



Children use vowels to help them spell consonants

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Abstract

English spelling is highly inconsistent in terms of simple sound-to-spelling correspondences but is more consistent when context is taken into account. For example, the choice between *ch* and *tch* is determined by the preceding vowel (*coach, roach* vs. *catch, hatch*). We investigated children's sensitivity to vowel context when spelling consonants in monosyllabic nonwords. Second graders (7-year-olds) tended to use vowel context correctly when spelling word-final consonants (codas). This use of context was progressively stronger for third and fifth graders as well as for college students. The increase is not due to differences in vocabulary because the contextual patterns are similar in reading materials targeted at all four age groups. Vowel letters (graphotactics) had a stronger influence than did vowel pronunciation. Children also used vowel context when spelling word-initial consonants (onsets); this effect was as strong for second graders as for adults. Thus, novice spellers take advantage of graphotactic information.

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Introduction

Spelling words in English can be a daunting task. Some words can be spelled correctly using simple sound-to-letter correspondences by parsing the word into individual sounds and representing each sound with one or more letters. This simple strategy is not as helpful as one might hope, however, because sound–letter relations are not always consistent. Many alternative letter choices may be available for each sound. For example, /k/ may

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be spelled *k*, *c*, *ck*, *cc*, *q*, or *ch*. (For an explanation of the phonetic symbols used in this article, see International Phonetic Association, 1999.) Children who know only one letter choice for /k/ may spell *care* as *kare*, *scratch* as *skrach*, or *truck* as *trok* (Treiman, 1993). Although these spellings are phonologically plausible and readable and could be considered good attempts at representing the words' written forms, they are not correct. Thus, a phonological strategy based on context-free sound–letter associations is of limited value in helping children to spell words correctly. The current study addressed the question of how children make sense of the many letter choices that are available to them when spelling English words.

Research has quantified the inconsistent nature of English sound-to-letter relations. Kessler and Treiman (2001) conducted statistical analyses on spelling consistencies in 3117 English monosyllabic words. Vowels were shown to be the least consistent part of the word to spell, but consonants also are sometimes inconsistent. On a scale of 0 to 1, with 1 meaning that a sound is always spelled the same way, onsets (i.e., the prevocalic consonants in a syllable) have average consistencies of .91 and codas (i.e., the postvocalic consonants in a syllable) have average consistencies of .82. These relatively low consistencies are mitigated somewhat by etymological constancy in English spelling. This allows us to apply our knowledge of French when spelling *quiche* or to infer that *tricycle* has the same /s/–c correspondence as in *bicycle* because the two words share the same Greek morpheme for “wheel.” However, such clues help spellers on only some kinds of words and only if spellers have enough knowledge to use them. When context-free phonological, morphological, and etymological strategies fail, spellers must rely on something else if they wish to avoid the laborious task of rote word-by-word memorization.

Use of context is another potential tool in the speller's arsenal. This strategy involves using surrounding elements to help spell other elements in a word. The potential value of this strategy is shown by the fact that sound–letter correspondences become more regular when other parts of the word are taken into consideration. Coda spelling consistency rises from .82 to .93 when vowels are considered (Kessler & Treiman, 2001). For example, when the vowel is taken into account, the options for spelling the coda /f/ are reduced. The spelling *ff* is likely to be the correct choice after certain vowels that traditionally have been called short vowels, as in *stuff*. In most other cases, the appropriate choice is *f* as in *roof* and *life*. Onset spellings are also significantly influenced by the vowel, but to a lesser extent than are codas: The consistency rises from .91 to .94. Only a few onset spellings are systematically affected by vowels. One example is /k/, which is typically spelled *c* as in *cost*. However, before certain vowels such as /ε/, the normal spelling is *k* as in *kept*.

These considerations suggest that context could help spellers to choose from among the possible spellings for individual sounds. The primary question addressed by the current study was whether children take advantage of this information when they spell. Our study focused on children's use of vowel context in the spelling of initial and final consonants. To study the developmental course of context use, we included children of different grade levels and a comparison group of adults.

Although few studies have addressed English-speaking children's use of context in spelling, several studies have looked at adults' use of contextual clues. Here we review studies done with adults before turning to the small body of research on the development of context-based strategies for spelling. Research suggests that adults are sensitive to vowel context when spelling codas and onsets. In a study by Perry, Ziegler, and Coltheart (2002) that looked at the influence of vowel context on spellings of codas, adults produced different

types of spellings for nonwords with final consonants such as *f* that could be doubled (or extended) depending on the vowel. In nonwords with traditionally short (or lax) vowels, adults tended to extend the final consonant (e.g., *nuff* to spell /nʌf/). In nonwords with traditionally long (or tense) vowels, adults tended to use a single consonant spelling (e.g., *nafe* to spell /nef/). Kessler and Treiman (2004) provided further evidence that adults use vowels to help spell codas. For example, they found that adults tended to apply to nonwords the English spelling pattern whereby /s/ is most likely to be spelled *se* following the vowel /aʊ/ (*house*) but *ce* following the vowel /ai/ (*nice*). Kessler and Treiman also found that adults took advantage of vowel context to limit onset spelling possibilities. For example, spellers tended to honor the pattern whereby /k/ is most likely to be spelled *k* before the vowel /i/ but *c* before /a/. Context is also applied in the consonant-to-vowel direction: Treiman, Kessler, and Bick (2002) found that college students showed sensitivity to both coda and onset contexts when spelling vowels. In all, these studies demonstrated that adults take advantage of context to help limit spelling possibilities.

Contextual clues may help experienced spellers deal with the irregularities of English, but do children also benefit from such clues? A few studies have begun to address this issue for English and other languages (e.g., Juul, 2005). With regard to the topic of interest here—children’s use of vowel context in spelling consonants—we are aware of only one previous study. Marsh, Friedman, Welch, and Desberg (1980) used nonword stimuli to ask whether children knew that initial /k/ is most often spelled with *c* when the following vowel is *a* and *u*. Second graders used *c* spellings 66% of the time when spelling /k/ before either *a* or *u*. However, this study did not include stimuli that contained initial /k/ followed by *e* or *i*. The lack of such a control makes it impossible to determine whether the children made use of context or simply favored the use of *c* to spell /k/ regardless of context.

Most studies on children’s use of context in spelling have focused on the use of consonantal context when spelling vowels. Varnhagen, Boechler, and Steffler (1999) asked children to spell nonwords that contained the vowel sound /a/. Half of the stimuli contained adjacent consonants that condition the spelling *o*, and the other half contained consonants that condition the spelling *a*. By third grade, children began to use consonantal context to some extent. Although the stimuli included items in which the onset was expected to influence the vowel spelling and those in which the coda conditioned the vowel, the data for the two conditions were not analyzed separately. Therefore, it is unclear whether children used onset context, coda context, or both to help them spell vowels. Treiman and Kessler (2005) addressed this issue in a recent study. They found that coda context effects begin to emerge for some vowels in children who spelled at a fourth-grade spelling level, typical of 9-year-olds. However, these effects were not reliable for all of the tested vowels until children reached a seventh-grade spelling level. Onset context effects appeared much earlier, beginning in first grade with one vowel and showing effects for all of the tested vowels by fourth grade. Thus, although onset context appears to be easier to use than does coda context, English-speaking children are rather slow in using consonantal context to help narrow down spelling choices for vowels.

If we were to find in the current study that young children use vowels to help spell consonants, an additional question would concern the nature of the context effects. Are children influenced by the pronunciation of the vowels (i.e., the phonology) or by their written form (i.e., the graphotactics)? Previous studies have treated the context as being phonological (e.g., Juul, 2005; Kessler & Treiman, 2001; Perry et al., 2002). However, many contextual effects are described more accurately as graphotactic in nature. The consonant

extension pattern mentioned earlier is a good example. It applies to one-syllable words that have a single consonant sound after the vowel. Several consonant spellings are extended—*f*, *l*, and *s* are doubled, and *k*, *ch*, and *ge* grow to *ck*, *tch*, and *dge*—when the vowel meets certain conditions. This condition is generally described as phonological: The spelling is extended after those vowels that are traditionally called short vowels and that are often called lax vowels by phonologists—in American English, /ɪ/, /ɛ/, /æ/, /ɑ/, /ʌ/, and /ʊ/. Thus, we get spellings such as *stiff*, *Jeff*, *stack*, *lodge*, *judge*, and *pull*, as opposed to *knife*, *hawk*, and *sail*, where the vowels are not short. An alternative account of the pattern is graphotactic: The consonant spelling is extended when the vowel is spelled by exactly one letter. In this account, *Jeff* is spelled with an extended *f* because the vowel is spelled by one letter, *e*, and *knife* does not have an extended *f* because the vowel is spelled by two letters: *i* plus final *e*. This graphotactic rule is more accurate because it better accounts for spellings such as *deaf*, *touch*, and *hook*, where the phonological rule would call for an extended consonant, and spellings such as *ball*, where the phonological rule would not call for an extension after the long (phonologically tense) vowel /ɔ/.

Young children, however, might not be sensitive to such graphotactic context rules. According to stage theories and phase theories of spelling development (e.g., Ehri, 1986; Frith, 1980), young spellers rely on phonological knowledge. Only at more advanced stages of spelling development do children gain the ability to use graphotactic information. On this view, we might expect context effects, when they first emerge, to be based on phonological context. However, research has shown that children have some knowledge of simple graphotactic patterns at an early age (Cassar & Treiman, 1997; Treiman, 1993). For example, even young children appear to know that double consonants such as *ff* may not appear at the beginnings of words. Research has not investigated whether children use more complex graphotactic rules, such as the extension rule described above, to help spell consonants. If they do, this would provide further support for the idea that children can use information other than phonology in spelling. In the current study, we asked whether children's use of extended consonant spellings is better accounted for by the phonology of the preceding vowel (short or long) or by its spelling (one letter or more).

A spelling production task was used to address our two questions: whether children use vowels to help spell consonants and whether children are more influenced by a phonological or graphotactic context. In the coda condition, participants spelled nonwords ending with consonants that are sometimes extended. In the onset condition, they spelled nonwords that begin with /k/, which is normally spelled *k* or *c* at the beginning of a word. In both conditions, the choice of spelling is highly inconsistent unless one considers the vowel, in which case the spelling becomes quite consistent. The stimuli were designed in pairs that differed only in their vowels, so that we could test whether the children's use of extended spellings, or choice of *k* versus *c*, was affected by the vowel pronunciation. In addition, because children had the freedom to use however many letters they wished in spelling vowels, we could determine whether their use of extended coda spellings was affected by the number of letters in their own spelling of the vowel.

To further examine the role of graphotactics, we also used a spelling choice task. Past research has used spelling choice tasks to investigate graphotactic knowledge (e.g., Cunningham, Perry, & Stanovich, 2001). A limitation of such a task is that different spellings usually imply different pronunciations, so it might be difficult to determine whether participants base their choices on the spelling or on their decoded pronunciation. However, the coda extension rule does not have that drawback because extending or failing to

extend the coda usually does not imply a different pronunciation. Participants in our study saw two nonwords, such as *soof–sooff* or *saf–saff*, and were asked to choose which looked more like a real word. Even if the participant pronounced the nonwords mentally, we predicted approximately the same distribution of possible pronunciations for both spellings. If participants preferred the extended spelling more often for pairs having single-letter vowels (*saff* rather than *saf*) than for those having multiple-letter vowels (*sooff–sooff*), we can be reasonably certain that the choice was due to graphotactics rather than to any difference in phonology. The choice task included pairs of spellings for all of the stimuli from the coda condition of the spelling task. The stimuli used to investigate vowel-to-onset influences, the onset /k/ nonword pairs, were not amenable to this choice task because pairs of spellings such as *kesk–cesk* imply different pronunciations (/kesk/ and /sɛsk/, respectively) and so do not allow us to factor out the role of phonology.

We studied children at different grade levels, as well as college students, to determine whether use of context changes with age. If children became increasingly proficient in the use of context, a natural explanation might be that they become more sensitive to more complex patterns as they mature or that repeated exposure to the same pattern over many years leads to more complete learning. However, another possible explanation could be that children see different sorts of spelling patterns as their vocabulary increases. Even as one might not expect young children to have learned the pattern that initial /sf/ is spelled *sph* because nearly all words beginning with *sph* are highly technical, perhaps the lexical evidence for the coda extension pattern or the spelling of onset /k/ changes substantially as children become exposed to more words in print. To test that possibility, we looked at the frequency of words that appear in reading materials targeted at different grade levels (Zeno, Ivenz, Millard, & Duvvuri, 1995). We asked whether the amount of exposure to the coda extension pattern and the onset /k/ changes substantially as children progress through school.

Method

Participants

The participants were children in second, third, and fifth grades as well as college students. Table 1 shows the mean age and number of participants at each level. All of the participants were native speakers of English who lived in the St. Louis, Missouri, metropolitan area, and none had current diagnoses of speech, reading, or hearing disorders. Teachers of the students reported that the coda extension and initial /k/ spelling rules were not explicitly taught in the students' spelling curriculum materials or during informal

Table 1
Characteristics of participants

Characteristic	Grade			
	Second	Third	Fifth	College
<i>n</i>	27	31	27	35
Mean age	7 years 8 months	9 years 3 months	10 years 8 months	19 years 10 months
Age range	7 years 1 month to 8 years 2 months	8 years 7 months to 10 years 2 months	10 years 2 months to 11 years 2 months	17 years 11 months to 22 years 1 month
Time of testing	September to October	April to June	September to October	September to November

classroom discussions led by teachers. All teachers taught reading and spelling using a combination of phonics and whole language instruction. The college students received course credit for their participation.

Stimuli

Production task

Monosyllabic nonwords were constructed in pairs that differed only in their vowel pronunciation. For each of four different coda consonants (/f/, /k/, /l/, and /tʃ/), five stimulus pairs were constructed whose coda consisted entirely of that consonant and that contrasted a short vowel, which conditions extended codas in normal English words, with a long vowel. These stimuli are listed in the pronunciation columns of Table 2. For the onset condition, five pairs of stimuli began with /k/ and contrasted the vowels /ε/ and /i/, which condition the spelling *k* in normal English words, with vowels that normally take *c*: /kɪft/–/kæft/, /kɪmp/–/kæmp/, /kεθ/–/kæθ/, /kεsk/–/kask/, and /kɪsp/–/kasp/.

Choice task

The stimuli were derived from the spoken stimuli used for the coda condition in the production task. Each of those spoken stimuli was spelled in two plausible ways, differing only in whether the coda extension rule was applied. A complete list of the stimuli can be

Table 2

Pronunciations of stimuli used in coda condition of production task and the corresponding spellings used in choice task

Coda	Short-vowel stimuli		Long-vowel stimuli	
	Pronunciation	Spelling choices	Pronunciation	Spelling choices
/f/	/væf/	<i>vaf–vaff</i>	/vef/	<i>vaif–vaiff</i>
	/sæf/	<i>saf–saff</i>	/suf/	<i>soof–sooff</i>
	/dʒæf/	<i>jaf–jaff</i>	/dʒof/	<i>joaf–joaff</i>
	/ʃæf/	<i>shaf–shaff</i>	/ʃef/	<i>shaif–shaiff</i>
	/fræf/	<i>frac–fracf</i>	/fref/	<i>fracf–fracff</i>
/k/	/gæk/	<i>gak–gack</i>	/gok/	<i>goak–goack</i>
	/mek/	<i>mek–meck</i>	/mok/	<i>moak–moack</i>
	/vek/	<i>vek–veck</i>	/vek/	<i>vaik–vaick</i>
	/wek/	<i>wek–weck</i>	/wuk/	<i>wook–woock</i>
	/næk/	<i>nuk–nuck</i>	/nik/	<i>neek–neek</i>
/l/	/θʌl/	<i>thul–thull</i>	/θul/	<i>thool–thooll</i>
	/jʌl/	<i>yul–yull</i>	/jil/	<i>yeel–yeell</i>
	/zʌl/	<i>zul–zull</i>	/zul/	<i>zool–zooll</i>
	/sʌl/	<i>sul–sull</i>	/sul/	<i>sool–sooll</i>
	/vʌl/	<i>vul–vull</i>	/vul/	<i>vool–vooll</i>
/tʃ/	/gætʃ/	<i>gach–gatch</i>	/gitʃ/	<i>geech–geetch</i>
	/jætʃ/	<i>yach–yatch</i>	/jotʃ/	<i>yoach–yoatch</i>
	/θetʃ/	<i>thech–thetch</i>	/θutʃ/	<i>thooch–thoatch</i>
	/fʌtʃ/	<i>fuch–futch</i>	/futʃ/	<i>fooch–footch</i>
	/vʌtʃ/	<i>vuch–vutch</i>	/votʃ/	<i>voach–voatch</i>

found in the spelling choice columns of Table 2. In addition, filler pairs of nonwords were included to provide heightened contrasts between plausible and illegal spellings: *nufs-plkd*, *wup-psg*, *ig-ui*, *teg-*%#*, *lep-iaa*, *ro-gjp*, *kolg-\$%&>*, *dest-knijf*, *fup-2#!*, and *zob-euei*.

Corpus analysis

For the analysis of children's vocabulary, we used words that had frequency counts broken down by grade level in the corpus of *Zeno and colleagues* (1995) and also had one-syllable pronunciations in the *Carnegie Mellon Pronouncing Dictionary* (Carnegie Mellon University, 1998).

Procedure

Each participant completed a production task and a choice task. Participants were tested in groups of two to four. For each task, the stimuli were randomized for presentation into three different orders and participants were randomly assigned to one of the three orders. Adult participants followed the same procedure as the children except that adults were first told that the instructions and task were designed for young children.

Production task

The participants were given an answer sheet showing 50 unique cartoon pictures of monsters. The participants were told that they would see some pictures of "silly monsters" and then would be asked to spell their "silly names." The experimenter pronounced each item, and the participants repeated it. If the nonword was pronounced incorrectly, the experimenter corrected the participants by saying the item again and required the participants to repeat the nonword until it was pronounced correctly. The participants then spelled each nonword on their answer sheets. Two practice items were presented at the beginning of the task to ensure that each participant understood the procedure. A short rest period was given halfway through the list.

Choice task

The participants were presented with an answer sheet showing pairs of nonwords. The participants were told to look at each pair of "silly words" and to circle the word that looked most like a real word. Two practice items were presented at the beginning of the task to ensure that each participant understood the procedure. A short rest period was given halfway through the list.

Corpus analysis

For each coda type in the production task, we selected the one-syllable words that end with the relevant consonant. From these words, we isolated the subset that contain one of the vowels used in the short vowel stimuli and that end in a typical or extended spelling for the consonant in question. For example, for coda /f/, we selected words that contained one of the vowels /æ/, /ʌ/, or /ɛ/ and whose coda is the single consonant /f/ spelled either *f* or *ff*. Words such as *tough*, which have unextendable spellings, were not included. We then

computed what fraction of the selected words has the extended spelling (in this case, *ff*). This computation was done separately for each of the four grade levels in our study (second, third, and fifth grades and college), weighting each word by the natural logarithm of two plus the frequency given for the word for the grade in question in [Zeno and colleagues \(1995\)](#). Analogous computations were done for words containing one of the long vowels used in production task stimuli (/i/, /u/, and /o/). These analyses were designed to show the degree to which short or long vowel pronunciations predict extended or unextended coda spellings for each of our four codas in each of the four grade levels. To analyze the predictive power of the graphotactics, analogous analyses were performed over words whose vowel, regardless of pronunciation, is spelled with one letter and then over words whose vowel is spelled with multiple letters.

Similar analyses were performed for words beginning with /k/, corresponding to the onset condition of the production task. We isolated words that begin with /k/ spelled *c* or *k* and that contain /i/ or /ε/, the vowels used to condition *k* in the production task. We then computed the fraction of those words that have the spelling *k* at each grade level. Analogous computations were done for words containing one of the vowels /æ/, /ʌ/, or /ɑ/, vowels that do not condition the spelling *k*. For the graphotactic analyses, analogous analyses were performed over words whose vowel spelling begins with one of the letters *e*, *i*, or *y*, on the one hand (conditioning *k*), or *a*, *o*, or *u*, on the other.

Results

The results are organized by stimulus condition. First we present results pertaining to the spelling of the coda, broken down by task (production or choice), followed by the corpus analysis of coda spellings. Then we present the results of the production task and corpus analysis for onset spellings. For all production task results, coda stimuli responses that were spelled using unextendable or implausible final consonants (e.g., *saph* for /sæf/, *youh* for /jotʃ/) and onset stimuli responses that spelled initial /k/ with some letter other than *k* or *c* (e.g., *gask* for /kask/), as well as any stimuli that were spelled without a vowel, were not included in the analyses because the conditional spelling rules that we were investigating do not apply in such conditions; for example, final *ph* would not be extended regardless of the preceding vowel. The proportions of responses that were excluded by these criteria were small, with a maximum of 7% in second grade and only 3% overall.

Coda spellings

Production task

[Table 3](#) shows, for each age group, the mean proportion of stimuli that the participants spelled with a final extended consonant, broken down by the pronunciation of the final consonant and the length of the vowel sound. The data were analyzed by participants (F_1) and by items (F_2), and only results with *p* values less than .05 in both types of analyses are reported. Analyses of variance (ANOVAs) were conducted using the variables of grade (second, third, fifth, or college), vowel (short or long), and coda (/f/, /k/, /l/, or /tʃ/).

In conformity with the patterns of English orthography, participants used more extended spellings after short vowels than after long vowels (main effect of vowel, $F_1(1, 116) = 390.23$, $F_2(1, 32) = 338.24$, $p < .001$ for both). Older participants were more

Table 3
Proportion of extended coda spellings in production task by pronunciation of stimulus vowel

Coda	Vowel	Grade				Overall
		Second	Third	Fifth	College	
/t/	Short	.13	.33	.56	.68	.44
	Long	.12	.17	.20	.16	.16
/k/	Short	.72	.68	.83	.77	.75
	Long	.45	.24	.22	.08	.24
/l/	Short	.44	.55	.75	.79	.64
	Long	.20	.18	.09	.05	.12
/tʃ/	Short	.10	.46	.64	.87	.54
	Long	.06	.27	.30	.47	.29
All	Short	.35	.51	.69	.78	.58
	Long	.21	.22	.20	.19	.20

likely to use extended codas than were younger participants (main effect of grade, $F_1(3, 116) = 11.73$, $F_2(3, 96) = 56.02$, $p < .001$ for both). In particular, older participants were more likely to use extended codas in the expected context after short vowels (interaction of vowel by grade, $F_1(3, 116) = 27.81$, $F_2(3, 96) = 74.20$, $p < .001$ for both). The mean difference between use of extended spellings after short vowels and use of extended spellings after long vowels increased steadily with age (second grade = .14, third grade = .29, fifth grade = .49, college = .58, each difference significant at $p < .001$).

Although the general pattern of English orthography calls for the extension of all of the tested codas after short vowels, participants' use of extension differed significantly for different codas (main effect of coda, $F_1(3, 348) = 17.45$, $F_2(3, 32) = 17.89$, $p < .001$ for both). Participants were especially likely to extend the spelling of /k/ to *ck* regardless of context. This tendency to treat codas differently varied by grade (interaction of coda by grade, $F_1(9, 348) = 10.79$, $F_2(9, 96) = 32.53$, $p < .001$ for both). Second graders, for example, rarely extended *ch* to *tch* or *f* to *ff*, but they were more like older participants in the frequency with which they used extended *ll*. Participants were also more likely to correctly apply the coda extension pattern to some codas than to others (interaction of vowel by coda, $F_1(3, 348) = 30.38$, $F_2(3, 32) = 11.35$, $p < .001$ for both): /l/ and /k/ were spelled correctly (difference between use of extension after short vowels vs. long vowels was 50 percentage points) twice as often as /tʃ/ and /f/ (24 and 26 percentage points, respectively).

Participants sometimes spelled short vowels using multiple letters (e.g., /sæf/ spelled as *saef*) and long vowels using one letter (e.g., /suf/ spelled as *suf*), even though such spellings are unusual in English. Analyses were conducted to determine whether participants' use of coda extension was based on vowel sound or length of vowel spelling. Analyses could not be conducted on all participants because not all of them provided both single- and multiple-letter vowel spellings for each vowel sound. However, the majority of second graders spelled both short and long vowels using both single- and multiple-letter spellings, and so we conducted logistic regression analyses on spellings from this subset of second graders ($n = 22$). The data were analyzed using a simultaneous regression with coda spelling as the dependent variable and with vowel pronunciation and vowel spelling as predictor variables. The participant identification numbers and coda pronunciation were also included as covariables. Vowel pronunciation did not predict coda spelling (Wald $\chi^2 = .61$,

$p = .437$), whereas number of letters in the vowel did significantly predict coda spelling in the expected direction. Each additional letter in the vowel spelling strongly decreased the likelihood that the coda spelling would be extended ($\beta = -3.52$, Wald $\chi^2 = 104.25$, $p < .001$).

Choice task

Table 4 shows the mean proportions of choices where the spelling with an extended coda was preferred over a spelling with an unextended coda, broken down by coda and whether the vowel was spelled with one or two letters. ANOVAs were conducted using the variables of grade (second, third, fifth, or college), number of letters in vowel (one or two), and coda (*ch*, *f*, *k*, or *l*).

As expected on the basis of the English orthography, participants preferred extended spellings after one-letter vowel spellings (main effect of vowel, $F_1(1, 116) = 823.26$, $F_2(1, 32) = 486.45$, $p < .001$ for both). Older participants overall chose extended spellings somewhat more often than did younger participants (main effect of grade, $F_1(3, 116) = 3.37$, $p = .021$, $F_2(3, 96) = 14.59$, $p < .001$), but disproportionately so when the vowel was spelled by one letter (interaction of vowel by grade, $F_1(3, 116) = 24.27$, $F_2(3, 96) = 71.30$, $p < .001$ for both); that is, more conventional spellings were increasingly favored with age. The difference between preferences for extended spellings after one letter than after two letters increased steadily across the age groups (mean differences: second grade = .34, third grade = .46, fifth grade = .67, college = .75, each difference significant at $p < .001$). The preference for extended spellings after one-letter vowels and shorter coda spellings after two-letter vowels was stronger for some coda types than for others (interaction of vowel by coda, $F_1(3, 348) = 48.26$, $F_2(3, 32) = 8.24$, $p < .001$ for both). It was particularly weak for coda (*t*)*ch*, with a difference of only 36 percentage points separating

Table 4
Mean proportions of extended coda choices in choice task

Coda	Letters in vowel spelling	Grade				Overall
		Second	Third	Fifth	College	
(c)k	1	.90	.85	.93	.93	.90
	2	.40	.23	.16	.15	.23
	All	.65	.54	.54	.54	.57
(f)f	1	.58	.69	.89	.91	.78
	2	.27	.25	.21	.22	.24
	All	.42	.47	.55	.57	.50
(l)l	1	.77	.72	.97	.96	.86
	2	.32	.21	.16	.05	.17
	All	.54	.47	.56	.50	.52
(t)ch	1	.48	.57	.83	.95	.72
	2	.38	.30	.39	.32	.34
	All	.43	.43	.61	.63	.53
All	1	.68	.71	.90	.94	.81
	2	.34	.25	.23	.18	.25
	All	.51	.48	.57	.56	.53

the preference for *ch* after one vowel versus two vowels, and it was stronger for *(l)l*, *(c)k*, and *(f)f*, where the differences were 67, 66, and 53 percentage points, respectively. There was also a marked preference for certain coda spellings at different grade levels regardless of vowel (interaction of coda by grade, $F_1(9, 348) = 6.05$, $F_2(9, 96) = 8.64$, $p < .001$ for both). For instance, younger children tended to prefer spellings with unextended *ch* more than did older participants, but younger children favored extended *ck* more than did older participants.

Corpus analyses

Table 5 shows the proportions of English words that are analogous to our production task stimuli that contain extended spellings. For example, the first numerical cell of the table indicates that, of real one-syllable words phonologically analogous to the short-vowel /f/ final nonword stimuli from the production task and ending in a typical spelling of /f/ (e.g., *staff* /stæf/), the spelling of the coda was an extended *ff* in 12% of the words found in reading materials targeted to second graders. The bottom half of the table shows the numbers obtained when a graphotactic criterion is used instead of a phonological one: It gives results for words where the vowel is spelled with exactly one letter. Analogous statistics for long vowels or for vowels spelled with multiple letters are not presented because extended spellings were never found in these cases.

The figures indicate that coda extension is highly reliable for /k/ and /l/ regardless of how the vowel condition is conceptualized. Coda extension is also highly reliable for /f/, but only if one counts the number of vowel letters. If one looks instead at the pronunciation of the vowel, coda extension fails to happen on most word tokens. This is due to the prevalence of the words *calf* and *half*, where the American English vowel /æ/ would predict extended *ff*. The frequency-weighted proportion of extended *ff* spellings increases through the grade levels as the word *staff* becomes increasingly common. This limited case is the only condition under which the lexical evidence for coda extension patterns increases across the grade levels. The coda consonant /tʃ/ has the weakest evidence for coda extension. This is due primarily to the prevalence of the words *touch*, *much*, and *such*, the last of which becomes especially frequent in college-level texts.

Table 5
Proportions of corpus words that have extended coda spellings of /f/, /k/, /l/, or /tʃ/ after short vowels and one-letter vowels

Vowel type	Coda	Grade level of texts			
		Second	Third	Fifth	College
Pronunciation short	/f/	.12	.19	.24	.42
	/k/	.96	.96	.96	.95
	/l/	1.00	1.00	1.00	1.00
	/tʃ/	.65	.66	.66	.58
One letter in spelling	/f/	1.00	1.00	1.00	1.00
	/k/	.96	.96	.96	.95
	/l/	1.00	1.00	1.00	1.00
	/tʃ/	.72	.72	.72	.64

Onset condition

Production task

Table 6 shows the mean proportions of spellings of initial /k/ that were *k*, broken down by the following vowel. ANOVAs were conducted using the variables of grade (second, third, fifth, or college) and vowel set. As predicted from the English orthography, the spelling *k* was significantly more likely before /ɛ/ and /ɪ/ than before /æ/, /ʌ/, or /ɑ/ (main effect of vowel, $F_1(1, 116) = 351.49$, $F_2(1, 8) = 80.63$, $p < .001$ for both). Older participants used more *k* spellings than did younger participants (main effect of grade, $F_1(3, 116) = 12.47$, $F_2(3, 24) = 18.43$, $p < .001$ for both), but there was no interaction between grade and vowel. Children as young as second grade used *k* spellings much more often when the following vowel was /ɛ/ or /ɪ/ than when it was some other vowel. This effect was as large statistically for the second graders as for the more experienced participants.

On nearly all trials, participants spelled /ɛ/ or /ɪ/ using *e* or *i*, respectively (97% of spellings), and spelled /æ/, /ʌ/, or /ɑ/ using *a*, *u*, or *o*, respectively (99% of spellings). Therefore, analyses could not be conducted to determine whether participants spelled the initial /k/ based on the vowel spelling or on the vowel sound.

Corpus analyses

Table 7 shows the frequency-weighted proportions of English words that are analogous to our /k/ initial stimuli that are spelled with *k*. At all grade levels, words that follow the regular pattern, such as *kiss* and *cat*, are in the clear majority. In fact, when vowel spelling is considered rather than vowel pronunciation, the patterns are nearly perfect; the only exceptions are a few proper nouns such as *Celts* and *Karl*. The main cause for the lower score when pronunciations are used is words such as *care* (/kɛr/). In all cases, the proportions are nearly constant across all grade levels: As a proportion of the entire text vocabulary, the patterns are just as strong in second grade as in college.

Table 6
Proportions of initial /k/ spellings in production task

Following vowel	Grade				
	Second	Third	Fifth	College	Overall
/ɛ/, /ɪ/	.73	.88	.87	.99	.87
/æ/, /ʌ/, /ɑ/	.22	.34	.27	.55	.35
All	.47	.61	.57	.77	.61

Table 7
Proportions of corpus words in initial /k/ that are spelled with *k*, broken down by the following vowel type

Vowel type		Grade level of texts			
		Second	Third	Fifth	College
By pronunciation	/ɛ/, /ɪ/	.83	.83	.84	.80
	/æ/, /ʌ/, /ɑ/	.02	.02	.01	.03
By spelling	<i>e</i> , <i>i</i>	.99	.99	.98	.98
	<i>a</i> , <i>u</i> , <i>o</i>	.02	.02	.01	.03

Discussion

The primary goal of this study was to investigate whether children use vowel context to help spell consonants. We found that children as young as second grade take advantage of contextual clues provided by the vowel to spell codas and that this use of vowel context increases with age. We also found that children as young as second grade use vowel context to help spell onsets. The effect of vowel context on onset spellings was as strong for second graders as for more experienced spellers.

These results are in contrast to some influential theories of literacy development (Goswami, 1993; Goswami & Bryant, 1990) suggesting that beginning spellers should be more sensitive to spelling clues within the rime (i.e., vowel–coda unit) than within other parts of words. These theories propose that young children do not first parse one-syllable words into small units such as phonemes, as suggested by stage theories of reading (Frith, 1980), but instead parse words into larger units: onset and rime. In a study by Goswami (1988), young children tended to use rimes more than other parts of words in spelling new words. For example, they used the rime *eak* from *beak* to help them spell a new word such as *peak*. They did not use the head of the word (onset + vowel), or *bea* from *beak*, as often as the rime. Some research has supported this rime advantage hypothesis in spelling. Kirkbride and Wright (2002) asked whether children benefit from explicit training in making analogies and whether rimes are indeed more salient to young spellers than are other units. Children were taught how to make analogies among heads, vowels, rimes, and codas. In spelling tests following training, children tended to use rime analogies more often than they used head, vowel, or coda analogies. However, other research has not found a rime advantage in spelling (Bernstein & Treiman, 2001; Nation & Hulme, 1996; Treiman & Kessler, 2005; Treiman et al., 2002).

Our study also failed to find a special role for rimes. The results suggest that young children are sensitive to contextual clues within the rime (vowel-to-coda context effects) as well as contextual influences that cross the onset–rime boundary (vowel-to-onset context effects). Sensitivity to the initial /k/ pattern was as strong for second graders as for adults, whereas sensitivity to the coda extending pattern was weaker for second graders than for more experienced spellers. The early and strong sensitivity to the initial /k/ pattern suggests that contextual influences that cross the onset–rime boundary are not necessarily difficult for children to learn.

One possible explanation for the differences we found in onset and coda spellings—that second graders attend to context as much as do adults when spelling onsets but not as much as adults when spelling codas—could conceivably have been differences in the children’s print vocabulary. If children saw much evidence for the onset /k/ pattern from an early age but less evidence for coda extension until they had acquired a more extensive print vocabulary, that difference in environmental input could have overwhelmed any natural predisposition to use rime units. However, our corpus analyses showed that this was not the case. The proportions of words containing the patterns of interest are similar across conditions (onset vs. coda) and across reading levels. The only exception was for words ending in /æf/, comprising a very small number of words. Thus, it appears that any difference in children’s use of vowel context between these conditions and across age groups is due not to substantial differences in their reading input but rather to cognitive factors. Perhaps children attend more carefully to the initial /k/ rule because the

beginnings of words are particularly salient. Feedback from reading might be important as well: Children may hesitate to spell *Kent* with a *C* because they realize that *Cent* could be pronounced with a /s/. In general, no such conflict occurs when the coda extension pattern is misapplied.

Differences in the input may account for certain of the smaller differences that we observed in how people apply the coda extension rule for different coda consonants. Both the production and the choice tasks showed a very strong application of the rule for /l/ and /k/, a weak application for /tʃ/, and an intermediate application for /f/. Younger children tended to avoid *tch* in all conditions, and this is understandable given that trigraphs are inherently difficult and are otherwise rare in English. But that does not explain the effects for the other codas, nor does it explain why children failed to show a stronger effect of vowel context for /tʃ/ on top of their avoidance of the trigraph. However, the behavioral results mirror the data from the corpus analyses rather closely. Although words in final /l/ and /k/ conform to the coda extension pattern with high regularity, the patterns were somewhat less clear for /f/ and especially for /tʃ/. A few common words, such as *half*, *touch*, *much*, and *such*, disturb the pattern and undoubtedly make coda extension appear less compelling for these consonants.

In addition to examining whether children use vowel context to help spell consonants, our study was designed to determine whether children's use of vowel context is based on phonological or graphotactic information. In other words, do children use vowel context to spell consonants based on how the vowel is pronounced or on how the vowel is spelled? Based on stage theories of spelling development (e.g., Frith, 1980) suggesting that sensitivity to graphotactic patterns develops late, we might expect to find that young children use only phonological context and that use of graphotactic context emerges in older children and adults. However, we did not find such a pattern. In our production task, children as young as second grade used more extended coda spellings following vowels that they spelled with one letter than following vowels that they spelled with multiple letters regardless of whether the vowels were pronounced short or long. These results suggest that even novice spellers take advantage of clues that are based on spelling or graphotactic information.

Many words in English cannot be spelled correctly by simply sounding out the words and representing each sound with the most common letter. It is often assumed that, when faced with words that cannot be spelled correctly using simple context-free sound–letter rules, children must memorize the words as wholes. The results of the current study suggest that spellers do not rely exclusively on whole word memorization in such cases. Instead, spellers often use context to provide clues about the correct spelling of a sound. Even second graders in our study showed some knowledge of contextual rules.

The younger children in our study did not use context as often as did more experienced spellers to spell codas. Thus, although young children are able to pick up on certain contextual clues that vowels provide, they may gain further benefit from explicit spelling instruction on how context helps one to choose among many letter choices. Current practice in early elementary education includes explicit instruction in phonemic awareness or access to individual sounds in words. This practice is supported by research showing that phonemic awareness is an important component of successful literacy development (e.g., Bradley & Bryant, 1983). Our results suggest that, in addition to teaching about the component sounds of words, information about contextual patterns should be explicitly taught as well. Teachers can create opportunities during spelling and phonics lessons for students

to discover the many patterns of written English and to generate ideas on when and why they occur. By explicitly pointing out regularities in English spelling, teachers can offer their students additional strategies beyond phonological sounding out and laborious rote memorization.

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References

- Bernstein, S. E., & Treiman, R. (2001). Learning a novel grapheme: Effects of positional and phonemic context on children's spelling. *Journal of Experimental Child Psychology*, *79*, 56–77.
- Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read: A causal connection. *Nature*, *301*, 419–421.
- Carnegie Mellon University. (1998). Carnegie Mellon pronouncing dictionary [data file]. Retrieved May 28, 2003, from <ftp://ftp.cs.cmu.edu/project/speech/dict/cmudict.0.6>
- Cassar, M., & Treiman, R. (1997). The beginnings of orthographic knowledge: Children's knowledge of double letters in words. *Journal of Educational Psychology*, *89*, 631–644.
- Cunningham, A. E., Perry, K. E., & Stanovich, K. E. (2001). Converging evidence for the concept of orthographic processing. *Reading and Writing: An Interdisciplinary Journal*, *14*, 549–568.
- Ehri, L. C. (1986). Sources of difficulty in learning to spell and read. *Advances in Developmental and Behavioral Pediatrics*, *7*, 121–195.
- Frith, U. (1980). *Cognitive processes in spelling*. London: Academic Press.
- Goswami, U. (1988). Children's use of analogy in learning to spell. *British Journal of Developmental Psychology*, *6*, 21–33.
- Goswami, U. (1993). Phonological skills and learning to read. In P. Tallal, A. M. Galaburda, R. R. Llinas, & C. von Euler (Eds.), *Temporal information processing in the nervous system: Special reference to dyslexia and dysphasia* (pp. 296–311). New York: New York Academy of Sciences.
- Goswami, U., & Bryant, P. (1990). *Phonological skills and learning to read*. Hillsdale, NJ: Lawrence Erlbaum.
- International Phonetic Association. (1999). *Handbook of the International Phonetic Association: A guide to the use of the International Phonetic Alphabet*. Cambridge, UK: Cambridge University Press.
- Juul, H. (2005). Knowledge of context sensitive spellings as a component of spelling competence: Evidence from Danish. *Applied Psycholinguistics*, *26*, 249–265.
- Kessler, B., & Treiman, R. (2001). Relationships between sounds and letters in English monosyllables. *Journal of Memory and Language*, *44*, 592–617.
- Kessler, B., & Treiman, R. (2004, June). *Sensitivity to statistical contextual patterns when spelling consonants*. Paper presented at the meeting of the Society for the Scientific Studies of Reading, Amsterdam.
- Kirkbride, S., & Wright, B. C. (2002). The role of analogy use in improving early spelling performance. *Educational and Child Psychology*, *19*, 91–101.
- Marsh, G., Friedman, M., Welch, V., & Desberg, P. (1980). The development of strategies in spelling. In U. Frith (Ed.), *Cognitive processes in spelling* (pp. 339–353). London: Academic Press.
- Nation, K., & Hulme, C. (1996). The automatic activation of sound-letter knowledge: An alternative interpretation of analogy and priming effects in early spelling development. *Journal of Experimental Child Psychology*, *63*, 416–435.
- Perry, C., Ziegler, J. C., & Coltheart, M. (2002). How predictable is spelling? Developing and testing metrics of phoneme-grapheme contingency. *Quarterly Journal of Experimental Psychology A*, *55*, 897–915.
- Treiman, R. (1993). *Beginning to spell*. New York: Oxford University Press.

- Treiman, R., & Kessler, B. (2005). *Spelling as statistical learning: Using consonantal context to spell vowels*. Manuscript submitted for publication, Washington University in St. Louis.
- Treiman, R., Kessler, B., & Bick, S. (2002). Context sensitivity in the spelling of English vowels. *Journal of Memory and Language*, 47, 448–468.
- Varnhagen, C. K., Boechler, P. M., & Steffler, D. J. (1999). Phonological and orthographic influences on children's vowel spelling. *Scientific Studies of Reading*, 3, 363–379.
- Zeno, S. M., Ivens, S. H., Millard, R. T., & Duvvuri, R. (1995). *The educator's word frequency guide*. Brewster, NY: Touchstone Applied Science Associates.