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Spelling as Statistical Learning:

Using Consonantal Context to Spell Vowels

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Abstract

Although English lacks one-to-one relationships between sounds and spellings, considering the context in which a phoneme occurs can often aid in selecting a spelling. For example, /ɑ/ is typically spelled as *a* when it follows /w/, as in *wand*, but as *o* when it follows other consonants, as in *pond*. In two experiments, we asked whether children's spellings of vowels in nonwords were affected by the following (Experiment 1) and preceding (Experiment 2) consonants. The participants in both experiments had spelling levels that ranged from kindergarten and first grade through high school. Children with higher levels of spelling skill took more advantage of context, and use of preceding context generally emerged earlier than use of following context. The results are interpreted within the framework of a statistical learning view of spelling and spelling development.

Key words: spelling, spelling development, sound-to-spelling relationships, context-sensitive spelling patterns, vowels

Spelling as Statistical Learning: Using Consonantal Context to Spell Vowels

The ideal writing system, we often think, is one in which each unit of sound is always represented with the same visual symbol. Writing systems that have one-to-one links between sounds and spellings have been labeled *consistent* or *shallow*, whereas those with more complex mappings have been called *inconsistent* or *deep* (e.g., Frost, 1992). Consistent writing systems appear to be easier to learn than inconsistent ones (e.g., Seymour, Aro, & Erskine, 2003), leading us to wonder why inconsistent systems exist at all. One reason is that writing systems often change over time from more consistent to less consistent. Even when a writing system is deliberately designed to have one-to-one links from spellings to sounds, it tends to drift away from this ideal. This occurs, in part, because the pronunciations of words change over time. Writing tends to be more conservative than speech, and spelling is not always updated to reflect changes in pronunciation. The English writing system, the focus of the work reported here, provides a good example of these tendencies. The American English vowel /ɑ/[1] is usually spelled *o*, as in *ponder*. But in quite a few words, such as *wander*, it is spelled *a*. The vowels differ in spelling because they originally differed in pronunciation. Subsequently, the *o* vowel developed the pronunciation /ɑ/ in most contexts, but *a* split, ending up as /æ/ in most contexts (e.g., *sap*) but as /ɑ/ after /w/ (e.g., *swap*). Because the original spellings did not change, /ɑ/ now has two different spellings. Which alternative is correct depends on the phonological environment in which the vowel sound occurs, in particular on whether it is preceded by /w/. Similar events have occurred for other English phonemes, as well as in other languages.

How do learners deal with the inconsistencies of English and other writing systems? Researchers and educators who have struggled with this question have not always appreciated that a consideration of context can often aid in the choice among alternative spellings for sounds with one-to-many mappings. Instead, they have tended to assume that people store the most common spelling of each phoneme pooled over all the contexts in which the phoneme appears—*o* in the case of /ɑ/—and individually memorize the spellings of words with the less common mappings. According to this view, *wander* is an exception to the context-free generalization or rule that /ɑ/ is typically spelled as *o*. The letter *a* in this word's spelling must be memorized as an exception to the general pattern. Indeed, researchers have often classified words such as *wander* as exceptions, lumping them together with more clear-cut exception words such as *front* and *chute* (e.g., Baron & Treiman, 1980). It has been assumed that spellers who correctly use *a* in *wander* must have relied on knowledge gained from previous experience with this specific word. Similarly, it has been assumed that people who spell the vowel of a nonword such as /twɑn/ with *a* could not have done so by applying general principles of English spelling. They must instead have activated a mental representation of an analogous word like *swan* and used that knowledge to spell the nonword.

In the work reported here, we test a different view of spelling, which we call a *statistical learning* view. According to this framework, people's knowledge of the systematic relationships between sounds and spellings cannot be characterized only in terms of general rules, such as that /ɑ/ is spelled as *o* in English. People also use and store information about how phonemes are spelled in particular contexts. Their knowledge is based on experience with the words of the language, for example the observation that *o* is a common spelling of /ɑ/ in certain environments while *a* is more common in other environments. Learning is statistical in that it goes beyond all-or-none patterns to encompass probabilistic patterns. Such learning is implicit: It does not require an explicit understanding of why spelling varies with context, something that spellers do not fully appreciate unless they have studied historical linguistics.

The idea that learning involves picking up the statistical patterns in the environment has been instantiated in connectionist theories, which are often implemented as computer models (e.g., Brown & Loosemore, 1994 for spelling; Harm & Seidenberg, 2004 for reading). Such models contain units that represent the phonology of a word and other units that represent the spelling; these populations of units are connected via an intermediate layer of units. The weights on the connections are adjusted over the course of training in which the models are exposed to pairs of spoken and printed words. Using these connections, a fully trained model can generate a plausible spelling even for an item it has not previously encountered. The generated spelling reflects the statistical regularities in the vocabulary on which the model was trained. Several researchers have explored the applicability of connectionist models to the development of spelling skills in children (Brown & Loosemore, 1994; Nation & Hulme, 1996; Pacton, Perruchet, Fayol, & Cleeremans, 2001). However, these studies do not speak directly to the issue of interest here: whether and how children use the surrounding context to help select among alternative spellings for vowel sounds.

So far, evidence on the role of context in spelling comes mainly from two sources. These are studies of the patterns in the language itself, or vocabulary statistics, and studies of experienced spellers. In the first line of research, Kessler and Treiman (2001) analyzed the links from sounds to spellings in monosyllabic, monomorphemic English words. The spelling of vowel sounds often proved to be more predictable when the *coda*—the consonant(s) that followed the vowel—was taken into account. As an example, /aɪ/ is often spelled as *i* before /ld/, as in *wild*, but is typically spelled as *i* followed by final *e* before codas such as simple /d/. For a few vowel phonemes, including /ɑ/, consideration of the initial consonant or cluster, the *onset*, increases the likelihood of choosing the correct spelling. Exposed to a writing system that has these characteristics, learners equipped with statistical learning mechanisms would be expected to pick up the patterns.

Indeed, a second line of research suggests that experienced spellers do honor a number of contextually based patterns. For example, Treiman, Kessler, and Bick (2002) found that college students were more likely to spell /ɑ/ as *a* in nonwords where it is preceded by /w/ than in nonwords where it is preceded by some other phoneme. Similar results were obtained for other context-conditioned patterns. Perry and Ziegler (2004), too, found that college students' spellings of vowels were influenced to some extent by the preceding and following consonants. These results suggest that experienced spellers know more than just the typical or context-free correspondences for vowels. As the statistical learning hypothesis predicts, they also know something about how vowel sounds are spelled in particular environments.

Adults who have had extensive experience with a writing system may take context into account in their spelling, but how do these skills develop? One view is that the ability to consider context is a late-developing skill, one that young children do not possess. Stage theories of spelling development take this position. For example, Marsh, Friedman, Welch, and Desberg (1980) proposed that children begin with a simple sequential phonemic encoding strategy, using sound-to-letter correspondences that are not sensitive to context. Only later, according to this theory, do children become able to use spelling rules that are conditioned by a phoneme's environment. This ability reflects the emergence of a new strategy, one that is not available to less mature children. Frith's (1985) theory makes similar claims. Based on such theories, we would expect contextual effects to emerge abruptly, somewhere between the second-grade and fifth-grade levels according to Marsh and colleagues. Once children are cognitively able to consider context, they should apply this ability to a variety of context-conditioned patterns.

An alternative position, and one that is more consistent with the connectionist modeling work, is that statistical learning skills exist from an early age. These skills are applied in learning to spell, as in other tasks. Supporting this view, even infants appear to possess certain statistical learning abilities (Saffran, Aslin, & Newport, 1996). If children do not make full use of context in spelling, this may reflect a lack of experience with the relevant patterns rather than a general inability to encode the frequencies of alternative spellings. On this view, we might expect contextual effects to strengthen gradually over time, in line with children's increasing opportunities to make the necessary observations. We might also expect children to honor some contextually conditioned patterns earlier than others, with variations in speed of learning reflecting the statistical properties of the input.

The experiments reported here were designed to study how children at various levels of spelling skill represent vowel sounds, asking whether effects of context on spelling emerge abruptly or gradually and whether children's use of contextual patterns is uniform or variable across vowels. Our focus on vowels is motivated by the fact that the spellings of vowels are less consistent than those of consonants in English, the language of interest here. Indeed, English-speaking children misspell vowels more often than consonants (e.g., Read, 1975; Treiman, 1993). Given the difficulty of vowel spelling, and given the gains that could potentially come from consideration of context (Kessler & Treiman, 2001), it is important to determine whether children use context to help narrow the range of possible spellings for vowels and when they begin to do so.

Only a few previous studies have examined the development of context sensitivity in English-speaking children's spelling of vowels. In one such study, Deavers and Brown (1997) presented spellers with nonwords such as /fotʃ/. Although the authors did not describe their stimuli in these terms, the vowels of these nonwords occur in contexts that favor spellings that are not necessarily typical in the majority of contexts. For example, /o/ is often spelled with *o* followed by final *e*, as in *tone*, and *oa* is less common overall. When the coda is /tʃ/, however, /o/ is generally spelled as *oa*, as in *coach*. In a dictation task using isolated nonwords, less skilled spellers (mean spelling age 8 years, 4 months) were more likely to produce spellings such as *foche* than spellings such as *foach*. More skilled spellers (mean spelling age 9 years, 10 months) produced approximately equal numbers of spellings of the two types. College students were more likely to produce spellings like *foach* than those like *foche*. These results suggest that context-conditioned spellings of vowels become more common with spelling skill and that development is quite gradual. A problem with this study for present purposes is that it did not include control nonwords like /fob/, which have the same vowels but in different contexts. Such nonwords would need to be included to determine whether context truly affected people's spellings of the vowels. A further limitation of the Deavers and Brown study is that only six nonwords with context-conditioned vowel spellings were tested.

Varnhagen, Boechler, and Steffler (1999) examined children's spelling of the vowel /ɑ/ in nonwords. They contrasted stimuli where the consonantal context should favor a typical spelling and stimuli where the context should favor an atypical spelling. The results suggested that context did not influence the vowel spellings of first graders. Context did appear to affect second graders and, to a greater extent, third graders. Because older children were not tested, we do not know when contextual effects reach adult levels. A limitation of this study is that only one vowel was tested and there were relatively few stimuli. Also, although the researchers included stimuli in which the coda would be expected to affect the spelling of the vowel and stimuli in which the onset would be expected to affect the vowel, they did not present the results for the two cases separately.

The present study was designed to overcome the limitations of the previous studies and so to increase our understanding of the development of context sensitivity in vowel spelling. Experiment 1 focused on effects of codas in the spelling of vowel sounds and Experiment 2 on effects of onsets. In each experiment, several different vowels were studied. *Experimental* *nonwords* were those in which a vowel's context was expected, on the basis of the vocabulary statistics calculated by Kessler and Treiman (2001), to suggest a spelling that was not necessarily typical overall. In *control nonwords,* the vowels occurred in consonantal contexts that were expected to support the most common spelling. For example, one of the experimental nonwords in Experiment 1, /glɛd/, contains /ɛ/ with the coda /d/, an environment in which some *ea* spellings would be anticipated on the basis of real words such as *head* and *dead*. The coda of the corresponding control stimulus, /glɛp/, does not favor *ea* spellings. We asked whether children of various levels of skill produced more critical context-conditioned vowel spellings—*ea* in this example—for the experimental nonwords than the control nonwords. We studied children with spelling levels ranging from kindergarten and first grade through high school, a larger range than in the studies of Deavers and Brown (1997) and Varnhagen et al. (1999). The younger children, in particular, would find it taxing to spell a large number of nonwords to dictation. Thus, we used a fill-in-the-blank spelling test. Participants saw *gl__d* for /glɛd/ and *gl__p* for /glɛp/, for example, and were asked to write in the missing letter or letters.

Experiment 1

Method

Stimuli. The stimuli included 10 pairs of experimental and control nonwords for each of five vowels. Within a pair, the pronunciations of the experimental and control nonwords had the same onsets and vowels but different codas. For example, the experimental stimulus /glɛd/ contains /ɛ/ before /d/, a context in which some *ea* spellings would be expected. The corresponding control stimulus, /glɛp/, has a coda that does not favor *ea* spellings of the vowel in English words. The Appendix shows the spoken forms of the critical stimuli. We also constructed 40 filler items. The fillers were monosyllables that had a variety of phonemes and syllable structures. They were included to add variety to the list. Because the filler stimuli did not contrast experimental and control contexts in the way that the critical items did, the results on the fillers were not analyzed. All 90 stimuli were presented to each participant.

For each critical and filler syllable, a fill-in-the-blank test item was prepared. The onsets and codas of the critical items were spelled with corresponding letters and a blank was left in which the child could comfortably write one or more vowel letters. For example, children saw *gl__d* for /glɛd/ and *gl__p* for /glɛp/. For this and the other pairs, the onset was spelled alike in the experimental and control items. If participants use different vowel spellings for the two items, therefore, this must reflect differences in the codas. For some of the items, such as those with /aɪ/, we anticipated that participants would use some spellings with a final *e*. Space was allotted for the child to fill in a final letter, if desired. In constructing the fill-in-the-blank choices for the fillers, we varied whether the missing segment was a consonant or a vowel and whether it was in the middle of the stimulus or elsewhere. Three different random orders of the stimuli were prepared. In each order, the experimental items, control items, and fillers were intermixed such that no more than two consecutive items had the same onset, vowel, or coda.

The vowels examined in this experiment were five of the six vowels that Treiman et al. (2002, Experiment 1) used. We used the same experimental and control stimuli as in that earlier study so that we could compare the results with those that Treiman et al. obtained with adults.[2] The associations studied here were ones in which the choice of a vowel spelling hinged on the identity of the coda, not on whether it was filled or empty. In this way, the coda-to-vowel associations examined in this experiment were similar to the onset-to-vowel associations studied in Experiment 2.

Procedure. The experimenter explained that participants would see spellings that were incomplete, and that their job was to fill in the missing letter(s). The task was demonstrated with *cat*, *dog*, and *like.* The experimenter made sure that the participants could perform the fill-in-the-blank task with these practice words. The experimenter then proceeded to the nonword items, explaining that these were made-up words and that there were no right or wrong answers for these items. The participants repeated each nonword after the experimenter before performing the fill-in-the-blank task, and incorrect repetitions were corrected. Participants were tested in groups of between two and four, with smaller groups for the younger children. Each group was randomly assigned to one of the random orders. The nonwords were presented over the course of three sessions for the younger students and two sessions for the older students, with rest breaks provided as needed. Participants were also given the spelling subtest of the Wide Range Achievement Test (WRAT; Jastak & Wilkinson, 1993).

Participants. A total of 105 students participated. They included 29 first graders, 28 second graders, 17 fourth graders, 19 sixth graders, and 12 ninth graders. All of the participants in this and Experiment 2 were native speakers of General American English from the Detroit or St. Louis metropolitan areas. The large majority were White. Typically, they had received mixed methods of reading instruction, including some phonics instruction. The children attended schools that served students of middle and upper middle socioeconomic classes, and so it is not unexpected that their grade-level equivalent scores on the WRAT were often higher than their grades in school. However, students in the same school grade often varied markedly in performance on the WRAT. For purposes of analysis, therefore, we grouped the participants on the basis of their performance on the standardized spelling test rather than on the basis of their school grade or age. Specifically, students were divided into those whose grade equivalents on the WRAT were kindergarten or first grade (henceforth called the K–1 group); second or third grade (2–3); fourth or fifth grade (4–5); sixth, seventh, or eighth grade (6–8); or ninth grade and above (9+). These cutoffs yielded fairly similar numbers of students in each group, as Table 1 shows. The table also provides information about the mean spelling grade level and mean age of the students in each group.

Results

For the critical stimuli containing /ɛ/, we tabulated the number of responses that used medial *ea*, with no final *e*. The critical vowel spelling for /i/ was *ee*, that for /ʊ/ was single *u* with no final *e*, that for /au/ was *ow*, and that for /aɪ/ was *igh*. We would expect participants to use more critical spellings for the experimental items than the control items if they consider the identity of the coda when selecting a spelling for the vowel. For example, participants who are sensitive to context should be more likely to fill in the blank with *ea* in the case of *gl__d* for /glɛd/ (experimental item) than in the case of *gl__p* for /glɛp/ (control item).

ANOVAs were carried out using the factors of vowel (/ɛ/ vs. /i/ vs. /ʊ/ vs. /aʊ/ vs. /aɪ/), consonantal context type (experimental vs. control), and participant spelling-ability group (K–1 vs. 2–3 vs. 4–5 vs. 6–8 vs. 9+). The dependent variable was the proportion of critical vowel spellings relative to all spellings. This and the other analyses we report were carried out both by subjects and by items. In the subjects analysis, vowel and consonantal context type were within factors and spelling-ability group was a between factor. In the items analysis, the results for each stimulus were pooled over all of the participants at a particular spelling level. Spelling-ability group and consonantal context type were within factors in the by-items analysis, as each stimulus pair had data for all spelling groups and for both experimental and control versions; vowel was a between factor. We report as significant only those effects with p values of less than .05 in both types of analyses. This procedure ensures that we focus on effects that generalize both across subjects and across stimuli.

The ANOVAs showed main effects of vowel (by subjects: $F(4,400) = 77.61$; by items: $F(4,45) = 190.56$; $p < .001$ for both), context (by subjects: $F(1,100) = 181.60$; by items: $F(1,45)$

= 205.27; $p < .001$ for both), and spelling ability (by subjects: $F(4,100) = 18.27$; by items: $F(4,180) = 134.95$; $p < .001$ for both). These main effects were qualified by two-way interactions involving vowel and spelling ability ($F(16, 400) = 5.41$; by items: $F(16,180) = 44.90$; $p < .001$ for both), context and spelling ability (by subjects: $F(4,100) = 26.80$; by items: $F(4,180) = 41.66$; $p < .001$ for both), and vowel and context (by subjects: $F(4,400) = 30.60$; by items: $F(4,45) = 30.56$; $p < .001$ for both). In addition, there was a three-way interaction of vowel, context, and spelling ability (by subjects: $F(16,400) = 5.85$; by items $F(16,180) = 8.47$; $p < .001$ for both). The three-way interaction means that the difference between experimental and control items was influenced both by the spelling ability of the participants and the particular vowel. Figure 1 shows the proportions of critical spellings for experimental and control items for each spelling-ability group. The results in the figure are pooled across the five vowels.[3]

In light of the interactions that appeared in the ANOVAs, we examined the results for each spelling-ability group and each vowel separately. For children in each group, we carried out two-tailed *t* tests to determine whether the proportion of critical spellings was significantly higher for the experimental items than the control items for each vowel. For the children in the K–1 group, none of the differences between experimental and control items were significant both by subjects and by items. The same was true for children in the 2–3 group. As Figure 1 shows, differences between experimental and control items were very small for children at these two lowest levels of spelling ability, providing no evidence that these children used coda context when spelling any of the vowels that were tested here. For children who performed at the fourth- and fifth-grade levels on the standardized spelling test, significant differences between experimental and control items were observed for two of the five vowels, /i/ and /aʊ/. For the 6–8 group, significant differences appeared for all five of the tested vowels. Thus, it was not until children performed on average at a seventh-grade level on the standardized spelling test that they showed a widespread sensitivity to the ways in which codas condition the spellings of vowels.

Additional analyses were carried out to determine whether the increase in context sensitivity with spelling grade level might reflect a change in the nature of the words to which children are exposed as they get older. It may be, for example, that words such as *dread*, with the *ea* spelling of /ɛ/ before /d/, are relatively uncommon in written materials targeted at younger children. If so, it would not be surprising that young children do not use the context-conditioned pattern in their own attempts to spell. To address this issue, we carried out additional analyses to determine how frequently the critical spellings occur in real English words that are found in materials written for children of different levels, using the grade-level corpora of Zeno, Ivenz, Millard, and Duvvuri (1995). Specifically, we calculated the proportion of monosyllabic words in reading materials targeted at children of each level in which each vowel was spelled in the critical manner. Counts were carried out for each vowel in the experimental context, in the control context, and regardless of context. For example, we calculated the proportion of English words in which /ɛ/ was spelled as *ea* in the experimental context (i.e., before /d/), the proportion of words in which /ɛ/ was spelled as *ea* in the control context (i.e., before /b/, /dʒ/, /g/, /k/, /p/, or /tʃ/), and the proportion of words in which /ɛ/ was spelled as *ea* across all contexts in which this vowel appears. For each ability group, statistics were computed with vocabulary counts appropriate to the upper end of the group, using the word frequency counts of Zeno et al. For the least skilled group, these were combined kindergarten/grade 1 counts; for the remaining groups, Grade 3, 5, 8, and 12, respectively. Words were counted only if Zeno et al. broke down the statistics by grade level. Each word was weighted by the log of its frequency (+2) for the relevant grades.

The vocabulary statistics turned out to be very similar across grade levels. This outcome speaks against the idea that the vocabulary to which children of different levels of skill are exposed differs systematically in the evidence it provides for the context-conditioned patterns of interest here. Given the similar results across grade levels, we report here the results based on the kindergarten/grade 1 counts.[4] Averaging across the five vowels in Experiment 1, the critical spelling appeared 73% of the time in the experimental contexts in English words. This spelling occurred only 4% of the time in the control contexts. Across all contexts—experimental contexts, critical contexts, and other contexts—the critical spelling occurred at a rate of 25%. Figure 1 shows that all groups of participants, even the most skilled group, used the critical spellings for experimental nonwords at rates well below 73%, the rate that would have been anticipated based on the occurrence of the spelling in this context in English words. For example, even the most skilled spellers did not produce as many *ea* spellings of /ɛ/ before /d/ as expected given how often *ea* occurs in this context in real English words. For control nonwords, participants used the critical spellings more often than anticipated given the occurrence of these spellings in these contexts in English.

Discussion

Previous research suggested that college students' selections of vowel spellings are influenced by the identity of the following consonants (Perry & Ziegler, 2004; Treiman et al., 2002). The same was true for the most skilled groups tested here. Indeed, the students with a high school spelling level performed quite similarly to the college students tested by Treiman et al. on the stimuli that were in common to the two studies. The change of task—from a free-spelling task in Treiman et al. to a fill-in-the-blank test here—did not markedly affect the results. Even for the most skilled group, though, the influence of context was not as large as one might expect given the sound-to-spelling correspondences in the words to which students of this ability level are exposed. The participants appeared to use their knowledge of the typical context-free spellings of the vowels as well as knowledge of how the spellings change across contexts. For example, the fact that *e* is the most common spelling of the sound /ɛ/, pooling across all contexts, seemed to pull participants toward *e* spellings of this vowel even before /d/. The results of Perry and Ziegler and Treiman et al. also support the idea that people's use of context is constrained by their knowledge of typical context-free spellings. In this sense, people's use of context-conditioned patterns is not statistically optimal given the patterns in the vocabulary to which they have been exposed.

With regard to the topic of most interest here—the development of context effects—the results of Experiment 1 suggest that coda-to-vowel influences take time to emerge. Children with spelling levels of kindergarten through third grade did not show reliable differences between experimental items and control items, which would have indicated context effects, for any of the tested vowels. Such effects appeared at the fourth- and fifth-grade spelling level for some vowels, but they did not become statistically reliable for all of the studied vowels until approximately the seventh-grade spelling level. Thus, adult-like use of coda context in the vowel spelling develops over an extended period of time rather than abruptly. Moreover, context effects emerge at different times for different coda-to-vowel associations. We will discuss the possible causes of these differences in the General Discussion.

To explain the slow and gradual course of development, one might look to characteristics of the vocabulary to which learners are exposed or to characteristics of the learners themselves. For the patterns studied here, the developmental changes we observed do not appear to reflect changes in the nature of words that children see. Indeed, our analysis of English vocabulary statistics showed strikingly similar results from the kindergarten and first grade level through the Grade 12 level. Thus, it is not the case that words like *head*, where /ɛ/ is spelled as *ea*, are less common relative to words like *bed*, where /ɛ/ is spelled as *e*, in the vocabularies of young children than in the vocabularies of older children and adults. The differences we observed appear to reflect, instead, characteristics of the children themselves. That is, less skilled spellers seem less likely to notice and use the fact that /ɛ/ may be spelled differently when it occurs before /d/ than when it occurs before consonants such as /p/. One hypothesis about why this is so is that the effects studied here require spellers to consider a later part of a word, the coda, when deciding how to spell the current portion, the vowel. That is, spellers must look ahead. It may be less natural for spellers to notice and use future context than to notice and use past context. In Experiment 2, we asked when children begin to consider the onset when spelling the vowel. According to the *serial processing hypothesis* just described, onset-to-vowel effects should emerge at an earlier point in development than coda-to-vowel effects.

Although the serial processing hypothesis suggests that onset-to-vowel effects will emerge earlier than coda-to-vowel effects, a different outcome is possible. Onset-to-vowel influences may emerge later than coda-to-vowel influences because associations of the former type are less common than associations of the latter type in English (Kessler & Treiman, 2001). According to this *context asymmetry hypothesis*, children have encountered a number of situations in which a coda influences the spelling of a vowel. Given the nature of the English writing system, they have encountered few cases in which the onset has an influence. This imbalance induces a bias such that children are more likely to notice new cases of the coda-to-vowel variety.

Yet a third hypothesis, and one that makes the same prediction as the context asymmetry hypothesis, may be called the *rime unit hypothesis*. On this view, speakers of English tend to treat the vowels and codas of syllables, or rimes, as isolable units. Spellers may be more likely to notice and use contextual influences on vowel spelling that are due to the coda than those due to the onset, because codas are more closely associated with the vowel structurally. The rime unit hypothesis is often linked with an analogy view of spelling: People activate a known word such as *dead* when spelling a nonword such as /glɛd/ and they choose analogies on the basis of shared rimes (e.g., Goswami, 1988). Some studies support the idea that rimes have a special status in spelling (Goswami, 1988; Treiman & Zukowski, 1988), but other studies do not (Bernstein & Treiman, 2001; Nation & Hulme, 1996; Treiman et al., 2002).

Experiment 2

We asked in Experiment 2 whether children's choices of spellings for vowel phonemes are affected by the preceding onset and when contextual influences emerge in the course of spelling development. The logic of this experiment was similar to that of Experiment 1 and that of a previous study of adults (Treiman et al., 2002, Experiment 2).

Method

Stimuli. The stimuli included 10 pairs of experimental and control nonwords for each of three vowels. The experimental and control syllables in each pair had different onsets but the same vowels and codas. For example, the experimental stimulus /kwɑp/, in which /ɑ/ is preceded by the /w/ that was expected to condition the *a* spelling, was paired with the control stimulus /blɑp/, in which /ɑ/ is preceded by a different consonant. In addition to the 30 critical stimuli, each participant was presented 20 filler nonwords. As in Experiment 1, the fillers were monosyllables that used different vowels than the critical stimuli and that included a number of different consonants as well. The Appendix shows the spoken forms of the critical stimuli for this experiment, which were virtually identical to the critical stimuli in Experiment 2 of Treiman et al. (2002). A fill-in-the-blank stem was prepared for each item. For critical items, the onset and the coda were spelled with corresponding letters and a blank was left in the middle that could fit one or more vowel letters. For example, children saw *qu__p* for /kwɑp/ and *bl__p* for

/blɑp/. For this and the other pairs, the coda was spelled alike in the two items. If children choose a different vowel spelling for *qu__p* than for *bl__p*, therefore, this choice must reflect the different initial portions of the two items. For filler items, the missing segments in the fill-in-the-blank test included consonants as well as vowels and initial and final segments as well as medial ones. Three different random orders of the stimuli were prepared for purposes of presentation. In each, the experimental items, control items, and fillers were intermixed such that no more than two consecutive items had the same onset, vowel, or coda.

Procedure. The procedure was like that of Experiment 1. The nonwords for the fill-in-the-blank spelling test were presented over the course of two sessions.

Participants. We tested 108 students. They comprised 27 first graders, 18 second graders, 19 fourth graders, 17 fifth graders, 18 sixth graders, and 9 ninth graders. The students were divided into groups based on their performance on the spelling subtest of the WRAT, as in Experiment 1. Table 1 shows the number of students in each group, together with the mean spelling grade level and the mean age for each group. The groups were very similar in terms of mean spelling grade level to those of Experiment 1, although there were some variations in age.

Results

For the critical stimuli containing /ɑ/, we tabulated the number of vowel spellings that began with *a*. Such spellings should be more frequent for experimental syllables such as /kwap/ than for control syllables such as /blap/ if spellers are sensitive to the influence of the preceding consonant on the spelling of the vowel. Spellings of the vowel with *au* or *aw* were not counted as critical vowel spellings, as these spellings could reflect a dialect in which /ɑ/ has merged with /ɔ/, which is normally spelled as *au* or *aw*. For /ɚ/ and /u/, the critical vowel spellings were those that were or began with *o*. If children consider the preceding segment when deciding how to spell the vowel, then such spellings, typically *or* as in *worm*, should be more common for /ɚ/ when the preceding segment is /w/ than when it is not. Also, *o*-initial spellings of /u/ should be more common when the vowel is preceded by a noncoronal consonant, as in the experimental nonwords (cf. *move*, *boot*), than when preceded by coronals, as in the control nonwords, where spellings like *oo* compete with spellings like *u* followed by final *e* or *ew* (*clue, crew*).

ANOVAs were carried out using the factors of vowel (/ɑ/ vs. /ɚ/ vs. /u/), consonantal context type (experimental vs. control), and participant spelling-ability group (K–1 vs. 2–3 vs. 4–5 vs. 6–8 vs. 9+). The dependent variable was the proportion of critical vowel spellings relative to all spellings. In the by-subjects analysis, vowel and consonantal context type were within factors and spelling-ability group was a between factor. In the by-items analysis, vowel was a between factor and consonantal context type and spelling-ability group were within factors. We found main effects of vowel (by subjects: $F(2,206) = 111.08$; by items: $F(2,27) = 316.12$; $p < .001$ for both) and context (by subjects: $F(1,103) = 271.48$; by items: $F(1,27) = 179.04$; $p < .001$ for both). These main effects were qualified by two-way interactions involving vowel and spelling ability ($F(8, 206) = 9.50$; by items: $F(8,108) = 61.04$; $p < .001$ for both) and context and spelling ability (by subjects: $F(4,103) = 17.53$; by items: $F(4,108) = 37.27$; $p < .001$ for both). In addition, there was a three-way interaction of vowel, context, and spelling ability (by subjects: $F(8,206) = 5.72$; by items $F(8,108) = 7.11$; $p < .001$ for both). Figure 2 shows the proportion of critical responses for experimental and control items for each spelling-ability group, pooled over the different vowels.

The interaction between consonantal context and spelling ability, evident in Figure 2, reflects the fact that the difference between experimental and control items increased in size from children who spelled at the kindergarten and first-grade level to children who spelled at the fourth- and fifth-grade levels. After this point, the size of the difference between experimental and control items remained fairly constant. The three-way interaction means that the spelling ability level at which the increase occurred differed among the three vowels. The least skilled spellers, those in the K–1 group, showed no significant differences between experimental and control items for /ɑ/ or /u/. However, these children did produce reliably more critical spellings ($p < .05$ by two-tailed t tests) for the experimental nonwords than the control nonwords in the case of /ɚ/. Even these young children, who were performing on average at a first-grade spelling level, were significantly more likely to use a spelling beginning with *o* for the vowel of a nonword like /wɚdʒ/ than the vowel of a nonword like /kɚdʒ/. Children in the 2–3 ability level group showed a significant difference between experimental and control items for /u/ as well as /ɚ/. For children in the 4–5 group, a reliable difference also appeared for /ɑ/. In large part, then, the increase in the size of the difference between experimental and control items across groups reflects an extension of the effect from just one of the studied vowels to all three.

As in Experiment 1, additional analyses were performed to determine how frequently the critical spellings occurred in real English words in vocabularies appropriate to children of each level. These analyses were carried out in the same way as the corresponding analyses of Experiment 1. Averaging across the three vowels in Experiment 2, the critical spelling appeared 94% of the time in the experimental contexts in English words. The critical spelling occurred 18% of the time in the control contexts, a substantial difference between the two contexts. Across all contexts—experimental contexts, critical contexts, and other contexts—the critical spelling occurred at a rate of 40%. These figures are based on analyses using the kindergarten and Grade 1 vocabulary; the results were very similar for the other grade levels. At all grade levels, all three of the tested vowels were spelled differently in experimental and control contexts.

Discussion

The results of Experiment 2 contrast markedly with those of Experiment 1. In Experiment 1, which examined influences of codas on the spelling of vowels, contextual effects did not begin to emerge until about the fourth-grade level. The effects were not reliable for all of the tested vowels until about the seventh-grade level. In Experiment 2, which examined onset-to-vowel influences, contextual effects appeared much earlier. They emerged for one of the vowels, /ɝ/, as early as the first-grade level, and they were reliably present for all of the tested vowels by fourth grade. In terms of these benchmarks, then, onset-to-vowel influences appear about three years earlier in the course of spelling development than coda-to-vowel influences. Possible reasons for these differences are considered in the General Discussion.

Although the findings of Experiment 2 differ in some ways from those of Experiment 1, they are similar in other ways. Even in the written vocabularies appropriate to young children, the vowels of Experiment 2 are spelled differently in experimental and control contexts. The developmental trends that we observed do not reflect any marked changes in the nature of the words that children see as they get older and more skilled. Also, no group of participants, even the most experienced spellers, used critical spellings for experimental nonwords as frequently as these spellings occur in the relevant contexts in real English words. Spellers seem to be drawn to the typical spellings of the vowels in that their spellings do not deviate as markedly from the typical ones as would be expected given the magnitude of the context effects in the input.

An apparent difference between the results of the two experiments is that the proportion of critical spellings among spellers of lower ability was larger in Experiment 2 than Experiment 1. This difference likely reflects the particular vowels that were used and the scoring procedures that were appropriate for these vowels. In Experiment 1, on average the vowel spellings had to match a two-letter sequence to qualify as a critical spelling. In Experiment 2, the spelling only had to begin with a single specified letter. Therefore, children whose productions contained a certain amount of guesswork—as is likely the case for the lower-ability groups—were more apt to produce a response that qualified as a critical spelling in Experiment 2 than in Experiment 1.

General Discussion

Literacy involves learning to spell as well as learning to read. The study of spelling and spelling development, however, has received less attention than the study of reading and reading development. Our study sought to redress this balance by examining one aspect of English that causes particular difficulty for learners, the spelling of vowels. If spellers internalized rules that coded only the single most common spelling of each vowel sound—*o* for /ɑ/, for example—they would make many mistakes. They would misspell the first vowels of *wander* and *quantity* with *o*, for example. Fortunately for learners of English, the spellings of vowels become more predictable when the sounds' environments are considered. With *wander* and *quantity*, the /w/ that occurs before the /ɑ/ provides a good clue that *a* is the proper spelling of the vowel. Equipped with knowledge of how spellings vary with context, people would perform more accurately. Previous studies suggest that college students use knowledge of this kind to benefit their performance (e.g., Perry & Ziegler, 2004; Treiman et al., 2002), consistent with a statistical learning view of spelling. Some information is available about the development of these skills for consonants (Hayes, Treiman, & Kessler, in press), but little such information is available for vowels.

The experiments reported here were designed to examine the development of context sensitivity in the spelling of vowels. One hypothesis, which follows from stage theories of spelling development such as that of Marsh et al. (1980), is that this sensitivity develops abruptly at some point between the second and fifth grade, and at the same time for all vowels. Our results do not support this view. Instead, we found that context sensitivity develops gradually, and at different times for different consonant-to-vowel associations. For several of the coda-to-vowel patterns in Experiment 1, it was not until the seventh-grade spelling level that we saw reliable evidence for sensitivity to the patterns. The onset-to-vowel associations that we examined generally emerged earlier—about three years earlier than the coda-to-vowel associations.

The earlier learning of onset-to-vowel-associations is not consistent with the context asymmetry hypothesis, which predicts that learners of English will have difficulty with onset-to-vowel associations because they are less common in the language than coda-to-vowel associations. Nor do the results support the rime unit hypothesis—that children find it easier to deal with patterns within the rime than patterns that extend beyond this unit and that they select analogies on the basis of shared rimes. According to the rime unit hypothesis, learners should have more difficulty with onset-to-vowel associations than coda-to-vowel associations, the opposite of the observed results. Thus, our results question the idea that rimes necessarily play a privileged role in the mapping between phonology and orthography (see also Bernstein & Treiman, 2001; Hayes et al., in press; Nation & Hulme, 1996; Treiman et al., 2002).

Why do children learn certain contextually based patterns more easily than others? We scrutinized the statistical properties of the three onset-to-vowel and the five coda-to-vowel associations studied here to try to determine why significant differences between experimental and control contexts emerged earlier for some associations than for others. According to the vocabulary statistics previously reported, all eight of the vowels tend to be spelled differently in experimental and control contexts, even in words that kindergartners and first graders see. From an early age, for example, children have an opportunity to observe *igh* spellings for /aɪ/ before /t/, as in *night*, *light*, and so on, and *i* plus final *e* spellings in other contexts, as in *like* and *time*. The vowels that showed the largest differences between experimental and control contexts in the proportion of critical spellings were not necessarily the vowels for which contextual influences emerged earliest in our experiments, however. What did appear to be associated with speed of learning was the dominance of the typical spellings. The vowel /aɪ/, for example, is most often spelled as *i* followed by final *e* in the monosyllabic words that children see, and this spelling occurs at a moderately high rate (66% of the time in words targeted at kindergarten and first-grade children). With /ɝ/, in contrast, the single most common spelling, *ir*, occurs much less often (26% of the time in the K–1 vocabulary). Of the eight vowels studied, /ɝ/ had the least dominant typical spelling and /aɪ/ had one of the most dominant. Correspondingly, contextual influences appeared earlier in the case of /ɝ/ (emerging when children performed at a first-grade spelling level) and later in the case of /aɪ/ (appearing not until the seventh-grade level). We hypothesize that, when a vowel has a single dominant spelling, children are less likely to notice the less common spellings and contexts in which they appear. Even when an atypical spelling occurs mainly in a certain environment, children will be slow to learn about the pattern. When a vowel does not have a single dominant spelling, learners are more likely to notice the alternative spellings and their contexts. The results for the eight vowels studied here conform fairly well to this hypothesis, in that we observed a significant rank-order correlation between the proportion of words that contained the dominant spelling and the grade level at which a reliable difference between experimental and control contexts emerged ($r_s = .80$, $p = .017$, two tailed; the correlation coefficient was the same regardless of which grade-level corpus was used to calculate the vocabulary statistics). With a total of just eight vowels, however, we cannot draw strong conclusions. Further research, using a larger number of cases, will be necessary to examine this and other factors that may affect the ease with which children learn about influences of context.

The proportion of words that contained the dominant spelling was greater, on average, for the coda-to-vowel associations of Experiment 1 than for the onset-to-vowel associations of Experiment 2. This difference may help explain why children generally learned the coda-to-vowel associations later. The serial learning hypothesis that we discussed earlier provides another possible reason for the later learning of coda-to-vowel associations. According to this hypothesis, people who are deciding how to spell a target segment find it easier to take account of a segment that comes before the target, one that they have already processed, than a segment that comes after the target. That is, it is more natural to consider the recent past than to look ahead to the future. Additional research will be needed to tease apart these possibilities.

Although context sensitivity emerges at different grade levels for different consonant-to-vowel associations, the patterns take time to learn even when children receive the kind of input that could support them. The same appears to be true for reading, both for human learners and connectionist models (Treiman, Kessler, Zevin, Bick, & Davis, 2006). The relatively slow course of development fits with the idea that learners encode general patterns—the most typical spellings or pronunciations across contexts—as well as specific, context-driven patterns (see also Treiman et al., 2002, 2003). People tend to abstract and to generalize, learning for example that *e* is the typical spelling of /ɛ/. This propensity to generalize across contexts means that even highly experienced readers and spellers do not use context to the extent that would be expected given the strength of the contextual effects in the language. In a sense, people are not perfect statistical learners. Direct comparisons between spelling and reading remain to be carried out, but the results to date suggest that sensitivity to context generally emerges earlier in reading than in spelling. The fact that readers' eyes take in several letters of a word at once may facilitate use of context in the assignment of sounds to letters. Spellers may be more prone to consider one phoneme at a time as they move from left to right across a word.

One possible limitation of the present study pertains to the use of a fill-in-the-blank spelling task. Although such tests are sometimes used for teaching and research purposes, it will be important to determine whether the results extend to the production of complete spellings. Some indication that they may comes from the fact that the vowel responses by the most skilled groups in our experiments were generally similar to those of college students on production tasks with the corresponding stimuli (Treiman et al., 2002). Further study will be required, though, to assess the generality of the findings across tasks.

Another topic for further research involves the generality of the findings across languages. Given the complexity and inconsistency of the English writing system, questions have been raised about whether findings and theories from studies with English will extend to other languages. However, we suspect that learning to spell in English is not all that different from learning to spell in a number of other writing systems. English is not the only writing system for which changes in pronunciation have led to complexities in sound-to-spelling translation, and English is not the only writing system for which phonological context can aid in the resolution of some of these complexities. For example, French contains nasalized vowels, such as /õ/, that are normally spelled with a vowel letter followed by *n* (e.g., /mõd/ *monde*), but that use *m* instead of *n* before *b* or *p* (e.g., /nõbʀ/ *nombre*). In French, as in English, it takes some time for children to learn about such patterns (Alegria & Mousty, 1994, 1996). This is so even though many of the contexts substantially increase the predictability of the vowel spelling. As another example, Danish contains context-conditioned patterns for both vowels and consonants. Studies suggest that Danish students take advantage of these patterns by 11 to 12 years of age (Juul, 2005).

We conclude that there is both good news and bad news with respect to the use of context in the spelling of English. The good news is that context can help in selecting the correct spellings of vowels and that people increasingly benefit from it with experience. The bad news is that sensitivity to context develops rather slowly in a number of the cases where it could help. The slow course of development may reflect, in part, the way in which children are taught. The formal and informal phonics instruction that is provided to many English-speaking children typically teaches generalizations such as that /ɛ/ is spelled as *e*. Deviations from a pattern, when they occur in words like *head*, are treated as exceptions that must be individually memorized.

Teachers may point out that certain sounds have more than one possible spelling. For example, they may tell children that /i/ may be spelled as *ee* or *ea*. However, teachers and phonics books do not usually offer much guidance on when each alternative is appropriate. Young students, as a result, may not consider surrounding context when choosing spellings for sounds. They may begin to do so only as they are exposed to increasing amounts of text and as their generalizations about sound-to-spelling correspondence begin to be driven more by statistical learning from the words to which they are exposed and less by the rules they have been taught. Teaching children that many sounds have more than one possible spelling and that the surrounding context can often help in selecting the correct one could be valuable, we believe, beyond the initial stages of learning to read and write. The goal of such instruction would not be to explicitly teach every contextually driven pattern of English. Instead, the goal would be to alert children to the fact that context is often useful in selecting spellings for sounds and that spellings that deviate from the norm need not always be individually memorized. With an understanding that context can be useful, and with exposure to words that exemplify certain selected patterns, children should be able to pick up other patterns on their own.

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Footnotes

[1]Phonemes are represented using the alphabet of the International Phonetic Association (1996, 1999). The vowel /ɑ/ in this discussion corresponds to /ɒ/ in standard British English. Pronunciations and word counts are reported in this paper in terms of General American norms, but the patterns and contrasts discussed are applicable to the standard pronunciations of most English-speaking countries.

[2]One of the vowels in the earlier study, /o/, was not well suited to the present format because the contrast in that case was solely between the presence or absence of a final *e* after the consonant (e.g., *toll* vs. *tote*). Because final *e* is rarely used after two consonant letters, spellers could ignore the vowel sound and decide whether to use final *e* based on the number of consonants in a supplied template.

[3]Detailed information about the responses to each vowel at each spelling level for this experiment and Experiment 2 may be found at http://brettkessler.com/ChildCtoVSpelling/

[4]The counts for the individual grade levels for this experiment and the following one may be found at http://brettkessler.com/ChildCtoVSpelling/

Appendix

Critical Stimuli for Experiments

For each vowel, the first keyword illustrates the critical context-conditioned spelling (in boldface) and the second shows the more typical spelling. Each pair is presented in the order experimental, control.

Experiment 1

/ɛ/ (*h**ea**d, step*): /glɛd/, /glɛp/; /klɛd/, /klɛb/; /gɹɛd/, /gɹɛdʒ/; /stɹɛd/, /stɹɛg/; /gɛd/, /gɛtʃ/; /jɛd/, /jɛb/; /θɛd/, /θɛk/; /vɛd/, /vɛp/; /kwɛd/, /kwɛg/; /smɛd/, /smɛk/

/i/ (*d**ee**p, team*): /ʃɹid/, /ʃɹig/; /fip/, /fiθ/; /gid/, /gim/; /jid/, /jið/; /snip/, /snim/; /pid/, /pɹig/; /θip/, /θist/; /skɹip/, /skɹiθ/; /smip/, /smið/; /zip/, /zist/

/ʊ/ (*b**u**tch, book*): /ʃʊtʃ/, /ʃʊf/; /fʊʃ/, /fʊf/; /jʊʃ/, /jʊf/; /klʊs/, /klʊf/; /lʊtʃ/, /lʊf/; /θʊl/, /θʊk/; /sʊl/, /sʊf/; /slʊtʃ/, /slʊk/; /smʊl/, /smʊf/; /zʊl/, /zʊf/

/au/ *(**ow**l, couch)*: /ʃaʊl/, /ʃaʊdʒ/; /maʊl/, /maʊtʃ/; /naʊl/, /naʊdʒ/; /θaʊn/, /θaʊs/; /vaʊn/, /vaʊs/; /zaʊl/, /zaʊtʃ/; /spaʊl/, /spaʊdʒ/; /pɹaʊn/, /pɹaʊdʒ/; /bɹaʊl/, /bɹaʊtʃ/; /smaʊn/, /smaʊtʃ/

/aɪ/ *(t**igh**t, drive)*: /dɹaɪt/, /dɹaɪb/; /glaɪt/, /glaɪb/; /gɹaɪt/, /gɹaɪv/; /gaɪt/, /gaɪf/; /jaɪt/, /jaɪs/; /θaɪt/, /θaɪf/; /staɪt/, /staɪb/; /zaɪt/, /zaɪf/; /pɹaɪt/, /pɹaɪb/; /paɪt/, /paɪf/

Experiment 2

/ɑ/ *(sw**a**p, stop)*: /kwɑp/, /blɑp/; /kwɑts/, /kɹɑts/; /skwɑnz/, /slɑnz/; /kwɑbd/, /klɑbd/; /wɑbz/, /tɹɑbz/; /twɑn/, /glɑn/; /wɑdʒ/, /blɑdʒ/; /skwɑmp/, /nɑmp/; /kwɑtʃ/, /flɑtʃ/; /gwɑt/, /kɹɑt/

/ɚ/ *(w**o**rd, chirp)*: /wɚdʒ/, /kɚdʒ/; /wɚp/, /kɚp/; /wɚtʃ/, /kɚtʃ/; /wɚg/, /kɚg/; /wɚʃ/, /kɚʃ/; /wɚf/, /blɚf/; /wɚb/, /slɚb/; /wɚn/, /blɚn/; /wɚpt/, /kɚpt/; /wɚθt/, /kɚθt/

/u/ *(b**o**ot, clue)*: /budʒ/, /fludʒ/; /guθ/, /ʃɹuθ/; /muk/, /pɹuk/; /hus/, /klus/; /hun/, /plun/; /sput/, /ʃɹut/; /skudʒ/, /fɹudʒ/; /smud/, /flud/; /swu/, /plu/; /muθ/, /dʒuθ/

Table 1

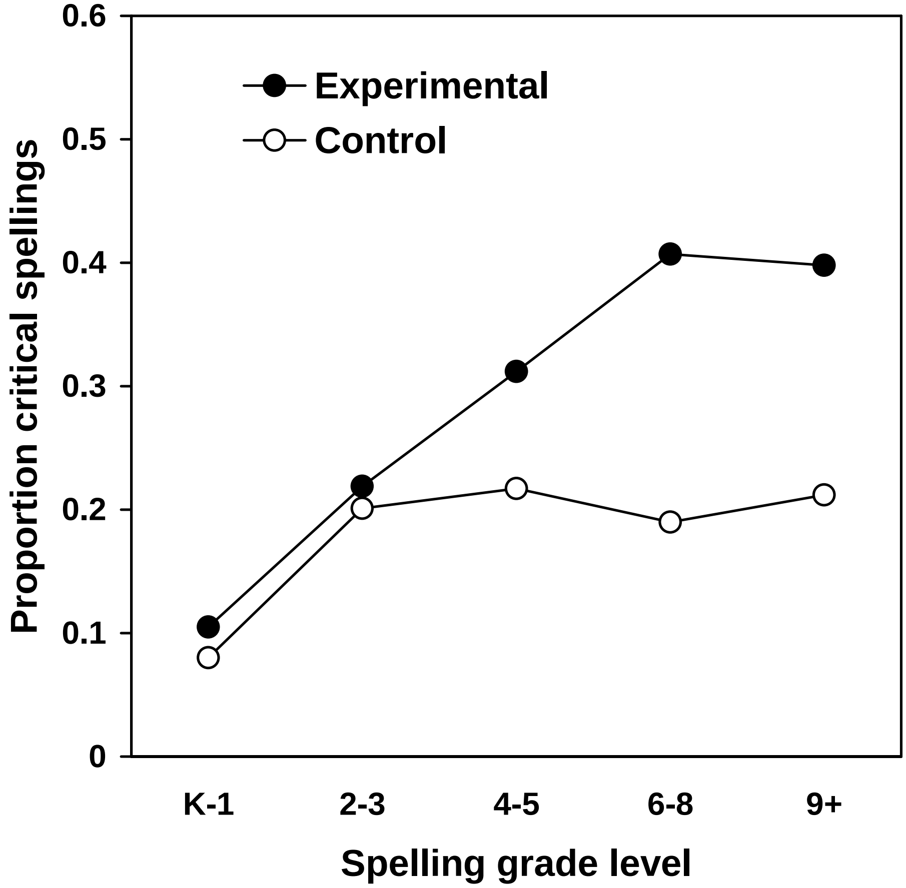
Information on Participants in Experiments 1 and 2

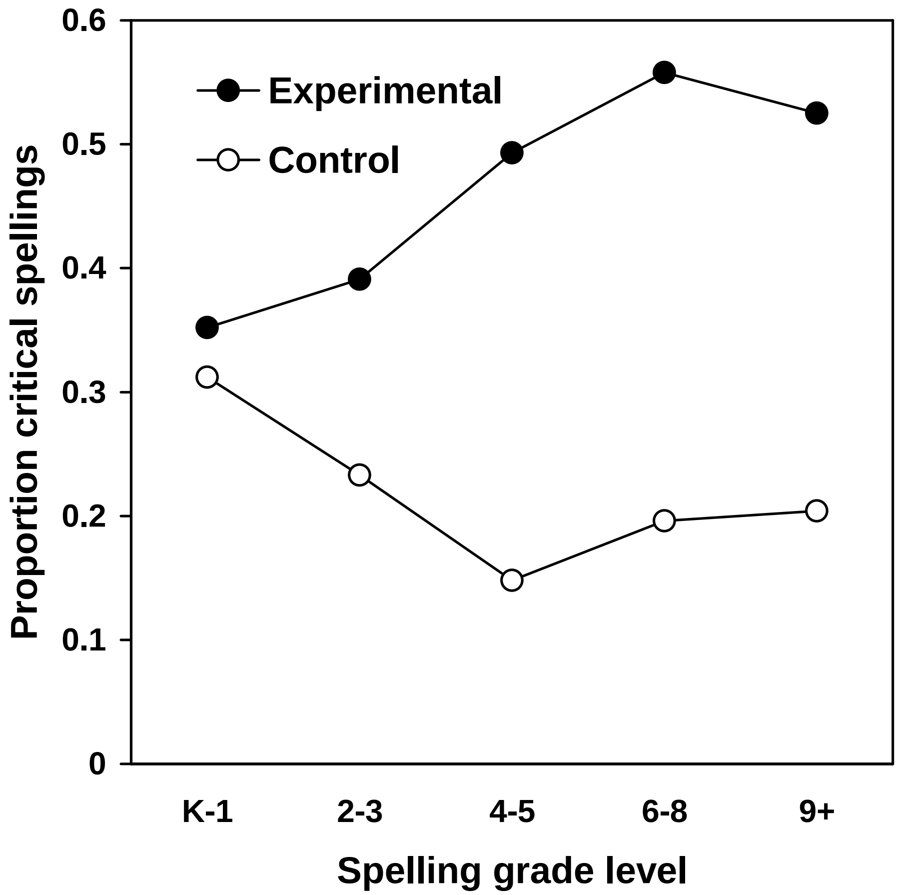
	Experiment 1 (coda context)			Experiment 2 (onset context)		
Group	*N*	Mean spelling grade level	Mean age	*N*	Mean spelling grade level	Mean age
K–1	23	1	6; 9	20	1	7; 1
2–3	21	2	7; 9	22	Between 2 and 3	7; 8
4 –5	19	4	8; 9	18	4	9; 10
6–8	23	7	10; 11	24	7	11; 4
9+	19	High school	13; 8	24	High school	11; 9

Figure Captions

Figure 1. Mean proportion of critical vowel spellings for experimental and control nonwords in Experiment 1 as a function of spelling level group, pooling across vowels.

Figure 2. Mean proportion of critical vowel spellings for experimental and control nonwords in Experiment 2 as a function of spelling level group, pooling across vowels.


0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion critical spellings
Experimental
Control
K-1
2-3
4-5
6-8
9+
Spelling grade level


0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion critical spellings
Experimental
Control
K-1
2-3
4-5
6-8
9+
Spelling grade level