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There's More to Children's Spelling Than the Errors They Make: Strategic and Automatic Processes for One-Syllable Words

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Researchers have attempted to understand the cognitive processing used in spelling by looking at children's spelling errors. The authors examined 2 other types of data—children's self-reported verbal protocols and on-line measures of spelling latencies. Elementary school children spelled 3 types of common 4-letter words, consonant–consonant–vowel–consonant, consonant–vowel–consonant–consonant, and consonant–vowel–consonant–silent *e*. Correctly and incorrectly spelled words were analyzed as a function of word type, verbal report, and keystroke latencies. Different typing patterns emerged for strategic and automatic reports and for different word types. Children seemed to use a relatively sequential read-out from long-term memory when directly retrieving a spelling, whereas they used a consonant pair strategy for final consonant clusters when sounding out words. Implications for spelling instruction are discussed.

A number of variables are correlated with spelling ability. There is little doubt that phonological ability, exposure to print, working memory capabilities, reading ability, and an understanding of spelling regularities are predictors of spelling ability (see Cunningham & Stanovich, 1991; Frith, 1980; Griffith, 1991; Stage & Wagner, 1992; Treiman, 1993). However, little is known about the cognitive processes in which children engage while spelling. The goal of the present research was to learn more about children's thought processes during spelling.

The information-processing framework provides one way to examine cognitive processing during spelling. Within this framework, the contributions of encoding, automatization, generalization, and strategy construction to children's cognitive processing are emphasized. These mechanisms are hypothesized to work together to improve children's thinking (Siegler, 1991). For example, the beginning speller may use a great deal of mental resources simply to encode words, perhaps resulting in a less efficient strategy choice when attempting to spell them. As knowledge of the phonological, orthographic, and morphological aspects of the spelling system develops, processing words, syllables, subsyllabic units, and individual phonemes becomes more automatic, freeing cognitive capacity for other types of processing. The speller may then become more flexible at choosing an appropriate strategy and generalizing to new situations (Siegler & Jenkins, 1989; Siegler & Shipley, 1995). Familiar words are eventually spelled automatically, using very little cognitive energy. We examined elementary school children's strategy selection for one-syllable words within an information-processing framework.

Several spelling strategies have been identified. The most common is a phonetic strategy, or phoneme-to-grapheme translation. Use of this strategy is hardly surprising given that phonological awareness is a major component of spelling ability (Bruck & Waters, 1990; Gentry, 1982; Griffith, 1991; Liberman & Shankweiler, 1985; Stage & Wagner, 1992; Treiman, 1985, 1993). Read (1975) indicated that young children's invented spellings are often phonemically related to the intended word. In order to apply a phonetic (or sound-out) spelling strategy, children must be able to identify and segment individual phonemes in a word.

Indeed, individual phoneme segmentation is difficult for young children (Goswami & Bryant, 1990; Liberman & Shankweiler, 1985; Treiman, 1991, 1992, 1993). In order to sound out a word, a child needs sufficient working memory capacity to both hold the word and segment it into phonemes while selecting the appropriate graphemes (Stage & Wagner, 1992; Varnhagen, Varnhagen, & Das, 1992). When spelling requires a good deal of attention, spellers may adopt a larger unit segmentation strategy, such as dividing the word into subsyllabic (e.g., onset-rime or consonant cluster) units.

Words with regular phoneme-to-grapheme correspondence (e.g., *must*) can be easily spelled using a simple phonetic spelling strategy. When the phoneme-to-grapheme conversion is not so simple, a child may use explicit rule-based strategies to produce the correct spelling. For

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example, the child may learn that the "silent *e*" at the end of a word "makes the vowel say its name," as in *cake.* On the other hand, many rule-based words can be spelled using orthographic knowledge rather than by applying a specific rule. For example, Treiman (1993) reported that children may correctly spell a plural noun ending in /s/ (e.g., *books*) and a plural noun ending in /z/ (e.g., *paws*), not because these children know the plural rule (i.e., to add an *s* when referring to more than one noun), but rather because /z/ and /s/ are usually spelled as *s.*

Words may also be spelled by analogy, such as *clip* is *lip* with a *c* in front of it. Goswami (1988) demonstrated that first-grade children could use analogies to other words when attempting to spell a test word. Goswami unexpectedly found that, for phonetically ambiguous words, young children used appropriate analogies more often than inappropriate analogies. For example, they compared *beak* to *peak* more often than to *meek.* She hypothesized that reading knowledge may be used to decide when analogy is appropriate.

At some point, correct spelling is simply and automatically retrieved from long-term memory. Direct retrieval of a known spelling pattern is likely a very effective and efficient approach to spelling. In addition, some words seem to have no rationale. For example, it is difficult to predict the spelling of the vowel phoneme in *street* (e.g., the /i/ could be represented as *streat* or *strete*), and so this word is most likely spelled by direct retrieval (Waters, Bruck, & Malus-Abramowitz, 1988).

Given that multiple strategic and automatic processes have been observed and inferred by researchers and educators, a number of developmental questions arise: When will a child choose one strategy over another? Are some strategies more likely than others to yield correct spellings? How and when does a child learn which strategies are most efficient and effective? How and when do children begin to simply and automatically retrieve spellings from long-term memory?

Some research has suggested that children might develop a hierarchy of spelling strategies. Strategies used by the beginning speller may be replaced with more efficient strategies, retrieval, or both as he or she becomes more adept at spelling (Gentry, 1982; Hanna, Hodges, & Hanna, 1971; Henderson & Beers, 1980). On the other hand, Siegler (1991; Siegler & Shipley, 1995) has suggested that children are remarkably adaptive at choosing among a variety of approaches for solving problems. In fact, Siegler and McGilly (1989) reported that more experienced problem solvers seem to be able to use multiple alternative approaches. On the basis of Siegler's and his collaborators' work, we anticipated that even young children would use a variety of spelling strategies as well as direct retrieval.

Strategy selection during spelling also may depend on the type of word being spelled (Varnhagen, 1995; Waters et al., 1988). We examined strategy selection and spelling for simple one-syllable words that could be spelled successfully using a phonetic strategy (consonant–vowel–consonant–consonant [CVCC] and consonant–consonant–vowel–consonant [CCVC] words like *rink* and *grin*) and words that could be spelled most successfully using rule-based or analogy strategies (consonant–vowel–consonant–silent *e* [CVC*e*] words like *ripe*). We expected that as children become more facile spellers, they may shift from using only phonetic strategies to using more effective and efficient rule-based strategies and to using retrieval. We expected that the younger children may not know the appropriate rule for spelling CVC*e* words and therefore may use less efficient and effective strategies to spell these words than words that can be spelled successfully using a phonetic strategy. We expected some of the younger children also to experience difficulties spelling the consonant clusters in CCVC and CVCC words. Treiman (1993) found that first-grade children often omitted the interior consonants of these types of words; she hypothesized that this might be due to difficulty in segmenting consonant clusters into separate phonemes.

Much of the work on cognitive processing in spelling has been based on inferences from the analysis of errors that children make in spelling (Bruck & Treiman, 1990; Frith, 1980; Treiman, 1991, 1993; Varnhagen, 1995; Waters et al., 1988). Minimal attention has been given to investigating correct spelling. When a child encounters an unknown or difficult word, the child may resort to a less sophisticated, more time-consuming spelling strategy or to an ineffective application of an appropriate strategy (Johnson & Siegler, 1996; Siegler, 1991; Siegler & Jenkins, 1989; Siegler & Shipley, 1995; Varnhagen, 1995). If so, then perhaps different strategies are used for known and unknown words. Thus, researchers may not be able to develop an understanding of how words are spelled correctly from analyzing misspelled words. In this study, we examined both correct and incorrect spellings.

Strategy use and retrieval were examined using on-line measures of letter typing times (Siegler, 1991). In addition, we used immediately retrospective verbal protocols to validate and extend the latency measures (Ericsson & Simon, 1993; Johnson & Siegler, 1997; Siegler, 1987; Siegler & McGilly, 1989). These two types of measures allowed us to begin to examine strategy selection and generalization as well as the development of automaticity in children's spelling. Using on-line, computer-controlled reaction time measures, researchers have acquired a better understanding of how children process information and solve problems (Siegler, 1991). We sought to apply the same approach in spelling.

Our reaction time measure was between-letter keystroke latencies. Massaro and Lucas (1984) found that although adult typing accuracy was not affected by word frequency, keystroke latencies were negatively correlated with word frequency. Although we controlled for word frequency, we expected older children who were more familiar with the spellings to type faster than younger children. In addition, to control for the effects of keyboarding skills, we asked children to type only with the index finger of their dominant hand and indicated a consistent, centrally located starting point for each word. Moreover, test words in each of the three conditions were matched for word frequency and for letter adjacency on the keyboard.

Our second measure involved self-reported verbal protocols. Using such measures, researchers have learned much about how children's memory is organized and how this organization changes across the elementary school period (Brown, Bransford, Ferrara, & Campione, 1983; Paris & Lindauer, 1982). Interviewing children about their memory skills and capacities has yielded results that are consistent with using overt measures of children's memory behavior and performance (Siegler, 1991). Even very young children can often verbalize how they solved a particular problem (Kreutzer, Leonard, & Flavell, 1975; Siegler, 1991). As well, retrospective reports do not affect strategy use or accuracy (Johnson & Siegler, 1997).

Investigating on-line reaction measures and self-reports of cognitive behavior together may provide a more direct link to cognitive processing during spelling than making inferences from spelling errors (Varnhagen, 1995). For example, Siegler (1987) showed how simply averaging solution times and percentage of errors on children's addition problems supported the previously held view that first- and second-grade children consistently solve addition problems by counting on from the larger addend (i.e., children solve a 3 + 6 addition problem by thinking "6, 7, 8, 9"). However, when solution times and percentage of errors were complimented with children's verbal strategy reports, Siegler showed that children used a variety of strategies and, in fact, used the counting on strategy on less than 40% of the trials.

Thus, one of our goals was to compare keystroke latencies and verbal reports. We expected to find different patterns of keystroke latencies for different reported strategies. This finding would support research in other areas of cognitive development indicating that children have insight into their strategy use and would provide a means for studying the development of children's correct spelling.

Our primary goal was to examine how children process words. To address this goal, we examined children's self-reported strategies (including reports of retrieval) and spelling correctness. Massaro and Lucas (1984) found that keystroke latencies in adults were constant across serial position within a word. One may presume that Massaro and Lucas' words were directly retrieved from long-term memory. Thus, we expected that when children reported using direct retrieval to spell a word, such words would demonstrate flat patterns of keystroke latencies. Past research on spelling errors has indicated that children often split words into more manageable units when learning to spell. Children processing words as different subsyllabic units might show different patterns of keystroke latencies. For example, segmenting a word into onset and rime units, such as hypothesized by Treiman (1992), may yield a different pattern of keystroke latencies than processing consonant clusters as a unit (see Varnhagen & Treiman, 1993).

We were also interested in how children represent vowels. Vowels, because of their unstable sound-to-spelling correspondence, are very difficult for children to master (Read, 1975; Treiman, 1993). Keystroke latencies for correct and incorrect vowels may reflect this difficulty. Furthermore, typing latencies of beginning spellers who are just learning about short- and long-vowel representations may show a similar difficulty.

We used familiar, one-syllable CCVC (e.g., *grin*), CVCC (e.g., *rink*), and CVC*e* (e.g., *ripe*) words to investigate children's spelling processes. Children in second through fifth grade were tested. The younger children were familiar with these simple sounds and were beginning to spell them in their writing; the older children were expected to be very familiar not only with the words, but also with their correct spelling. Children typed the words on a computer keyboard. The computer was used to present the dictated-words spelling test and to record keystrokes and their latencies. After typing each word, the child was asked to report what strategy or strategies he or she used to spell the word. Correctness, keystroke latencies, and verbal reports were analyzed across word types and grades.

Method

Participants

Participants were 93 English-speaking children in second through fifth grades attending middle-class elementary schools. These elementary schools followed the provincially mandated language experience approach to literacy instruction. Although separate, explicit spelling instruction was not a part of the curriculum, all schools considered spelling to be an important component of literacy.

Children participated on a voluntary basis. Written parental consent was obtained for each child. The study included 20 second graders (M = 7.65 years, SD = 0.38), 28 third graders (M = 8.68 years, SD = 0.28), 22 fourth graders (M = 9.61 years, SD = 0.45), and 23 fifth graders (M = 10.59 years, SD = 0.29).

Inclusion was based on average spelling ability as determined by performance on the Edmonton Public School Board (1981) spelling achievement test and supported by teacher nomination. Teachers in each classroom administered the spelling achievement test in January to assess children's spelling skills at mid-year. Words were considered correct if they were spelled the same as on the given list. Words were considered incorrect if they contained different endings or were capitalized when not required. Letter reversals (e.g., *b* for *d*) and random capitals were accepted for second graders if the intention of the child was clear. Each child's raw score was converted to a percentile according to local norms. Performance between the 50th and 80th percentile was considered average.

Materials

The test words were 36 four-letter words differing in placement of the vowel and consonants: 12 CCVC words, 12 CVCC words, and 12 CVC*e* words (see Appendix). Words were matched across type for word frequency (Carroll, Davies, & Richman, 1971), phonetic regularity, orthographic regularity, and onset-rime letter location on the keyboard. Phonetic regularity was determined by common pronunciation of the phonemes in the word (e.g., *pink* was included because the vowel is pronounced in the typical fashion for such words, but *pint* was not included). The last letter of the onset and the vowel of the rime were matched across word types (e.g., *ra* in *drag, ramp,* and *rate*) in order to avoid a confound between letter adjacency on the keyboard and use of an onset-rime segmentation strategy (e.g., compare keyboard moves from the second consonant of the onset to the vowel in *drip* and *flip*).

Words and context sentences were recorded using the digitized speech capability of a Macintosh microcomputer (cf. Varnhagen & Treiman, 1993). Words were presented to the participants using a dictated words spelling test format in which the spelling word is pronounced, pronounced in a context sentence, and repeated (e.g., "*rink.* The children played in the hockey rink. *rink.*"). A tone and blinking cursor in the response box indicated when the child was to begin typing. The computer recorded each keystroke and its latency in milliseconds.

Procedure

Computerized data collection occurred in February and March. Each child was tested individually for approximately 15 min. Before the session, the child was informed of the nature of the tasks and asked for permission to proceed. The child was told that he or she would be taking a spelling test on a computer but would not be graded on performance. The child was instructed that after he or she had typed each word, the researcher would ask how he or she spelled the word so the child should attend to that while spelling. The child was familiarized with the Macintosh computer, how to type with one finger, how to correct mistakes by using the Delete key, and how to press the Return key when finished spelling.

Children were given two practice trials prior to data collection. The practice trials used the same computerized dictated words spelling test format as the test trials. During practice, the researcher reminded the child to attend to what he or she was thinking while spelling the word and then to tell the researcher "What was going on in your head?" during spelling.

The researcher sat beside the child while the computer spelling test was being administered. No specific feedback was given regarding the child's performance. The researcher was available to clarify any questions the child had about the procedure and was able to control the computer with a Start–Stop key. The child was instructed to type with only the index finger of his or her dominant hand. A happy-face sticker in the lower center of the keyboard above the space bar was used as a starting point for each test word. The child was asked to place his or her index finger on the happy face. When the child was ready, the researcher pressed the Enter key to elicit the test word. Once the child completed typing a test word to his or her satisfaction, the child pressed the Return key. The researcher then asked the child how he or she spelled that word and wrote down the response. When the strategy report was completed, the researcher pressed the Enter key to continue with the next word. Test words were presented in a random order. If the child asked if a word was correct, the researcher responded only with an encouraging comment, such as, "You're doing a great job."

Results and Discussion

We analyzed the data for percentage of correct spellings, verbal report, types of errors made in incorrectly spelled words, keystroke latencies for correct spellings, and keystroke latencies for incorrect spellings. Only correctly spelled words that were typed with no backspaces for corrections were included in the keystroke latency analyses for correctly spelled words. For example, if *rink* was spelled "r" "i" "k" "delete" "n" "k," although it was considered correct and was included in the percentage of correct spellings and in the verbal report analyses, it was not included in the keystroke latency analysis.

Percentage Correct

It was not surprising to find that children's spelling improved across grades. As shown in Table 1, the percentage of correctly spelled words increased across second and third grade and reached a ceiling in fourth grade.

Table 1
Percentage of Correctly Spelled Words

	Word type							
	CCVC		CVCC		CVC*e*		Average	
Grade	%	*SD*	%	*SD*	%	*SD*	%	*SD*
2	80	13	73	21	61	28	71	21
3	86	17	89	21	82	20	85	19
4	96	7	98	4	97	6	97	6
5	96	11	99	3	99	2	98	5
Average	90	14	90	18	85	22	88	18

Note. CCVC = consonant–consonant–vowel–consonant; CVCC = consonant–vowel–consonant–consonant; CVC*e* = consonant–vowel–consonant–silent *e*.

A one between-subjects (grade) by one within-subject (word type) analysis of variance (ANOVA) of percentage correct revealed a main effect for grade, $F(3, 89) = 26.37$, $p < .05$. More errors were made by second-grade children than by older children, and third graders made more errors than fourth and fifth graders, honestly significant difference (HSD) = .08, $p < .05$. There was also a main effect for word type, $F(2, 178) = 5.19$, $p < .05$. CVC*e* words were significantly more difficult than either CCVC or CVCC words, HSD = .05, $p < .05$. There was also an interaction for word type and grade, $F(6, 178) = 3.85$, $p < .05$. More errors were made by second- and third-grade children on CCVC words than by older children. More errors on CVCC words were made by second-grade children than by children in the other three grades. Children in second grade made more errors than third graders, who, in turn, made more errors than fourth or fifth graders on CVC*e* words, HSD = .12, $p < .05$.

Verbal Report

Children had no difficulty reporting their cognitive behavior while spelling. In fact, children reported using a number of different spelling strategies as well as retrieval. Coding of the children's reports was done in two stages. Preliminary coding consisted of 10 categories, and in cases where multiple reports were given for one word (e.g., "I knew how to spell it, and I sounded it out"), the coding for each report was recorded. For the second round of scoring, the four most frequent reports—retrieval, phonetic, explicit rule, and analogy—were adopted. The least frequently used strategy reports were combined into a fifth new category coded as other.

Words for which children said they "knew" how to spell the test word were coded as having been spelled using direct retrieval. Words for which the child reported having "sounded it out" were classified as having been spelled using a phonetic strategy. When children reported comparing the test word to another known word, such as "*clip* is *lip* with a *c* in front of it," the word was coded as being spelled by an analogy strategy. When children explicitly stated an orthographic convention, such as, "the *e* makes the *a* say its name," the word was coded as a rule strategy. The fifth category, other, included reports that words were spelled with strategies such as, "My Grampa smokes a pipe too," "Pink is my favorite color," and "I guessed." These "strategies" constituted 4% of the verbal reports.

Multiple reports were obtained for 15% of the words. Many of these occurrences were based on a predominant report supplemented by some other idiosyncratic strategy. Children reported a combination of the retrieval strategy and other strategy on 7% of the words. For example, children reported such combined approaches as "I know it. We go to the rink all the time." In a similar manner, phonetic strategy was combined with the other strategy 3% of the time, as in "I sounded it out, and then I checked to see if it looked right." In such cases, we rated the child as using a retrieval or a phonetic strategy, respectively.

Rule-based and phonetic strategies were combined on 2% of the words. A rule strategy cannot, in fact, be used alone without additional knowledge to produce a correct spelling. For example, knowing the silent *e* rule indicates either implicit or explicit understanding of the phonetic basis of this orthographic convention. In cases where rule use was explicitly stated and combined with phonetic strategies, we considered the report as rule. An independent researcher rated 20% of the classifications with reliability of $K = .98$; disagreements in classifications were resolved by discussion. Table 2 outlines the percentage of strategies used and the percentage of correct spellings by word type for each strategy.

Collapsing across grades, we found that retrieval and phonetic strategies were used most frequently for all word types. Z tests for proportions indicated that these two reports were used significantly more often than would be expected if children were randomly selecting among the five most common reports: For CCVC, $Z = 22.39$ and 7.44, $ps < .05$, for retrieval and phonetic, respectively; for CVCC, $Z = 19.17$ and 8.00, $ps < .05$, for retrieval and phonetic, respectively; and for CVC*e* words, $Z = 19.27$ and 4.03, $ps < .05$, for retrieval and phonetic, respectively.

It was somewhat surprising to find that children reported using phonetic strategies 29% of the time for CVC*e* words, whereas an explicit rule-based strategy was reported only 10% of the time. Young children are often taught the silent *e* rule because they are not expected to have relatively sophisticated phoneme–grapheme correspondence knowledge, such as marking long medial vowels. As it is unlikely that a phonetic strategy alone will yield a correct CVC*e* spelling, children reporting a phonetic strategy may be marking the long vowel as part of their representation of it. Thus, the silent *e* rule strategy may simply be an explicit form of sounding out. In any event, across grades, when they were not using direct retrieval, children seemed to be relying more on their phonetic understanding of spelling than on explicit rules. This assumption was supported by examining the multiple strategy reports: When a child explicitly stated rule use, in over half of the instances the child also reported a phonetic strategy.

We analyzed reports using a one between-subjects (grade) by one within-subject (report) repeated measures ANOVA for different word types. There was a significant report by grade interaction for each word type, $F(12, 356) = 13.77$, 12.73, and 9.61, $ps < .05$, for CCVC, CVCC, and CVC*e* words, respectively. Children in fourth and fifth grade used retrieval significantly more often than phonetic strategies, regardless of word type. On the other hand, second graders used phonetic strategies more often than retrieval. Third graders used these two approaches equally often, HSDs = .20, .21, and .23, $ps < .05$, for CCVC, CVCC, and CVC*e* words, respectively. These findings support Varnhagen's (1995) results concerning a progression from effortful

Table 2
Percentage of Reported Strategy Used and Percentage of Correctly Spelled Words

Word type and grade	Strategy				
	Retrieval	Phonetic	Rule	Analogy	Other
CCVC					
Grade 2	28 (93)	61 (80)	1 (0)	4 (73)	6 (74)
Grade 3	43 (97)	42 (76)	3 (38)	6 (92)	6 (74)
Grade 4	64 (97)	29 (89)	0	5 (100)	2 (75)
Grade 5	87 (97)	11 (96)	0	1 (100)	1 (75)
CVCC					
Grade 2	23 (90)	55 (70)	0	14 (68)	8 (65)
Grade 3	39 (98)	46 (84)	3 (67)	6 (95)	6 (94)
Grade 4	61 (99)	32 (95)	0	6 (100)	2 (83)
Grade 5	84 (98)	12 (100)	0	4 (100)	1 (50)
CVC*e*					
Grade 2	20 (73)	44 (48)	18 (95)	9 (37)	8 (62)
Grade 3	41 (92)	32 (55)	13 (95)	6 (72)	7 (97)
Grade 4	63 (99)	26 (84)	8 (83)	2 (100)	1 (100)
Grade 5	83 (100)	14 (99)	0	2 (100)	1 (100)

Note. Percentage of words correctly spelled appears in parentheses. CCVC = consonant–consonant–vowel–consonant; CVCC = consonant–vowel–consonant–consonant; CVC*e* = consonant–vowel–consonant–silent *e*.

phonetic strategies to automatic retrieval processes as competence in spelling increases.

Overall, the verbal report analyses indicated that older children consistently chose retrieval over any of the reported spelling strategies. This finding was not surprising given that the test words were relatively simple four-letter words that would be very familiar to children in these grades and that the number of words spelled correctly reached ceiling in fourth grade. As well, this finding supports the reliability of the verbal reports. The most variation in strategy choice occurred in second and third grade. Thus, even as early as second grade, children use a number of spelling strategies as well as direct retrieval. There were significant (though small) negative correlations between number of different reports and percentage of correct spellings for each word type; correlations ranged from $r = -.21$ to $-.26$, $ps < .05$. This trend of increased variation with decreased percentage of correct spellings indicates that children are likely to use more approaches when they have difficulty spelling a word. However, we do not mean to imply that strategy variation causes error; Siegler (1991) suggested that children will often choose from a variety of fallback strategies to solve difficult problems. Perhaps younger children are more inclined to try out different strategies because they are less adept at choosing among strategies.

Verbal Report and Correctness

In order to address the question of differential effectiveness of different cognitive reports, we performed a one between-subjects (grade) × one within-subject (report) repeated measures ANOVA for each word type on percentage of correctly spelled words. These analyses included those children who reported both phonetic strategies and retrieval: 14, 19, 11, and 13 children in second through fifth grade, respectively, reported using both phonetic strategies and retrieval for CCVC words; 14, 23, 11, and 16 children in second through fifth grade, respectively, reported using both phonetic strategies and retrieval for CVCC words; and 13, 20, 12, and 15 children in second through fifth grade, respectively, reported using both phonetic strategies and retrieval for CVC*e* words. Only phonetic reports and retrieval were included because these approaches were reported significantly more often than the others. There was no report by grade interaction; however, there was a main effect for report. Retrieval yielded a higher percentage of correctly spelled words than phonetic strategies for all word types, $F(1, 53) = 12.59$, $F(1, 60) = 9.07$, and $F(1, 56) = 12.55$, $ps < .05$, for CCVC, CVCC, and CVC*e*, respectively.

Because retrieval was underrepresented at the lower grades and phonetic strategies were underrepresented at the higher grades, the analysis of children reporting both does not fully describe strategy effectiveness by grade. In order to analyze strategy effectiveness by grade, we performed one-way ANOVAs of percentage of correctly spelled words for each report and word type. These analyses allowed us to examine effectiveness for all children who used a particular approach, not merely those who chose both. Explicit rule use was analyzed as well as phonetic strategies and retrieval for the CVC*e* words because the youngest children reported using an explicit rule-based strategy about as often as retrieval.

There was no grade effect for correctness of retrieval for either the CCVC or the CVCC words. When retrieving these words, regardless of grade, children were very successful in their spelling. However, there was a significant grade effect for retrieval on the CVC*e* words, $F(3, 71) = 5.70$, $p < .05$. Children in second grade were less successful than children in the other three grades when using retrieval on CVC*e* words, HSD = .17, $p < .05$. Average second-grade spellers have evidently not yet mastered silent *e* words, even when they think they have.

There was no grade effect for the phonetic report for CCVC words. Children in all grades were moderately successful at spelling these words when they selected a sounding-out strategy. There was a significant grade effect for the phonetic strategies on the CVCC and CVC*e* words, $F(3, 76) = 6.90$ and $F(3, 72) = 10.96$, $ps < .05$, respectively. Children in second grade who chose a phonetic strategy for CVCC words were less successful than fourth or fifth graders, HSD = .18, $p < .05$; no significant differences were found between second and third grade.

It appears that CCVC words are easier to sound out for younger children than CVCC words. Consistent with Treiman's research on younger children, 23% of the CVCC errors in our data were omissions in the final consonant cluster (Treiman, 1991; Treiman, Zukowski, & Richmond-Welty, 1995). Children in second and third grade who reported phonetic strategies on CVC*e* words were less successful than fourth or fifth graders, HSD = .26, $p < .05$. The higher success rate of older children who reported using a sounding-out strategy was most likely a result of using more sophisticated grapheme-to-phoneme correspondence information in their spelling.

There was no grade effect for rule use with the CVC*e* words; children at all grade levels were equally successful when applying an explicit rule to spell these words. More important, the results indicated that the explicit rule strategy was more effective than a phonetic strategy for children in Grades 2, $Z = 2.52$, $p < .05$, and 3, $Z = 2.35$, $p < .05$. This finding supports our hypothesis that the explicit rule strategy may simply be a more sophisticated form of sounding out; young children who could verbalize the silent *e* rule were generally more successful at spelling the CVC*e* word.

Percentage of strategies selected and correct spellings analyzed by item revealed similar patterns to our analyses by subject and therefore are not reported.

Types of Errors

The 390 words that were spelled incorrectly in this study (12% of the total number of words spelled) were classified and examined separately for each of the three word types. Overall, 52% of incorrectly spelled words came from second graders, 37% from third graders, 7% from fourth graders, and 5% from fifth graders. *Z* tests for proportions indicated that second-grade children made significantly more errors than third graders, $Z = 2.77$, $p < .05$. Errors were spread widely across participants (100% of second graders and 93% of third graders contributed incorrect spellings). Patterns of errors were comparable for second and third grade; coupled with the few errors by older children, we collapsed across grades to present the error analysis shown in Table 3.

For each word type, errors were classified as vowel errors, consonant errors, or phoneme reversals. Some words contained both a vowel error and a consonant error; therefore, the number of errors is higher than the number of incorrectly spelled words.

Vowel errors were common, supporting the hypothesis that vowels are difficult to represent (Read, 1975; Treiman, 1993). Vowel substitutions were generally illegal phoneme representations for CCVC and CVCC words (e.g., *clap* for *clip*) but legal representations for CVC*e* words (e.g., *cayp* for *cape*). These legal substitutions for CVC*e* words suggest a degree of sophistication in children's knowledge of the spelling system. A child who spelled *rate* as *rait* appeared to know not only that something must be added to the letter *a* to make it represent the long *a* sound, but also what kind of addition will legitimately bring about this result. Consistent with inferences of using a letter name strategy (cf. Beers, 1980; Ehri, 1986; Gentry, 1982; Treiman, 1994), final *e* omissions on CVC*e* words were generally accompanied by a phonetic strategy report. Finally, addition of a final *e* to CCVC and CVCC words was relatively common and was generally accompanied by a phonetic report.

Consonant errors were somewhat less common. Single consonant errors were rare; the errors that occurred were generally on CVC*e* words and were legal substitutions (e.g., *wripe* for *ripe*). Consonant cluster errors differed in CCVC and CVCC words. The majority of CCVC errors consisted of a phonologically based substitutions (cf. Treiman, 1993) for the first consonant in the cluster, such as *jrag* for *drag* and *chrap* for *trap*. Children made substitution errors in CVCC words, but they also were likely to omit the first consonant in the cluster, particularly when it represented a nasal followed by a voiceless stop (as in *limp, rink,* or *pond*). Because a nasal consonant changes the sound of the vowel, young children may have difficulty separating the vowel from the nasal consonant and thus are more likely to spell *rink* as *rik* than to spell *task* as *tak* (Treiman et al., 1995).

Table 3
Percentage of Errors Made in CCVC, CVCC, and CVCe Words

Type of error	Example	Word type: CCVC	CVCC	CVC*e*
Vowel errors				
Substitution	*clap* for *clip*	20	30	54
Omission	*crt* for *cart*	3	1	0
e addition	*stabe* for *stab*	41	26	n/a
e omission	*cap* for *cape*	n/a	n/a	33
Total vowel errors		64	57	87
Consonant errors				
Consonant cluster errors				
Substitution	*jrag* for *drag*	29	32	n/a
Omission	*rap* for *ramp*	8	37	n/a
Other	*tastck* for *task*	4	1	n/a
Total		40	70	n/a
Single consonant errors				
Substitution	*kart* for *cart*	7	6	29
Omission	*raie* for *rare*	0	0	1
Total		7	6	30
Total consonant errors		47	76	30
Phoneme reversals	*durm* for *drum*	5	3	0

Note. CCVC = consonant–consonant–vowel–consonant; CVCC = consonant–vowel–consonant–consonant; CVC*e* = consonant–vowel–consonant–silent *e*; n/a = error not applicable (could not be made).

Keystroke Latencies

Correctly spelled words. All analyzable keystroke latencies corresponding to correctly spelled words were examined for extreme scores. If the latency for any keystroke was greater than the mean plus four times the standard deviation, we omitted latency data for each letter the child typed for that word from the statistical analyses. Out-of-range latencies accounted for less than 1% of the total data.

All keystroke latencies were analyzed by participant as well as by item. Only the details of the participant analyses are reported; item analyses yielded similar results. In addition, we analyzed keystroke latencies separately for CCVC, CVCC, and CVC*e* words. Keystroke latencies for phonetic strategies and retrieval were analyzed for all word types as these were the most frequent reports. A one between-subject (grade) by one within-subject (report) repeated measures ANOVA assessed keystroke latencies for correctly spelled words according to verbal report. As with the analyses of strategy effectiveness, these analyses excluded a large number of children who did not report using both phonetic strategies and retrieval, but the patterns reported here are comparable to the complete data.

We were not surprised to find that younger children were slower than older children; each word type revealed a main effect for grade, $F(3, 47) = 8.59$, $F(3, 55) = 9.18$, and $F(3, 42) = 7.94$, $ps < .05$, for CCVC, CVCC, and CVC*e* words, respectively. Children in second grade were significantly slower than third, fourth, or fifth graders, HSDs = 776, 621, and 722 ms, $ps < .05$, for CCVC, CVCC, and CVC*e* words, respectively.

We had expected that retrieval would require less cognitive processing than strategy use and therefore would be fast and automatic compared to a sounding-out strategy. In line with this prediction, there was a main effect for report for each word type; retrieval was faster than sounding out in all cases, $F(1, 47) = 10.38$, $F(1, 55) = 17.80$, and $F(1, 42) = 7.67$, $ps < .05$, for CCVC, CVCC, and CVC*e*, respectively. Because so few children reported using all three strategies (retrieval, phonetic, and rule use) for CVC*e* words, a repeated measures ANOVA could not be calculated to compare these three approaches, and separate independent measures *t* tests were used. Keystroke latencies for retrieval were significantly faster than rule-based strategies, $t(95) =$

3.09, $p < .05$. Keystroke latencies for rule-based and sounding-out strategies were not significantly different.

We examined letter-by-letter keystroke latencies to see if typing patterns reflected an attempt to spell these one-syllable words according to subsyllabic structure. Typing patterns were analyzed separately for report and word type using a one between-subjects (grade) by one within-subject (letter position) repeated measures ANOVA. Phonetic strategies and retrieval were analyzed for the CCVC and CVCC words; phonetic and rule strategies and retrieval were analyzed for the CVC*e* words. We analyzed reports separately in order to include all children who reported a particular approach, even though any one participant may not have used all approaches. There was a main effect of letter position for all word types and reports, with the exception of the rule-use report pattern for the CVC*e* words, $F(3, 216) = 20.66$ and $F(3, 192) = 7.61$, $ps < .05$, for retrieval and phonetic reports with CCVC words, respectively; $F(3, 216) = 10.36$ and $F(3, 213) = 9.15$, $ps < .05$, for retrieval and phonetic reports with CVCC words, respectively; and $F(3, 195) = 13.01$ and $F(3, 180) = 3.65$, $ps < .05$, for retrieval and phonetic reports with CVC*e* words, respectively. The solid lines in Figures 1, 2, and 3 show the keystroke latencies by report for correctly spelled CCVC, CVCC, and CVC*e* words, respectively.

Patterns of keystroke latencies for correctly spelled CCVC words did not differ for retrieval and phonetic reports (see Figure 1). For each pattern, there was a significant decrease in typing time from the first to the second letter, HSDs = 283 and 391 ms, $ps < .05$, for retrieval and phonetic reports, respectively. The remaining latencies were relatively fast and showed no change across letter position. Thus, for CCVC words, use of a phonetic strategy resulted in an overall typing time greater than that for retrieval, but both had comparable patterns of typing.

Patterns of keystroke latencies for CVCC words (see Figure 2) showed a similar decrease from the first to the second letter, HSDs = 247 and 420 ms, $ps < .05$, for retrieval and phonetic reports, respectively. In addition, words for which children reported using a phonetic strategy showed a jump in latency from the second letter (vowel) to the third letter (first consonant in the cluster pair), followed by a decrease across the consonant cluster. This consonant cluster effect indicates that the children may be processing the consonant cluster of CVCC words as a unit.

Comparisons across the first two letters for CCVC and

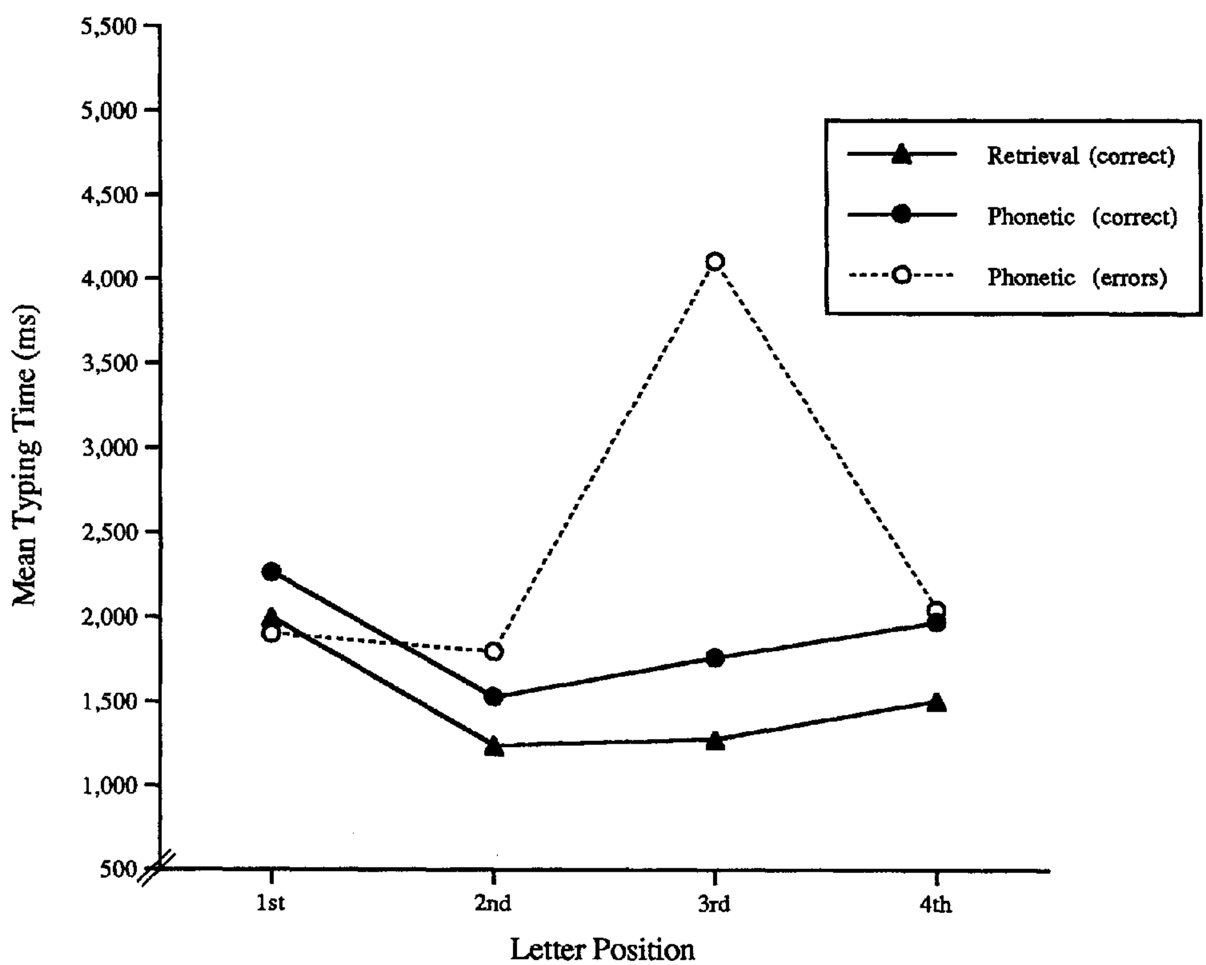

Figure 1. Mean typing time for consonant–consonant–vowel–consonant words.

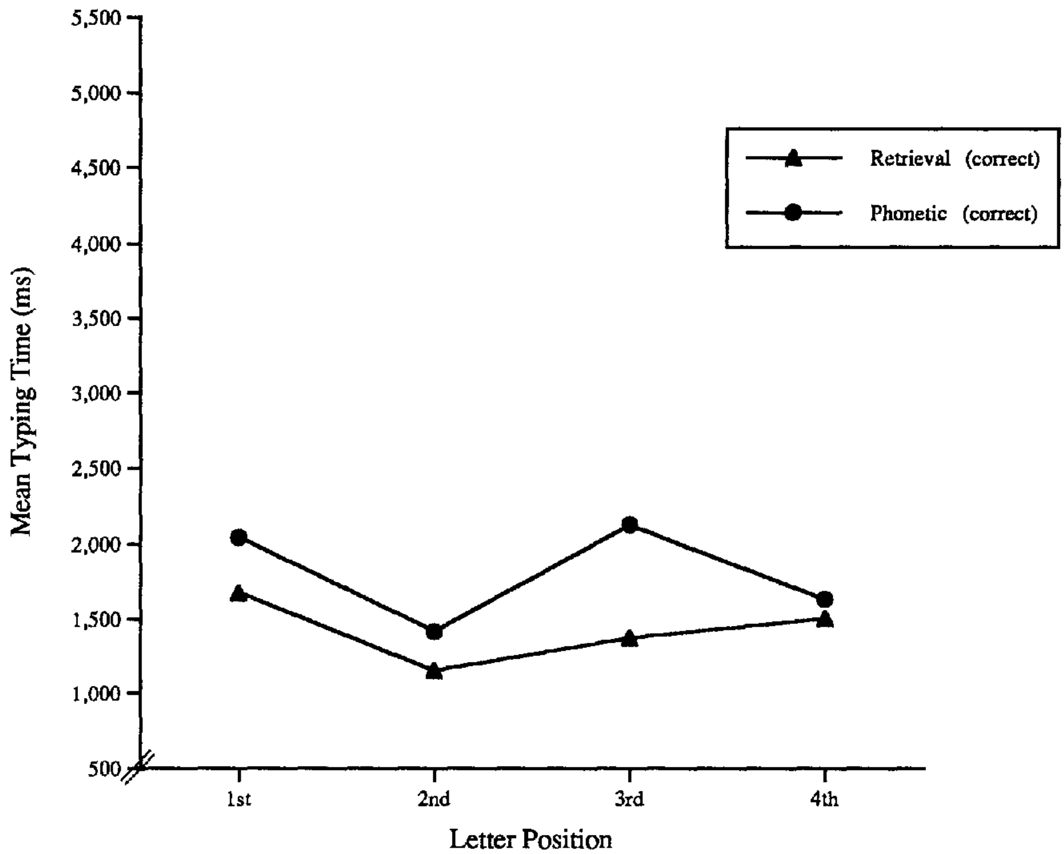

Figure 2. Mean typing time for correctly spelled consonant–vowel–consonant–consonant words.

CVCC retrieval and phonetic patterns were not statistically significant. Although the patterns of keystroke latencies for retrieval words were very similar for the first two letters of the CCVC and CVCC words, the first letter in the consonant cluster in the CCVC words was slightly slower than the single first consonant in the CVCC words; in a similar manner, the first letter of the CCVC words for which children reported using a phonetic strategy was slightly slower than the first letter in the corresponding CVCC pattern. Although the patterns are suggestive of a possible consonant cluster effect, they are confounded with the long latency to type the first letter of all words.

The different patterns in typing times for the third and fourth letters of the CCVC and CVCC phonetic report words also suggest a consonant cluster effect, in this case for the cluster occurring at the end of the CVCC words. To support this, we performed a one between-subjects (CCVC vs. CVCC words) × one within-subject (third vs. fourth letter) ANOVA. Word type was treated as a between-subjects variable because not all children contributed times to each word type. A significant interaction between word type and letter position was found, $F(1, 141) = 8.69, p < .05$. As with the individual pattern analyses, there was a significant decrease across the two final consonants in the CVCC words compared with no difference across the final two letters in the CCVC words, HSD = 430 ms, $p < .05$.

Taken together, these findings provide at least some support for the notion that children process subsyllabic units when they type words correctly. Moreover, the subsyllabic unit used in correct spelling appears to be the consonant cluster, rather than onsets and rimes found by Treiman and Zukowski (1988) in their investigation of adults' incorrect spelling. Our findings are also consistent with Bruck and Treiman's (1990) findings that children find initial consonant clusters difficult to spell and with Varnhagen and Treiman's (1993) findings that children use a consonant cluster segmentation strategy when spelling known words. Furthermore, it may be that consonant cluster units are used only when phonetic strategies are used.

The CVC*e* words (see Figure 3) showed a similar first two letter typing pattern to the other types of words. The decrease in typing time was significant for the retrieval words, HSD = 275 ms, $p < .05$, but not for the phonetic strategy report words. On the other hand, the difference in keystroke latencies between the second and third letter for both the retrieval and phonetic report CVC*e* words were statistically significant, HSD = 580 ms, $p < .05$. The words for which children used an explicit rule showed a similar pattern; however, there was no effect of letter position for this seldom reported strategy.

The interpretation of the letter-by-letter typing patterns for CVC*e* words is a little less clear than for the other two

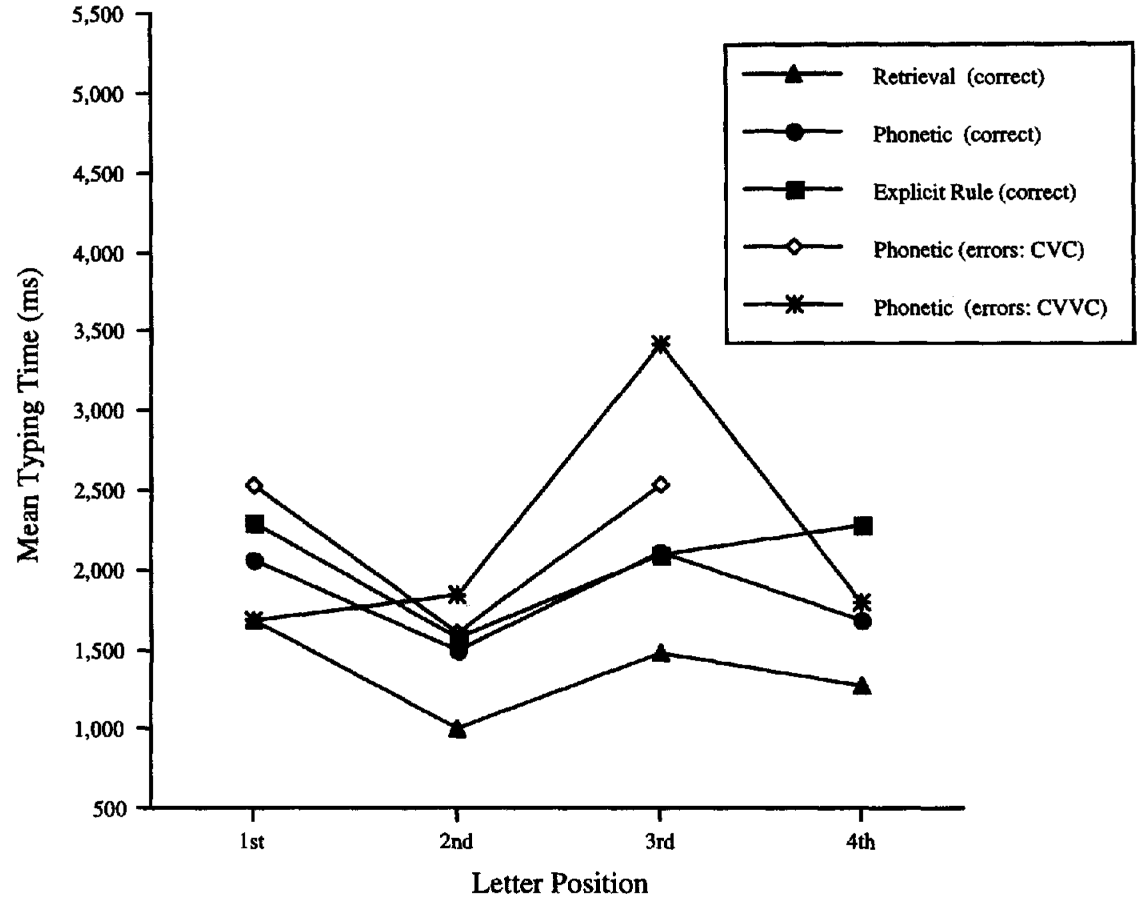

Figure 3. Mean typing time for consonant–vowel–consonant–silent *e* words. CVC = consonant–vowel–consonant; CVVC = consonant–vowel–vowel–consonant.

types of words; it appears that the medial vowel in the CVC*e* words is generally typed faster than the surrounding consonants. Past research on children's spelling errors (Read, 1975; Treiman, 1993) suggests that children have difficulty with vowels. Perhaps in the case of the CVC*e* words, the fact that "vowel says its name" leads to faster typing times for the vowels. However, across all word types, vowels appear to be typed somewhat faster than consonants, although this effect was not generally statistically significant. Once a child knows how to spell a word, vowels might be processed in a relatively fast and automatic manner, regardless of reported spelling strategy.

Incorrectly spelled words. As with the correctly spelled words, analyzable keystroke latency analyses for incorrectly spelled words were examined for extreme scores. Out-of-range latencies comprised less than 1% of the data.

We analyzed keystroke latencies for incorrectly spelled words for evidence of subsyllabic segmentation and vowel difficulty: Vowel substitutions were analyzed for CCVC (e.g., *clup* for *clip*) words; vowel substitutions in CVCC words were often accompanied by a consonant cluster error, limiting meaningful analysis. Words omitting the final *e* (e.g., *cap* for *cape*) or with an extra, phonologically legal vowel (e.g., *cayp* for *cape*) were analyzed for the CVC*e* words. We analyzed the keystroke latencies only for phonetic strategy reports; there were insufficient numbers of analyzable errors available when other strategies were used. Our results need to be interpreted with caution because of the high variability and few children included in our analyses (n = 13 for the CCVC error pattern, n = 31 for the CVC error pattern, and n = 19 for the CVVC error pattern).

We expected that when children were unsure of the correct spelling of a word, they would take longer to produce a spelling and, therefore, the overall keystroke latencies for errors would be slower than for correct words. Separate t tests for each word type were used to compare average keystroke latencies for incorrectly spelled words with average times for correctly spelled words. Keystroke latencies associated with phonetic reports for the CCVC and CVC*e* errors words were not significantly different from the correctly spelled CCVC and CVC*e* words.

There was no difference in overall typing time. However, as was expected, different typing patterns emerged for incorrectly spelled words compared with correctly spelled words; these general trends are illustrated by the dotted lines in Figures 1 and 3. Typing patterns for incorrect words were analyzed using one within-subject (letter position) repeated measures ANOVA for CCVC, CVC*e* words spelled as CVC (i.e., omitting the final *e*), and CVC*e* words spelled as CVVC (i.e., adding a second vowel in an apparent attempt to make the long vowel sound). There was a position effect for the CCVC and CVC*e* (when spelled as CVVC) errors, $F(3, 36) = 4.71$ and $F(3, 54) = 2.75$, $ps < .05$, for CCVC and CVVC representations, respectively; there was no significant position effect for the CVC*e* (when spelled as CVC) errors.

Unlike the keystroke latencies for correct words when the vowel came relatively quickly, the vowel took longer to type than the consonants for CCVC errors, HSD = 1,948 ms, $p < .05$. Also, the second vowel in CVVC errors took longer to type than the other letters, HSD = 1,738 ms, $p < .05$. These results are consistent with previous research (Read, 1975; Treiman, 1993) suggesting that children have difficulty with vowels when learning how to spell a word. The longer typing time for the second vowel in CVVC errors suggests that additional cognitive processing may occur when these children realize that another letter needs to be added to the first vowel in order to represent a long vowel sound.

Unlike the keystroke latencies for correct words, there was no first and second letter position effect for any of the word types for incorrectly spelled words. Thus, no support for a consonant cluster effect was found for the incorrectly spelled words.

Although there was no significant difference in keystroke latencies between letters for the CVC*e* errors when spelled as CVC words, the pattern is almost identical to the correctly spelled words (see Figure 3). These children seem to be on their way to correctly spelling these words, and although they have not yet mastered the silent *e* rule, it is not surprising that their spelling patterns are so similar to children who have mastered this convention.

We did not analyze keystroke latencies for the consonant errors because there were too few words in any one report category to provide meaningful analyses. As well, the words that had consonant errors were often characterized by frequent backspacing or multiple letters representing a single phoneme (e.g., *tasck* for *task* or *ringck* for *rink*).

General Discussion

Previous studies of children's spelling have primarily examined errors. One goal of this study was to develop and test additional measures for investigating the development of children's spelling from an information-processing framework. Verbal reports and typing latencies were compared for correctly and incorrectly spelled words.

Our results demonstrate that verbal reports and typing latencies are veridical: Spelling correctness differed consistently as a function of report. As well, typing latencies were quantitatively and qualitatively different for words reported to have been spelled using different approaches.

Direct retrieval increased in frequency across grades but was generally the most effective approach at each grade. Retrieval also lead to faster typing times. These findings provide empirical evidence for the commonly held assumption that retrieval is an adaptive approach to spelling; as has been found in other domains, retrieval was effective and efficient (cf. Siegler & Shipley, 1995). Phonetic strategies decreased in frequency across grades and were slightly less effective than retrieval. Phonetic strategies also resulted in slower typing times as compared to retrieval. Younger children particularly had more difficulty in sounding out the more difficult CVCC and CVC*e* words. Explicit rule-based and analogy strategies were less frequently reported than phonetic strategies or retrieval and were more variable in their effectiveness. The pattern of typing latencies for rule use revealed a long latency to type the final *e*, consistent with attempting to apply the silent *e* rule.

These results, though not particularly surprising, are important. They support the idea that children can provide reasonable and accurate verbal reports of cognitive behavior (Johnson & Siegler, 1997; Siegler, 1991). Our examination of multiple, converging measures allows us to make stronger statements about children's cognitive processes while spelling than if we had merely drawn inferences from children's errors. This is certainly not the first study to find that younger children make phonetic spelling errors and older children spell correctly. However, instead of drawing an inference that younger children are using phonetic strategies and older children retrieve the words, our method provides direct evidence that younger children did report using phonetic strategies and that it did take them longer to spell the words than older children, who reported retrieval and spelled the words quickly and correctly.

Thus, our study has methodological implications for future research in children's spelling development. Future studies should not just collect errors but should measure some form of cognitive processing. We collected immediately retrospective verbal reports and validated these with on-line measures of typing latencies.

More important than simply validating our methods was finding out how children construct and generalize spelling strategies and become fast, automatic spellers (Siegler, 1991; Siegler & Jenkins, 1989; Siegler & Shipley, 1995). Although reporting "I used the silent *e* rule" for CVC*e* words might be considered very different from reporting "I sounded it out," we found that the associated typing latencies were very similar for all letters but the final *e*. As well, children who sounded out the word but omitted the *e* also had similar typing patterns. These latency patterns indicate a relationship between rule-based and phonetic strategy reports. All children may have been using phoneme-to-grapheme translation processes for the sound in the CVC*e* word, but the longer latency to type the final *e* for the children reporting an explicit rule may have reflected a conscious attempt to apply the silent *e* rule while spelling. Those children who correctly sounded out the word may have simply known that the long medial vowel is represented by a final *e*, and those children who omitted the final *e* may have simply been using a letter name representation in their sounding out (Treiman, 1993, 1994). These findings point to further research questions regarding children's use of specific phoneme-to-grapheme translation strategies.

Using our multiple, converging method, we were able to begin to investigate how children segment and sound out different units in words. We did not find strong evidence that children spell these simple words by segmenting them into onset and rime units (Treiman, 1992). On the other hand, we did find evidence that children treat consonant clusters as a unit. We found a consonant cluster effect in the typing latencies for CVCC words (a possible consonant cluster effect in CCVC words was confounded with a first letter effect) when children sounded out the words. Children do not appear to store consonant clusters in long-term memory, however, for the effects were not present for retrieval. Perhaps subsyllabic segmentation is a working memory strategy that conserves cognitive resources while the child is selecting phoneme-to-grapheme correspondences. Such conservation is not required once a child has committed the word to long-term memory. This hypothesis is supported by the large number of consonant cluster errors children made on the CVCC words.

Our analysis of typing latencies, verbal reports, and spelling correctness has also provided interesting insights into how children learn to represent vowels. We had expected vowels, with their inconsistent phoneme-to-grapheme correspondence (Read, 1975; Treiman, 1993), to be difficult for the children. However, vowel typing latencies were no longer than consonants for correctly spelled words, regardless of whether the children reported using retrieval or a spelling strategy. Incorrect vowels resulted in very long typing times for the CCVC and CVC*e* words in which they occurred, however. This finding indicates that although it may be difficult to learn vowel spellings, once learned, children have little difficulty representing them. Future research, possibly using a microgenetic approach, needs to be done to examine typing latencies as children learn how to represent both long and short vowels.

Our findings have implications for spelling instruction. First, it is important for teachers to ask children how they spelled words rather than drawing inferences from spelling errors. Children's strategy reports provide valuable insights into their processing (Siegler, 1987; Siegler & Jenkins, 1989). For example, a child who spells *cake* as *caek* may have been taught the silent *e* rule but not know how to apply it properly. Moreover, our findings suggest the value of teaching a variety of strategic approaches when spellings cannot be retrieved automatically from memory. Simply teaching children to sound out unfamiliar words may not always be the best instructional approach. The relative inefficiency of phonetic strategies, particularly coupled with the number of letter substitutions and omissions, suggests that young children may have difficulty completely segmenting even our simple three- and four-phoneme words and applying correct grapheme-to-phoneme correspondences. Perhaps, as Goswami (1988) argued, an analogy strategy (e.g., "*rink* is *ink* with an *r* in front of it") would be more beneficial than attempting to sound out such words. In addition, instruction may need to focus on phonological checking strategies (e.g., "If there was no *n* in *rink* it would be *rik*. What is *rik*?"), a strategy that was almost never reported in this study, even by the older children.

In conclusion, combining strategy reports and on-line measures with an analysis of children's spelling provides converging evidence that can be used to increase researchers' understanding of spelling development. In addition to exploring the cognitive processes underlying children's spelling errors, researchers need to know how children spell words correctly in order to help guide children in choosing appropriate strategies for spelling new words. By trying to understand how children choose different spelling strategies, how they generalize them to new words, and how they become fast automatic spellers, researchers can advance theories of children's spelling development as well as design classroom activities that make use of children's flexible approaches to representing English orthography.

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Appendix

Test Words

CCVC	CVCC	CVC*e*
drag	ramp	rate
star	tank	tape
scar	cart	cape
trap	raft	rare
grab	rank	rake
stab	task	tame
flip	limp	lice
spin	pink	pipe
grin	rink	ripe
clip	link	lime
spot	pond	pole
drum	rust	rule

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