Visual and Auditory Priming Influences the Production of Low-Frequency Spellings

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Abstract

Three experiments investigated whether production of low-frequency spellings could be influenced by other words containing those spellings. Participants saw visually-presented primes (Experiment 1) or heard primes presented auditorily and produced their spelling (Experiments 2 and 3). Primes either shared both orthography and phonology (e.g., *chaplain*) or only orthography (e.g., *ordain*) with the target word (e.g., *porcelain*). Following the primes, participants attempted to produce the correct spellings of auditorily-presented target words containing low-frequency spellings, such as the *ai* in *porcelain*. Participants correctly spelled the targets' low-frequency spelling more often when preceded by either type of prime, relative to unprimed targets. Furthermore, priming only occurred when the prime's spelling was produced correctly; primes spelled incorrectly reduced the correct production of target spellings. These results suggest that unlike the priming of nonwords, the basis of lexical priming of real words is orthographic, resulting from the priming of specific graphemes that increases the probability of reactivating the same spelling pattern in the target.

Keywords: orthography; priming; production; spelling

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Certain words in the English language are notoriously difficult to spell (Deighton, 1973; Norback & Norback, 1974; Proctor, 1993; Shaw, 1993). However, spelling the entire word is not usually problematic; rather, specific letters are often the culprit, and deficits can be linked to the number of occurrences of a particular spelling. Regular-inconsistent words contain sounds that may be spelled in more than one way (e.g., Houghton & Zorzi, 2003), and the inconsistency often arises from a vowel (e.g., Kessler & Treiman, 2001). For example, the vowel /I/ is spelled with an *i* in *cousin,* but it can also be spelled with an *ai* as in *certain,* an *e* as in *frozen,* an *o* as in *button,* etc. Furthermore, these various spellings can be either high or low in terms of their frequency of usage in words. A high-frequency spelling is common, found in many words. For example, the letter *i* in *cousin* is a high-frequency spelling because many words contain that spelling for that vowel, e.g., *bulletin*, *robin*, *origin*. In contrast, a spelling is low-frequency if it is unique or uncommon, such as the *ai* in *porcelain*, which occurs in considerably fewer words, e.g., *mountain*, *villain*. These low-frequency spellings, along with irregular spellings that are spelled differently from their pronunciations, e.g., *yacht*, are the cause of many spelling difficulties (e.g., Burt & Tate, 2002; Holmes & Ng, 1993; vos Savant, 2000; Waters, Bruck, & Seidenberg, 1985). The present research investigated whether production of low-frequency spellings could be facilitated by presenting those spellings in other words, using a priming paradigm.

Previous priming studies have demonstrated priming of spelling production, i.e., recent presentation of words can influence production of those words' spellings (e.g., Barry & Seymour, 1988; Jacoby & Hollingshead, 1990). Typically, the methodologies of priming studies involve exposing participants to the “prime” word in some way, such as through reading, writing, or typing individual words. Then, after some delay, participants are asked to spell the primes (which are now the target words). Studies using correct spellings as primes have shown that recent presentation of a correctly-spelled word increases the ability to produce the correct spelling of that word (e.g., Bradley & King, 1992; Dixon & Kaminska, 1997; Jacoby & Hollingshead, 1990). However, having identical primes and targets is not necessary to achieve these priming effects. Research on lexical priming of nonword spelling has shown that prior presentation of a rhyming word influences the spelling of nonwords (e.g., Barry, 1992; Barry & de Bastiani, 1997; Barry & Seymour, 1988; Burden, 1989; Campbell, 1985; Folk & Rapp, 2004; Perry, 2003; Snowling, 1994). In fact, both rhymes (e.g., *boot*) and non-rhyming words containing the same vowel (e.g., *mood*) increased the spelling of /vut/ as *voot* relative to unrelated control words, although the effect was smaller for non-rhyming words (e.g., Barry, 1992; Barry & de Bastiani, 1997). Nonword primes can also influence nonword spelling (e.g., Perry, 2003), suggesting that these priming effects can operate not only at the whole-word level, but also at the level of individual sound-to-spelling correspondences (e.g., Barry & Seymour, 1988).

Priming sound-to-spelling rules when spelling nonwords is consistent with interactive dual-route models (e.g., Barry & de Bastiani, 1997; Barry & Seymour, 1988; Folk & Rapp, 2004; Houghton & Zorzi, 2003), which would also predict priming of low-frequency spellings when spelling real words. Dual-route models of spelling propose that there are two different mechanisms by which the spelling of a word can be produced. One route is an assembled or phonological route, which constructs spellings by parsing a word into its sounds and then mapping the individual sounds to letters. This route accesses spelling indirectly via its sounds and is used for spelling nonwords as well as high-frequency spellings that are predictable given the sound-to-spelling patterns of English. The other route is the word-specific or lexical route, which retrieves the spellings of known words as a whole unit from an orthographic lexicon stored in long-term memory. This route accesses the spellings of known words directly, so it is used for spelling words that contain low-frequency spellings, or spelling patterns that do not typically occur for a given sound; we memorize these exceptions to the "typical" spelling. Because the lexical route is memory-based, spelling errors using this route are more likely to arise when a word's spelling has not been well-learned or has not been used in a relatively long time. Priming a similar spelling via recent presentation can make these exception spellings more accessible than other possible spellings.

However, the alternative prediction, that priming will not occur, can be made based on the results of Folk and Rapp (2004). In their lexical priming experiments, using real-word primes and nonword targets, they found priming when the primes (e.g., *head*) and targets rhymed (e.g., *pead*) and when they shared the syllable initial consonant and vowel (e.g., *heaf*). However, they found no priming when the primes and targets only shared a vowel (e.g., *leam*). The present studies used primes and targets consisting of multisyllabic words, so that the speech sound or sounds to be primed were only a small portion of the entire word, usually a vowel or a vowel plus a consonant. Therefore, such minimal overlap between primes and targets may be insufficient for priming to occur. Another reason that lexical priming of words may not occur is that the priming effects for nonwords dissipate over time. Perry (2003) found lexical priming of nonwords across one or two intervening fillers (to a similar degree), but the amount of priming was considerably less than when no filler items intervened. The present studies instituted much larger intervals between the primes and targets, and it is unknown whether priming effects can be achieved over intervals beyond a couple of intervening items.

We designed three experiments to examine orthographic priming of low-frequency spellings in real words, i.e., whether presentation of a particular spelling pattern can prime the production of similarly-spelled words. Experiment 1 investigated whether low-frequency spellings influenced production of other words containing low-frequency and high-frequency spellings using primes presented visually. Experiments 2 and 3 used auditorily-presented primes to investigate priming as well as the importance of phonology by using primes that were pronounced identically to the target spelling (Experiment 2), or primes containing the intended spelling but that were pronounced differently (Experiment 3).

Experiment 1

In this experiment, we investigated whether primes containing a low-frequency spelling (e.g., *certain*) influenced the ability to spell other stimuli, specifically words containing the same low-frequency spelling (e.g., *porcelain*) and words containing a high-frequency spelling (e.g., *cousin*). Unlike previous priming studies, our primes and targets consisted of multisyllabic words. Nonetheless, we predicted that low-frequency spellings would facilitate spelling production of other words with those identical spellings. In contrast, presentation of low-frequency spellings was not expected to impact high-frequency spellings. High-frequency spellings like the *i* in *cousin* contain many words with that spelling (e.g., *bulletin*, *robin*, *origin*), and because of these vowels' high sound-to-spelling consistency, their spellings would be easy to spell, independent of recent presentation of other spellings.

Method

Participants. The 48 participants were undergraduate students aged 18-23 (39 females and 9 males, *M* = 19.7 years, *SD* = 1.5) recruited from introductory psychology and cognitive psychology classes. Participants received either partial course credit or extra credit for their participation. All participants were native English speakers.

Apparatus and Materials. The experiment was performed on Pentium II, 350 MHz, PC-compatible computers using a computer program written in Visual Basic 5.0. Seventy-nine words containing a high-frequency spelling and 112 words containing a low-frequency spelling were compiled from various books on spelling (Deighton, 1973; Norback & Norback, 1974; Proctor, 1993; Shaw, 1993). High- and low-frequency spellings within each word were determined by assessing the number of words reported in Kučera and Francis (1967) with that spelling and pronunciation, so that high-frequency spellings were defined as occurring in more words than low-frequency spellings. A pilot study auditorily presented subsets of these words to 72 college students, who were asked to produce the correct spellings. The results of the pilot study yielded twelve complementary low- and high-frequency spellings, such as *ai* and *i*, for a particular speech sound(s)[1].

Four words were selected for each speech sound: a target word that contained the low-frequency spelling, a target word that contained the high-frequency spelling, and two prime words that contained the same low-frequency spelling as the low-frequency target. It was not always possible to choose two primes where both shared phonology with the low-frequency target spelling (e.g., *canoes* and *tomatoes* as primes for *heroes*), but one of the primes (e.g., *tomatoes*) always contained the same phonology as the target. The low-frequency spellings in the prime words were spelled with at least 80% accuracy in the pilot study to ensure that primes were words that most participants knew how to spell. For the targets, the low-frequency spelling was spelled correctly with 20-80% accuracy in the pilot study to avoid ceiling and floor effects. In contrast, the corresponding high-frequency spelling was spelled correctly with an accuracy of

95% or better in the pilot study, indicating their ease of spelling (we were unable to find words spelled with a lower degree of accuracy). In terms of the words' Pastizzo and Carbone (in press) frequency[2], the primes consisted of both low- and high-frequency words (M = 68.6, SD = 111.3), as did targets with a high-frequency spelling (M = 71.0, SD = 159.1). In contrast, targets with a low-frequency spelling were also low in word frequency (M = 2.8, SD = 4.8). Primes and targets are shown in Appendix A.

The priming phase consisted of 24 words, 12 prime words and 12 filler words. Each participant was primed twice for six of the 12 target spellings, with the two primes per target spelling presented five words apart. The six spellings selected for priming were counterbalanced across participants in four different versions. The other six target spellings were not presented during the priming phase to get a baseline probability of producing the target spelling independent of priming. Whether a particular target was primed or unprimed was counterbalanced across versions. The remaining 12 words were unrelated fillers intermixed among the primes, presented to minimize participants' detection of any relationship between the primes. In the test phase, 36 words were presented, where 12 were target words containing the low-frequency spelling, 12 were target words containing the high-frequency spelling, and 12 were new, unrelated filler words. The various ordering of the primes and targets resulted in one to 39 possible words that intervened between seeing the second prime and hearing the target.

Procedure. In the priming phase, participants were shown a list of 24 words visually presented one at a time and were asked to read silently half of the words and to spell aloud letter-by-letter the other half, with exposure task blocked and order of the two exposure tasks counterbalanced across participants. This manipulation was not expected to differentially influence priming, similar to Hadley, Abrams, and McCord (2000), but was included in the event that possible differences specific to our priming task arose. The priming task was self-paced, with participants pressing a key to bring on the next word. In the test phase, participants heard 36 auditorily-presented words through a computer speaker and were asked to write down the correct spelling for each word. Participants could replay the word as many times as they chose by pressing a key. The first 24 words alternated between the 12 target words containing the low-frequency spelling of the primes and 12 new, unrelated filler words. The 12 target words containing the high-frequency spelling were then presented; the high-frequency spellings followed the low-frequency spellings so that they did not interfere with the priming manipulation. At the conclusion of the spelling test, all participants were given a written and verbal debriefing.

Results and Discussion

To examine whether reading silently versus spelling aloud differentially affected spelling production, a 2 (Target Spelling: low-frequency, high-frequency) x 2 (Exposure Condition: reading primes silently vs. spelling primes aloud) repeated-measures analysis of variance (ANOVA) by participants ($F1$) and by items ($F2$) was performed on the proportion of time the "target spelling" was spelled correctly. The target spelling was designated as the specific vowel that was primed (e.g., the *ai* in *porcelain* versus the *i* in *cousin*). Since the target spelling was the dependent measure, it was counted as correctly spelled when reproduced correctly even if spelling errors occurred in other places within the word. This analysis yielded no main effect of exposure condition, $F1(1,47) = 1.34$, $MSE = .03$, $p > .26$, $F2(1,22) = 1.28$, $MSE = .01$, $p > .27$, nor any interaction with exposure condition, $F1 < 1$, $F2 < 1$, so the remaining analyses collapsed this variable into a single priming condition.

A 2 (Target Spelling: low-frequency, high-frequency) x 2 (Priming Condition: primed, unprimed) ANOVA was performed on the proportion of target spellings correctly produced. Table 1 displays the means and standard errors from this analysis, converted into percents. There were significant main effects of target spelling, $F1(1, 47) = 164.11$, $MSE = .04$, $p < .01$, $F2(1, 22) = 46.45$, $MSE = .03$, $p < .01$, and priming condition (marginal in the item analysis), $F1(1, 47) = 4.47$, $MSE = .01$, $p < .04$, $F2(1, 22) = 2.88$, $MSE = .01$, $p < .10$. These effects were moderated by a significant Target Spelling x Priming Condition interaction, $F1(1, 47) = 4.70$, $MSE = .02$, $p < .04$, $F2(1, 22) = 4.15$, $MSE = .01$, $p < .05$. Further analysis of this interaction revealed significant priming of low-frequency spellings, where the target spellings that were preceded by primes were spelled correctly more often than unprimed target spellings, $p1 < .03$, $p2 < .02$. In contrast, primes had no effect on high-frequency spellings, where the target spellings were produced equivalently with and without presentation of low-frequency primes, $p1 > .49$, $p2 > .82$.

Insert Table 1 about here

As predicted, the results demonstrated a significant priming effect for target words containing a low-frequency spelling. Presenting primes that contained a low-frequency spelling increased production of those same spellings embedded in other words. These results are consistent with dual-route theories, where low-frequency spellings are produced via the lexical route, and priming occurs because seeing the correct spelling within the prime makes that same spelling more accessible when attempting to spell the target. These priming effects are also consistent with repetition priming effects on spelling production (e.g., Bradley & King, 1992;

Dixon & Kaminska, 1997; Jacoby & Hollingshead, 1990) and demonstrate that priming can occur for particular spelling patterns within whole words, contrary to Folk and Rapp (2004), who did not find priming of a single vowel when spelling nonwords. The lexical priming of words may not require larger units, such as the word body, because those particular spelling patterns, even a single vowel, have been used before in that exact context, enabling their reactivation. Furthermore, the relatively large number of words intervening between primes and targets indicate that these priming effects are not due to residual activation left in the spelling system from exposure to the prime word, which would have dissipated across so many items. Instead, the priming effects seem to be caused by changes in resting activation levels of a sound-to-spelling rule, which modify the speed and probability that a node is subsequently activated (see Perry, 2003, for more detail on this argument).

In contrast, priming low-frequency spellings had no effect on the ability to spell high-frequency spellings. Ceiling effects occurred, where participants were nearly perfect in producing a high-frequency spelling, both before and after priming, suggesting that the orthographic representations of these common spellings are stable and therefore resistant to the recent influence of low-frequency spellings. These ceiling effects also support the idea that high-frequency spellings are assembled via the phonological route, which is less susceptible to errors when words are spelled the way they sound.

Experiment 2

Despite finding priming in Experiment 1, several questions remain. By using visual presentation, the prime's correct spelling was always given. Therefore, it cannot be determined how well participants knew those spellings and represented them in memory. To account for an individual's knowledge about the primes' spellings and how that knowledge contributes to priming, primes were presented auditorily instead of visually in Experiment 2, and participants were asked to spell the primes. Auditory presentation also offers the advantage of a direct comparison of primes spelled correctly versus incorrectly and their effects on subsequent spelling production. Several studies using misspellings as primes have shown that presenting misspellings decreases the ability to produce the correct spelling of the identical word (e.g., Brown, 1988; Dixon & Kaminska, 1997; Jacoby & Hollingshead, 1990), suggesting that the correctness of the prime's spelling may be a critical determinant of producing low-frequency target spellings.

If the priming effects in Experiment 1 were due to priming the specific spelling patterns, then the direction of the priming effects in Experiment 2 should depend on the particular spelling produced in the prime. Specifically, priming of targets' low-frequency spellings should only occur for primes spelled correctly. For example, spelling *mountain* (a prime) would require retrieval of the rule that /I/ is spelled with *ai* in this word. Consequently, spelling *porcelain* (a target), which utilizes the same spelling rule, would be easier because of the recent use of the identical rule. In contrast, misspelling the primes should not increase production of similarly-spelled words and in fact could adversely influence the ability to produce the target spellings correctly because of priming the wrong spelling pattern. The particular misspelling produced within the prime may also be important. Misspelling the prime using a high-frequency spelling (e.g., *mountin)* may be especially likely to influence the spelling of the target by using the same spelling pattern (e.g., *porcelin*) because of spelling's high sound-to-spelling consistency.

Method

Participants. Participants included 45 young adults, 31 female, 14 male, who ranged in age from 18-22 (*M* = 19.4 years, *SD* = 1.3). Participants were recruited from introductory psychology classes and participated in fulfillment of partial course credit. All participants were native English speakers.

Apparatus and Materials. A computer program written in Visual Basic 5.0 presented the experiment. Using a pilot study similar to the one described in Experiment 1 to identify targets, 24 low-frequency target spellings[3] were selected, five of which had been used in Experiment 1 and could be adapted for this experiment. Each target spelling was assigned a target word containing the low-frequency spelling (e.g., *porcel<u>ai</u>n*) and was paired with a single prime word containing the same orthography and phonology as the target (e.g., *chapl<u>ai</u>n)*. Only one prime was used instead of two primes to see if a single exposure was sufficient to induce priming and to ensure that the prime's phonology always matched the target's spelling. In the pilot study, participants spelled both primes and targets. Targets' low-frequency spellings were spelled correctly 58.7%, whereas the low-frequency spelling in the primes was spelled correctly 70.1% of the time. Primes and targets were generally low in Pastizzo and Carbone (in press) word frequency, with primes (M = 6.3) and targets (M = 6.5) having similar word frequencies. Appendix B lists the primes and targets used in Experiment 2.

The priming phase consisted of 36 words, 16 prime words intermixed with 20 filler words that did not overlap in spelling with any of the primes or targets. In the test phase, 24 words containing a low-frequency spelling were presented. Type of prime (primed, unprimed) was counterbalanced across participants in three experimental versions, where eight primes were presented, and the remaining eight primes were not presented, so that some targets' spellings would be assessed without prior exposure. Words in both the priming and test phases were randomly ordered, with the exception of two words, *descendant* and *pageant*, that were fixed in positions 2 and 23 in the test phase because of their phonological and orthographic overlap, which could potentially cause priming inadvertently.

Procedure. In the priming phase, words were auditorily presented via computer one at a time, and participants were asked to type the word's correct spelling in a box appearing on the computer screen. To minimize mishearings, participants could replay each word once by clicking the mouse button; however, only one replay was permitted to avoid an excessive amount of exposure to a particular prime. The priming phase was self-paced, allowing participants to press the Enter key after typing their response to hear the next word. To ensure that priming was not a function of immediate testing following primes in Experiment 1, a delay between priming and the test was instituted by having participants complete math exercises for 15 minutes following the conclusion of the priming phase. Then, the test phase consisted of the targets auditorily presented one at a time, and participants typed each word's spelling. In this phase, targets could be replayed as many times as necessary by clicking the mouse button. After the test phase, a post-experiment questionnaire was administered verbally to assess participants' awareness of any relationship between the primes and targets and to evaluate participants' intent to use the primes as cues to facilitate their production of the target's spelling. All participants were then given a written and verbal debriefing.

Results and Discussion

Responses on the post-experiment questionnaire were evaluated to assess participants' awareness of the priming manipulation and intent to use the primes as cues to facilitate production. Only two participants reported that they noticed a relationship between words spelled in the first spelling test (priming phase) and words spelled in the second spelling test (test phase). However, both described a relationship that was irrelevant to our priming manipulation, e.g., one person stated that "several of the words had two of the same letters in a row, e.g. accommodate". Mishearings were excluded from all analyses and rarely occurred, with 0.4% of primes and 1.7% of targets having mishearings. Because the primes were presented auditorily, analyses were conducted separately for primes whose low-frequency spelling (e.g., the *ai* in *chaplain*) was spelled correctly versus incorrectly, and the means and standard errors from both analyses converted into percents are shown in Figure 1.

Insert Figure 1 about here

A paired samples t-test was conducted by participants (*t*1) and by items (*t*2) to compare the proportion of target spellings correctly produced for primed versus unprimed targets. For primes whose low-frequency spelling was produced correctly (which occurred 64.8% of the time), the t-tests revealed a significant priming effect, $t1(44) = 2.7$, $SE = .04$, $p < .01$, $t2(22) = 2.5$, $SE = .05$, $p < .02$, demonstrated by greater production of the target spelling within targets following primes relative to unprimed targets. In the analysis for primes spelled incorrectly, the paired-samples t-tests revealed a marginally significant inhibitory effect, $t1(38) = -1.74$, $SE = .06$, $p < .09$, $t2(19) = -3.45$, $SE = .05$, p < .01, where target spellings were produced correctly *less* often following primes spelled incorrectly than when targets were not primed.

The next analysis explored whether these inhibitory effects were a result of priming from the incorrect spelling. Misspelled primes were categorized as having the high-frequency spelling (e.g., misspelling *chaplain* as *chaplin*) or having some other spelling (e.g., *chaplan*). Among these two types of misspellings, primes were misspelled more often using the high-frequency spelling, occurring 66.7% of the time when errors were made. A paired-samples t-test was conducted to compare whether targets were more likely to be misspelled using a high-frequency misspelling (e.g., *porcelin*) when following a misspelled prime relative to unprimed targets. This test was significant, $t(27) = 2.85$, $SE = .07$, $p < .01$, demonstrating a greater probability of misspelling the target's low-frequency spelling in the same way as the prime ($M = .89$, $SE = .05$) compared to targets that were not primed ($M = .70$, $SE = .05$).

The results of Experiment 2 extended the priming observed in Experiment 1 to auditorily-presented primes and demonstrated that priming can occur across even longer prime-target intervals (across items as well as an additional 15-minute delay), consistent with Perry's (2003) claim that these priming effects are due to changeable resting levels, in this case of specific sound-to-spelling rules. Furthermore, priming was contingent on correctly spelling the low-frequency spelling within the prime. Incorrectly spelling the prime's low-frequency spelling was detrimental to production of the target spelling, resulting in a decreased ability to spell similarly-spelled words, consistent with research showing that perception of misspellings can negatively influence later production of those same misspelled words (e.g., Brown, 1988; Dixon & Kaminska, 1997; Jacoby & Hollingshead, 1990). Incorrectly spelling the prime also served as its own priming effect. Misspelling the prime with a frequent spelling for that sound (e.g., *reciept*) increased the likelihood of misspelling the target using that same spelling (e.g., *concieve*), i.e., the misspelling produced in the prime was later primed for production when spelling the target.

Because the primes and targets overlapped in both orthography and phonology, the locus of the priming effects observed in Experiment 2 cannot be precisely determined. The priming effects could be due to either priming the specific graphemes in the target or priming the representations of mappings between individual phonemes and their corresponding graphemes (e.g., Barry & Seymour, 1988; Folk & Rapp, 2004). This issue will be examined in Experiment 3.

Experiment 3

Experiment 3 examined whether phonological overlap was necessary for the priming effects observed in Experiments 1 and 2 to occur. Folk and Rapp (2004) examined this issue in the priming of nonword spelling. Preceding nonword targets, e.g., /hɛf/ to be spelled *heaf*, they used word primes that had either orthographic overlap (the prime word's vowel, e.g., *leaf*, shared only orthography with the target spelling of the nonword's vowel) or phonological overlap (the prime word's vowel, e.g., *deaf*, shared both orthography and phonology with the nonword target spelling). They found significant priming from both types of primes, such that the target's vowel was spelled similarly to the prime, but there was less priming in the orthographic overlap condition. Folk and Rapp (2004) concluded that both orthographic and phonological factors contributed to priming of nonword spelling, such that orthographic overlap in the prime lexically preactivated the target graphemes (letters), and phonological overlap in the prime sublexically preactivated the phoneme-to-grapheme mappings within the target.

In Experiment 3, primes were chosen that contained a speech sound whose spelling was orthographically identical but phonologically distinct from the target, e.g., *ordain* as a prime for *porcelain*. In this experiment, the prime's spelling was not usually a low-frequency spelling anymore (e.g., *ai* is a common spelling for the sound /eI/), so we used the terminology "designated spelling" within the prime to refer to the vowel used to prime the low-frequency spelling within the target. If phonological overlap contributes to the priming effects observed in our previous experiments, then less priming should occur in Experiment 3 when primes and targets only overlap orthographically.

Method

Participants. Participants included 48 young adults, 37 female, 11 male, who ranged in age from 18-24 (*M* = 18.8 years, *SD* = 1.4). They were recruited from the same sources as previous experiments, although none had participated in either Experiments 1 or 2. All of the participants were native English speakers.

Apparatus and Materials. A PC-compatible computer using a program written in Visual Basic 5.0 was used to perform the experiment. Fifteen of the target spellings used in Experiment 2 were selected, as these were the ones amenable to finding primes that overlapped solely in orthography. As in Experiment 2, these targets contained low-frequency spellings that were difficult to spell in the pilot study (*M* = 58% correct) and were paired with a prime word containing the same spelling (orthography) but different phonology or pronunciation (e.g., *ordain)*. With respect to the frequency of the entire word, both the primes (*M* = 14.9) and targets (*M* = 8.3) were low in Pastizzo and Carbone (in press) word frequency. Appendix C lists the primes and targets used in Experiment 3.

The priming phase consisted of 28 words, eight prime words intermixed with 20 filler words that did not overlap in spelling with any of the primes or targets. Each participant was exposed to eight primes in the priming phase; seven primes were not presented to provide a baseline for correctly spelling the targets without prior exposure. The test phase contained 15 targets with low-frequency spellings. The target spellings were counterbalanced across participants as either primed or unprimed (not presenting the prime). Words in both the priming and test phases were presented in random order.

Procedure. The same procedure used in Experiment 2 was administered here.

Results and Discussion

As was done in Experiment 2, responses on the post-experiment questionnaire were evaluated. Three participants said that they noticed a relationship between the two spelling tests, but their description of the relationship had no bearing on the actual prime-target relationship. Two participants were excluded from analysis for not completing the experiment. Mishearings occurred infrequently, with 0.4% of primes and 1.0% of targets experiencing mishearings, and were excluded from analysis. As in Experiment 2, separate analyses were conducted as function of correctly or incorrectly spelling the designated spelling (e.g., the *ai* in *ordain*) when spelling the primes, and the means and standard errors from both analyses converted into percents are shown in Figure 2. Overall, the designated spelling within primes was spelled correctly 92.1% of the time, consistent with the high sound-to-spelling consistency of these vowels.

Insert Figure 2 about here

A paired samples t-test by participants ($t1$) and by items ($t2$) was conducted to compare the proportion of target spellings correctly produced for primed versus unprimed targets. For primes whose designated spelling was produced correctly, there was a marginally significant priming effect (in the participant analysis only), $t1(45) = 1.94$, $SE = .03$, $p < .06$, $t2(14) = 1.04$, $SE = .04$, $p > .31$, such that for primes whose designated spelling was produced correctly, their target spellings were spelled correctly more often than unprimed target spellings. However, for primes whose designated spelling was spelled incorrectly, there was no significant difference between primed targets and unprimed targets, $t(21) = 1.27$, $SE = .11$, $p > .22$, $t2(7) = .12$, $p > .90$, noting that the latter analyses were able to include only a subset of participants ($N = 22$) and items ($N = 8$) because of participants/items never spelled incorrectly.

To compare the sizes of the priming effects in Experiments 2 and 3, a 2 (Experiment: 2, 3) x 2 (Priming Condition: primed, unprimed) ANOVA was performed on the proportion of target spellings correctly produced. This analysis was done by participants only because the items differed across experiments. The results revealed only a significant main effect of Priming Condition, $F1(1,89) = 10.81$, $MSE = .03$, $p < .01$. Neither the main effect of Experiment, nor the Experiment x Priming Condition interaction, approached significance, $F1\text{s} < 1$.

Consistent with the previous experiments, orthographic priming occurred in Experiment 3 when the primes' spelling did not overlap in phonology with the target, similar to the findings of Folk and Rapp (2004) for priming of nonword spelling. However, the size of the priming effect in this experiment was equivalent to the priming effect found in Experiment 2, where the primes shared both phonology and orthography with the target. This finding suggests that phonological overlap did not contribute to priming effects on spelling production, contrary to Folk and Rapp (2004), who found larger priming effects when primes shared both phonological and orthographic overlap with nonword targets. The existence of priming independent of phonological overlap, along with the similarity of the priming effects for primes with and without phonological overlap, indicates that the source of lexical priming of real words is orthographic in nature. The mechanism underlying these priming effects is that spelling the prime preactivates specific graphemes and makes them more accessible for activation when spelling the target, rather than preactivation of the phoneme-to-grapheme mappings.

While correctly spelling the prime's designated spelling facilitated production of the target's low-frequency spelling, incorrectly spelling the prime's designated spelling had no significant effect, contrary to Experiment 2. However, this null finding should be interpreted with caution because the power to detect an effect in the incorrectly-spelled primes analysis was low; a large amount of participants were excluded, due to a high probability of spelling the prime's designated spelling correctly. Despite this nonsignificance, the trend for an inhibitory priming effect was consistent with that observed in Experiment 2, which was able to use primes whose low-frequency spelling was misspelled more often.

General Discussion

The results of the three experiments presented here demonstrate that the production of low-frequency spellings embedded within words can be facilitated by recent exposure to other words containing those spellings. The stability in the size of the priming effects across experiments (6.5-9.5%) is impressive, given the use of differing modalities (visual versus auditory), number of primes (one versus two), and presence or absence of phonological overlap. These findings are consistent with other types of priming effects, such as repetition priming effects on spelling production (e.g., Bradley & King, 1992; Dixon & Kaminska, 1997; Jacoby & Hollingshead, 1990) as well as lexical priming effects in the spelling of nonwords (e.g., Barry, 1992; Barry & de Bastiani, 1997; Barry & Seymour, 1988; Burden, 1989; Campbell, 1985; Folk & Rapp, 2004; Perry, 2003; Snowling, 1994). However, the present experiments extend these data by demonstrating that these priming effects can apply to specific spelling patterns embedded within different *words* and that the basis of priming the spellings of words is orthographic, in contrast to nonword priming that results from priming individual phoneme-to-grapheme mapping representations (Folk & Rapp, 2004). Although previous research has established that phonology is important in children learning to spell (e.g., Treiman, 1993, 2003; Treiman, Berch, Tincoff, & Weatherston, 1993) as well as adults' spelling (e.g., Treiman & Barry, 2000; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995), the present results suggest the *priming* effects obtained in spelling production rely more on orthographic overlap.

Priming of words and nonwords fundamentally differed in another aspect: the time course of priming. Perry (2003) showed that there was a significant reduction in priming of nonword spelling when one or two words intervened between the prime and target. In the present experiments, all of the primes were presented before spelling the targets, creating a significant number of intervening words, and priming still occurred, even with an additional 15-minute delay (in Experiments 2 and 3). Thus, priming of words can be demonstrated across much longer distances than has been shown with nonwords. Perhaps the impact of recent exposure on spelling production is more beneficial when spelling real words because their spellings were well-established in memory prior to priming, allowing them a greater amount of reactivation that does not decay as rapidly.

It is important to acknowledge the priming facilitated target spelling only when that spelling was correctly produced in the prime. Incorrectly spelling the prime not only decreased the likelihood of correctly producing the target spelling but also made it more likely that the error would match that produced in the prime. Therefore, the effect of encountering misspellings is more pervasive than previously thought (e.g., Brown, 1988; Dixon & Kaminska, 1997; Jacoby & Hollingshead, 1990); in addition to decreasing the ability to later spell the same words, producing misspellings can also harm the ability to spell similarly-spelled words (although this effect was marginal and only occurred for primes sharing both orthography and phonology with the target). Whether production of misspellings is necessary to achieve these effects is unknown; simply perceiving misspellings may also have an adverse effect on producing other words' spellings.

The findings of Experiment 1, where targets with low-frequency spellings showed priming but high-frequency spellings did not, suggest that words with less stable orthographic representations benefit more from the priming provided by recent exposure. If so, individual differences in spelling ability, i.e., good versus poor spellers, may also differentially affect priming. In general, poor spellers have more difficulty in correctly producing irregular and low-frequency spellings (e.g., vos Savant, 2000; Waters et al., 1985), which suggests that their orthographic representations for these words have weakened or were never well-learned. Consequently, recency of presentation of the low-frequency spelling via priming may help poor spellers more than good spellers (who have effectively memorized the low-frequency spellings), resulting in more priming for poor spellers.

In conclusion, the present research demonstrates that exposure to a particular low-frequency spelling can implicitly benefit production of that spelling within other words. Through exposure to these low-frequency spellings in other words, people can strengthen their orthographic representations to all words containing that spelling. It is worth noting that the benefits of recent presentation may cause a relatively long-term change in the strength of orthographic representations, meaning that the duration of these orthographic priming effects could be long-lasting. In support of this suggestion, Dixon and Kaminska (1997) found priming effects on spelling that lasted for one week. Whether these effects can last even longer, such as a month or year, and whether they are mediated by individual spelling ability, are questions for future research.

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Appendix A

Primes and Target Words Corresponding to Low- and High-Frequency Target Spellings

in Experiment 1

Low/High-Frequency Spelling	Prime Words	Target Word (Low-Frequency Spelling)	Target Word (High-Frequency Spelling)
ai/i	mountain certain	porcelain	cousin
cle/cal	article cycle	chronicle	magical
sy/cy	busy fantasy	hypocrisy	democracy
ege/edge	college privilege	allege	knowledge
oes/os	tomatoes canoes	heroes	autos
el/al	novel travel	parcel	fatal
or/er	collector junior	emperor	snicker
i/y	petticoat handicap	handiwork	bodyguard
ie/ei	relief brief	siege	weight
silent n /no n	column autumn	solemn	system
silent h /pronounced h	exhibit exhaust	exhort	inhabit
double consonant /single consonant	permission disappear	satellite	impolite

Appendix B

Primes and Targets Corresponding to the Target Spelling in Experiment 2

Target Spelling	Prime Word (Same Orthography, Same Phonology)	Target Word (Low-Frequency Spelling)
ible	plausible	feasible
ai	chaplain	porcelain
ant	resistant	descendant
cle	ventricle	chronicle
ea	endeavor	pageant
ege	sacrilege	privilege
el	chisel	mackerel
ence	persistence	existence
ury	luxury	perjury
ey	barley	odyssey
ff	graffiti	diffuse
fore	forecast	foresee
dge	ledger	bludgeon
ei	receipt	conceive
ise	franchise	chastise
it	deficit	pundit
eum	linoleum	mausoleum
oes	heroes	echoes
rh	rhubarb	rhythm
ar	calendar	beggar
eu	leukemia	maneuver
our	courtesy	bourbon
sy	hypocrisy	ecstasy
oe	amoeba	phoenix

Appendix C

Primes and Targets Corresponding to the Target Spelling in Experiment 3

Target Spelling	Prime Word (Same Orthography, Different Phonology)	Target Word (Low-Frequency Spelling)
ible	bible	feasible
ai	ordain	porcelain
ant	recant	descendant
ea	meager	pageant
ege	siege	privilege
el	parallel	mackerel
ence	commence	existence
ury	bury	perjury
ey	disobey	odyssey
ei	neighbor	conceive
ise	precise	chastise
oes	canoes	echoes
ar	seminar	beggar
our	hourglass	bourbon
oe	toenail	phoenix

Author Notes

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Footnotes

[1]Because of constraints of certain spelling rules, the low- and high-frequency spellings of two targets did not match each other in phonology (*siege* and *weight*; *exhort* and *inhabit*).

[2]Recent norms for spoken word frequency have been provided by Pastizzo and Carbone (in press), which are very current and have been shown to correlate highly with written frequency counts, such as Kučera and Francis (1967).

[3]Because priming was only found for targets with low-frequency spellings in Experiment 1, Experiment 2 used those targets only, eliminating high-frequency spellings.

Table 1

Correct Production of High- and Low Frequency Target Spellings (in %) as a Function of Priming Condition in Experiment 1 (Participant Analysis).

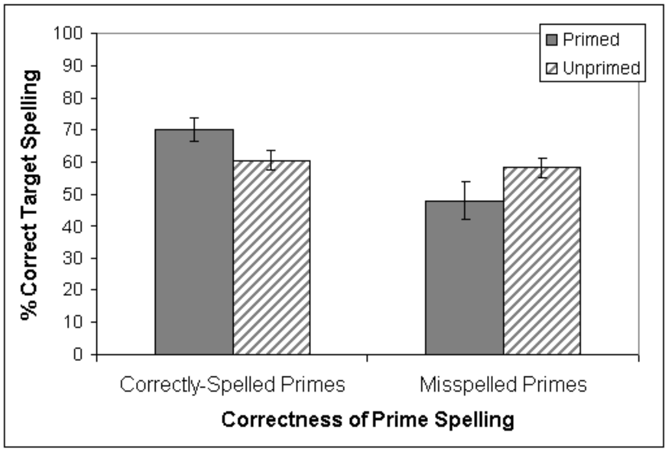
	Target Spelling			
	High-Frequency Spelling		Low-Frequency Spelling	
Priming Condition	*M*	*SE*	*M*	*SE*
Primed	98.3	0.7	67.7	3.1
Unprimed	99.0	0.6	60.1	3.4
Priming Effect	**-0.7**		**7.6***	

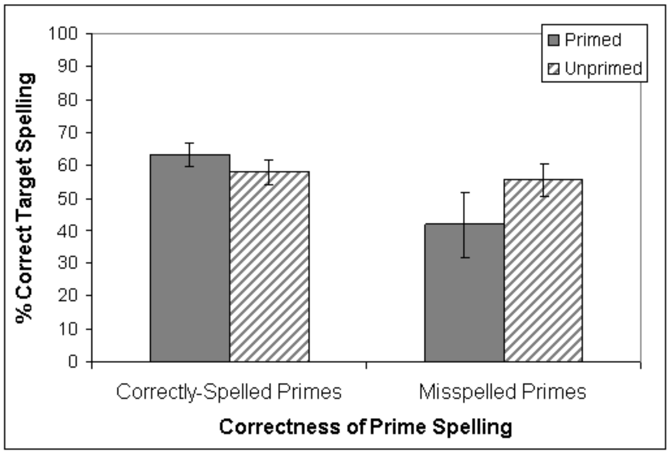
Note: Asterisk indicates a significant priming effect, $p < .05$.

Figure Caption

Figure 1. Correct production of low-frequency target spellings as a function of priming condition and correctness of prime spelling in Experiment 2.

Figure 2. Correct production of low-frequency target spellings as a function of priming condition and correctness of prime spelling in Experiment 3.


100
90
80
70
60
50
40
30
20
10
0
% Correct Target Spelling
Primed
Unprimed
Correctly-Spelled Primes
Misspelled Primes
Correctness of Prime Spelling


100
90
80
70
60
50
40
30
20
10
0
% Correct Target Spelling
Primed
Unprimed
Correctly-Spelled Primes
Misspelled Primes
Correctness of Prime Spelling