Strategy Development and Learning to Spell New Words: Generalization of a Process

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The authors used microgenetic methods in 2 experiments to examine children's and adults' progress from initial attempts at spelling nonwords to later direct memory retrieval of the spellings. Participants repeatedly spelled nonwords presented in computerized, dictated-word spelling tests over several weeks. Following each spelling, participants provided retrospective strategy reports. Half of the children showed a gradual shift from spelling words with effortful backup strategies to fast retrieval; half of the children continued using backup strategies that were fast and effective for them. Relatively more adults shifted from backup strategies to retrieval, but otherwise their patterns of spelling development were quite similar to those of the children. This research provides support for the generalizability of the overlapping waves model to nonalgorithmic domains. It also demonstrates parallels between children and adults in learning to spell new words.

Spelling is necessary for written communication. Efficient written communication requires the writer to retrieve most spellings from memory. As is the case with many skills, learning to spell words quickly and effortlessly is an important achievement, because it frees up attention that need no longer be focused on the mechanics of the task (Juel, 1991). Berninger et al. (1998) found that not only did spelling training result in improved performance on dictated-word spelling tests, but it also improved length of original compositions. The goal of this study was to examine how children learn to spell new words and to compare their performance with that of adults, already proficient spellers, who are encountering novel words. Children must approach the task of spelling new words strategically in order to spell correctly. Although much work has been done on describing children's spelling strategies, few researchers have focused on how children move from applying effortful and not necessarily successful spelling strategies to fast, effortless, correct spelling. Learning to spell new words in adulthood is also a topic that has been largely ignored, as is the case in many domains that tend to be mastered in childhood.

Learning to Spell

Children have a number of spelling strategies available to them. Many children use phonological spelling strategies (e.g., Griffith, 1991; Nunes, Bryant, & Bindman, 1997; Treiman, 1993; Varnha-

gen, 1995): They "sound out" words to themselves and match corresponding letters (graphemes) to the sounds (phonemes). However, reliance on sounding out words may not be adaptive for written communication, because phonological strategies do not yield correct spellings in many cases (e.g., Laxon, Coltheart, & Keating, 1988; Read, 1971; Treiman, 1993; Treiman, Cassar, & Zukowski, 1994). As well, heavy reliance on phonological strategies has been associated with poor spelling and poor reading (e.g., Barron, 1980; Bruck & Waters, 1988, 1990; Frith, 1980). It would appear, then, that other strategies might also be necessary for effective written communication.

Children may also use orthographic knowledge, that is, apply spelling rules, such as "*i* before *e* except after *c*" (e.g., Cassar & Treiman, 1997), or orthographic conventions, such as doubling a final consonant before adding -*ing* in order to keep a vowel short (e.g., Varnhagen, McCallum, & Burstow, 1997). As well, children use morphological knowledge in their spelling. This involves using knowledge of the root word to aid in spelling a compound word or a word with a prefix or suffix, such as using knowledge of the word *signature* to spell the silent *g* in *sign* (Treiman et al., 1994).

Children may also make analogies to a known word (Goswami, 1988). Forming analogies is more efficient than applying phonological, orthographic, or morphological strategies, because part of the new word can be retrieved. This strategy is more complicated than applying phonological, orthographic, or morphological knowledge to spelling, because the child must also compare the to-be-spelled word with a known word. However, even very young children have been shown to be proficient at spelling words by analogy (Goswami, 1988; Laxon et al., 1988; Marsh, Desberg, & Cooper, 1977; Sternberg & Rifkin, 1979; Varnhagen, Boechler, & Steffler, 1999).

Finally, when children have used some strategy or combination of strategies to attempt the spelling of a word, they may write the word or spell it out loud to determine whether a particular spelling looks or sounds correct (Tenney, 1980; Varnhagen, 1995). Each of these strategies is inefficient and potentially ineffective, however,

compared with fast, accurate retrieval of spelling patterns from long-term memory.

Several approaches have been used to describe children's transition from their initial attempts at spelling to the end point of retrieval. A number of theorists (e.g., Ehri, 1992; Gentry, 1992; Henderson, 1985) have suggested that children shift from reliance on one specific type of strategy to reliance on another type of strategy while developing spelling skills. Although many of the specific features differ, these stage theories contain some common elements: Children's earliest attempts at spelling include letters that children know how to form but that do not conform to phoneme–grapheme correspondences. These early representations are then followed by more readable attempts at spelling in which the children demonstrate some understanding of phoneme–grapheme correspondences but often do not represent all of the phonemes. Once they are able to engage in complete phonological analysis of words, children then begin to represent all of the phonemes, but without regard to orthographic constraints or morphological conventions. This level, finally, is followed by a series of stages or substages in which children learn about different types of constraints on spelling.

According to the overlapping waves theory (cf. Rittle-Johnson & Siegler, 1999; Siegler, 1995a; Varnhagen et al., 1997), children have a number of different strategies in their repertoires at any given time, but they shift their reliance on different strategies over time. As they learn about a task, children show increasing reliance on more effective strategies and decreasing reliance on less effective strategies. According to this theory, children might possess and be able to use knowledge of phonology, orthography, and morphology in their spelling even from a very early age, but they rely more on different strategies at different points in time.

Stage and overlapping waves theories make somewhat different predictions about the course of development. According to stage accounts, children progress from unsophisticated forms of phonological analysis through more mature phonological and orthographic strategies to retrieval. Progress is sequential, unidirectional, and occurring in a fixed order, and it makes use of children's increasingly mature knowledge of the structure and roles of the sound-spelling system. Overlapping waves theories, on the other hand, predict that strategy development is not so regular and sequential. Children may oscillate among more and less sophisticated strategies.

Whereas the overlapping waves model has been applied quite successfully in some domains, there is some uncertainty about applying it to spelling. The overlapping waves model works in algorithmic domains, that is, domains in which executing the correct strategy correctly will invariably lead to the correct answer (Rittle-Johnson & Siegler, 1999). For instance, Siegler and his colleagues have successfully applied this model to addition (Siegler & Shrager, 1984), subtraction (Siegler, 1987), time telling (Siegler & McGilly, 1989), and physics learning (Maloney & Siegler, 1993). Cooney, Swanson, and Ladd (1988) applied it to mental multiplication.

Spelling, however, is a nonalgorithmic domain, one in which no strategy, regardless of how carefully selected and executed, can guarantee success (Rittle-Johnson & Siegler, 1999). Varnhagen et al. (1997) and Rittle-Johnson and Siegler (1999) have explored the overlapping waves model in describing children's spelling development. Varnhagen et al. examined children's naturalistic spelling

from Grades 1 through 6 in a cross-sectional design. Children at all grade levels made errors consistent with phonological, orthographic, and morphological spelling strategies. However, children in early grades made a greater proportion of phonological errors, whereas children in higher grades made a greater proportion of developmentally more mature errors. Rittle-Johnson and Siegler examined children's spelling test performance longitudinally in Grades 1 and 2. They found that children used strategies in Grade 2 that were similar to their Grade 1 strategies.

Spelling development in both studies was consistent with the overlapping waves model. This model is characterized by (a) variability of cognitive strategies, (b) adaptive choice among strategies, and (c) gradual change. Both Varnhagen et al. (1997) and Rittle-Johnson and Siegler (1999) found variability in strategy use, even at the earlier grades. Rittle-Johnson and Siegler found that children were more likely to use a backup strategy than retrieval for more difficult words, an indication of adaptive strategy choice. Varnhagen et al. and Rittle-Johnson and Siegler observed gradual changes in strategy use across grades.

Neither study, however, provides a complete and precise description of the change process in children. Varnhagen et al. (1997) examined different cohorts of children, allowing for both increased error due to increased individual differences and systematic bias that may be caused by differences in teaching practices from year to year. Rittle-Johnson and Siegler (1999), although they used the same group of children, examined development across a 12-month span. Without frequent, short-term testing, the information obtained is "more like snapshots than movies. . . . A movie is ideal, but even a sequence of still photos, taken before, after, and at frequent intervals during . . . yields a much finer understanding of the change than do before-and-after shots" (Siegler & Crowley, 1991, p. 607). The experiments we report use the microgenetic method and thus allow a fine-grained investigation of the change process.

A microgenetic study is a short-term longitudinal study. That is, the same participants are observed with high frequency over a short period of time. This sort of procedure allows a sequence of photos like those in Siegler and Crowley's (1991) description so that something might be learned about the process of a transition rather than simply the starting and ending points. In two experiments, we used microgenetic methods to investigate how children and adults learn to spell new words. Our goal in Experiment 1 was to examine children's progression from early attempts to spell new words to the point at which they could quickly and effortlessly retrieve the spellings from memory. Through this investigation we also hoped to shed light on the overlapping waves model of spelling development. In Experiment 2, we investigated the generalizability of overlapping waves in spelling from children to adults.

Experiment 1

We tested Grade 1 children in Experiment 1 to study children who were just beginning to learn to spell. They would likely be using some of the first strategies that children learn. We selected children of average to above average spelling ability to ensure that they could complete the task. The children spelled consonant–vowel–consonant (CVC) nonwords, such as *rin* and *vod*. These stimuli were simple and within the children's spelling ability, but

because they were nonwords specifically constructed for this study, it was unlikely that the children would have encountered them prior to the study. Nonwords were presented aurally on a computer in order to ensure that all children received the stimuli in the same manner. The computer program also recorded the typing latencies for each participant for each nonword. Latency analyses allowed us to verify strategy reports (Pressley & Afflerbach, 1995; Rittle-Johnson & Siegler, 1999; Robinson, 2001; Siegler & Stern, 1998; Steffler, Varnhagen, Friesen, & Treiman, 1998; Varnhagen, 1995) and examine the change process (Siegler, 1996; Siegler & Jenkins, 1989; Siegler & Stern, 1998).

On the basis of previous research (cf. Rittle-Johnson & Siegler, 1999; Steffler et al., 1998), we expected typing latencies to be longer for phonological strategies than for analogy strategies because of more extensive use of phoneme–grapheme correspondence analyses required for phonological strategies. Similarly, we expected retrieval to be associated with shorter typing latencies because retrieval requires less cognitive processing than more effortful strategy application.

Applying the overlapping waves model, we expected that the children would improve in speed and accuracy and would gradually shift toward heavier reliance on retrieval for spelling. We further expected children to progress along variable pathways to correct spelling. Some children might shift from phonological strategies to retrieval. Others might adopt analogy strategies on their way to retrieval. Consistent with the principle of adaptive choice (Rittle-Johnson & Siegler, 1999; Siegler, 1986; Siegler, 1996), some children might never shift strategies but continue to use strategies that have consistently yielded correct spellings for them in the past. Conversely, using a stage model, children would be expected to progress from one strategy to the next in a fixed order. They may well have different starting points, as some children may be slightly more advanced than others, but the trajectories for individual children would be expected to be the same. Specifically, children would be expected to progress from phonological strategies through orthographic and then analogy strategies to an endpoint of retrieval.

The children's strategies were evaluated through retrospective strategy reports; after spelling a nonword, the child was asked how he or she knew how to spell it. Siegler and his colleagues have used retrospective strategy reports extensively, even with young children, in studying strategy use in mathematics (see Rittle-Johnson & Siegler, 1999; Siegler & Jenkins, 1989). Varnhagen and her colleagues (Steffler et al., 1998; Varnhagen, 1995; Varnhagen et al., 1999) have used retrospective strategy reports with young children in the study of spelling strategies. Robinson (2001) found that children, even as early as in Grade 1, can provide valid and nonreactive strategy reports. We also used typing latencies to assess the veridicality of the children's verbal reports.

Method

Participants. Participants were 11 Grade 1 children, 7 girls and 4 boys, with an average age of 6 years 10 months ($SD = 3$ months) at the end of the testing sessions. One additional girl and 1 additional boy were dropped from the analysis; 1 of these children had a learning disability, and the other was so easily distracted as to render the latency measures meaningless. The children came from a school in a middle- to upper-middle-class, predominantly Caucasian neighborhood in northern Canada.

Spelling was taught in the classroom, following a balanced literacy program (e.g., Blair-Larsen & Williams, 1999) that is widely implemented in the local schools. Reading instruction included shared reading of large books, small-group guided reading with the teacher, independent reading, and home reading. Writing instruction included shared and independent writing experiences. One of the foundations of this program involves manipulating letters and spelling words. Each week, children were given the letters to an unidentified word and used those letters to build words of differing lengths before eventually identifying the word. The words built by the children were sorted into "word families," thus teaching the children to spell through analogy. Other components of the program included a "word wall"—frequently spelled words were posted on the wall for easy reference—as well as word books the children kept in their desks. Finally, the children received some training in phonics, including identification of patterns such as diphthongs and digraphs.

All of the participants spoke English fluently and spelled at grade level or above according to the Spelling subtest of the Wide Range Achievement Test–3 (WRAT-3; Wilkinson, 1993). Specifically, 2 children tested at the Grade 1 level, 5 at the Grade 2 level, 3 at the Grade 3 level, and 1 at the Grade 5 level ($M = 2.4$, $SD = 1.1$). These students' teachers felt this distribution of scores captured the range of differences in reading ability in the sample.

Stimuli. Stimuli were 10 nonwords; 5 nonwords (*dop, lat, lun, rin,* and *tet*) had high-frequency real-word neighbors (e.g., *dop* had 13 real-word neighbors, including *chop, dip, dog, pop,* and *shop*), and 5 nonwords (*fep, mib, nup, vab,* and *vod*) had low-frequency real-word neighbors (e.g., *feb* had 3-real-word neighbors: *fed, pep,* and *rep*). Based on the third-grade norms from Carroll, Davies, and Richman (1971), the average frequency of real-word neighbors for nonwords with high-frequency real-word neighbors was 1,667.20 ($SD = 940.73$, range = 1,028–3,290). Average frequency of real-word neighbors for nonwords with low-frequency real-word neighbors was 41.60 ($SD = 34.50$, range = 8–98).

None of the stimuli contained ambiguous sounds or consonants that could change the standard pronunciation of the vowel (e.g., the *a* is pronounced differently in *car* than in *can* or *cat*). None of the stimuli sounded or were spelled the same as any English word (e.g., *bak* was not used because it could be spelled as *back*).

Ten sentences were constructed for each nonword. Each sentence was short and simple, presenting the nonwords as nouns (e.g., "I have a *nup*"). Real nouns were used in the construction of the sentences in order to preserve a consistent concept of each nonword. For example, sentences were written about an apple, and then the stimulus nonword, *nup,* was substituted for the word *apple*. Nonwords were presented in this manner to provide a more realistic simulation of the naturalistic reading and writing experience. Children encountered their new words in the context of sentences that provided them with context and meaning. The nonwords and sentences were recorded using the digitized speech function of the Macintosh computer and assessed for clarity by the woman who had recorded them and by a naive adult male who was asked to type phonologically feasible spellings for each nonword.

Procedure. Participants were tested individually. Following familiarization with the task, each child heard a CVC nonword, a sentence containing the nonword, and then the nonword again (e.g., "*nup*. My *nup* is red. *nup*."). The participant was asked to spell the nonword on the computer keyboard. He or she was then questioned about his or her strategy (e.g., "How did you know how to spell that?"). This procedure was repeated for the 10 stimuli—each presented once—after which the researcher and child together read the sentences containing the nonwords. This simulated the naturalistic experience of encountering a new word in print. This exercise was repeated three times each week (Monday, Wednesday, and Friday) over the span of approximately 4 to 7 weeks. There were 10 sentences for each nonword, and these were repeated in sequence once a participant had completed all 10. Each participant repeated the exercise until he or she reported retrieving 80% of the words from memory on two

consecutive trials or, if the child never reported retrieval, until the child's strategy reports were stable over at least four trials. Several of the children who reported some retrieval did not reach either of the given criteria. These children were terminated as a group when a session occurred in which the collective use of retrieval (in the children who used this strategy) exceeded the use of all other strategies combined. The number of sessions required for this to occur ranged from 11 to 19.

At several points during testing, children who had not yet reported retrieval were probed to determine whether they were not using retrieval or simply were not reporting it. At the 7th session, they were asked whether they were doing anything differently that was improving their performance. At the 9th and 10th sessions, they were asked how they knew how to spell the word *the* and their name, respectively. At the 12th session, they were asked whether they would expect to perform better on a spelling test of the nonwords than they would have at the beginning of testing, and why. This is an extension of the type of probing used by Rittle-Johnson and Siegler (1999) when participants said they did not know what kind of strategies they had used.

At the end of testing, the children were administered the Spelling subtest of the WRAT-3 (Wilkinson, 1993). This test was administered to the children as a group and was conducted at the end of the testing period to best accommodate the children's scholastic schedule.

Scoring of strategy reports. Scoring was based on children's retrospective reports. These reports were consistently clear, leaving very little ambiguity in scoring. Children's overt behavior was also observed, but only their oral reports were used in scoring strategies. The only behavior exhibited that may be considered indicative of strategy use was the overt sounding out of words, which is ambiguous, as it could simply represent the sounding out of whatever letter the child was seeking. A response was scored as *phonological* if the child claimed to have used the sounds to determine the spelling (e.g., "I sounded it out," "*r* makes /r/, *i* makes /i/, and *n* makes /n/"). If the child claimed to have used another word to assist in spelling (e.g., "I already knew how to spell *in*, so I put an *r* in front of it"), the response was scored as *analogy*. If the child claimed to know or remember the word (e.g., "I know that one now," "I remember it from last time"), the response was scored as *retrieval*. Some responses could not be easily categorized (e.g., "I don't know," "I know *mib* from the show *Men in Black*"); these were scored as other and were treated as *nonstrategic* spelling. We had a naive researcher independently score 20% of the data to check reliability. The proportion of responses on which the second researcher agreed with the original classification was used to determine reliability; agreement occurred for 99.5% of the checked data.

Results

We report nonparametric rank-order statistics and analyses below. Because the children were learning to spell the words, we obtained many expected ceiling effects in accuracy, leading to differences in variability that invalidate use of parametric tests. To be consistent with the accuracy analyses, we report rank-order statistics and analyses for the latency data as well. Almost all of the nonparametric results reported below were comparable to results from parametric analyses of the same data, however. All results reported below are significant beyond the .05 level.

Analyses were conducted by subject and by item. In the results reported below, the first analysis is by subject and the second by item. In the vast majority of analyses, the item results are identical to the subject results.

Improvement in accuracy and speed. We collapsed children's accuracy and speed measures into quartiles because the children each completed different numbers of sessions. If a child's sessions were not divisible by 4, extra sessions were placed in earlier quartiles (e.g., if a child completed 10 sessions, they were divided as 3–3–2–2). Increase in accuracy levels and decrease in typing latency over time are depicted in Figure 1.

We analyzed improvements in percentage of nonwords spelled correctly over quartiles with a Friedman test (Siegel & Castellan, 1988). This analysis was significant by child and by item, $\chi^2(3, Ns = 11 \text{ and } 10) = 13.12 \text{ and } 9.04$, respectively. We used Wilcoxon signed-ranks tests to decompose this effect into quartile-by-quartile differences; children's accuracy improved from the first to the second quartile ($z = 2.10$ for both analyses), with accuracy at ceiling (over 95%) from the second quartile on.

We analyzed median typing latencies across quartiles with a Friedman test. Typing time decreased across quartiles, $\chi^2(3, Ns = 11 \text{ and } 10) = 21.22 \text{ and } 22.73$. Wilcoxon signed-ranks tests revealed that although accuracy improved to ceiling from the first to the second quartile, typing time decreased from the first to the second quartile ($z = -2.67 \text{ and } -2.66$) and from the second to the third quartile ($z = -2.67 \text{ and } -2.19$).
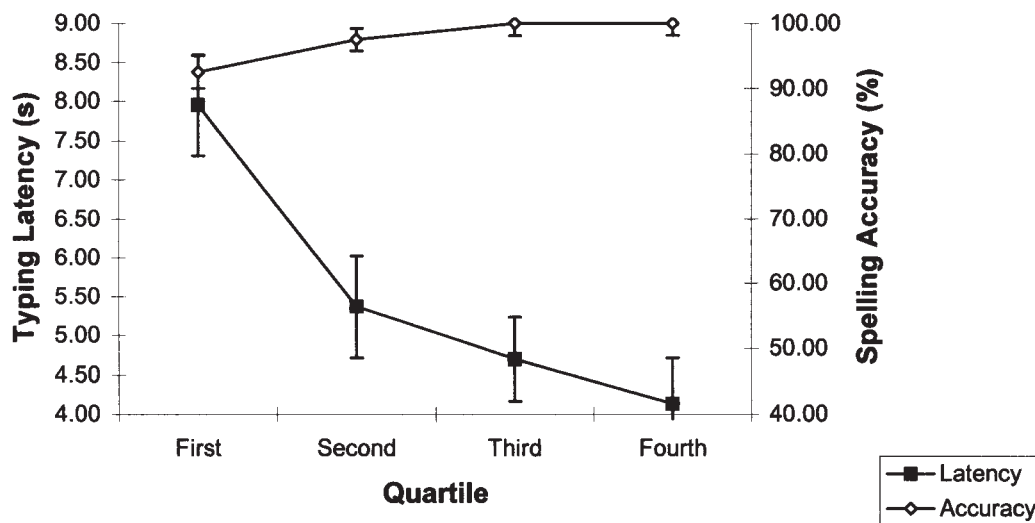

Figure 1. Changes in children's accuracy and latency across quartiles.

Variability in strategy reports. The distribution of children's reports, both across children and across sessions, is summarized in Table 1. Possibly because the words were simple, children did not report combinations of strategies, with the exception of analogy, which necessarily requires retrieval (e.g., reporting for the spelling of *lat,* "I knew how to spell *cat*").

Phonological strategies were reported by all but one child and were the most commonly reported type of strategy. Fewer children reported using analogy, and this strategy was used on less than one quarter of the words. Six children reported retrieving the nonwords from long-term memory, and retrieval reports predominated for these children in later sessions. Almost two thirds of the children reported "I don't know" or a strategy that couldn't be classified, but these "other" reports accounted for a very small proportion of the children's reports.

Across sessions, children reported a median of 2 strategies, with a range of 2 to 4 (7 children reported 2 strategies, 1 child reported 3 strategies, and 3 children reported 4 strategies). Children were remarkably consistent in their strategy reports; a strategy report provided for a specific nonword in one session was repeated in the next session 83.3% of the time. When children changed their reports, 55.1% of the time they shifted from one backup strategy to another, 30.3% were shifts to reporting retrieval, and 14.5% were shifts from reporting retrieval to reporting a backup strategy.

Strategy effectiveness. Accuracy and latency measures for each type of self-report are shown in Table 2. The results are shown by item; too few children reported using phonology, analogy, and retrieval consistently enough to warrant presentation and analysis by child. Accuracy was highest for nonwords spelled by retrieval or analogy and slightly less for nonwords spelled using a phonological strategy, Friedman $\chi^2(2, N = 10) = 12.97$. Typing times for nonwords spelled correctly by retrieval were fastest, followed by nonwords spelled using analogy and nonwords spelled using phonological strategies, Friedman $\chi^2(2, N = 10) = 12.80$.

Different trajectories in strategy development. Children differed in their strategy development across the study. Five children shifted from backup strategies to retrieval (i.e., retrieval was reported for nonwords more often than all backup strategies combined) over the course of the study and 6 did not. Of the 6 children who did not shift to using retrieval on a majority of the nonwords by the end of the study, 3 consistently reported phonology or analogy, 2 consistently reported phonology, and 1 consistently reported analogy.

Children who shifted from reporting backup strategies to retrieval show slightly different trajectories in accuracy and typing latency than do children who continued reporting backup strategies

Table 1

Percentage of Children Reporting Using Each Strategy or Retrieval at Least Once and Percentage of Reported Use for Spelling the Nonwords

Report	Percentage of children reporting use	Percentage of use
Phonology	90.9	54.3
Analogy	72.7	22.6
Retrieval	54.5	17.7
"Other" report	45.5	5.3

Table 2

Medians (and Interquartile Ranges) for Children's Accuracy and Typing Latency by Item as a Function of Report

Report	% Correct	Latency (in seconds)
Phonology	93.8 (7.0)	7.9 (2.7)
Analogy	100.0 (0.0)	6.7 (5.2)
Retrieval	100.0 (6.7)	5.7 (1.0)

throughout the study. Table 3 shows a comparison of accuracy and latency for children who shifted to retrieval and children who continued using backup strategies throughout the study.

Children who consistently reported using backup strategies across the study, with no shift to retrieval, showed significant improvements in accuracy across quartiles, Friedman $\chi^2(3, N = 10) = 15.64$, with a significant improvement in accuracy from the first to the second quartile (Wilcoxon $z = 2.23$). These children also became faster at typing the nonwords across quartiles, Friedman $\chi^2(3, N = 10) = 10.40$, and showed significant improvement in latency from the first to the second quartile ($z = -1.99$).

By contrast, children who shifted to reporting retrieval showed slow improvement in accuracy accompanied by slow decrements in typing latency over quartiles. A Friedman test for accuracy across quartiles was not significant. These children did become faster at typing the nonwords across quartiles, however, Friedman $\chi^2(3, N = 10) = 12.60$, with a significant decrease in typing time from the first to the fourth quartile (Wilcoxon $z = -2.02$).

Shifting from backup strategies to retrieval. The trajectory in strategy reports for those children who reported shifting to retrieval is shown in Figure 2. Children's reports of backup strategies decreased across quartiles, Friedman $\chi^2(3, N = 10) = 7.72$. The shift was gradual, however, with children reporting significantly less use of backup strategies in the fourth quartile than in the first quartile (Wilcoxon $z = -2.02$). Conversely, children's retrieval reports gradually increased across quartiles, Friedman $\chi^2(3, N = 10) = 11.15$, with statistically significant increases between first and fourth quartile reports (Wilcoxon $z = 2.02$).

Children's accuracy and latency measures showed remarkable changes from the first to the third quartiles, yet their strategy shifts occurred much more gradually. Across all sessions, the 5 children who shifted from backup strategies to retrieval were most likely to stick with a particular strategy, either phonology or analogy, from one session to the next, regardless of whether the nonword was spelled correctly (*Mdn* = 80%, interquartile range [IQR] = 12.7%) or incorrectly (*Mdn* = 75%, IQR = 7.7%) during the previous session.

On the other hand, when these children did shift, they were more than three times as likely to shift from reporting a backup strategy to reporting retrieval (*Mdn* = 54%, IQR = 24.1%) than to reporting another strategy (*Mdn* = 11.9%, IQR = 26.5%); this difference was marginally significant with a Wilcoxon signed-ranks test ($z = 1.75$, $p < .07$). Similarly, considering strategy shifts as a function of spelling correctness, children were more likely to shift to retrieval following a correct spelling (*Mdn* = 54%, IQR = 29.0%) than following an incorrect spelling (*Mdn* = 10%, IQR = 23.6%; $z = 2.02$). Shifting from a backup strategy to retrieval also resulted in an initial increase in typing latency in the session immediately preceding retrieval (*Mdn* = 5.1 s, IQR = 2.4 s)

Table 3

Medians (and Interquartile Ranges) for Accuracy and Typing Latency by Quartile for Children Who Did Not and Did Shift From Using Backup Strategies to Retrieval

Shift	Quartile			
	First	Second	Third	Fourth
% Correct				
No shift to retrieval	92.5 (0.8)	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)
Shift to retrieval	87.2 (14.4)	96.0 (5.6)	93.3 (12.5)	100.0 (8.8)
Latency (in seconds)				
No shift to retrieval	9.0 (4.6)	4.2 (2.2)	4.1 (1.4)	3.9 (1.6)
Shift to retrieval	7.8 (1.9)	5.7 (3.0)	5.0 (1.2)	4.4 (0.9)

followed by a decrease in latency in the session immediately following retrieval (*Mdn* = 4.7 s, IQR = 1.0 s).

Discussion

Children began by spelling the nonwords using predominantly phonological or analogy strategies. They became accurate and fast over the first two quartiles of testing. This was followed by a gradual shift, by some children, to retrieval. Those children who did not shift to retrieval were accurate and fast at spelling the nonwords practically from the beginning of the study. The children's strategy variability and their different trajectories in developing accurate and fast spelling of the nonwords clearly support an overlapping waves model of children's spelling development.

Variability in spelling strategies. Our analysis of latency as a function of strategy report adds to the growing body of evidence (e.g., Rittle-Johnson & Siegler, 1999; Robinson, 2001; Siegler & Stern, 1998; Steffler et al., 1998; Varnhagen, 1995) that children can accurately report their cognitive strategies. The children approached the spelling task strategically, selecting among one to

three strategies and retrieval. As well, the children used multiple strategies, not simply relying on phonology or analogy for the entire list. Children's use of multiple spelling strategies supports the contention that children have a large repertoire of spelling strategies, even as beginning spellers attempting very simple words (e.g., Rittle-Johnson & Siegler, 1999; Treiman & Cassar, 1997; Varnhagen et al., 1997).

Children's adaptive choices. Regardless of how they approached the spelling task, all children became faster and more accurate at spelling the nonwords over time. According to the principle of adaptive choice (Rittle-Johnson & Siegler, 1999; Siegler, 1986; Siegler, 1996), children select a strategy that will require the least amount of effort while, at the same time, being most likely to achieve a correct response.

Retrieval is clearly the most adaptive method for spelling the nonwords. We created the short, regular nonword stimuli to promote ease of learning the spellings and thus allowing the children to use retrieval. And most children did, indeed, switch from slower, more effortful backup strategies to retrieval. Why, though,
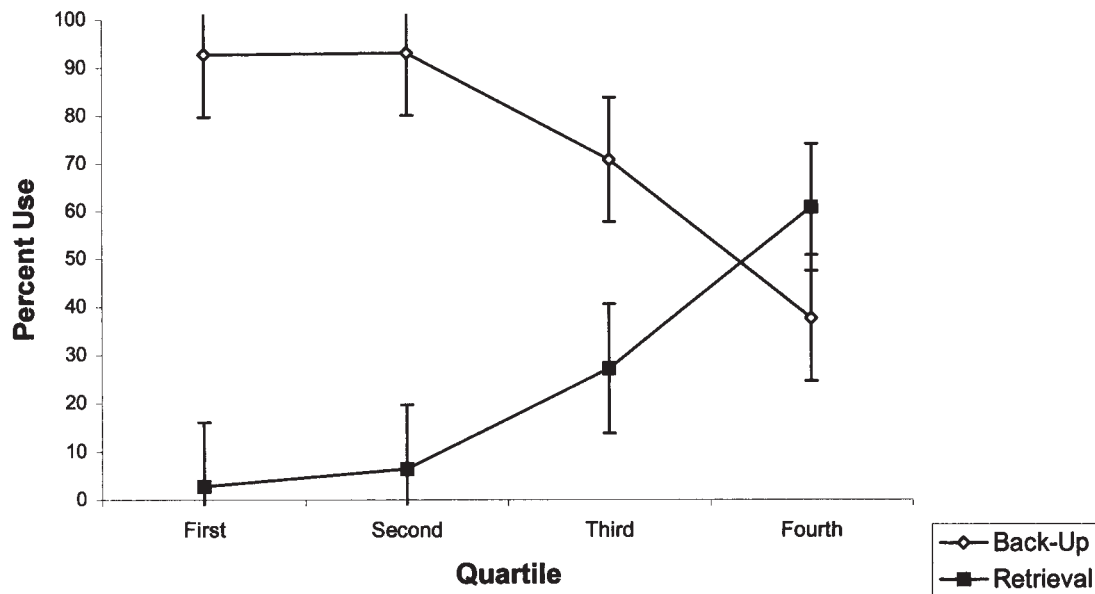

Figure 2. Trajectory in the shift in reports from backup strategy use to retrieval by the 5 children who used retrieval.

did some children never retrieve the words, instead relying on theoretically less efficient and effective strategies of phonology and analogy? The children who did not shift to retrieval were, from the beginning of the study, more accurate in their spelling and were quite quick in their spelling by the second quartile. Possibly these nonshifters did not experience sufficient effort or difficulty to necessitate a shift to retrieval (cf. Bruck & Treiman, 1992). Thus, for the nonshifters, their strategic approach was adaptive. For the other children, who were experiencing more cognitive effort and less success in the early sessions, shifting to retrieval was their adaptive approach to the spelling task.

Learning new words. Shifting from backup strategies to retrieval was gradual; children first became accurate and fast in their spelling and then shifted. It appeared that children needed to spell a nonword correctly, perhaps several times, before they were able to retrieve that nonword from memory. This may be due to some sort of inefficiency in attempting to retrieve a nonword before achieving a correct spelling. Shifting to retrieval then accounted for a slightly shorter typing latency for the words. This suggests that even once the children had "learned" to spell the nonwords correctly, there was some benefit to retrieving the spellings from memory. However, the process of becoming somewhat familiar with the nonwords, and perhaps of becoming increasingly familiar with the computer keyboard, may have contributed to their improvements in speed.

An overlapping waves model of spelling development. The results of Experiment 1 support an overlapping waves model to describe children's spelling development. Three major predictions of this model are variability in strategy use, adaptive strategy choice, and gradual change. The results of Experiment 1 confirmed all three predictions. In contrast, a stage theory would predict that change would be less gradual, as children switched from less to more mature strategies. Shifts in strategy use would be expected to be invariable and unidirectional. Instead, children sometimes used backup strategies for nonwords they had previously retrieved from memory. Also, shifts in reliance directly from phonological strategies to retrieval in some children whereas others progressed from phonology to analogy refute the idea of invariable trajectories.

According to our proposed overlapping waves model, beginning spellers bring a wealth of knowledge of the English spelling system to bear on their earliest writing. They have a naive understanding of how sounds map onto spellings and can therefore use phonological knowledge in their spelling (Read, 1971; Treiman, 1993; Treiman & Cassar, 1997; Treiman et al., 1994). They recognize that similar sounding words may have similar spellings, and they use this knowledge to spell by analogy (Goswami, 1988; Varnhagen et al., 1999). They also have at least an implicit understanding of their working memory such that they strive to accomplish the spelling task effectively and efficiently (Siegler, 1996). This leads them to be able to choose adaptively among their repertoire of spelling strategies as well as analyze the effects of their selection.

Adaptive choice for one child may be to spell a new word by sounding it out, segmenting the word into phonemes and applying the closest sounding letter to represent each phoneme. Adaptive choice for another child may involve using analogy to a known word or part of a word in order to ease the cognitive load of conducting a complete segmentation of the word. These two children may be equally successful (or unsuccessful) at spelling the

word but will have arrived at the spelling via different strategies and having taken different amounts of effort and time. Adaptive choice also means that the children analyze the effect of their strategies on the task of spelling, both in terms of accuracy and in terms of effort or speed; this analysis will influence strategy use the next time that word or a similar word is encountered.

With repeated experiences spelling the new word and other words, children become both more accurate and more efficient in selecting and applying spelling strategies. For one child, this may involve inventing new strategies or generalizing previous strategies; for another child, this may involve sticking with an effective and efficient strategy; for still another, it may involve a shift to retrieval of the spelling from long-term memory.

This overlapping waves model provides a very different account of spelling development than does a stage model. The overlapping waves model emphasizes strategy variability, idiosyncratic development, and change occurring as a function of adaptive choice based on effectiveness and efficiency. These features are very process centered. Stage models of spelling development (e.g., as proposed by Ehri, 1992; Gentry, 1992; Henderson, 1985), by contrast, emphasize the development of knowledge of the spelling system and how children learn to use their knowledge to spell effectively. These features are more task centered.

Different theoretical approaches to understanding spelling lead researchers to adopt different methods for studying spelling development. These methods then tend to confirm the perspective taken. For example, stage theorists often analyze spelling errors and design spelling tasks that will allow them to classify spelling errors according to spelling stage. Taking an overlapping waves perspective, however, leads to rather different research methods, including collecting verbal reports, using other measures of cognitive processing such as typing latencies, and analyzing correct spelling. Although stage and overlapping waves models may be set up as conflicting theories, it is likely that aspects of both perspectives—and methods derived from these perspectives—will ultimately provide a complete theory of spelling and spelling development.

Experiment 2

Do adults follow the same trajectories in learning to spell new words? We addressed this question in Experiment 2, which was designed to examine the generality of spelling learning processes. University students spelled complex nonwords made up of root words and endings that exist in the English language but do not go together (e.g., *refusion* was made up of the root word *refuse* and the suffix -*sion*). Nonwords were used to ensure that all words would be novel to all participants. All nonwords followed orthographic rules for combining roots and affixes. Nonwords were presented, and typing latencies measured, in the same manner as in Experiment 1. Participants were tested on a regular basis from their first encounter with the stimuli until they could spell the words quickly and with little effort. Using this microgenetic method allowed us to study change in progress (Siegler, 1994).

As with Experiment 1, participants' strategies were evaluated through retrospective report; after spelling a nonword, the participant was asked how he or she had determined the spelling. Participants typed their spellings, allowing a precise and accurate measurement of typing latency. We analyzed typing latency to examine the change process (cf. Siegler & Jenkins, 1989), which

seems important in light of Siegler and Jenkins's (1989) findings on changes in latencies prior to strategy discoveries and our finding with the children in Experiment 1.

We expected that adults would show the same pattern of gradual improvement in speed and accuracy as did the children and would gradually shift toward heavier reliance on retrieval for spelling. We also expected that adults might experience temporary periods of being slower and less accurate immediately prior to shifting strategy use.

Method

Participants. Participants were 34 introductory psychology students, 32 women and 2 men. The first session was completed for course credit. At the end of the first session, participants were offered a small monetary sum to continue their participation for multiple sessions. Seventeen women and 1 man (mean age = 22 years 10 months, SD = 8 years 6 months) agreed to continue with the study. One woman was later dropped from the study because she had difficulty following instructions for strategy report. Fifteen women and 1 man (mean age = 20 years 7 months, SD = 3 years 1 month) declined to continue. These groups were analyzed to determine whether there were significant preexisting differences between the two. All participants reported English as their first language and reported having learned to spell using a phonics approach. Their mean score on the Spelling subtest of the WRAT-3 was 110.85 (SD = 7.73).

Stimuli. Stimuli were 20 nonwords based on existing roots and suffixes, paired together in ways that do not exist in real English words. The real-word roots were *bellow, bypass, chastise, contact, desist, digress, embrace, exit, follow, obsess, pilfer, refuse, reject, relate, replace, return, suspect, taper, vacate,* and *waver,* and the real suffixes were *-er, -or, -able, -ible, -sion, -tion, -ence, -ance, -cious,* and *-tious.*

Four sentences were developed for use with each nonword. The sentences were designed to provide a context in which the meanings of the nonwords would be clear, permitting the use of morphological strategies. After the fourth session with a given participant, the sentences were repeated over the next four sessions in the same order. The nonwords and sentences were recorded using the digitized speech function of the Macintosh computer.

Procedure. Participants were tested individually. In the first session, the participant completed a spelling education questionnaire, the Spelling subtest of the WRAT-3, and the computerized nonword spelling test. As in Experiment 1, using the digitized speech function of the computer, the participant heard the nonword, a sentence containing the nonword, and then the nonword again (e.g., "*Digressible.* Professor Gab is always behind in lecturing because he's very *digressible. Digressible.*"). The participant then spelled the nonword on the computer keyboard and explained to the researcher how he or she arrived at that spelling. This was repeated for all 20 nonwords—each presented once—after which the participant was asked to read out loud a list of the sentences. At the end of the first session, participants were asked whether they would be willing to return 3 days each week for several more weeks, to repeat the strategy-report portion of the session only. Participants who continued were paid $25 at the conclusion of the study.

Each continuing participant repeated the nonword spelling and reading tasks over three sessions per week, continuing until he or she reported retrieval for 80% of the nonwords for two consecutive sessions. There were five cases in which a participant who had not reached this level of retrieval was terminated. Four of these were cases in which a participant showed no retrieval or declining levels of retrieval after 12 sessions. The fifth case was one of a participant who chose to terminate participation after 7 sessions.

Scoring of strategy reports. As with Experiment 1, scoring was based on participants' retrospective reports. A response was scored as *phonological* if the participant claimed to have used the sounds to determine the spelling (e.g., "I just spelled it the way it sounded: *bell-ow-er*"). If the

participant claimed to have used another word to assist in spelling, the response was scored as *analogy* (e.g., "I added *-cious* to *embrace* because it's like the word *delicious*"). If the participant used the meaning of the word to assist in spelling, the response was scored as *morphological* (e.g., "*-er* is the typical ending when changing a verb to a noun, so I changed *return* to *returner*"). If the participant's response was based on spelling conventions, it was scored as *orthographic* (e.g., "I added *-ious* to *replace,* keeping the final consonant from the stem to form *replacious*"). If the participant used the appearance of the written word to determine its correctness, the response was coded as *visual checking* (e.g., "It looks right"). If the participant claimed to know or remember the word, the response was scored as *retrieval* (e.g., "I remembered it from the last session"). If the participant claimed to have used some combination of the approaches described, the response was scored as a *combination* ("I remember that this ends in *-ious,* but I don't remember what consonant comes before it, so I used the final consonant from the root word"; these combined strategy reports were provided by only 4 participants and never made up more than 5% of a participant's reports for a given tercile). If a participant was unable to provide a report or if the report provided did not fit into any of the above categories, the response was coded as *nonstrategic.* A naive researcher independently scored 30% of the data to check reliability; agreement occurred for 94.3% of the checked data.

Results

We report nonparametric rank-order statistics and analyses below. All of the obtained results were equivalent to those obtained using parametric tests. All results reported below are significant beyond the .05 level.

Continuing versus noncontinuing participants. The participants who chose to return for repeated sessions were compared with those who chose to terminate their participation to determine whether there were preexisting differences between the two groups. This was done to determine whether the results obtained from the continuing participants could be considered generalizable to a larger group. The two groups did not differ on most measures. They were equivalent in terms of age, spelling ability (as measured by the WRAT-3), educational spelling history, self-ratings of spelling ability, and typing latency during the first session. There was one measure on which the groups did differ. The continuing participants spelled slightly more nonwords correctly during the first session (Mdn = 15.00, IQR = 8.00) than did the noncontinuing participants (Mdn = 12.50, IQR = 10.00), Mann–Whitney U = 74.5.

Improvements in accuracy and speed. Because the participants each completed different numbers of sessions, we collapsed their accuracy and speed measures into terciles. We used terciles instead of quartiles because adults completed the task in fewer sessions than did the children; terciles thus allowed for comparable session groupings. For instance, if a participant completed 9 sessions, each tercile for that participant would include the averages across 3 sessions. If a participant completed 10 sessions, they were divided as 4–3–3. Figure 3 shows the increase in accuracy levels over time and the decrease in typing latency over time. Although there was a substantial increase in accuracy in each tercile, decrease in latency was minimal.

We analyzed improvements in accuracy over terciles using a Friedman test. The dependent variable was the percentage of nonwords spelled correctly in each tercile. There was a significant main effect of tercile, $\chi^2(2, Ns = 16 \text{ and } 20) = 30.55$ and 26.88, by participant and by item, respectively. A Wilcoxon signed-ranks
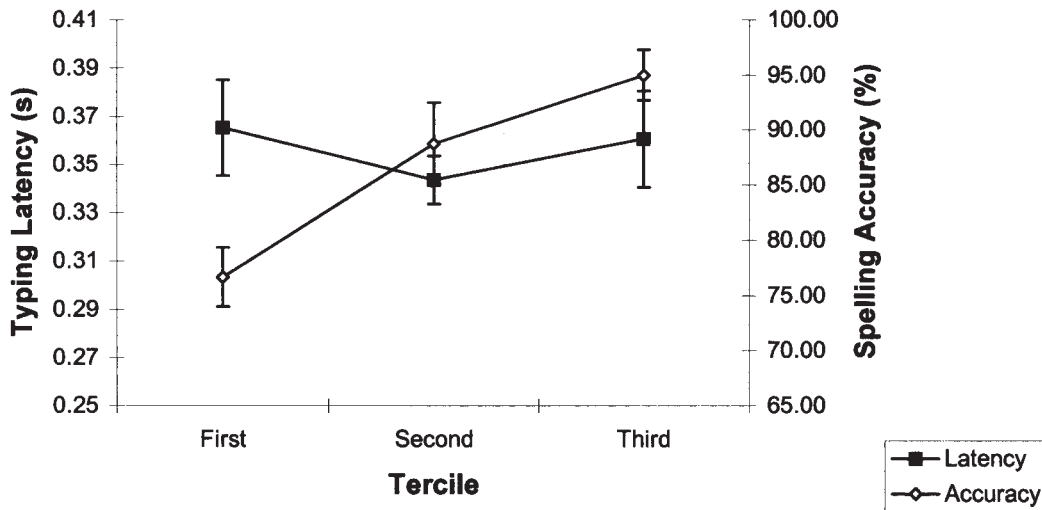
Figure 3. Changes in adults' accuracy and latency across terciles.

test used post hoc revealed that accuracy improved both from the first- to the second-session tercile ($z = 3.55$ and 3.10) and from the second- to the third-session tercile ($z = 3.31$ and 3.62, by participant and by item, respectively).

The measure of speed used in the analysis was median per-letter typing latency for the endings of the nonwords. Per-letter latency was used because some endings had more letters than others (e.g., -*er* vs. -*cious*), unlike in Experiment 1, in which all stimuli contained the same number of letters. These data were analyzed only for nonwords for which the ending was correctly spelled and intact (i.e., the participant had not deleted and retyped part of the ending). Typing latency was analyzed across terciles using a Friedman test. This analysis was nonsignificant for the analysis by participant but significant for the analysis by item, $\chi^2(2, N = 20) = 10.90$. Post hoc Wilcoxon signed-ranks analyses revealed a significant decrease in latency from the second to the last tercile ($z = -2.20$ and -3.29, by participant and by item, respectively).

Variability in strategy reports. Table 4 illustrates the distribution of participants' reports, both across participants and across sessions. Participants reported some use of analogy, but overall, participants reported using phonology and retrieval the most. Most participants also had some nonstrategic reports; however, these

made up a very small percentage of overall reports. Visual checking was also reported by a majority of the participants, but again, in small amounts. No other strategy was reported by a majority of the participants. Participants reported an average of 6.1 strategies, with a range of 4 to 8 (2 adults reported 4 strategies, 4 reported 5 strategies, 4 reported 6 strategies, 4 reported 7 strategies, and 3 reported 8 strategies). Adults were also relatively consistent in strategy reports; a strategy report provided for a specific nonword in one session was repeated in the next session 65.5% of the time. When they changed their reports, 39.0% of the time they shifted from one backup strategy to another, 49.9% were shifts to reporting retrieval, and 11.1% were shifts from reporting retrieval to reporting a backup strategy.

Strategy effectiveness. Accuracy and latency measures for the four most common types of self-report are shown in Table 5. As with Experiment 1, the results are shown by item because few participants reported using all four approaches to spelling the nonwords. Accuracy was highest for nonwords spelled by analogy, orthography, and retrieval, and lowest for nonwords spelled by phonology, $\chi^2(3, N = 20) = 13.37$. Typing times were highly variable and showed no significant differences as a function of self-report.

Different trajectories in strategy change. Participants differed in their strategy development across the study. Eleven participants shifted from predominantly reporting using phonological strategies to reporting retrieval over the course of the study, 2 shifted from predominantly reporting analogy to reporting retrieval, 2 shifted

Table 4
Percentage of Adults Reporting Using Each Strategy or Retrieval at Least Once and Percentage of Reported Use for Spelling the Nonwords

Report	Percentage of participants reporting use	Percentage of use
Phonology	94.12	33.78
Analogy	100.00	13.52
Morphology	64.71	3.33
Orthography	76.47	6.58
Visual checking	58.82	3.89
Retrieval	94.12	35.07
Nonstrategic	82.35	3.16
Combinations	41.18	0.66

Table 5
Medians (and Interquartile Ranges) for Adults' Accuracy, and Typing Latency by Item as a Function of Report

Report	% Correct	Latency (in seconds)
Phonology	80.2 (38.0)	0.36 (0.06)
Analogy	90.5 (32.4)	0.38 (0.09)
Orthography	100.0 (10.1)	0.33 (0.07)
Retrieval	95.2 (10.5)	0.35 (0.06)

from orthography to retrieval, and 2 did not shift their strategy usage.

Participants who shifted from reporting backup strategies to retrieval showed different trajectories in accuracy than did those who continued reporting backup strategies throughout the study. Table 6 shows a comparison of accuracy and latency for participants who shifted to retrieval and those who continued using backup strategies throughout the study.

Participants who consistently reported using backup strategies across the study, with no shift to retrieval, did not show significant changes in accuracy or latency across terciles. Participants who shifted to reporting retrieval increased in accuracy across terciles, Friedman $\chi^2(2, N = 20) = 26.60$, but did not statistically significantly decrease in latency across terciles.

Shifting from backup strategies to retrieval. The trajectory in strategy reports for those participants who reported shifting to retrieval is shown in Figure 4. Participants' reports of backup strategies decreased rapidly across terciles, Friedman $\chi^2(2, N = 20) = 29.10$. The shift was more rapid than in Experiment 1, with participants reporting significantly less use of backup strategies in the first than in the second tercile (Wilcoxon $z = -3.41$) and less use of backup strategies in the last than in the second tercile (Wilcoxon $z = -3.19$). Conversely, retrieval reports increased across terciles, Friedman $\chi^2(2, N = 20) = 29.10$, with statistically significant increases between first and second tercile reports and second and last tercile reports (Wilcoxon $z = 3.41$ and 3.19, respectively).

Consistent with the rapid shift from backup strategies to retrieval across sessions, participants were more likely to shift from reporting a backup strategy to reporting retrieval ($Mdn = 50\%$, $IQR = 25.7\%$) than to reporting another strategy ($Mdn = 40\%$, $IQR = 16.9\%$); this difference was marginally significant with a Wilcoxon signed-ranks test ($z = 1.76$, $p < .08$). Unlike in Experiment 1, shifting to retrieval was not always associated with correct spelling: Participants were only slightly more likely to shift to retrieval following a correct spelling ($Mdn = 31\%$, $IQR = 17.7\%$) than following an incorrect spelling ($Mdn = 23\%$, $IQR = 21.1\%$).

Shifting from a backup strategy to retrieval also resulted in an initial increase in typing latency in the session in which retrieval first occurred ($Mdn = 0.38$ s, $IQR = 0.08$ s), followed by a decrease in latency in the session immediately following retrieval ($Mdn = 0.35$ s, $IQR = 0.06$ s). This latency trend was nonsignificant.

Table 6
Medians (and Interquartile Ranges) for Accuracy and Typing Latency by Tercile for Adults Who Did Not and Did Shift From Using Backup Strategies to Retrieval

	Tercile		
Shifting pattern	First	Second	Third
% Correct			
No shift to retrieval	79.2 (9.2)	81.3 (6.3)	91.3 (6.3)
Shift to retrieval	76.7 (11.9)	88.8 (18.3)	95.0 (6.9)
Latency (in seconds)			
No shift to retrieval	0.38 (0.03)	0.38 (0.06)	0.36 (0.03)
Shift to retrieval	0.37 (0.11)	0.34 (0.08)	0.36 (0.06)

Discussion

Overall, our findings with adults in Experiment 2 were very similar to the findings with children in Experiment 1. Adults were variable in their self-reports, selecting among a range of strategies to spell the novel word combinations. Interestingly, a predominant self-report was using phonology to spell the nonwords. Almost all adults reported using phonology at least once in their spelling, and it was the most commonly reported backup strategy. Adults also became more accurate and somewhat faster in spelling over time.

Children showed a larger difference in spelling latency than did adults. Although the children had been exposed to computers and keyboard layout, the adults presumably had much more experience with typing than the children, so their typing latencies were already quite fast. Because we were unable to completely control for number of letters in the adult nonwords, our latency measure (median typing time for correctly spelled word suffixes) was likely less reliable than the latency measure used with the children (total typing time for the three-letter nonwords).

Both children and adults showed shifts in strategy use. More adults shifted from backup strategies to retrieval. However, those children who did not shift were already fast and accurate in using their preferred backup strategy; for these children, strategy use was adaptive, and they did not have to memorize the correct spellings.

Conclusions

In two experiments, we investigated how young children and adults develop automaticity in spelling. We approached our question from an overlapping waves perspective (cf. Rittle-Johnson & Siegler, 1999; Siegler, 1995b; Treiman & Cassar, 1997; Varnhagen et al., 1997). Using this perspective, we examined whether young children possess a range of strategies, choose adaptively among their repertoire of strategies, and gradually develop the ability to retrieve correct spelling from memory. We also investigated whether children and adults use different processes to learn to spell novel words. Although previous work (i.e., Rittle-Johnson & Siegler, 1999; Treiman & Cassar, 1997; Varnhagen et al., 1997) indirectly supports the overlapping waves perspective of spelling development, this study represents a direct examination by studying individuals' spelling development from their first encounters with new words, through repeated exposures and attempts to spell, to fast, accurate spelling.

This study has both theoretical and educational implications. In terms of theories of spelling development, this study provides support for our overlapping waves model of spelling development. Both children and adults showed variability in spelling strategies, adaptive choice in their strategy selection, and gradual change from effortful backup strategies to fast retrieval of spelling from memory.

Another theoretical implication is that the findings support generalizability in the process of learning suggested by overlapping waves. Previous studies have shown that this model seems to apply across different domains (e.g., Cooney et al., 1988; Maloney & Siegler, 1993; Rittle-Johnson & Siegler, 1999; Siegler, 1987; Siegler & McGilly, 1989; Siegler & Shrager, 1984; Varnhagen et al., 1997). On the basis of our results, we argue that overlapping waves applies across different ages as well. Although we did find differences between the children and the adults, the process involved in learning to spell new words *does* appear to be universal.
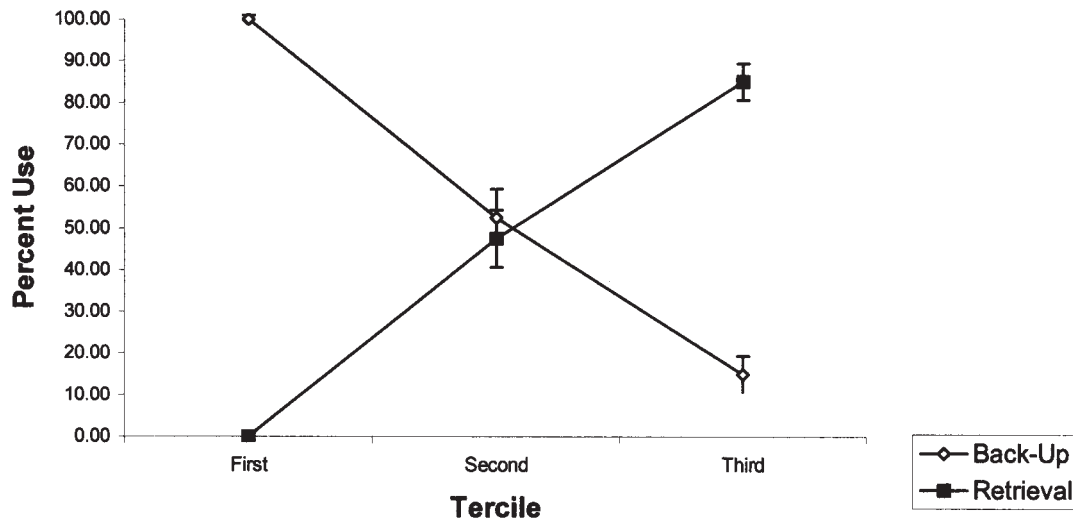
Figure 4.   Trajectory in the shift in reports from backup strategy use to retrieval by the 15 adults who used retrieval.

In terms of educational implications, these findings are important for recognizing that there are multiple means to accomplish the same end, namely correct spelling. Not all people use the same spelling strategies or use them in the same sequence. Not all words need to be committed to memory. As well, children or adults who do not retrieve all words from memory are not necessarily at a lower "stage" of development than children who do retrieve. It is essential to expose children, even (or perhaps especially) very young children, to multiple strategies that can be used in attempting to spell new words. Our results indicate that children are capable of using more spelling strategies than is often realized—this suggests that instruction in multiple strategies is appropriate for even the earliest spellers. In addition, children need continued experiences with a spelling in order to hold it in memory for later retrieval. Just because a child has spelled a spelling test word correctly does not mean that child has committed the word to memory.

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