Automatic activation of orthography in spoken word recognition: Pseudohomograph priming

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Abstract

There is increasing evidence that orthographic information has an impact on spoken word processing. However, much of this evidence comes from tasks that are subject to strategic effects. In the three experiments reported here, we examined activation of orthographic information during spoken word processing within a paradigm that is unlikely to involve strategic factors, namely auditory priming where the relationship between prime and target was masked from awareness. Specifically, we examined whether auditory primes that were homographic with their spoken targets (e.g., the pseudohomograph /dri:d/, which can be spelled the same as the target word "*dread*") produced greater facilitation than primes that were equally phonologically related to their targets but could not be spelled the same as them (e.g. /šri:d/ followed by the spoken word "*shred*"). Two auditory lexical decision experiments produced clear pseudohomograph priming even though the participants were unaware of the orthographic relationship between the primes and targets. A task that required participants to merely repeat the spoken target revealed an effect of orthography on error rates, but not on latencies. It was concluded that, in literate adults, orthography is important in speech recognition in the same way that phonology is important in reading.

Keywords: Spoken word recognition

Orthography

Auditory lexical decision

Masked auditory priming

Abstract phonology

Before learning to read and write, we are able to readily understand spoken words. For each word that we know, there must be some sort of representation in lexical memory that can be activated when the corresponding acoustic signal is presented. This means that the input representation in lexical memory either corresponds directly to a normalized version of the acoustic signal or that it requires the signal to be transformed into a phonetic code, and/or abstracted further into a phonemic representation (see e.g., Klatt, 1989 for the various possibilities). When we become literate, it has been argued that the orthographic processes required for reading simply make use of the existing spoken word recognition system via the recoding of orthography into phonology (e.g., Frost, 1998, Van Orden, 1991). Such an account assumes that the phonological representation that mediates between an orthographic stimulus and its meaning is the same as that mediating between an acoustic stimulus and its meaning.

From this description, then, there is no reason to suppose that the introduction of orthography into the lexical processing system would have any impact at all on the recognition of spoken words. Orthographic processing is merely appended to the extant spoken word recognition system. There is increasing evidence, however, that orthographic information does have an impact on spoken word processing, and this has been demonstrated using a range of different auditory tasks of which the following is just a selection.

Seidenberg and Tanenhaus (1979) found shorter latencies to say that two spoken words rhymed when those words were matched on orthography (e.g. *pie tie*) than when not matched (e.g. *guy tie*). In a fragment monitoring task, Taft and Hambly (1985) observed that neutral schwas were treated as though they were actually the orthographically indicated vowel (e.g., /læg/ being erroneously identified as the beginning of /ləgu:n/, i.e., *lagoon*). Ziegler and Ferrand (1998) and Pattamadilok, Morais, Ventura, and Kolinsky (2007) revealed a delay in lexical decision responses to spoken French words (like *grès*) whose pronunciation could potentially be given a different spelling (i.e. creating a nonword, like *grêt*, *grai*, etc) relative to words (like *sonde*) whose pronunciation could only be spelt in the one way, while Ventura, Morais, Pattamadilok, and Kolinsky (2004) reported the same thing in Portuguese. Using a priming paradigm, Jakimik, Cole, and Rudnicky (1985), Slowiaczek, Soltano, Wieting, and Bishop (2003), and Chéreau, Gaskell, and Dumay (2007) have shown that auditory lexical decision responses to monosyllabic words are facilitated when primed by a spoken word whose orthography overlaps (e.g., *ten* primed by *tender*, *gravy* primed by *gravel*, or *tie* primed by *pie*), whereas pure phonological overlap produces no such priming (e.g., *jasmine jazz*, *symbol simple*, or *guy tie*). Other studies by Castles, Holmes, Neath, and Kinoshita (2003), Dijkstra, Roelofs, and Fieuws (1995), Hallé, Chéreau, and Segui (2000), Ventura, Kolinsky, Brito-Mendes, and Morais (2001), Treiman and Cassar (1997), Ziegler and Muneaux (2007), and Ziegler, Muneaux, and Grainger (2003) have drawn similar conclusions.

With it being consistently shown that orthographic information has an impact on spoken word processing, the critical question now becomes whether this orthographic impact merely arises strategically in order to help make decisions about a spoken target word, or whether it is sufficiently automatic that it occurs in the normal course of processing a verbal utterance. If the latter is true, theories of speech recognition would be deficient if they were to ignore the role of orthography.

Most of the tasks previously employed could be subject to strategic effects. For example, the explicit analysis of rhyming (e.g., Seidenberg & Tanenhaus, 1979), word fragments (e.g., Taft & Hambly, 1985; Ventura et al., 2001) and phonemes (e.g., Castles et al., 1998; Dijkstra et al., 1995; Hallé et al., 2000) might all benefit from using orthography as a means of holding information in working memory. An orthographic version of the word allows the information to be held in a different modality to the phonological material that is being manipulated or compared. Orthography might itself provide a more concrete version of the target than does its corresponding phonology, hence mediating the analysis of the phonological information through visual imagery.

The unprimed auditory lexical decision task used by Pattamadilok et al (2007), Ventura et al. (2004), Ziegler and Ferrand (1998), Ziegler and Muneaux (2007), and Ziegler et al. (2003) does not require the listener to consciously reflect upon the phonological characteristics of the target word because the incoming utterance can directly activate a representation in lexical memory. Yet it appears that the lexical decision response is hard to make purely on the basis of such an auditory input representation given that those studies found an effect of orthographic factors in spoken word recognition. While this could be taken to mean that orthographic information does automatically participate in the response, it could also be argued that the orthographic information only comes into play when real words need to be discriminated from nonsense words. The mere fact that the incoming utterance matches with lexical information does not ensure that the utterance is a real word, because there could still be more of the signal coming in. Such uncertainty about responding in the task might therefore lead the listener to generate as many cues as possible, and this includes orthographic information.

In addition, an experiment that directly compares utterances of different types (as required in unprimed lexical decision experiments) is crucially reliant on the exact matching of experimental conditions on everything other than the manipulation of interest. That is, one must be certain that there is control over factors such as word frequency, similarity to other words, and the point at which the auditory signal uniquely defines the word. Because it is impossible to exactly match such factors across the manipulated conditions, it is preferable to employ a task that examines responses to the same word under different experimental conditions. The priming paradigm offers such a situation because it is the nature of prime that determines the experimental manipulation, not the target whose response is being measured.

However, the problem with those studies that have revealed orthographic effects in primed auditory lexical decision (i.e., Chéreau et al., 2007; Jakimik et al., 1985; Slowiaczek et al., 2003) is that participants were always aware of the prime and, hence, the orthographic relationship between prime and target could have been consciously used to aid target identification. Although attempts were made to reduce the use of such a strategy by increasing the number of unrelated primes and targets in the experiment (Slowiaczek et al., 2003) or by decreasing the inter-stimulus interval (Chéreau et al., 2007), the relationship between the prime and target could nevertheless be processed consciously. When the relationship between a prime and target is available to consciousness, the possibility remains that the basis for this relationship (e.g., orthographic overlap) is noticed after some of the early trials, and is subsequently drawn upon to help perform the task.

The importance of eliminating conscious processing of the prime-target relationship is well-established in the domain of visual lexical processing. The vast majority of recent visual priming studies ensure that awareness of the relationship between the prime and target is eliminated through the use of a masked prime (see Kinoshita & Lupker, 2003, for examples of such studies). In this way, the impact of a prime on responses to a target cannot be attributed to any conscious strategies that might have otherwise been adopted to facilitate performance in the task (see e.g., Forster & Davis, 1984). Such a masked priming paradigm has been used to provide important evidence for the claim that phonology is automatically activated in visual word recognition. In particular, a phonological relationship between a prime and target has been found to facilitate lexical decision responses to the target (see Rastle & Brysbaert, 2006, for an overview). To illustrate, Ferrand and Grainger (1992, 1993, 1994; Grainger & Ferrand, 1994, 1996) found that, under certain conditions, lexical decision responses to visually presented French words (e.g., *foie*) were facilitated by a masked homophone (e.g., the word *fois*) or pseudohomophone (e.g., the nonword *foit*). In addition, Rastle and Brysbaert (2006) demonstrated that masked pseudohomophone priming held up in English even when potential confounding factors were controlled. For example, lexical decision times to *ripe* were faster when preceded by the pseudohomophone *rype* than when preceded by *rupe* (which is a nonhomophone that controls for graphemic similarity).

The fact that phonological priming occurs when participants are not aware of the relationship between the prime and target has been taken as clear evidence that phonology is automatically activated in visual word recognition (see Rastle & Brysbaert, 2006) and, following from this, that reading draws to a considerable extent on phonological representations. The strongest position in relation to this has been that reading is a largely phonological event with orthography merely providing a portal into the phonologically based lexical system (e.g., Frost, 1998, Van Orden, 1991). Such a view would be greatly weakened, however, if it could be demonstrated that orthographic information is just as automatically activated in spoken word recognition as has been shown for phonological information in silent reading. That is, if the same type of evidence that has been used to support automatic phonological effects in a visual task can be provided in relation to orthographic effects in an auditory task, it would have to be concluded that the lexical processing system qualitatively changes after we learn to read (cf. Ziegler & Muneaux, 2007), with orthography playing the same sort of role in adult spoken word recognition as phonology plays in adult visual word recognition.

To establish whether such evidence can be obtained, the present study sought to use the auditory counterpart of the masked pseudohomophone priming paradigm, namely, by examining pseudohomograph priming in a situation where the relationship between the prime and target was not consciously processed. While a "pseudohomophone" is a visually presented nonword that is likely to be pronounced identically to a real word (e.g., *rype*), a "pseudohomograph" is a spoken nonword that can be spelled identically to a real word. For example, /dri:d/ (rhyming with *bead*) can be spelled *dread*, /stæl/ can be spelled *stall*, and /fu:t/ (rhyming with *hoot*) can be spelled *foot*. If the orthography of a masked spoken prime is automatically activated, it should therefore be the case that /dri:d/ facilitates responses to the spoken target /drɛd/ (i.e, *dread*), /stæl/ facilitates responses to /stɔ:l/ (i.e, *stall*), and /fu:t/ facilitates responses to /fʊt/ (i.e., *foot*), all relative to controls where the spoken prime is unrelated to the target.

Of course, such facilitation could arise merely as a result of similar phonology rather than orthography, so a further condition is required. In this further "nonhomograph" condition, the identical phonological relationship is maintained between prime and target, but importantly, the prime cannot be spelled in the same way as the target. Examples are, /šri:d/ (rhyming with *bead*) preceding /šrɛd/ (i.e., *shred*), /kræl/ preceding /krɔ:l/ (i.e, *crawl*), and /pu:t/ (rhyming with *hoot*) preceding /pʊt/ (i.e., *put*). Such a nonhomograph condition also needs to be compared to an unrelated condition acting as the baseline. So, an orthographic effect would be indicated by finding that a pseudohomographic prime facilitates lexical decision times, while a nonhomographic prime does not. This would imply that, for example, the spelling *dread* (along with *dreed*) is automatically activated when /dri:d/ is heard, and this facilitates the recognition of the target /drɛd/ because of its matching orthography. On the other hand, the spelling *shread* (along with *shreed*) might be similarly activated when /šri:d/ is heard, but because the target /šrɛd/ is spelled *shred* rather than *shread*, its recognition is not facilitated.

In order to conclude that any pseudohomograph priming that might be observed has arisen from automatic orthographic activation, it is necessary to ensure that participants are not consciously aware of the relationship between the spoken prime and target, as has been ensured in visual masked priming experiments. However, masking a prime in auditory word recognition is not as straightforward as in the visual modality. In the standard visual masked priming paradigm (cf. Forster & Davis, 1984), a lowercase prime is preceded by a row of hash marks (####) of similar length and is replaced by an uppercase target. The auditory equivalent of hash marks is some sort of meaningless speech-like noise, but it is unclear what the appropriate amount of such noise should be to achieve effective masking. In addition, instead of physically differentiating the prime and target by varying their letter-case, the acoustic features of the prime would need to be manipulated. Finally, the exposure duration of a prime can be readily controlled when visually presented, but not when spoken because the signal takes time to unfold. Thus, the choice of parameters for achieving masked auditory priming is uncertain.

Nevertheless, Kouider and Dupoux (2005) have reported conditions under which they were able to observe masked auditory priming. Spoken primes were compressed (by 35%, 40%, 50% or 70%) and reduced in intensity (by 15dB). Masks consisted of randomly selected, compressed and attenuated words played in reverse. One such mask preceded the prime and another four immediately followed it. The target was then superimposed on this sequence of attenuated signals such that it immediately followed the prime. The target was neither attenuated nor compressed, which made it obvious which part of the trial required the lexical decision judgement.

Given that Kouider and Dupoux (2005) were able to find repetition priming under these conditions, their methodology initially appeared to be a suitable way to test masked pseudohomographic priming. However, there are several important differences between the materials used by Kouider and Dupoux and the materials required to test pseudohomographic priming that potentially weaken the effectiveness of using their paradigm. First, Kouider and Dupoux only examined repetition priming, whereas pseudohomographic priming requires facilitation of a target that is physically similar, but not identical to the prime. Second, the majority of pseudohomographs that can be generated along with a matching nonhomograph are monosyllabic (e.g., /dri:d/), while all of the items used by Kouider and Dupoux were polysyllabic. Compressing a monosyllabic utterance is likely to be far more detrimental to the identity of the utterance (particularly its vowel) than compression of a polysyllabic utterance. Finally, pseudohomographic and nonhomograph primes are nonwords, whereas the masked priming that Kouider and Dupoux observed was only with items that were words. Being a nonword is another factor that would work against the full identification of a compressed prime.

Data collected from a pilot study adopting the methodology of Kouider and Dupoux (2005) confirmed the failure of the paradigm to detect priming with monosyllabic primes (using a 50% prime compression). Not only was there no facilitation arising from monosyllabic pseudohomographic and nonhomographic primes, but identity priming was also lost.

It was therefore apparent that a different methodology was required to examine pseudohomophone priming. In order to eliminate the involvement of task specific strategies, the critical feature of a priming experiment is not so much that the prime be masked from awareness, but that the relationship between the prime and target not be consciously registered by the participant. To this end, Experiment 1 adopted a set of parameters that aimed to disguise the prime in such a way that its relationship with the target would be obscured, but where the prime was not compressed. If participants were to show pseudohomographic priming under such conditions, being unaware that the prime was orthographically related to the target, it would strongly indicate that orthographic information is automatically activated in spoken word recognition.

EXPERIMENT 1

In the first experiment, auditory lexical decisions were measured to targets presented under three priming conditions: (a) Preceded by a phonologically similar nonword that could be spelled in the same way as the target (i.e., a Pseudohomograph), (b) preceded by a phonologically similar nonword that could not be spelled in the same way as the target (i.e., a Nonhomograph), and (c) preceded by an unrelated nonword as a baseline condition.

In order to disguise the monosyllabic nonword prime, it was embedded within a string of other syllables that were meaningless to the listener, but were somewhat distinct from the prime in terms of their phonetic properties. This was achieved by using Vietnamese syllables spoken by a Vietnamese/English speaker who was native in his pronunciation of both languages. The vowels and consonants of Vietnamese differ phonetically from those of English, and tonal information also differentiates the languages. In addition, Vietnamese does not have consonant clusters. This means that an English nonword surrounded by Vietnamese syllables produced by the same speaker, should be distinctive, but not so distinctive that it attracts undue attention. With the addition of a 23dB attenuation of this string of syllables relative to the target, it was considered likely the prime would be fully processed, but that its relationship to the target would go unnoticed. In order to establish this, after completing the experiment, each participant was explicitly asked about their awareness of the relationship between the primes and targets.

Under these experimental conditions, we could therefore examine whether Pseudohomographs produced more priming than Nonhomographs, indicating whether or not orthographic information was activated. If participants showing such a pattern of data were unaware of the relationship between the primes and targets, then this would suggest that the orthographic priming did not arise from a task-specific strategy.

Method

Materials

A target word in the Pseudohomograph condition was selected on the following basis. First, there had to be an alternative pronunciation of its spelling that created a nonword. In turn, a normal spelling of this alternative pronunciation had to be the same as that of the target. For example, the spelling of the word /drɛd/ (i.e., *dread*) could also be pronounced /dri:d/ (rhyming with *bead*), and a likely spelling of /dri:d/ is *dread* (as well as *dreed*). Thus, /dri:d/ was used as a prime that was homographic (and heterophonic) with the target /drɛd/. In order to meet the necessary constraints, the targets were mostly irregular words in the sense that their pronunciation was not the most typical translation of their orthography, while the primes corresponded to the most typical translation. That is, the primes were a regularized pronunciation of the irregular target word (e.g., /dri:d/ is the regularized pronunciation of *dread*).

A further constraint was the need for a Nonhomograph condition where the target rhymed with the Pseudohomograph target, but differed in the spelling of its rime. So, /šrɛd/ rhymes with /drɛd/, but has a differently spelled rime (*ed* vs *ead*). The prime for a Nonhomograph item rhymed with the prime of its paired Pseudohomograph item (i.e., /šri:d/ rhyming with /dri:d/). In this way, a Nonhomograph prime would be very unlikely to be given the same spelling as its target (e.g., the /i:d/ of the nonword prime /šri:d/ would never be spelled *ed*, as in *shred*).

All primes and targets were monosyllabic, and Pseudohomograph targets were approximately matched overall with their corresponding Nonhomograph targets on word frequency as determined by the subjective frequency norms of Balota, Pilotti, and Cortese (2001), as well as both the spoken and written CELEX norms (Baayen, Piepenbrock, & van Rijn, 1993) with means of 96 vs 119 per million and 132 vs 137 per million respectively. They were also approximately matched on the number of words that differed from them by one phoneme (i.e., Phonological N: With a mean of 13.8 vs 12.5 respectively). The mean duration of the target was 584 ms for the Pseudohomographs and 528 ms for the Nonhomographs. There were 22 Pseudohomograph-Nonhomograph pairs and these can be found in the Appendix.

To create a condition against which each of the Pseudohomograph and Nonhomograph conditions could be compared, Unrelated primes were used. Here, each Pseudohomograph and Nonhomograph target was preceded by a nonword that was phonologically (and orthographically) distinct from the target. For each condition, this nonword was half of the time a regularized irregular word: For example, the prime /pʌš/ (rhyming with *hush*) is the regularization of the irregular word *push* (which was never used as a target in the experiment). In the remaining Unrelated items, the prime was not systematically related to any real word (e.g., /stu:m/).

A Latin Square design was adopted so that responses could be measured for each target under the related and unrelated conditions without any participant receiving the same target twice. This required two subgroups of participants. One subgroup was presented with eleven of the Pseudohomograph targets and their eleven matching Nonhomograph targets preceded by a related prime, along with the other 22 targets preceded by an unrelated prime. The second subgroup received the opposite prime-target pairings.

In addition to the word targets, 30 nonword items were designed for use as distractor targets in the lexical decision task, the same items being used for both subgroups of participants. Half of the nonword targets were preceded by a phonologically similar nonword (e.g., /θri:t/-/θreɪt/), and the remaining half were preceded by a phonologically dissimilar nonword (e.g., /sælt/-/tri:p/). For the latter two nonword conditions, half of the primes were regularizations of real words that were not presented as targets in the experiment (e.g., /θri:t/ being a regularization of *threat*, and /sælt/ being a regularization of *salt*). The other half were not (as in /fju:n/-/fu:n/ and /kwaɪl/-/deɪk/). The mean duration of the nonword targets was 582 ms.

Both the primes and the targets were recorded by a Vietnamese speaker who was born and raised in the English-speaking environment of Australia, and had a native-like pronunciation in both languages. He also recorded 72 Vietnamese syllables that were distinct in sound from any English words. The Vietnamese syllables (i.e., the masks) and the nonword primes were attenuated by 23dB. A sequence of mask-prime-mask was then constructed for every prime, with each mask being randomly selected from the pool of 72. The second mask of each sequence was then immediately followed by the relevant non-attenuated target.

Procedure

Participants were told that they would hear through headphones a sequence of trials, each of which consisted of a series of nonsense sounds followed by a louder utterance. They were told to ignore the series of nonsense sounds and decide whether the louder utterance was a real word or not. The response was to be made as quickly, but as accurately as possible by pressing a "Yes" or "No" button.

There were twelve practice trials consisting of six word targets and six nonword targets with primes fitting into each of the conditions. The 74 trials (with 44 word targets and 30 nonword targets) were then presented in a different random order for each participant using DMDX display software (Forster & Forster, 2003).

After completing the experiment, participants were given a sheet of paper stating the following: "Prior to each utterance that you responded to, you would have heard a series of other sounds. Did you notice any relationship between those other sounds and the utterance you responded to? Yes or No? If "yes", what was the relationship?"

Participants

The 30 participants were all first-year Psychology students at the University of New South Wales, randomly allocated equally to the two experimental files. They were all monolingual English speakers.

Results

Awareness of the prime

Exactly half of the participants reported that they did not notice any relationship between the target and the other sounds. The other half correctly reported that something that sounded like the target sometimes occurred within the other sequence of sounds. So in the analysis that follows, a comparison is made between those who were aware of the prime ("Detectors") and those who were not ("Non-Detectors").

Analysis of lexical decision responses

One item pair was eliminated from the analysis owing to more than 50% errors in at least one condition (*mow*/*foe*). RTs greater or less than two standard deviations away from the mean for each participant were replaced by the cutoff value, affecting 4.21% of responses. As required by the Latin Square design, the two subgroups of participants were treated as a between-groups factor in the analysis, but the statistics from this are meaningless and hence not reported. The mean RTs and error rates are found in Table 1.

Table 1 about here

On the RT measure, a larger difference was found between the Pseudohomograph and Unrelated conditions than between the Nonhomograph and Unrelated conditions, $F_1(1, 26) = 4.61$, $p < .05$; $F_2(1, 40) = 3.82$, $p < .1$; $minF'(1, 65) = 2.09$, $p > .1$; ES[1] = 42, CI[2] ± 43, with no (three-way) interaction between this and the ability to detect the prime, F's < 1. The Pseudohomograph effect was significant, $F_1(1, 26) = 5.33$, $p < .05$; $F_2(1, 20) = 4.74$, $p < .05$; $minF'(1, 44) = 2.51$, $p > .1$; ES = 31, CI

± 30, regardless of prime detection, F's < 1. For Nonhomograph items there was no such relatedness effect, F's < 1, and while Detectors showed a trend toward facilitation and Non-Detectors an inhibitory trend, this interaction was not significant, $F_1(1, 26) = 1.28$, $p > .1$; $F_2(1, 40) = 1.68$, $p > .1$; *minF'*< 1. The only result that was significant on the accuracy measure was the priming effect for Pseudohomographs in the participant analysis, $F_1(1, 26) = 4.99$, $p<.05$; $F_2(1, 20) = 1.82$, $p>.1$; *minF'*(1, 34) = 1.34, $p > .1$; ES = 1.89, CI ± 2.92.

Discussion

The results of this experiment are quite striking. A clear effect of orthography emerged even when the participants were unaware of the relationship between the prime and target. The implication, therefore, is that an orthographic transcription of the spoken prime was automatically activated, facilitating the recognition of a spoken word that corresponded to that orthographic form. It seems that conscious strategies did not play a role in generating this orthographic effect because awareness of the relationship between the prime and target, if anything, decreased the size of the RT effect.

The measure of awareness, however, was a very general one. When asked at the end of the testing session whether they had noticed any relationship between the targets and their preceding sounds, participants may have decided not to report anything if they only sometimes detected a relationship or, conversely, decided to report something when they only detected a relationship in one or two trials. In other words, we cannot be sure that the dichotomy into "Detectors" and "Non-Detectors" was clear-cut. More importantly, it is possible that a relationship was detected at the time of processing, but that this fact was simply not remembered by the participant when interrogated at the end of the session. What is therefore needed is a more direct questioning of participants about the relationship between each target and the sounds that preceded it, and this was undertaken in Experiment 2.

EXPERIMENT 2

The purpose of Experiment 2 was to replicate the orthographic effect under the same presentation conditions as in the previous experiment, but this time, to ask participants about the relationship between prime and target for each item. In order to avoid alerting the participants to the possibility that the primes and targets were related, awareness of the relationship was measured only after the lexical decision experiment was completed. Awareness was measured by presenting the experimental items again and asking participants, after each one, to rate on a 7-point scale the degree of similarity between the target and any of the sounds heard in the sequence of utterances that preceded it. Thus, they were alerted to the possibility that the target was preceded by a related utterance and could, therefore, provide an indication of what they would have detected had they been aware of the existence of the relationship between prime and target in the lexical decision experiment.

When explicitly looking for a relationship between the prime and the target, it is possible that participants will notice the orthographic relationship, giving a higher rating to the Pseudohomographs than the Nonhomographs relative to their controls. If this is the most typical rating pattern, then any orthographic effect arising in the prior lexical decision task could not be confidently ascribed to the automatic activation of orthography because such priming may have arisen from an awareness of the orthographic relationship in the Pseudohomograph condition. On the other hand, if the most typical similarity rating does not differentiate the Pseudohomographs from the Nonhomographs, then any differential priming effects between the two conditions cannot be explained in terms of a conscious strategy. That is, the pattern of priming would not be a reflection of the type of prime-target relationship that participants detect when consciously looking for such a relationship.

Method

Materials and procedure

The materials were identical to those used in Experiment 1. The same lexical decision task was adopted, but this time, all the experimental items were repeated at the completion of the lexical decision phase for similarity ratings. The participants were given the following instructions: "You will now be presented with some of the same items that you just heard. For some of the items you might detect a similarity between the target word and one of the sounds embedded in the sequence that precedes the target. Please rate on a scale from 1 to 7 the degree of similarity that you detect. A rating of 1 means that there is nothing in the sound sequence that is similar to the target, and 7 means that the sound sequence includes the actual target word. Please use the keys at the top of the keyboard to enter your ratings".

Participants

A further 34 monolingual first-year Psychology students were tested in this experiment, equally split between the two item files. None had participated in Experiment 1.

Results

Analysis of lexical decision responses

The lexical decision data were treated in the same way as in Experiment 1, including elimination of the item pair *mow*/*foe* because of low accuracy. This time, though, there was no division into Detectors and Non-Detectors. Two participants were removed because of error rates greater than 30%. Cutoff values were applied on 4.17% of trials. The mean RTs and error rates are found in Table 2.

Table 2 about here

The results of Experiment 1 were essentially replicated here. Although the interaction between relatedness and orthographic similarity only reached clear significance in the participant analysis, $F_1(1, 30) = 5.83$, $p < .05$; $F_2(1, 40) = 2.55$, $p > .1$; *minF'*(1, 66) = 1.77, $p > .1$; ES = 30, CI ± 38, there was a significant relatedness effect for Pseudohomographs, $F_1(1, 30) = 10.38$, $p<.01$; $F_2(1, 20) = 4.64$, $p<.05$; *minF'*(1, 37) = 3.21, $p < .08$; ES = 26, CI ± 25, but not for Nonhomographs, F's < 1. The error analyses revealed no effects, all F's < 1.14.

Analysis of similarity ratings

The ratings of similarity between the prime and target (on a scale of 1 to 7) are also found in Table 2. It was apparent that the phonological similarity between primes and targets was readily detected, with a highly significant relatedness effect, $F_1(1, 30) = 297.47$ $p<.001$; $F_2(1, 40) = 284.86$, $p<.001$; *minF'*(1, 69) = 145.52, $p < .001$, ES = 2.76, CI ± 0.33. However, the lack of any interaction with the type of relatedness, F's < 1, indicated that orthographic overlap between prime and target had no impact on ratings of similarity. In addition, the magnitude of the orthographic effect on lexical decision times for each participant (i.e., the advantage of Pseudohomographs over Nonhomographs relative to their controls) showed no correlation with the magnitude of the same effect on their similarity ratings, $r = 0.04$.

Combined analysis of Experiments 1 and 2

Given that the same conditions were used in Experiments 1 and 2, the two experiments were combined for a further analysis. The weak interaction observed in the item analysis of the two individual experiments between type of prime and relatedness was now significant, $F_1(1, 57) = 10.46$ $p<.01$; $F_2(1, 40) = 5.13$, $p<.05$; *minF'*$(1, 76) = 3.44$, $p < .1$, ES = 38, CI ±34. The significance of the Pseudohomograph priming was also strengthened, $F_1(1, 57) = 12.36$, $p<.001$; $F_2(1, 20) = 7.54$, $p<.02$; *minF'*$(1, 46) = 4.68$, $p < .05$, ES = 28, CI ±21, but there was still no Nonhomograph priming, F's <1.

Discussion

Experiment 2 replicated the findings of Experiment 1 inasmuch as phonologically related primes and targets produced facilitation only when the prime could be spelled identically to the target. Importantly, such an orthographic effect was very likely to have arisen automatically because, even if participants had consciously detected any similarity between a masked prime and its target, it is apparent from the ratings that this would have been based on their sound rather than their spelling. In other words, when explicitly asked to focus on the potential relationship between prime and target, participants were only conscious of their phonological similarity.

It might be argued, however, that orthographic similarity was detected over and above phonological similarity, but that the ratings did not reflect this owing to a ceiling effect. That is, the similarity ratings were as high as two non-identical utterances would allow and their orthographic identity did not change the fact that they were not pronounced identically. By this account, then, phonological similarity would be seen as being more important in defining the relationship between prime and target than orthographic similarity, though the latter could still have been activated as a cue to help perform the lexical decision task.

Against such an argument, though, is the implausibility of a ceiling effect when there was still a third of the scale that could have been used (i.e., an average of 2.5 points out of 7). Moreover, even if there were a ceiling effect, it is apparent from the ratings that when explicitly focusing on the relationship between a spoken prime and target, phonological similarity is obvious and overwhelms any orthographic relationship. This means that if participants were equally aware of the similarity between prime and target in the lexical decision task, there should have at least been a phonological priming effect, even if an orthographic match between prime and target were to increase this effect. The fact that no phonological priming was observed at all suggests that whatever the participants based their similarity ratings on had little impact on priming.

A further argument that might be mounted against unconscious orthographic activation is that the instructions for the ratings emphasized phonology. In wording the instructions, the target was not referred to as a "sound", but it proved impossible to do the same for the prime because there was no other way of indicating what the target was to be compared to. Therefore, it might be argued that the focus of the participants was directed toward the phonology of the prime and target when rating their similarity, despite the participants being fully aware of the orthographic relationship between them. In response to this, however, it needs to be pointed out that the lexical decision instructions also referred to the prime and target purely in phonological terms, yet the priming that was observed was orthographically based. Importantly, there was no priming at all on the basis of phonological similarity, despite the fact that the instructions referred to "sounds" and "utterances". If the ratings were biased by the focus of the instructions on phonology, it would be hard to explain why the lexical decision responses were not similarly biased.

If orthography is automatically activated, it is worth asking why orthographic identity had no impact on the similarity ratings (aside from the unlikely possibility that there was a ceiling effect). The answer to this might be that the automatic activation of orthography does not play a role in conscious processing when phonological similarity draws attention away from it. Obviously, there would have been awareness of the orthographic relationship between prime and target if attention had been explicitly directed toward that relationship, but it does not appear to be something that is self-generated. When there is no conscious focus on the relationship between the prime and target (i.e., in the lexical decision task), the automatic impact of orthography can come into play. Under these circumstances, the impact of orthography is greater than that of phonology because the prime and target are identical with respect to the former, but are only similar with respect to the latter. In fact, it appears that identity rather than mere similarity is required before facilitation can be observed, given that there was no phonological priming at all.

It was mentioned earlier that the lexical decision task could be open to the influence of strategies that might generate an orthographic effect (i.e., in relation to unprimed lexical decision studies such as Ventura et al., 2004, and Ziegler & Ferrand,1998). In particular, orthographic information might be recruited when there is uncertainty associated with making the binary "yes"/"no" response. The orthographic effects that might arise from this are those inherent in the target stimulus itself (e.g., its orthographic consistency) rather than those emerging from a relationship between the target and a masked prime. Nevertheless, it would be ideal to demonstrate the orthographic priming effect in a different task that does not involve a binary response.

The use of a naming response (i.e., shadowing of the spoken target) eliminates the decision component and, therefore, if an orthographic effect were observed when the spoken stimulus is simply repeated by the participant, this would strongly support an automatic effect. When Ventura et al. (2004) and Pattamadilok et al. (2007) used such a shadowing task, the orthographic consistency effect disappeared. However, it was apparent that shadowing was being performed at a very low level of processing because there was no sign of a frequency effect or a word/nonword difference either, (leading Ventura et al., 2004, and Pattamadilok et al., 2007, to conclude that the orthographic consistency effect arises during lexical processing).

Nevertheless, Slowiaczek et al. (2003) observed priming effects in a shadowing task and even reported that the orthographic effects that they obtained in the auditory lexical decision task were upheld in the shadowing task. For example, repetition of the word /greɪvi:/ (i.e., *gravy*) was facilitated by the prior presentation of /grævəl/ (i.e., *gravel*), whereas /sɪmpəl/ (i.e., *simple*) was not significantly primed by /sɪmbəl/ (i.e., *symbol*). Although a lack of interaction between the two types of prime-target relationship weakens their claims of orthographic priming, the results of Slowiaczek et al. (2003) still suggest that the shadowing task might hold some promise in being able to reveal orthographic effects. Experiment 3 therefore tests whether Pseudohomograph priming can be distinguished from Nonhomograph priming in a shadowing task.

EXPERIMENT 3

Method

Materials and procedure

The materials were identical to those used in Experiment 2. This time, however, participants were instructed to repeat aloud the target utterance. A voice-key was triggered by the onset of the spoken response and, in order to disentangle the recording of the target and the participant's response, latencies were measured from the offset of the target. Errors were recorded when the response did not match the target. Similarity ratings were again collected after the experiment following the same procedure as in Experiment 2.

Participants

A further 38 monolingual first-year Psychology students were tested in this experiment, with 20 allocated to each item file. None had participated in the earlier experiments.

Results

The data were treated in the same way as for Experiment 2, including the rejection of the error-prone pair *mow*/*foe*. Two participants were removed owing to their continual failure to trigger the voice-key, and cutoffs were applied to 1.88% of responses. Table 3 presents the mean shadowing times along with error rates, as well as similarity ratings. Errors were determined by a native English speaker who was unaware of the experimental conditions. Errors included mispronunciations that created a nonword (e.g., /s^č/ pronounced /sæč/) or word substitutions (e.g., *wall* for *wool*). Hesitations or stumbles would have been recorded as errors, but there were none.

Table 3 about here

Analysis of RTs showed no indication of any priming effects, all F's <1. However, the mean response time to the nonwords (408 ms) was significantly longer than that to the words (380 ms)[3], $F_1(1, 36) = 10.39$, $p < .01$; $F_2(1, 70) = 3.42$, $p < .1$; $minF'(1, 102) = 2.57$, $p > .1$; ES = 28, CI ±30. In contrast to the RT data, error rates revealed a significant interaction between relatedness and orthographic similarity, $F_1(1, 36) = 6.33$, $p < .05$; $F_2(1, 40) = 6.42$, $p < .02$; $minF'(1, 76) = 3.19$, $p < .1$; ES = 3.45, CI ± 2.25. This arose from the fact that the Nonhomographs showed significant inhibition relative to the Unrelated baseline, $F_1(1, 36) = 4.68$, $p<.05$; $F_2(1, 20) = 5.09$,

$p < .05$; *minF'*$(1, 53) = 2.44$, $p > .1$; ES = 1.95, CI ± 1.80, while the Pseudohomographs showed a non-significant facilitatory trend, $F_1(1, 36) = 3.20$, $p>.1$; $F_2(1, 20) = 2.05$, $p > .1$; *minF'*$(1, 44) = 1.25$, $p>.1$; ES = 1.50, CI ± 2.19. There were more errors made on the nonwords (5.68%) than the words (2.32%), $F_1(1, 36) = 8.16$, $p < .01$; $F_2(1, 70) = 9.53$, $p < .01$; *minF'*$(1, 90) = 4.40$, $p < .05$; ES = 3.45, CI ± 2.23.

Analysis of the similarity ratings showed exactly the same outcome as for Experiment 2: Relatedness was highly significant, $F_1(1, 36) = 370.81$, $p<.001$; $F_2(1, 40) = 297.32$, $p<.001$; *minF'*(1,) =, $p < .001$, ES = 2.75, CI ± 0.32, with no sign of an interaction with type of relatedness, F's < 1.29.

Discussion

The latency to repeat the spoken target was not affected at all by the nature of the prime, which contrasts with the findings of Slowiaczek et al. (2003) who observed orthographically based priming for shadowing latencies. However, participants were conscious of the primes in the Slowiaczek et al. (2003) study and, therefore, their priming effect may have been strategically generated. Furthermore, the interaction observed by Slowiaczek et al. (2003) on the latency measure between orthographic priming and phonological priming was by no means significant and, also, there was significant priming on error rates regardless of the prime-target relationship. So, it is possible that a conscious strategy in that study led to facilitation based on any relationship between the prime and target.

It was the interaction between Pseudohomograph priming and Nonhomograph priming on error rates that provides an indication of orthographic effects in the shadowing task of Experiment 3. The interaction came about, not because of a significant facilitation on the part of the Pseudohomographs (though there was a trend in that direction), but because primes that were phonologically similar to their targets, but orthographically different (i.e., Nonhomographs), rendered those targets harder to pronounce. It seems that phonological similarity between prime and target was enough to interfere with the correct pronunciation of the target, but that such interference could be overcome by virtue of the prime helping to activate the target word on the basis of its identical orthography.

The weakness of this argument is that the same pattern of results was not observed on the latency measure, particularly given that this measure was apparently tapping into lexical processes: Not only were latencies shorter when naming words than when naming nonwords, but faster latencies were associated with higher word frequency as determined by the subjective frequency norms of Balota et al. (2001), $r(42) = -.30$, $p < .05$. The failure to find the same Pseudohomograph priming on shadowing times as for lexical decision times might, therefore, imply that orthography is not automatically activated in spoken word recognition. However, if such a case were argued, the error pattern in the shadowing task would still need to be explained.

An alternative possibility is that a shadowing response is based on a sublexical translation from the auditory signal to the articulatory program, but that this translation can also be supported by a lexically stored articulatory program if it is activated quickly enough. The response to real words, and especially to higher frequency words, will therefore be expedited by the use of such lexical information relative to lower frequency words and nonwords. Importantly, it is possible to disrupt the sublexical generation of the articulatory program if there is a previous auditory signal (i.e., a prime) that is associated with similar, but non-identical articulatory gestures, hence reducing the accuracy of shadowing (e.g., generating /sæč/ instead of /sʌč/, or /wɔːl/ instead of /wʊl/). This could potentially happen with both Pseudohomograph and Nonhomograph primes, except that the former can overcome the disruption by means of the greater lexical support generated through the orthographic match between the prime and target. This support is not strong enough to facilitate response times, but is able to resolve any conflict within the developing articulatory program.

While an interpretation of the shadowing results is certainly not straightforward, it needs to be said that the pseudohomophone priming effect in visual word recognition has not been subjected to similar scrutiny. A naming task eliminates the decision component and, hence, addresses the issue of strategically based effects. However, when visual stimuli are to be named, the phonological activation required to perform the task means that the finding of a phonological priming effect, such as pseudohomophone priming (e.g., Lukatela & Turvey, 1994), is hardly surprising. The equivalent to a shadowing paradigm with visual materials would be a visual copying task. Given the lack of a pseudohomograph priming effect on latencies in the shadowing task of Experiment 3, the finding of a pseudohomophone priming effect on latencies to start copying a visually presented letter-string would potentially provide support for the idea that phonology is more important in reading than orthography is in speech processing. However, such data have never been reported.

GENERAL DISCUSSION

Previous research has demonstrated that orthographic information plays a role in the processing of spoken words, but there is nothing in that research that precludes the possibility that this only happens in order to perform the specific task at hand. Orthography might either provide additional cues for making a response, or facilitate the use of working memory that is required when processing auditory information in the particular task. In contrast, the present research provides evidence that the activation of orthographic information associated with an utterance is something that happens automatically. Facilitation is found in a lexical decision task (Experiments 1 and 2) when the spoken nonword prime can be spelled the same as the spoken target word (e.g., /dri:d/-/drɛd/), but not when the same phonological relationship between prime and target has a different spelling (e.g., /šri:d/-/šrɛd/), and this is true even though the relationship between the prime and target is effectively masked from awareness. It is apparent, then, that orthographic information makes an important contribution to the processing of spoken words.

Although a lack of awareness of the orthographic characteristics of the prime prevents the adoption of a conscious strategy that maps the orthography of the prime to that of the target, it could nevertheless be argued that orthographic information is activated purely for the strategic purpose of discriminating words from nonwords, and that this has an unconscious impact on the processing of the prime. In other words, if orthographic information provides added cues for deciding whether the target is a word or not, orthographic processing might remain unconsciously engaged throughout the whole trial, including the prime. So, while the matching of orthography between prime and target occurs automatically and not under strategic control, it cannot be categorically stated that orthography is always activated in the recognition of spoken words. Indeed, the data generated in the shadowing task (Experiment 3) where there is no decision component, supports this in terms of the RT data. However, even in that task, the error data imply that orthography plays a role when no decision is required to make the response.

At the very least, it can be said that the involvement of orthography in auditory word recognition might be no different in terms of automaticity to the involvement of phonology in visual word recognition. That is, the finding of a facilitatory effect on visual lexical decisions from a masked pseudohomophonic prime (e.g., *ripe* primed by *rype* more than by *rupe*), has led to the conclusion that phonology is automatically activated in visual word recognition (e.g., Rastle & Brysbaert, 2006). Any argument that might be made about the pseudohomograph priming effect being task-induced in the auditory lexical decision task can also be made in relation to the pseudohomophone priming effect observed in visual lexical decision. That is, if it can be argued that orthographic information is recruited solely to expedite auditory lexical decision performance, then the same thing can be said about phonological information in relation to visual lexical decision performance.

It should also be pointed out that the control conditions in the present study were more stringent than those used in studies of pseudohomophone priming. In particular, while a nonhomophone prime like *rupe* controls for the graphemic similarity of the pseudohomophone *rype* to its base-word (i.e., *ripe*), Taft (1982) suggests that there could be a direct association between two graphemes that are phonologically interchangeable (like *y* and *i*, but not *u* and *i*) with phonology being bypassed altogether. For this reason, a better test of pseudohomophone priming, and one that would be equivalent to the design used here to demonstrate pseudohomograph priming, would be to examine whether, for example, *leaf* is primed by the pseudohomophone *leef* relative to an unrelated control prime, whereas *deaf* is not primed by the nonhomophone *deef* relative to an unrelated control prime. Besner, Dennis, and Davelaar (1985) report such a result in the unmasked priming paradigm, but it has never been examined under masked conditions. Moreover, Taft (1991) criticizes the materials used by Besner et al. (1985) on the grounds that many of their items ignored the graphemic environment of the interchangeable letters.

It can be seen, then, that the evidence for an automatic involvement of orthography in speech processing is equivalent to the evidence for an automatic involvement of phonology in reading, at least within the priming paradigm. In fact, given that an acoustic signal is more variable and degraded than a printed letter-string, it could be argued that the necessity for extra cues is greater in speech recognition than in reading and that, therefore, the importance of orthographic activation in auditory lexical processing is potentially greater than phonological activation in visual lexical processing.

We turn now to a consideration of the actual mechanisms involved in the orthographic priming effect. Many models of lexical processing argue that activation resonates between orthographic and phonological units of representation (e.g., Jacobs, Rey, Ziegler, & Grainger, 1998; Stone, Vanhoy, & Van Orden, 1997; Taft, 1991). Such resonance at the sublexical level (e.g., between graphemes and phonemes, and/or larger subsyllabic units) means that acoustic input activates a phonemically-based representation which, in turn, activates the associated orthographic representation. For example, presentation of /dri:d/ might activate units representing /i:/, /dr/, /i:d/, etc, which then send activation to their corresponding orthographic units (e.g., /i:/ → *ee* and *ea*; /i:d/ → *eed* and *ead*). Recognition of the target word /drɛd/ could then be potentially facilitated as a result of either primed orthographic representations or primed phonological representations. Orthographically based priming would occur if the spoken target is itself transformed into an orthographic representation (e.g., /drɛd/ → *dread*) hence matching with the sublexical orthographic units (e.g., *dr* and *ead*) that were activated by the prime. Phonologically based priming would occur if these sublexical orthographic units send activation back to their corresponding phonological units, thus pre-activating the phonological form /drɛd/ via the link that exists between *ead* and /ɛd/ (and/or between *ea* and /ɛ/).

In fact, we can rule out the phonologically based priming as an explanation because it should also happen with Nonhomographic items, like /šri:d/-/šrɛd/. That is, the pathway /i:d/ → *ead* → /ɛd/, activated by the prime, should facilitate recognition of /šrɛd/ to the same extent that it facilitates recognition of /drɛd/. On the other hand, the orthographic representation generated from the target /šrɛd/ (i.e., *shred*) will not have been pre-activated by the prime /šri:d/ because there is no link from the phonological unit /i:d/ to the orthographic unit *ed*. So, the results support the idea that the spoken target word is recoded into its orthographic form and that the facilitation arises within the orthographic processing system.

Note that this orthographic facilitation depends on sublexical orthographic information being activated for the prime (e.g., /dr/ → *dr* and /i:d/ → *ead*). Such a conclusion appears to conflict with the fact that neither Zeigler and Ferrand (1998) nor Ventura et al. (2004) obtained their orthographic consistency effect when the items were nonwords, which might imply that their orthographic effect arose lexically rather than sublexically. However, as Zeigler and Ferrand (1998) point out, the impact of sublexical resonance on lexical decision times to nonwords could well be obscured by the simple "timing out" of the response when no lexical representation reaches the activation threshold that allows recognition. One of the advantages of the present priming study is that the involvement of sublexical information in orthographic activation cannot be obscured by the requirement of a "No" response because the impact of sublexical resonance arises from the nonword prime rather than the word target.

Having said this, though, an alternative basis for the orthographic effect can be suggested that does not involve sublexical resonance between phonology and orthography at all. This is the possibility that the lexicon contains abstract phonological representations that are influenced by orthography (e.g., Taft, 2006; Taft and Hambly, 1985) and that the orthographic priming effect therefore arises solely within the phonological system. The proposed abstract representations can be seen as phonemic versions of the spelling of the word rather than phonemic abstractions of the phonetic form of the word. So, for example, *lagoon* is represented phonologically as /lægu:n/ (rather than /ləgu:n/), *folk* as /folk/ (rather than /foʊk/), and *dread* as /dri:d/ (rather than /drɛd/). The idea is that the phonological representation amalgamates orthographic and phonological information (see also Ehri & Wilce, 1980) and serves as a mediator, both at input and output, between spelling and sound.

Evidence comes from judgements of whether a visually presented nonword is pronounced identically to a real word or not (Taft, 2006) using participants from a non-rhotic dialect of English where post-vocalic *r* is not pronounced (making *floor* homophonic with *flaw*, for example). Such non-rhotic speakers are found to have considerable difficulty detecting the homophony of a nonword with a word when a post-vocalic *r* is involved. For example, Taft (2006) found that it was hard for non-rhotics to classify *cawn* and *forl* as homophones (i.e., homophones of *corn* and *fall* respectively), though only when performing the task silently. It was suggested that the post-vocalic *r* is manifested as /r/ within the phonological representation even for a non-rhotic speaker because it is found in the spelling of the word. A person only becomes non-rhotic when the letter-string is overtly pronounced. Thus, the abstract phonological representations of *cawn* and *corn* do not match, even though they are homophonic for the non-rhotic speaker.

Such a notion of orthographically influenced phonological representations provides an alternative account for the orthographic effects observed in auditory tasks. In particular, orthographic representations are not explicitly activated, but rather, the effects arise within the phonological system. Thus, /dri:d/ primes the homographic word /drɛd/ because the latter is actually represented at some level as /dri:d/, reflecting the *ea* found in its spelling.

Regardless of whether the pseudohomograph priming observed in the present study should be explained in terms of orthographic representations or in terms of orthographically influenced phonological representations, the point remains that when we learn to read and spell, our processing of spoken words fundamentally changes.

Orthographic information is shown to have a clear impact on auditory word recognition in a situation where conscious strategic effects are minimized.

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Appendix

The following are the Pseudohomograph and Nonhomograph items used in Experiment 1. Note that pronunciations are given for Australian English.

PSEUDOHOMOGRAPHS			NONHOMOGRAPHS		
Prime	**Target**	**Spelling of Target**	**Prime**	**Target**	**Spelling of Target**
/mɔst/	/moʊst/	most	/rɔst/	/roʊst/	roast
/trʌθ/	/tru:θ/	truth	/jʌθ/	/ju:θ/	youth
/fɔlk/	/foʊk/	folk	/dZɔlk/	/ dZoʊk/	joke
/čælk/	/čɔ:k/	chalk	/hælk/	/hɔ:k/	hawk
/flu:d/	/flʌd/	flood	/stu:d/	/stʌd/	stud
/swæp/	/swɔp/	swap	/stæp/	/stɔp/	stop
/dri:d/	/drɛd/	dread	/šri:d/	/šrɛd/	shred
/loʊs/	/lu:z/	lose	/broʊs/	/bru:z/	bruise
/kælf/	/kɑ:f/	calf	/stælf/	/stɑ:f/	staff
/pʌl/	/pʊl/	pull	/wʌl/	/wʊl/	wool
/taʊč/	/tʌč/	touch	/saʊč/	/sʌč/	such
/broʊd/	/brɔ:d/	broad	/froʊd/	/frɔ:d/	fraud
/wɔ:θ/	/wɜ:θ/	worth	/bɔ:θ/	/bɜ:θ/	birth
/saʊp/	/su:p/	soup	/laʊp/	/lu:p/	loop
/fu:t/	/fʊt/	foot	/pu:t/	/pʊt/	put
/grɔs/	/groʊs/	gross	/dɔs/	/doʊs/	dose
/frɔnt/	/frʌnt/	front	/blɔnt/	/blʌnt/	blunt
/jaʊŋ/	/jʌŋ/	young	/laʊŋ/	/lʌŋ/	lung
/stæl/	/stɔ:l/	stall	/kræl/	/krɔ:l/	crawl
/swɔ:d/	/sɔ:d/	sword	/sweɪf/	/seɪf/	safe
/hi:rt/	/ha:t/	heart	/pi:rt/	/pa:t/	part
/maʊ/	/moʊ/	mow	/faʊ/	/foʊ/	foe

Table 1: Mean lexical decision times (msec) as measured from the onset of the target and % error rates (in parentheses) for Experiment 1.

	Example	Detectors RT	Detectors Effect	Non-Detectors RT	Non-Detectors Effect
PSEUDOHOMOGRAPHS					
Related prime	/dri:d/-/drɛd/	891 (0.50)	**+30** **(+2.99)**	880 (0.50)	**+31** **(+0.97)**
Unrelated prime	/p^š/-/drɛd/	921 (3.49)		911 (1.47)	
NONHOMOGRAPHS					
Related prime	/šri:d/-/šrɛd/	903 (5.78)	**+11** **(-0.70)**	901 (2.02)	**-17** **(+2.42)**
Unrelated prime	/graʊp/-/šrɛd/	914 (5.08)		884 (4.24)	

Table 2: Mean lexical decision times (msec) as measured from the onset of the target and % error rates (in parentheses) for Experiment 2, along with ratings of similarity between prime and target (max 7).

	Example	RT	Effect	Similarity ratings
PSEUDOHOMOGRAPHS				
Related prime	/dri:d/-/drɛd/	820 (1.83)	**+26 (+1.07)**	4.54
Unrelated prime	/pʌš/-/drɛd/	846 (2.90)		1.76
NONHOMOGRAPHS				
Related prime	/šri:d/-/šrɛd/	863 (3.91)	**-4 (+0.40)**	4.39
Unrelated prime	/graʊp/-/šrɛd/	859 (4.31)		1.71

Table 3: Mean shadowing times (msec) as measured from the offset of the target, and % error rates (in parentheses) for Experiment 3, along with ratings of similarity between prime and target (max 7).

	Example	RT	Effect	Similarity ratings
PSEUDOHOMOGRAPHS				
Related prime	/dri:d/-/drɛd/	368 (1.55)	**+5** **(+1.43)**	4.57
Unrelated prime	/pʌš/-/drɛd/	373 (2.98)		1.78
NONHOMOGRAPHS				
Related prime	/šri:d/-/šrɛd/	387 (3.10)	**+5** **(-1.60)**	4.39
Unrelated prime	/graʊp/-/šrɛd/	392 (1.50)		1.74

Footnotes

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1 : The effect size (ES), as reported throughout, is based on the item analysis.

2 : Confidence intervals were determined from the PSY program for statistical analysis (Bird, Hadzi-Pavlovic, & Isaac, 2000) which calculates the exact square error, and thus the precise confidence interval, for each contrast in a simultaneous analysis (see Bird, 2004). This approach differs from procedures that use only an estimated square error to calculate confidence intervals (e.g., Masson & Loftus, 2003).

3 : The item mean for each word was the average of the related and unrelated conditions under which the word was presented.