonological overlap, either by itself or in combination with orthographic overlap, however, showed neither facilitatory or inhibitory effects relative to unrelated controls.

The lexical decision results are in agreement with a number of earlier visual lexical decision studies. Similar to the Meyer et al. results, we did find a significant inhibition for orthographically similar non-rhymes (the Spelling condition) and we did not obtain a

significant effect for orthographically similar rhymes (the Both condition). Similar to Martin and Jensen (1988), we observed no facilitatory effect of orthographically dissimilar rhymes (the Sound condition).

5 Experiment 4

5.1 Method

5.1.1 Participants

Twenty subjects attending the Pennsylvania State University received extra credit in an introductory psychology course for their participation. All were native speakers of American English and reported no hearing impairments. No subjects had participated in any of the other experiments.

5.1.2 Materials

The stimuli consisted of all of the pairs with word targets from Experiment 1.

5.1.3 Procedure

All stimuli (primes and targets) were presented visually. Subjects participated in a naming task in which they were asked to name the target word as quickly and accurately as possible. Subjects' vocal responses were fed via a Realistic Stereo Electret (33-1065) microphone and Archer mini amplifier to a voice-activated relay (RB-100). The relay triggered a response which sent a signal to the computer (Swan 386/25) controlling the experiment. The subjects' responses were measured from the onset of the target stimulus to the onset signal from the voice activated relay. Subjects' responses were also recorded on a cassette tape deck (Sanyo M S540) to insure that subjects were pronouncing the target word correctly. All other procedures were the same as in Experiment 1. The entire experiment lasted approximately 10 minutes.

5.2 Results

ANOVAs were conducted for subjects (F1) and items (F2) for both the reaction time and error data. In the shadowing task, errors occurred because the subject mispronounced the target or the reaction timer was not triggered by the subject's voice. No errors or reaction times below 200 ms and above 2000 ms are included in the analyses. The target CLOVE had a high error rate (28%) and was eliminated. The overall error rate for the naming experiment was 3.9%. All means presented are taken from the subject analyses. Mean shadowing latencies and errors for all conditions are presented in Table 4.

	Related	Unrelated	Unr-Rel
Both (orthographically similar rhymes)	782 (2.8)	771 (2.2)	-11
Sound (orthographically dissimilar rhymes)	824 (2.8)	795 (5.0)	-29
Spelling (orthographically similar nonrhymes)	840 (8.8)	833 (1.8)	-7

Table 4. Mean lexical decision latencies (msec) for correct responses and percentage errors (in parentheses) to targets preceded by related (orthographically similar rhymes, orthographically dissimilar rhymes, and orthographically similar nonrhymes) and unrelated primes in Experiment 4.

A two-way repeated measures analysis of variance (ANOVA) was conducted: Priming Condition (Both vs. Sound vs. Spelling) X Relatedness (related vs. unrelated). There was a significant main effect of Priming Condition [$F(2,34) = 15.24$, $p < .001$, $MSe = 2117$; $F(2,56) = 7.36$, $p < .01$, $MSe = 5604$]. A Newman-Keuls post-hoc test showed that the Spelling condition (837 ms) was significantly slower than the Sound condition (810 ms) and the Both condition (777 ms); the Sound condition was significantly slower than the Both condition.

In addition, there was a main effect of Relatedness in the subject analysis [$F(1, 17) = 6.20$, $p < .05$, $MSe = 1123$]. However, this inhibitory effect was not significant by items [$F(1,56) = 1.75$, $p > .10$, $MSe = 6011$]. Response times to related pairs (815 ms) were slightly slower than to unrelated pairs (800 ms).

The Priming Condition X Relatedness interaction was not significant [$F_s < 1$]. Means for each condition are presented in Table 4.

Both subject and item analyses were also conducted for the error data. A significant interaction of Priming Condition and Relatedness was observed [$F(2,34) = 4.33$, $p = .0211$, $MSe = 1.86$], [$F(2,56) = 3.49$, $p = .037$, $MSe = .51$]. Differences in number of errors between the related and unrelated pairs were large for the Spelling condition (15 errors and 3 errors, respectively) and negligible in the Both (5 and 4, respectively) and Sound conditions (5 and 9, respectively) (See Table 4).

5.3 Discussion

Experiment 4 investigated phonological and orthographic priming effects in a visual naming task. The amount of priming was equal across all experimental conditions. Both orthographic and phonological overlap either in combination or separately did not produce significant amounts of facilitation or inhibition relative to unrelated controls. These results are in agreement with Peter et al. (1990) who show no effect of phonological overlap in a

naming task.

It should be noted that although the reaction time data did not show any effects, there was a significant finding for the error data. A significant interaction for errors showed that the difference in number of errors between related and unrelated pairs was significantly greater for the Spelling condition, with the related condition having substantially greater number of errors than the unrelated condition. Although the reaction time data do not differentiate among the three experimental conditions, the error data suggest that it is significantly more difficult to process stimuli preceded by orthographically related primes as compared to an unrelated control condition. Similar to the pattern of data in visual lexical decision (Experiment 3), then, orthographic relatedness by itself appears to produce a substantial amount of inhibition in a visual naming task.

6 Overall Analysis

One of the advantages of the present series of experiments is that identical stimuli and conditions are used to examine the effects of phonological and orthographic relatedness. Two factors were also manipulated — the task demands (lexical decision and naming) required of the subjects and the modality (auditory and visual) of presentation of the stimuli. Given this design, an overall ANOVA can be conducted to tap into the relevant effects and interactions across all four experiments.

In order to assess the effects of the modality of presentation and the nature of task used, we performed a four-way ANOVA with the following factors: Modality (auditory vs. visual), Task (lexical decision vs. naming), Priming Condition (Both vs. Sound vs. Spelling) and Relatedness (related vs. unrelated). Only effects that were significant in both the subject and item analyses will be reported.

The four-way ANOVA showed several significant main effects. There was a main effect of Priming Condition [$F(2,140) = 24.36$, $p < .0001$, $MSe = 2894$; $F(2,49) = 3.50$, $p < .05$, $MSe = 23706$]. Newman-Keuls post-hoc tests revealed that the Spelling condition (827ms) was significantly slower than the Sound condition (794 ms) ($p < .01$) and the Both condition (785 ms) ($p < .01$). The difference between the Sound and the Both conditions was not significant. The effect of the experimental conditions is most likely due to different targets in each condition. In the spelling condition, many of the word targets were irregular words because the condition necessitated choosing a set of words which did not sound the same as the primes. Thus, it is possible that subjects' response times happened to be slower in the Spelling condition than in the other conditions. It is specifically for this reason that having one control condition for all three prime

conditions is unwise. Recall from the design of the present set of experiments that differences among conditions is not critical since each priming condition had its own unrelated control condition with matching targets. The difficulty of matching stimuli across priming conditions was the major reason for selecting a separate, matched unrelated condition for each priming condition.

Also, mean response times to stimuli in the visual modality (733 ms) were significantly faster than in the auditory modality (865 ms) [$F(1, 70) = 21.60$, $p < .0001$, $MSe = 89716$; $F(1, 49) = 126.81$, $p < .0001$, $MSe = 17453$]. This is not a surprising finding, since visual target stimuli can be seen in their entirety from onset on the screen whereas auditory targets are presented over time, with an average duration in the present experiments of 576 ms.

Finally, mean response times to related pairs (781 ms) were significantly faster than to unrelated pairs (816 ms) [$F(1, 70) = 30.31$, $p < .0001$, $MSe = 4546$; $F(1, 49) = 31.88$, $p < .0001$, $MSe = 3549$], suggesting an overall effect of priming of related pairs across all modalities, tasks, and experimental conditions. This results suggests that orthographically and phonologically related primes did have an effect on processing of subsequent target items.

The four-way ANOVA also showed a number of significant interactions. In general, the priming effect varied as a function of Task or Modality. There was an interaction between Task and Relatedness [$F(1, 70) = 10.74$, $p < .01$, $MSe = 4546$; $F(1, 49) = 10.98$, $p < .01$, $MSe = 4547$]. The priming effects (i.e., the differences between related and unrelated conditions) were significantly larger in lexical decision (56 ms) than in the shadowing task (14 ms). The priming effect was significant for lexical decision ($p < .01$) but not for the naming data. In general, priming effects have been shown to be more pronounced in lexical decision as compared to naming due to a possible influence of postlexical processes (e.g., Balota and Chumbley 1984). This has been shown for semantic priming effects and has now been shown for orthographic and phonological priming effects as well. In addition, there was a Modality X Relatedness interaction [$F(1, 70) = 40.54$, $p < .0001$, $MSe = 4546$; $F(1, 49) = 21.68$, $p < .0001$, $MSe = 7089$]. The difference between unrelated and related conditions was significant in the auditory modality (77 ms) ($p < .01$) but no significant differences were found in the visual modality (-5 ms). Across all conditions, stimuli presented auditorily showed a substantially greater amount of priming compared to the same stimuli presented visually.

Also, differences in Task varied as a function of Modality. That is, there was a significant interaction between Task and Modality [$F(1, 70) = 16.13$, $p = .0001$, $MSe =$

89716; $F(1,49) = 300.28$, $p < .0001$, $MSe = 5163$]. In the auditory modality, pronunciation latencies (823 ms) were significantly faster than lexical decision latencies (906 ms) ($p < .01$) while in the visual modality, pronunciation times (805 ms) were significantly slower than lexical decision times (659 ms) ($p < .01$). The modality of stimulus presentation affected the nature of the response, with auditory presentations speeding naming latencies and visual presentation speeding lexical decision responses.

Most importantly, there was an interaction of Priming Condition X Relatedness [$F(2,140) = 10.55$, $p = .0001$, $MSe = 3418$; $F(2,49) = 12.18$, $p = .0001$, $MSe = 3549$]. The difference between the unrelated and related pairs was 45 ms in the Both condition, 43 ms in the Sound condition and only 2 ms in the Spelling condition. Thus, this interaction reflects the priming effect for the Both ($p < .01$) and Sound ($p < .01$) condition, and the lack of an effect in the Spelling condition, across all tasks and modalities. In general, phonological relatedness (Both and Sound conditions) resulted in greater priming effects.

It may be expected that there would be a three-way interaction among Priming Condition and Relatedness and Modality, since there was significant facilitation for the Both and Sound conditions in the auditory modality, whereas there was inhibition in the visual modality in the Spelling condition. However, this interaction was not significant [$F_s < 1$]. The lack of a significant interaction suggests that, overall, the relation among the three experimental conditions in terms of their priming is similar in both modalities.

The four-way ANOVA also revealed one three way interaction: Priming Condition X Relatedness X Task [$F(2,140) = 8.91$, $p < .001$, $MSe = 3418$; $F(2,49) = 4.46$, $p < .02$, $MSe = 4547$]. In the lexical decision task, the differences between the unrelated and related conditions were significant in the Both condition (110 ms) ($p < .01$) and the Sound condition (67 ms) ($p < .01$), but not for the Spelling condition (-8 ms). In contrast, in the shadowing task, the magnitude of the differences was similar across the three experimental conditions: Both (15 ms), Sound (16 ms), and Spelling (-11 ms).

7 General Discussion

The present series of experiments investigated phonological and orthographic priming effects. Two modalities (auditory and visual) and two tasks (lexical decision and naming) were contrasted. The same stimuli are used throughout to allow comparisons across modalities and tasks. A series of four experiments thus examined orthographic and phonological priming in an auditory lexical decision task (Experiment 1), an auditory naming task (Experiment 2), a visual lexical decision task (Experiment 3), and a visual naming task (Experiment 4).

In Experiments 1 and 2, phonological overlap, either by itself or in combination with orthographic overlap, produced consistent facilitatory effects relative to unrelated controls. These effects were observed in both lexical decision and naming tasks. Orthographic relatedness alone, however, did not show such facilitation, with overlap in spelling showing no significant priming effect in an auditory lexical decision or naming task. It appears that when stimuli are presented auditorily, phonological relatedness dominates and produces substantial priming effects regardless of the task demands.

Experiments 3 and 4 examined these same conditions with visual presentation. In Experiment 3, orthographic overlap alone produced significant inhibitory effects relative to unrelated controls in a lexical decision task. Phonological overlap, either by itself or in combination with orthographic overlap, however, showed neither facilitatory nor inhibitory effects relative to unrelated controls. The overall pattern across conditions is similar to those data obtained in the auditory modality in that phonologically related conditions pattern together in contrast to the orthographically similar nonrhyme condition. In Experiment 4, a visual naming task, no priming effects were observed in any of the experimental conditions. Both orthographic and phonological overlap either in combination or separately did not produce significant amounts of facilitation or inhibition relative to unrelated controls. There was, however, a significant increase in the number of errors in the orthographically related condition. For orthographically related nonrhymes, related conditions displayed a significantly greater number of errors than their unrelated controls. Taking into account a possible speed-accuracy trade-off, a pattern similar to the previous experiment emerges, with orthographic overlap alone patterning independently from the other two phonologically related conditions.

Since identical stimuli were used and identical experimental conditions were contrasted in all four experiments, an overall analysis was conducted to tap into the relevant effects and interactions across experiments. The overall analysis revealed that across both tasks and modalities there was more priming for phonologically related conditions relative to the orthographically related condition. There was a significant facilitatory effect for the Both and Sound conditions relative to their unrelated controls but no priming (either facilitatory or inhibitory) observed for the Spelling condition. Interestingly, the overall analysis also revealed a similar relation across modalities among the three experimental conditions in terms of their priming as shown in Figure 1.

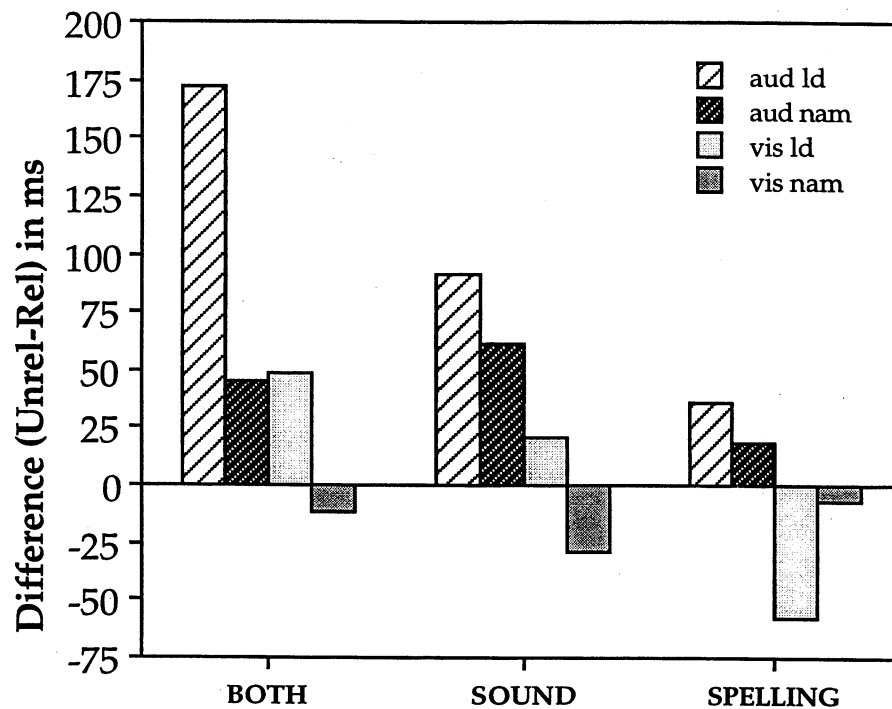


Figure 1. Priming effects (in msec) for related conditions (orthographically similar rhymes, orthographically dissimilar rhymes, and orthographically similar nonrhymes) measured against unrelated control conditions in auditory lexical decision (Experiment 1), auditory naming (Experiment 2), visual lexical decision (Experiment 3), and visual naming (Experiment 4).

The specific pattern of the Both and Sound conditions reacting together in contrast to the Spelling condition showed up as a facilitation of the phonologically related conditions and no effect for orthographic relatedness in the auditory modality whereas in the visual modality, this pattern tended to be an inhibitory effect for the orthographically related conditions and a lack of priming for either of the phonologically related conditions.

The failure to find rhyme priming effects with visual presentation has typically been interpreted as indicating that there is no automatic phonological activation during visual word recognition. However, this interpretation leaves several questions unanswered. If there is no phonological mediation, one would still expect facilitation for the Both condition in addition to the Spelling condition, as a consequence of orthographic similarity. However, the present study shows a different pattern — namely a lack of facilitatory

effects for both orthographically and phonologically related conditions. Instead, there is only significant inhibition in the orthographically similar nonrhyme condition.

The overall pattern of results obtained in the present experiments is compatible with recent research by Grainger and Ferrand (Ferrand and Grainger 1992; Ferrand and Grainger 1994; Grainger and Ferrand 1994). Ferrand and Grainger used a masked lexical decision paradigm to investigate the role of phonological information in visual word recognition. Their specific approach was to investigate the particular time course of phonological and orthographical effects. Their data in conjunction with those of others (e.g., Van Orden 1987; Van Orden, Johnston and Hale 1988; Perfetti, Bell and Delaney 1988; Lukatela and Turvey 1990) clearly support the hypothesis that phonological information is automatically and very rapidly activated during written word recognition. More specifically, their results with very short prime exposures indicated that phonological information builds up more slowly than orthographic information. At longer prime durations, however, phonological priming effects increase while orthographic effects are inhibitory. Grainger and Ferrand interpret these results within an interactive activation framework (McClelland and Rumelhart 1981). In this framework, between-level effects (orthographic, phonological, word) are facilitatory and occur at short prime durations while within-level effects (between word units) are primarily inhibitory and occur at longer lags. The present series of experiments fall within the longer prime durations category. The strong inhibitory effects that are observed for the orthographically similar rhymes in the visual word recognition experiments are compatible with the interactive activation model.

The results for the auditory experiments must also be explained. Unlike the visual results, the auditory lexical decision and naming experiments do not show inhibitory effects. Instead, strong facilitatory priming is observed for both phonologically related conditions at the long lag prime durations. The auditory input substantially changes the resulting pattern of priming. It is possible that an investigation of the time course of activation will reveal the presence of inhibitory effects earlier (or later) in the processing scheme. However, such predictions will be quite difficult to corroborate since methodological manipulations of very brief presentations are not trivial with auditory stimuli.

The present auditory results do not exhibit the robust inhibitory priming effects of orthographic information found in the visual experiments. Not unexpectedly, both auditory lexical decision and naming show robust priming with phonologically related prime conditions. These effects hold even in the face of conflicting orthographic information (the orthographically dissimilar rhymes). Phonological information without matching

orthographic information does facilitate auditory word recognition.

The present series of experiments display an overall primacy of phonological information in both auditory and visual processing (see, for example, Lukatela and Turvey 1991; Van Orden, Pennington and Stone 1990). Moreover, orthographic information does not seem to have as much influence in auditory word recognition as phonological information has in visual word recognition.

The overall analysis also revealed that the pattern of priming across conditions interacted with task. In lexical decision, there are significant effects of phonological relatedness and no priming for orthographic relatedness alone, regardless of modality of presentation. In contrast, in naming tasks, there is a less pronounced pattern, with small facilitatory effects for all phonologically related conditions and small inhibitory effects for the orthographically related condition. In naming, the phonological and orthographic relation between prime and target had a diminished effect on processing of the target.

In general, there are misgivings about the lexical decision task as an index of lexical access (Balota and Chumbley 1984 1985; Chumbley and Balota 1984; Seidenberg, Waters, Sanders and Langer 1984). The lexical decision task is often considered to involve substantial postlexical decision processes. Naming, however, probably involves some decision processes, though to a lesser extent than does lexical decision. Slowiaczek and Hamburger (1992) claim that naming may be more sensitive to phonological information at the lexical level due to the fact that fewer postlexical processes are operative. The present results for naming, however, do not show more sensitivity to phonological information. Both the facilitatory phonological and inhibitory orthographic effects are lessened. Although the present results do show a reduced effect of phonological and orthographic information in naming tasks, the general pattern across experimental conditions holds, with phonological relatedness producing facilitation and orthographic nonrhymes producing inhibition.

A number of expected effects also were observed in the overall analysis. Response latencies to visually presented stimuli were faster than to auditory stimuli, not surprising given the temporal differences in stimulus presentation between the modalities. Also, there were significant differences among experimental conditions, with the Spelling condition overall being slower than either of the phonologically related conditions. Although this by itself may not be earth-shattering, it is pertinent for studies examining orthographic and phonological effects since it underscores the need to use appropriate control conditions in evaluating priming effects. It is precisely due to such possible confounds that the present series of experiments contained unrelated conditions for each experimental condition.

These unrelated conditions re-arranged the stimuli from each related condition to ensure appropriate controls.

In sum, the present results in general are in agreement with experiments that have been run for visual word recognition. Our results, however, contrast most sharply with the results obtained in auditory word recognition. Unlike earlier research, the present data show significant priming effects for phonologically related stimuli. Moreover, these effects are present in both lexical decision and naming tasks. A number of factors may contribute. First, only a handful of experiments have examined orthographic and phonological effects in the auditory modality and no clear conclusions have yet emerged. Second, most of these have not included appropriate control conditions with which to measure their effects. Third, there are a number of irregularities in their methodologies (e.g., timing intervals, repetition of stimuli, unbalanced groups of stimuli). And finally, the prior auditory experiments manipulated initial overlap rather than final or rhyme similarity. Together, these differences make it difficult to interpret their results as well as impossible to compare them to the visual word recognition research. The present research attempted to remedy these shortfalls within the auditory literature and to provide a single methodology with which to contrast the visual and auditory modalities. Only in this context can the relative contributions of phonology and orthography to auditory and visual word recognition be properly evaluated.

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