TEACHING SILENT-‘E‘ WORDS TO INDIVIDUALS WITH INTELLECTUAL DISABILITIES

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ABSTRACT

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The literature on reading in persons with intellectual disabilities (ID) contains little guidance for teaching word-attack skills, particularly for word patterns beyond consonant-vowel-consonant words (CVC). One approach involves incorporating spelling and matrix training to facilitate development of the alphabetic principle, which denotes phoneme-grapheme relations that generalize across words. Our previous studies have demonstrated recombinative generalization of onset and rime units within CVC words following computerized matrix training where participants learned to construct words on the computer. The present study extends this work to CVC and CVCe (i.e., silent-_e) words. In this study, words were not constructed letter-by-letter, but by making only two selections: onset and rime. Participants were three adults with high-moderate ID and minimal reading skills. All participants demonstrated recombinative generalization within a rime set (e.g., learning to spell some at/ate words resulted in spelling untaught at/ate words). Secondary measures of emergent reading and written spelling showed that the computerized task resulted in both these untrained modalities. Thus, the procedures proved effective in producing the alphabetic principle and untrained reading and spelling.

Keywords: alphabetic principle, phonological awareness, reading, spelling, intellectual disabilities, matrix training, computerized instruction

Written text is a powerful and valuable method of communication. The ability to read not only expands available opportunities for leisure activities, but also provides individuals the capacity to function independently in society. Individuals who cannot read (or cannot read well) may have difficulty with even basic tasks such as deciphering signs, reading menus, using public transportation, and filling out forms for employment or a doctor‘s appointment. The inability to read may deter employment, impede communication and community/societal participation, and create an overreliance on other, more literate individuals.

Despite the widespread importance of this skill, the National Adult Literacy Survey found that 21-23% of adults (40 to 44 million) possessed skills in the lowest level of literacy (i.e., Level 1). Additionally, adults who had intellectual disabilities (ID) were about four times more likely than their peers to score in Level 1. In fact, 87-90% of adults with ID possessed Level 1 literacy skills, which include locating specific information in brief text and entering basic personal information. Average proficiency scores for this population ranged from 115-145 of the 225-point maximum of Level 1 scoring across three literacy scales. This low skill level creates many unnecessary barriers for individuals (Kirsch, Jungeblut, Jenkins, & Kolstad, 1993).

Although literacy deficiency in individuals with ID has generated interest among the scientific and educational communities, much of the research and instruction has been based on sight-word recognition (see Saunders, 2007, for a review). This teaching method limits the reading repertoire to only those words that are taught directly, thus furthering dependence on others. The key to autonomous reading acquisition is learning to read new words that have not been directly taught, a skill referred to as ―word attack.”

Research in the area of reading has generated a basic understanding of the prerequisites and mechanisms of word-attack skills for typically developing children (Adams, 1990; National

Reading Panel [NRP], 2000; Snow, Burns, & Griffin, 1998): phonological awareness, phonemic awareness, and the alphabetic principle. As defined in the reading literature, phonological awareness refers to the general ability to attend to the sounds of language as distinct from its meaning (Snow et al., 1998). Put another way, "phonological awareness refers, in part, to recognizing that spoken syllables contain smaller units of sound, and noticing that the same subsyllable sound occurs in different words" (Stewart, Hayashi, & Saunders, 2010, p. 1). These smaller sounds may include onsets and rimes (e.g., in the word "rat": 'r' is the onset [first letter] and 'at' is the rime [remainder of the word]).

For example, a reader who demonstrates phonological awareness can identify rhyming words (e.g., which word rhymes with "at": "fin" or "fat"?). Phonemic awareness is a subset of phonological awareness that functions at the level of the individual sounds (phonemes) in words rather than larger units. Readers who demonstrate phonemic awareness are able to segment spoken words into individual phonemes (e.g., hear "can" and say /c/-/a/-/n/) or delete sounds from words (e.g., say "can" without the 'c').

Phonological awareness is important because it is a basic building block in the development of the alphabetic principle, the knowledge that letters represent specific sounds within words. That is, readers can identify each sound in a word as corresponding with each letter in a word. Despite the importance of these discoveries, they have had relatively little impact on the literature in the field of reading for individuals who have ID, particularly adults.

One approach to establishing the alphabetic principle involves the incorporation of spelling with reading instruction. Because spelling instruction involves phoneme-grapheme correspondence, linking spelling with reading instruction may facilitate phonemic awareness (Bradley & Bryant, 1984; NRP, 2000). In fact, spelling has been found not only to promote

knowledge of the alphabetic principle (Hohn & Ehri, 1983), but also the acquisition of reading (Ehri & Wilce, 1987). Despite evidence of the potential value of spelling, there has been relatively little research designed to develop systematic instruction that integrates spelling and reading.

As previously noted, the alphabetic principle involves generalization. That is, the alphabetic principle is demonstrated when the student spells or reads a word that is not directly taught. One procedure that programs for generalization is matrix training. Matrix training uses a grid (matrix) of all possible combinations of two stimulus components (e.g., adjective-noun combinations), creating multiple exemplars to highlight similarities and differences of stimuli to promote recombinative generalization (Goldstein, 1993). Recombinative generalization is the "differential responding to novel combinations of stimulus components that have been included previously in other stimulus contexts" (Goldstein, 1983, p.281; for a recent review, see Suchowierska, 2006). That is, the trained and untrained word combinations form a matrix, ensuring exposure to all critical units (Mueller, Olmi, & Saunders, 2000).

In the early literature, matrix training was primarily used to teach novel combinations of whole words. For example, if we were to teach a child to name a blue circle, a blue triangle, and a red triangle, we could then test for naming of a red circle. Use of matrix training is not limited to whole words and naming, but can also be extended to individual sounds within words and spelling. For example, the sound-letter relations in the previously acquired words "hat" and "mug" can be recombined to form the words "mat" and "hug".

While previously shown to be effective in facilitating reading acquisition of pre-reading children (Mueller et al., 2000) and adults with ID (Saunders, O'Donnell, Vaidya, & Williams, 2003) using a computerized whole-word selection task, researchers have recently begun to look

at recombinative generalization methods as a means to link reading and spelling via constructed-spelling procedures. In constructed-spelling procedures, participants construct words from an array of letters following an auditory sample. That is, when a spoken word is presented, the participant spells the word by selecting from a provided array of letters (Mackay & Sidman, 1984). This has been examined using computerized instruction in Brazilian children with reading difficulties (de Souza, de Rose, Faleiros, Bortoloti, Hanna, & McIlvane, 2009) as well as North-American adults with ID (Stewart, Hayashi, & Saunders, 2010; Stewart & Saunders, under revision).

Stewart and Saunders (under revision) used a constructed-spelling procedure to teach the alphabetic principle to three illiterate men with mild-moderate ID whose skills were limited to sight-word reading at the first-grade level. Using a computerized session, participants constructed words letter-by-letter following a spoken-word sample. Measures of two untaught skills, writing and reading, were obtained for each participant following completion of the study.

The authors initially used 2 matrices of words, each composed of 12 onsets. In one matrix, all of the words contained the rimes _ag‘ and _ed‘; in the other, the rimes were _un‘ and _it‘. Participants were first tested on a group of four words (e.g., rag, led, lag, and red), were taught to construct two words (e.g., rag and led), and then were tested on the novel recombination of the onsets and rimes (e.g., lag and red). Following the final generalization test, all four words were presented in a session with differential reinforcement until criterion was met. After learning to construct some words with the two rimes in a matrix, participants began to construct novel words without any direct training. In order to construct the untaught words correctly, the participant had to recognize that the untaught words rhymed with one of the taught

words (i.e., contained the same rimes as the taught words). Such recognition defines phonological awareness.

Difficulty with word discrimination may vary dependent on the similarity of letters present in a word. Because discrimination of vowels may be the most difficult (McCandliss, Beck, Sandak, & Perfetti, 2003), Stewart and Saunders (under revision) added a second component to the experiment. Following completion of the initial two matrices, twelve 5-word sets were added. These five words contained the rimes _ap‘, _ep‘, _ip‘, _op‘, and _up‘. These rimes differed by the vowel, while the coda (i.e., last letter) remained the same. This arrangement was designed to promote abstraction of the vowel. Only one generalization test was given for each set and training was provided for all five words following the generalization test. These generalization tests required the recombination of each of the five rimes with new onsets.

Together, these procedures resulted in substantial increases in computerized construction of all 156 words in the study, as well as generalization to many untaught words. Mean generalization for each participant ranged from 68-91%. Measures of generative reading and spelling (i.e., writing with pencil and paper) showed improvement for each individual, despite the lack of direct instruction in these areas. Overall, the procedures proved effective in teaching letter-by-letter constructed spelling of words, in producing generalization to untaught words, in generating gains in untaught written spelling, and in generating modest gains in untaught reading in all three adult males with mild-moderate ID.

In two studies, de Souza, de Rose, Faleiros, Bertoloti, Hanna, and McIlvane (2009) used recombinative generalization to teach reading to 21 typically-developing Portuguese children, ages 8-12, struggling with reading in school. While Stewart and Saunders (under revision) taught adults with ID to construct words letter-by-letter, de Souza et al. used larger units (i.e., syllables)

in teaching typically developing children. Many Portuguese words are composed of two consonant-vowel syllables that may be recombined to form novel words. For example, the syllables in the word ―boca" (mouth) may be recombined to form the word for handle, ―cabo" (de Souza et al., p. 24).

Twelve children participated in Study 1. All were selected based on teacher reports of reading difficulties and the inability to read and spell (via constructed-response and cursive-writing measures) simple words in a preliminary assessment. Participants were taught to construct words by selecting syllables following a spoken sample (e.g., select _bo' and _ca' following the spoken sample ―boca").

Following training, the authors tested for generalization to untaught words (i.e., recombined syllables) and also assessed emergent reading and writing. All participants demonstrated generalization in the constructed spelling task, constructing new words that had not been directly taught. Additionally, emergent reading and writing were shown in all children in both training and generalization words.

The current study seeks to extend work on matrix training and constructed spelling procedures, focusing on adults with ID. The literature on word-attack skills on individuals with ID has focused almost exclusively on consonant-vowel-consonant words (Saunders, 2007). The current study seeks to expand previous findings by examining more complex consonant-vowel-consonant-vowel words. More specifically, the current study examines the acquisition of sound-print relations with and without a silent-_e'. We found no published studies examining this complex word structure in adults or children with ID.

Similar to deSouza et al. (2009) and Stewart and Saunders (under revision), matrix training was used and participants were taught to construct words (using a computer) following a

spoken sample. Words in the matrices were divided in a manner similar to Stewart and Saunders: by onsets and rimes. In this case, rimes were divided into sets based on long and short vowel sounds (e.g., at and ate).

Words were constructed by selection of the onset (one selection), followed by the selection of whole rime (one selection). The rime was presented as a unit because every sound in the spoken –silent-_e'" word does not correspond with every printed letter in the word: the _e' is silent and the vowel is long, rather than short. If a reader were to try to sound out this word from left to right, as is standard practice in early reading instruction, the word –rate" would be pronounced /r/-/ă/-/t/-/ĕ/: –ratteh" or even /r/-/ă/-t/-/ē/: –ratty". The rimes as a unit, however, remain constant (e.g., –at" will always be at, –ate" will always be ate.)

The primary questions of the study involved the computerized matrix training and testing tasks. There were three interrelated questions. First, would our teaching procedures establish the correct construction of long- and short-vowel words with the same vowel and final consonant sound (e.g., mat/mate)? Second, would teaching the construction of some words *within* a rime set result in generalization to other words with the same rimes (e.g., rat/rate)? Third, would teaching rime sets containing long- and short-_a' words with one final-consonant sound (e.g., at/ate) result in generalization *across* rime sets containing long- and short-_a' words with a different final consonant sound (e.g., would participants construct more an/ane words correctly after learning to construct at/ate words)? Additional questions involved emergent reading and written spelling. That is, would emergent reading and written spelling develop following the computerized matrix training and testing task?

Method

Participants

We selected 3 adults (Doug, Molly, and Evan) from residential group homes whose IQ scores placed them in the high-moderate level of ID. They (a) named lower-case letters with at least 96% accuracy, (b) scored within the first-grade-level on the Word-Identification subtest of the Woodcock Reading Mastery Test-Revised (Woodcock, 1987), (c) made no more than two correct responses on the Word-Attack subtest of the Woodcock (which presents increasingly difficult nonwords), (d) wrote their first and last names, and (e) scored at least 95% correct on a 4-choice, 56-trial, word-word identity matching session composed of study words. The latter test ensured that participants could visually discriminate printed words.

Further participation depended on the results of pretests specific to the words taught in the study (these tests will be described in detail in the procedures section). Criteria for participation were: (f) accuracy of less than 40% correct on initial pretests (to be described later) of reading and written spelling, (g) no more than 50% and no less than 35% accuracy on an initial computerized comprehensive construction test of the study words, (h) a score of at least 75% selection accuracy on the first letter of study words from the initial comprehensive construction test (see Table 1). These criteria were selected to ensure that participants had some reading skills, as both long vowel sounds and the silent-_e‘ are more advanced reading skills. Doug was the lead participant and completed the study before the other participants began. Minor procedural differences between Doug and other participants will be noted where relevant.

Setting and Apparatus

Sessions were conducted in small, private rooms (containing a table and several chairs) at the agency day centers of each participant‘s community-based service provider. Sessions were

Table 1

Participant demographics, scores on standardized tests, and comprehensive study-test scores.

			Woodcock[a]					
		WAIS[b]	Word ID	Word Attack	PPVT[c]	Comprehensive Tests		
Name	Age	(FS)	(grade)	(grade)	(age)	Construction	Reading	Spelling
Doug	32	N/A	1.5	K.0 .1	6:7	51%	32%	27%
Molly	28	54	1.5	1.0	13:1	36%	33%	37%
Evan	44	51	1.7	1.0	5:0	48%	38%	13%

[a]Woodcock Reading Mastery
[b]Weschler Adult Intelligence Scale-Fourth Edition. Score reported are full scores (FS). Scores were unavailable for Doug.
[c]Peabody Picture Vocabulary Test. Ages are represented as years: months.

run on an iBook G3 500MHz CD 12-inch laptop computer from Apple Inc. An external, add-on, touch-sensitive, KTMT-1214 *Magic Touch* touchscreen device by Keytec Inc. was attached. A stylus was used to touch the screen. MTS PPC 11.5.4 software was used in the identity-matching sessions, while SPELL 9.1.1 software operated word-construction tasks for training and testing sessions (Dube, 1992). Sessions with Doug and Molly were conducted Monday through Friday for approximately 30-60 minutes. Sessions with Evan were conducted for approximately 15-45 minutes, 3-4 days per week.

Interobserver Agreement

Interobserver agreement (IOA) was assessed on all expressive (i.e., reading) measures using point-by-point agreement. This was calculated using the equation [a/(a+d)] x100, where a = # of agreements and d = # of disagreements. Sessions to be scored for IOA were recorded with a camcorder pointed away from participants‘ faces. Flashcards used during the sessions were held in front of the camera before they were presented to the participant.

Procedures

Rime Sets

There were a total of five rime sets with long and short _a‘ and one set each with long and short _e‘ and _o‘ (i.e., et/ete and ot/ote) for a total of seven rime sets. Each rime set was laid out into a matrix so that each onset would be paired with both the long- and short-vowel rime (e.g., the onset _p‘ created the words "pat" and "pate"). Figure 1 shows the 12 pairs of words in the at/ate rime set (i.e., a total of 24 at/ate words). The remaining six rime sets each contained eight pairs of words; these sets are shown in Appendix B. There were more words in the at/ate set because these words were more likely to already be in a participant‘s sight-word vocabulary. Nonwords were included, in part, to ensure that all possible combinations of onsets and rimes

	at	ate
c	cat*^	cate*
n	nat	nate
f	fat*	fate*^
l	lat	late^
r	rat*^	rate*
p	pat	pate
m	mat*^	mate*
t	tat	tate
d	dat	sate
s	sat	date
g	gat*	gate*^
h	hat*	hate*

Figure 1. Word pairs in the at/ate matrix. Words with asterisks appeared in the comprehensive reading test for Molly and Evan. For Doug, the comprehensive reading test consisted of all 24 words from the at/ate set, 10 words from an/ane, 8 from ot/ote, and 8 from et/ete (not marked in the table). The remaining matrices may be found in Appendix B. Words with carets (^) are those words that appear in the written-spelling test for Molly and Evan. For Doug, the written-spelling test consisted of five words from at/ate, five from an/ane, and four each from ap/ape, ot/ote, and et/ete (not marked in tables).

were included. The final _a‘-containing rime set (i.e., af/afe) remained untrained.

Constructed Spelling

When a construction trial began, the computer displayed a blackened construction area and blank choicepool selection area (see Figure 2 for construction sequence). The spoken sample, which was presented through the iBook‘s internal speakers, repeated every 3 seconds. After an initial touch to the construction area, a choicepool consisting of 4 onsets and 4 rimes appeared, and the construction area became white. Participants constructed the printed word by touching onsets and rimes in the choicepool. Selections were immediately displayed in the construction area. The small, dark box in the upper left corner allowed participants to remove any selections and –start over.” Once the word was constructed, participants touched a dark circle in the upper right corner (i.e., the –done” button) to indicate that they completed their construction. The computer then scored the trial and advanced to the next.

In training sessions, correct constructions produced a brief series of chimes, a flash of the computer screen, and the delivery of a nickel by the experimenter; incorrect constructions produced a brief buzz. Nickels and computer-generated feedback were never delivered in testing and cumulative practice sessions. At the end of the session, participants received a $0.50 bonus if overall session accuracy was 90% or above. Money could be exchanged immediately following the session for smaller items, such as soda or keychains, or could be saved for larger items, such as clothing or tools. Saved or leftover money was recorded and tracked after every session by coloring in pictures of the items, one dollar at a time. Once the entire picture was colored in (i.e., all of the money was earned) the item was given to the participant. All items were selected in advance by the participants during shopping excursions. In the event that a participant was unable to attend a shopping excursion, the experimenter and participant created a –wish list” that

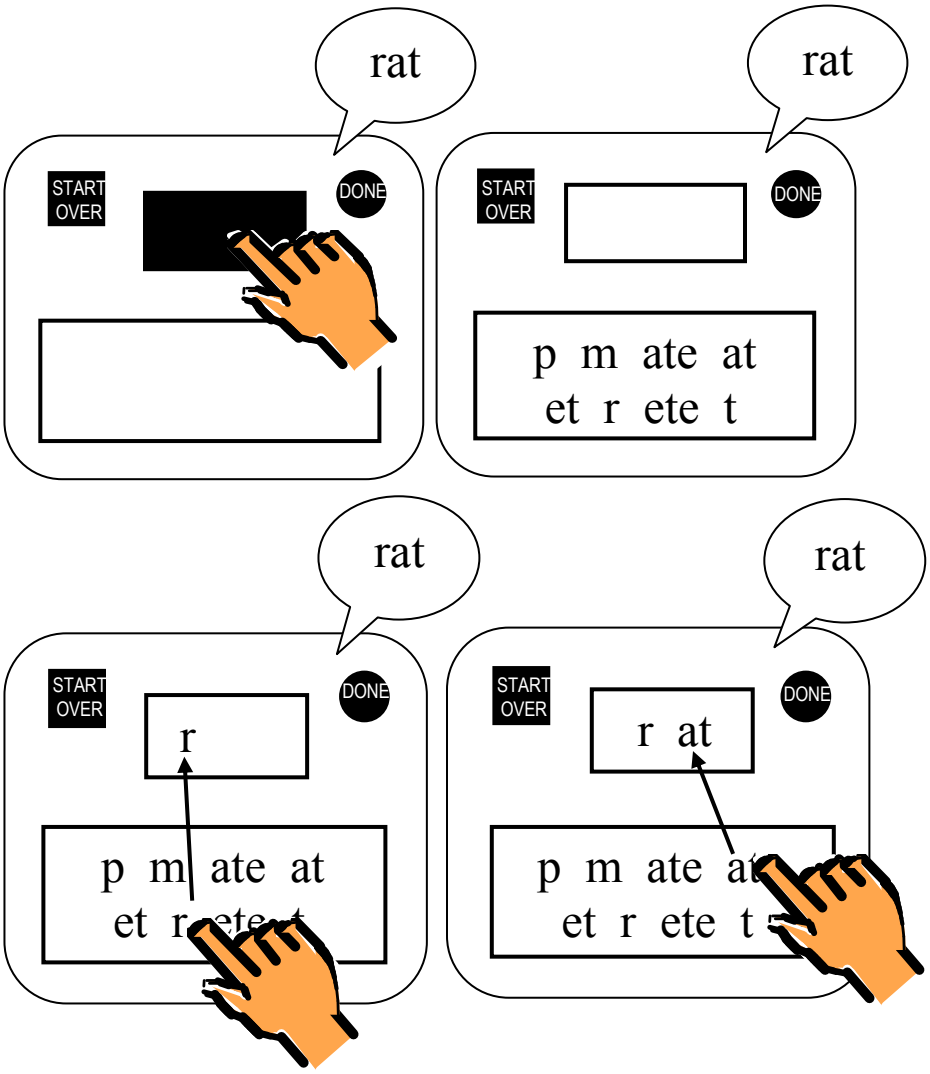

Figure 2. Diagram of one trial of the computerized construction task.

the experimenter used as a shopping list.

Experimental Questions and Design

The primary questions (as presented in the introduction) were (1) would our teaching procedures establish the correct construction of long- and short-vowel words with the same vowel and final consonant sound, (2) would teaching the construction of some words *within* a rime set result in generalization to other words with the same rimes, and (3) would teaching rime sets containing long- and short-_a‘ words with one final-consonant sound result in generalization *across* rime sets containing long- and short-_a‘ words with a different final consonant?

Questions one and three were addressed using a multiple-probe-across-rime-sets design. The probes were comprehensive construction tests (described fully below) that assessed all words in all seven rime sets. These tests were given before any training and upon completion of each of the rime sets, thus including both taught and untaught rime sets (see flowchart, Figure 3). The inclusion of five long- and short-_a‘ rime sets allowed for the assessment of generalization that might occur across _a‘-containing rime sets. The inclusion of rime sets with long- and short-_e‘ and _o‘ words controlled for extra-experimental influences by demonstrating that improvement was specific to the _a‘-containing sets (accuracy would be expected to remain low for the _e‘- and _o‘-containing sets). Additionally, the rime set af/afe remained untrained and was also composed almost entirely of nonwords (i.e., there is one real word in the set), which are unlikely to be learned in the natural environment.

These two characteristics (longer baseline and the high proportion of nonwords) allowed for another, more stringent measure of the occurrence (or nonoccurrence) of generalization across _a‘-containing rimes. The multiple-probe design also allows for the assessment of maintenance across time, as completed word sets continue to be tested throughout the course of

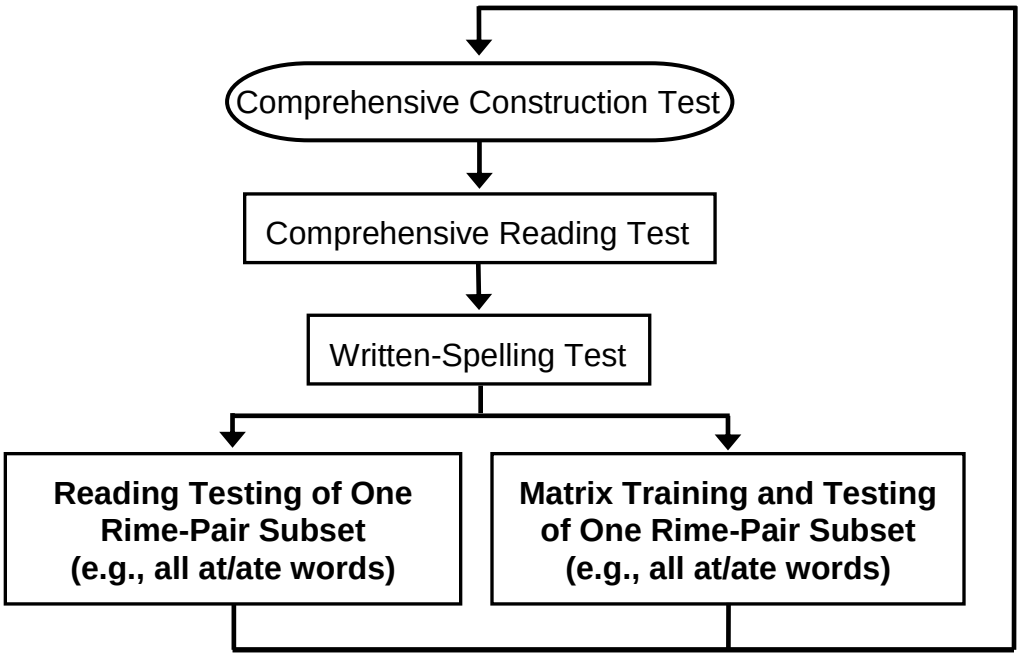

Figure 3. Flowchart of the overall study sequence. This sequence was repeated for each rime-pair subset. For a more detailed account of reading testing and matrix-training sequences (the bolded portion of this flowchart), see Figure 4.

the study. Question 2 was addressed for each rime set by showing the percentage of words constructed correctly via generalization, along with the percentage previously acquired (i.e., correct in the comprehensive test), as well as those that were directly trained in the study.

Two additional questions addressed emergent reading and written spelling using a multiple-probe-across-rime-sets design (similar to questions 1 and 2). For emergent reading, the probes were comprehensive reading tests composed of a sampling of 60 words from the study (described fully below) that followed matrix training and testing of each rime set. For written spelling, the probes were written-spelling tests that took place immediately following the comprehensive reading tests (described fully below).

Comprehensive Tests

Comprehensive construction tests. To ensure that participants understood the construction task, they were taught to construct one pair of words prior to receiving the first comprehensive test (–go" and –no" for Doug, –wif" and –wife" for Molly and Evan). As shown in the flowchart in Figure 3, comprehensive construction tests, conducted without feedback, were presented before any training and after construction training and testing for each rime set (e.g., at/ate, an/ane). Seven comprehensive tests were given in total. All 120 words shown in the matrices (see Figure 1 and Appendix B), presented once each, were randomly assigned to one of four test sessions. These tests began with eight trials of the baseline (i.e., pretaught) words and branched to the full test session if there were no errors during the first eight trials.

The remainder of the session was composed of 52 trials, including 22-24 trials of the baseline words and 28-30 randomized test words. If there were errors in the first eight trials, test trials were not presented, and participants completed a full session of baseline word trials. For Doug, only the rime sets at/ate, et/ete, and ot/ote were tested in the first comprehensive test (i.e.,

pretest); the additional sets were added to the comprehensive test after the first word set (at/ate) was completed (i.e., at the time of the second comprehensive test), and fat/fate served as the baseline. The choicepool consisted of four onsets and four rimes. Choicepool composition can be found in Appendix A.

Comprehensive reading tests. As shown in the flowchart in Figure 3, comprehensive reading tests were presented before the start of the study and post-matrix training and testing of each full rime set. These tests consisted of 60 selected study words presented randomly, one time each, on flashcards in Century Gothic font size 72. There were 12 words from the at/ate rime set and eight words from each of the remaining rime sets (i.e., an/ane, ap/ape, ad/ade, ot/ote, and et/ete) with the inclusion of as many real words as possible. For Doug, selected words consisted of all 24 from the at/ate set, 10 from an/ane, 8 from ot/ote, and 8 from et/ete.

No feedback was provided. Participants‘ complete responses were transcribed (including letter names or sounds); however, only the first whole-word response was scored as correct or incorrect. If the participant did not respond within five seconds, the flashcard was removed and the next trial began. If a participant responded with letter sounds or letter names, the experimenter left the flashcard out and prompted for a whole word, if necessary. In their everyday speaking, Doug and Molly had difficulty with articulation of some initial consonants (e.g., rat for lat). If these misarticulations were consistent, they were counted as correct.

Written-spelling tests. Written-spelling tests took place immediately following the comprehensive reading tests (see flowchart, Figure 3). For Molly and Evan, these written-spelling tests were composed of 30 words: 6 at/ate and 4 each of an/ane, ap/ape, ad/ade, ot/ote, et/ete, and af/afe (see Figure 1 and Appendix B). For Doug, the first two written-spelling tests contained fewer rimes and fewer trials (15). Following completion of the first two rime sets,

additional trials were added. For Molly and Evan, the full 30-trial spelling test was delivered pre and post study. Throughout the course of the study, probes of the completed and upcoming rime sets were administered. That is, following the completion of matrix training for the at/ate set, the six at/ate (completed set) and four an/ane (upcoming set) words were tested. Doug completed the full, 26-trial writing test between each rime set.

Construction Training Procedures

These procedures were used each time the construction of new words was taught. Two words were taught at a time. Training sessions began with trials that had a visual model—the whole printed word—presented at the top of the construction area. Once a criterion of four consecutive correct constructions with the visual model was met, the visual model was removed (leaving only the auditory sample) for the remainder of the 30-trial session. If 9 of the last 10 unprompted trials in a session were correct, a 30-trial session with no visual model was presented. Criterion for this session was 90% accuracy on each rime. Before an individual rime set test (Test 1 or 2 in matrix training and testing) or practice session, participants were also required to meet this criterion on one 30-trial session with intermittent (i.e., 50%) feedback and one with no feedback. Because individual rime set tests and practice sessions contained no feedback, this decrease in feedback provided participants with experience with no-feedback sessions prior to test sessions.

Individual Rime Set Teaching and Testing

As shown in bold in the flowchart in Figure 3, a teaching and testing phase for one rime set occurred in between comprehensive tests. The teaching and testing phase included both matrix training and testing within the construction task and reading testing. The phase ended with reading training. The flowchart in Figure 4 shows the sequence. Although matrix training

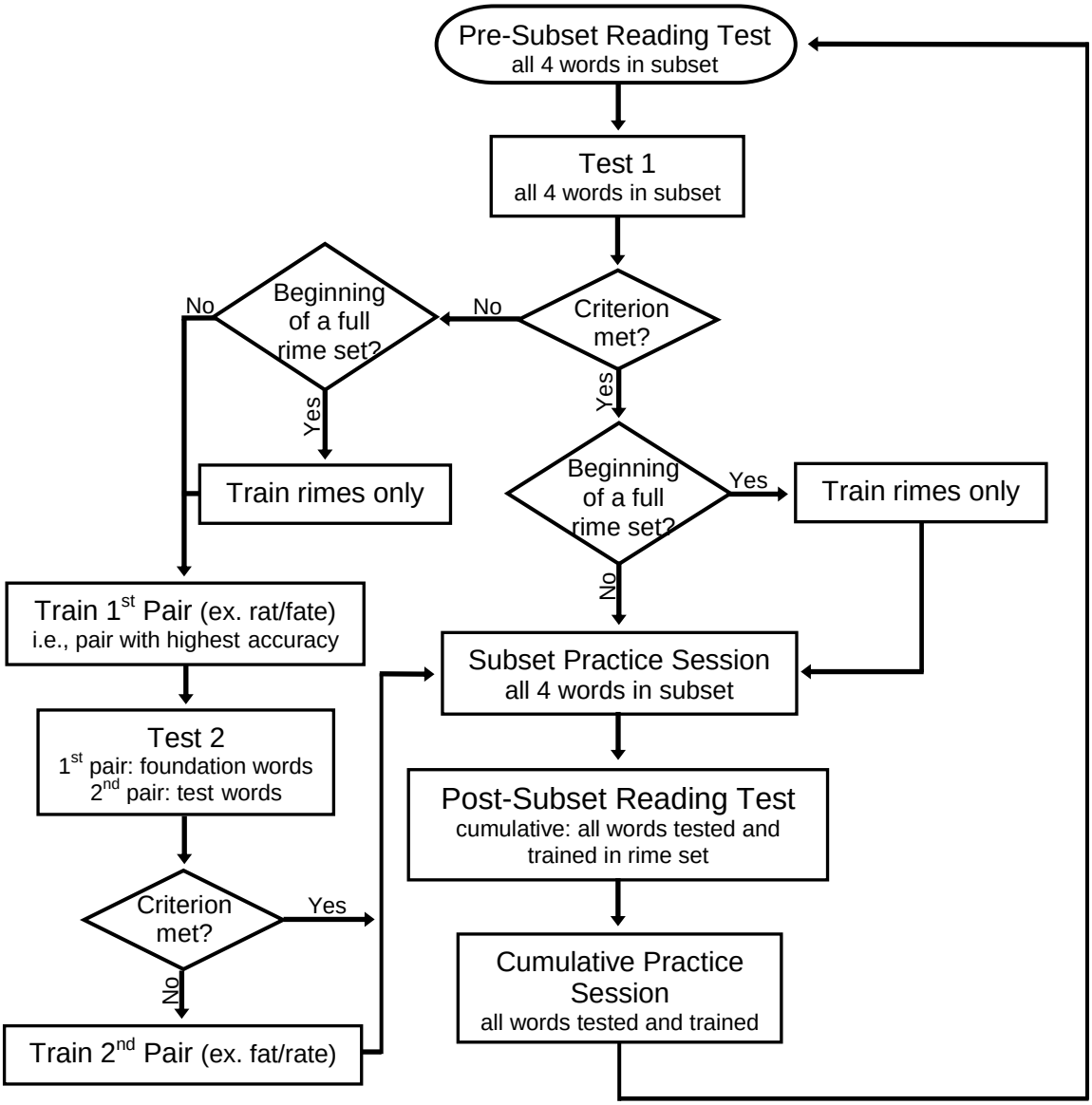

Figure 4. Flowchart of individual rime set training and testing. This flowchart depicts a more detailed account of matrix training and testing and reading testing (i.e., the bolded portion of Figure 3).

and testing are shown together in Figure 4, they are separated into their appropriate headings below. Choicepool composition can be found in Appendix A.

Matrix training and testing. Following each comprehensive test, the rime set to be taught next was divided into subsets of four words, containing all four combinations of two onsets and the two rimes (e.g. nat/cate and cat/nate), and a pretest (Test 1) of the first four-word subset was given. In Test 1, each test word was presented five times within a session containing baseline words. For Set 1, baseline words were –wif" and –wife". For all subsequent tests, the previously taught subset served as baseline words. For all tests, the generalization criterion was defined, on a per word basis, as 80% (i.e., 4/5 correct words).

Following Test 1 of the initial subset for each rime, the individual rimes (e.g., at and ate by themselves) from the rime set underwent training before progression to training of the whole words. The individual rimes were then interspersed in all training and testing sessions (see Figure 4). For Doug, rime training was added following the third subset of the at/ate rime set, but was part of training for the first subset for all subsequent rime sets.

Teaching of the whole words began by teaching the pair in the subset responded to with the highest accuracy. Subset pairs always contained both onsets and both rimes (e.g., cat/nate) and were trained to a criterion of at least 90% correct per rime. Upon reaching criterion, another test (Test 2) was given. The trained words from the set served as baseline words for Test 2, where 5 test trials for each of the two untaught words were interspersed throughout the session. If the generalization criterion (80% correct for each untrained word) was not met in Test 2, the two tested words were trained to a criterion of 90% accuracy. If the generalization criterion was met, or if training was completed for the words assessed in Test 2, all four words in the subset were presented together in training (subset practice session).

When accuracy on the four-word subset reached criterion during these practice sessions, a cumulative practice session, containing all previously presented words within the rime set, was conducted (reading training shown in Figure 4 will be described below). Upon meeting criterion in the cumulative practice session, the next four-word subset was tested (Test 1). That is, the test-teach-test cycle (just described and shown in Figure 4) repeated until completion of the final rime set rime (i.e., et/ete). The comprehensive test was delivered again at the completion of every full rime set (e.g., all at/ate words, all an/ane words).

Individual rime set reading tests and training. Before the four words in a rime subset underwent matrix testing and training, a pre-subset reading test of the four words was delivered (see flowchart, Figure 4 for sequence). This task was procedurally similar to the comprehensive reading test. These tests did not occur for Doug.

Following matrix training and testing of a four-word subset, a cumulative, post-subset reading test was delivered. This test included all words from the current rime set that had undergone constructed spelling testing and training (e.g., all at/ate words trained and tested in the constructed spelling task). Thus, the final, cumulative post-subset reading test of a full rime set included all words from that rime set. Incorrect responses on real words in this final test (all sets contained both real and nonwords) resulted in training of these words, plus their same onset pairs (e.g., an error on –pat" resulted in training of –pat" and –pate"). This training occurred following the final, (computerized) cumulative practice session of the rime set (for simplicity, real-word training is not shown on the flow chart).

The reading-training procedures were similar to those described above, with the exception that incorrect responses resulted in a verbal prompt of the correct answer, which participants then repeated (i.e., a delayed-prompt procedure). Unprompted and prompted correct

responses resulted in verbal praise and advancement to the next trial. Training on real words and their same onset pairs continued to a criterion of four out of five consecutive correct responses per word. These trained words were then retested on the following day and any errors resulted in retraining. This testing and training of missed words continued until no errors were made on a retest.

For Doug, only a final, cumulative post-subset reading test was delivered and all incorrect words *and nonwords* were trained to a criterion of two consecutive correct responses per word. Testing and training continued for Doug until a completion criterion of 90% overall on the initial test of a following day was met. The post-subset reading tests for Doug were not only cumulative within a rime set but were also cumulative across rime sets. That is, by the end of the study, Doug was receiving a post-subset reading test that included all words trained and tested throughout the course of the study. These procedures became unwieldy and were thus streamlined for subsequent participants.

RESULTS

The results will be described in two sections: Matrix Training and Testing and Comprehensive Tests. Matrix training refers to the computerized individual rime set training and testing that occurred for six of the seven rime sets (the af/afe set remained untrained). Comprehensive tests were delivered before and after training and testing of each individual rime set.

Matrix Training and Testing

Figure 5 addresses the question of whether or not teaching the construction of some words *within* a rime set result in generalization to other words with the same rimes (question 2). In each of the participants‘ graphs in this figure, there is one bar for each rime set that was tested

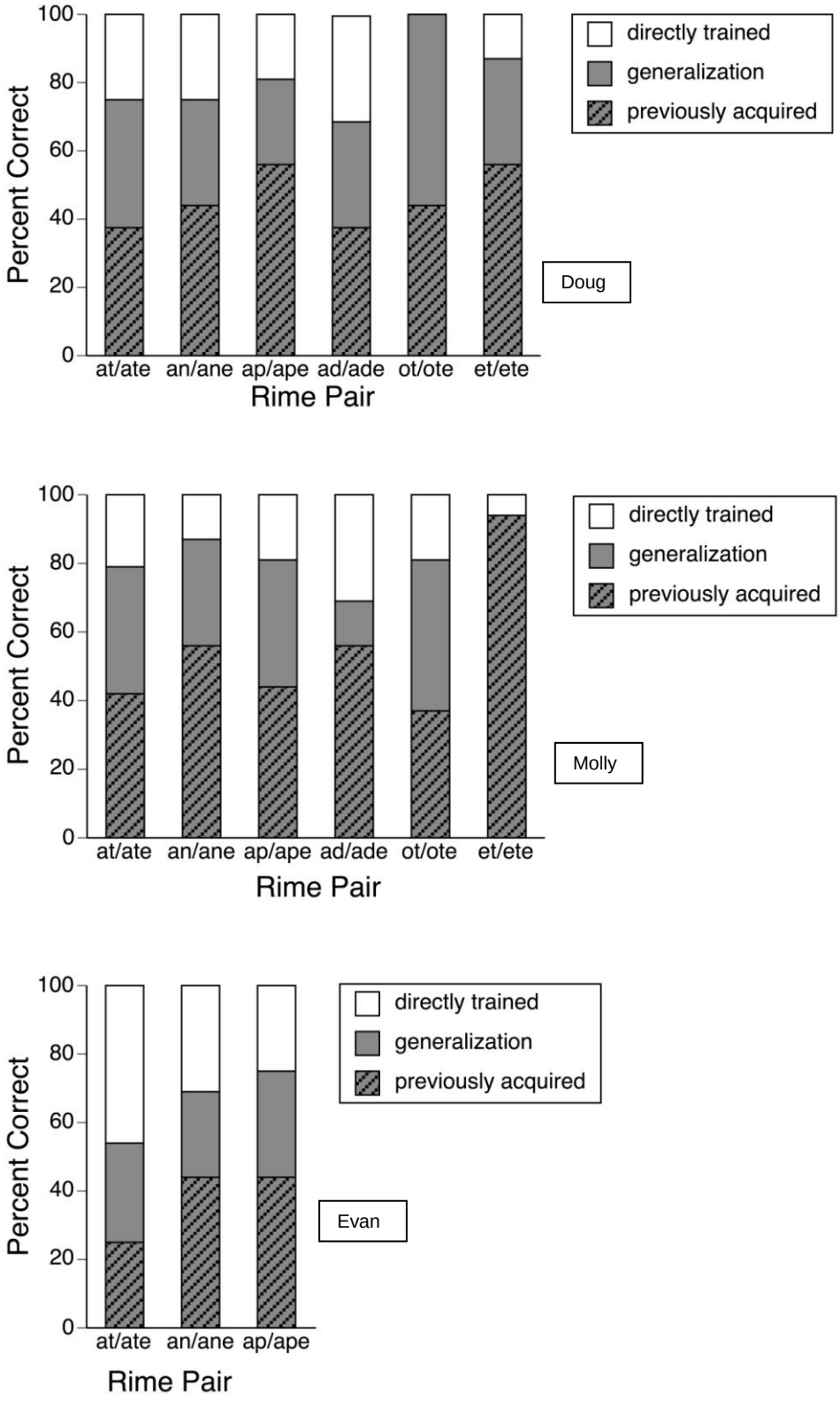

Figure 5. Within rime set matrix training/testing results for Doug (top), Molly (middle), and Evan (bottom).

and trained. At the bottom of each stacked bar (the gray, hatched portion of the bar) are the percentages of previously acquired words.

Previously acquired words were defined as those words that were (a) correct in the comprehensive construction test that immediately preceded the start of the rime set and (b) were constructed correctly at 80% or higher accuracy in Test 1 or 2 (i.e., before being taught). Percentages of previously acquired words for Doug and Molly were similar and ranged from 37-56% across all rime sets (excluding Molly‘s et/ete set, addressed in the Discussion). Evan, who completed three rime sets, had percentages of previously acquired words that ranged from 25-44%.

The top, white sections of the stacked bars reflect the percentage of words that underwent direct training. These words did not meet generalization criterion during matrix training in either Test 1 or Test 2. Percentages of words that required direct training for Doug and Molly (excluding Molly‘s et/ete set) ranged from 0-31%. Percentages for Evan ranged from 25-46%.

The solid gray sections of the stacked bars represent the percentage of untaught, unknown words that met generalization criterion. Generalization criterion was met when untaught words were constructed with at least 80% accuracy in Test 1 or 2 and were not correct in the comprehensive construction test delivered immediately prior. That is, these unknown words were constructed correctly without any direct training. Across all three participants and in all rime sets, generalization occurred (to varying extents) and little direct training was needed. Percentages of untaught, unknown words that met generalization criterion for Doug and Molly ranged from 13-56% (excluding Molly‘s et/ete set). Percentages for Evan ranged from 29-31%.

Comprehensive Construction Tests

The comprehensive construction tests occurred between (i.e., before and after) completion of matrix training for each full rime set. Data from all seven comprehensive construction tests (four for Evan) are displayed in Figure 6, with separate columns for each participant (left: Doug, middle: Molly, and right: Evan) and separate panels in each column for each rime set. Phase change lines indicate the completion of computerized matrix training and testing of the full rime set. Accuracy for the long and short vowel sounds are averaged for each data point (e.g., _at‘ and _ate‘ scores are averaged together). Dark circles indicate accuracy on the rime portion of the word, while grey squares indicate accuracy on the whole word. A dip in whole word accuracy, when rime-only accuracy is higher, indicates incorrect selection of an onset(s).

The multiple-baseline graphs in Figure 6 answer questions 1 and 3: (1) would our teaching procedures establish the correct construction of long- and short-vowel words with the same vowel and final consonant sound, and (3) would teaching rime sets containing long- and short-_a‘ words with one final-consonant sound (e.g., at/ate) result in generalization *across* rime sets containing long- and short-_a‘ words with a different final consonant sound (e.g., would participants construct more an/ane words correctly after learning to construct at/ate words). Question 1 is answered by examining accuracy following the phase-change line (i.e., matrix training). In all 3 participants, accuracy increased following matrix training and remained high over the course of the study. The use of other-vowel containing rimes (i.e., ot/ote and et/ete) served as a measure of extra-experimental influences, as high accuracy on these words would not be expected after training of the long- and short- _a‘ words. That is, if accuracy was high on _a‘-

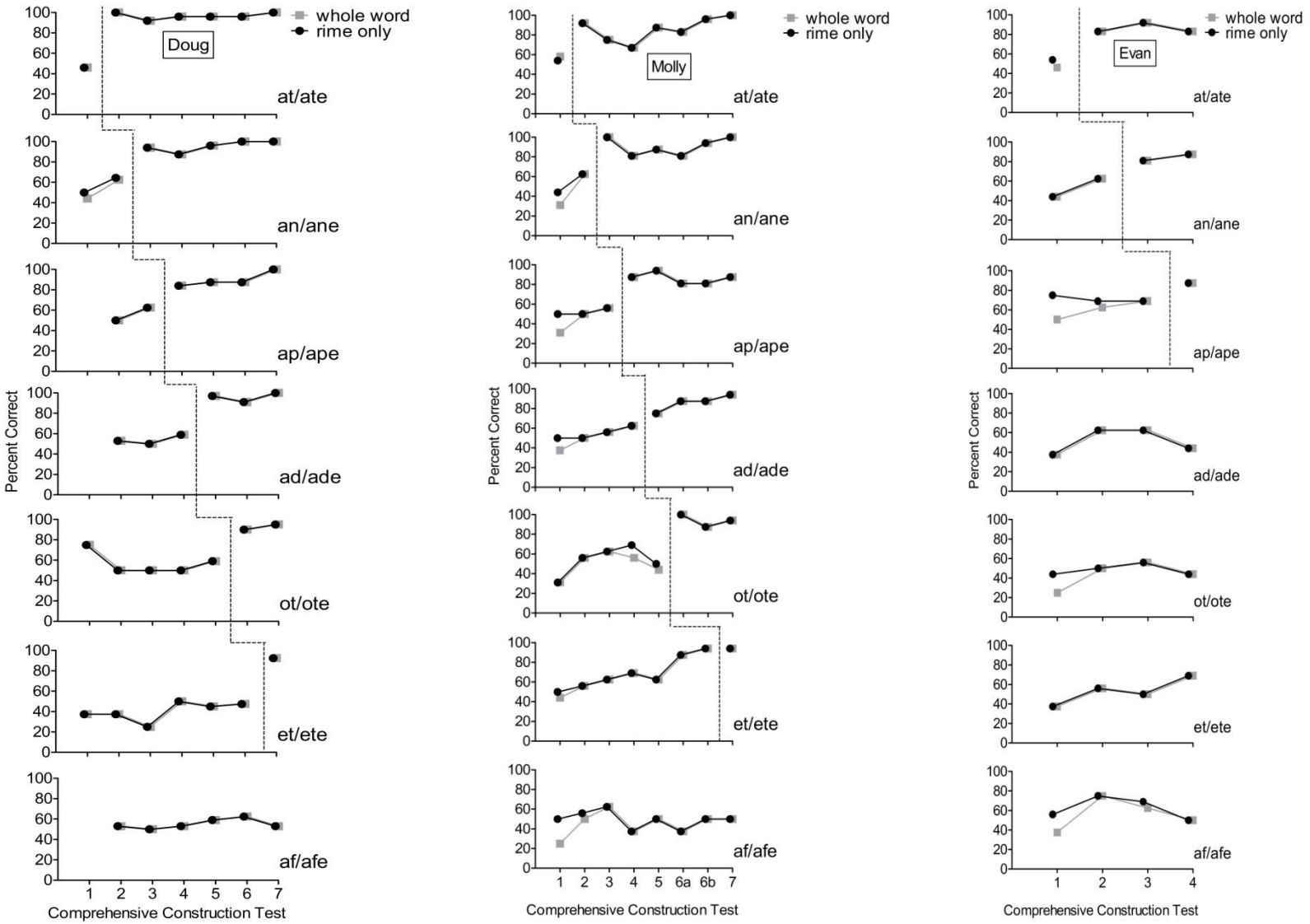

Figure 6. Comprehensive construction test scores, broken into rime sets, for Doug (left), Molly (middle), and Evan (right).

containing rimes after training with these rimes, but accuracy with the other-vowel containing rimes were unaffected then we would conclude that the changes were the result of our procedures. Examination of the ot/ote and et/ete rime sets shows that accuracy remains relatively unaffected throughout training of the _a‘-containing rimes (i.e., accuracy with these rimes did not increase until at least one of them was taught), with accuracy around chance level (i.e., 50%).

Question 3 is addressed by assessing changes in other _a‘-containing rimes following matrix training (e.g., does matrix training of at/ate words affect accuracy in an/ane words?). This across-rime generalization did not occur, as increases were not seen in one _a‘-containing rime set following the training of another (e.g., there were no increases in the an/ane set following training of the at/ate set). Although there are slight increases in accuracy for some _a‘-containing rimes before they were taught, accuracy before training was rarely above 62.5% and was consistently below accuracy following training. Because onsets were correct the majority of the time, and participants learned to select only the rimes with the correct final consonant sound, the variation in accuracy on the construction task was determined by the choice between the long and short vowel, thus chance levels functionally were 50%.

Comprehensive Reading and Written-Spelling Tests

The two secondary questions of the study involved whether or not participants would (1) read words on flashcards and (2) write words on paper after learning to construct them on the computer prior to any training on reading or written spelling. More specifically, would emergent reading and written spelling develop following (computerized) matrix training? Figure 7 shows reading accuracy before and after matrix training. The data points that precede the phase-change line represent accuracy in the comprehensive reading tests. The single data points that follow the

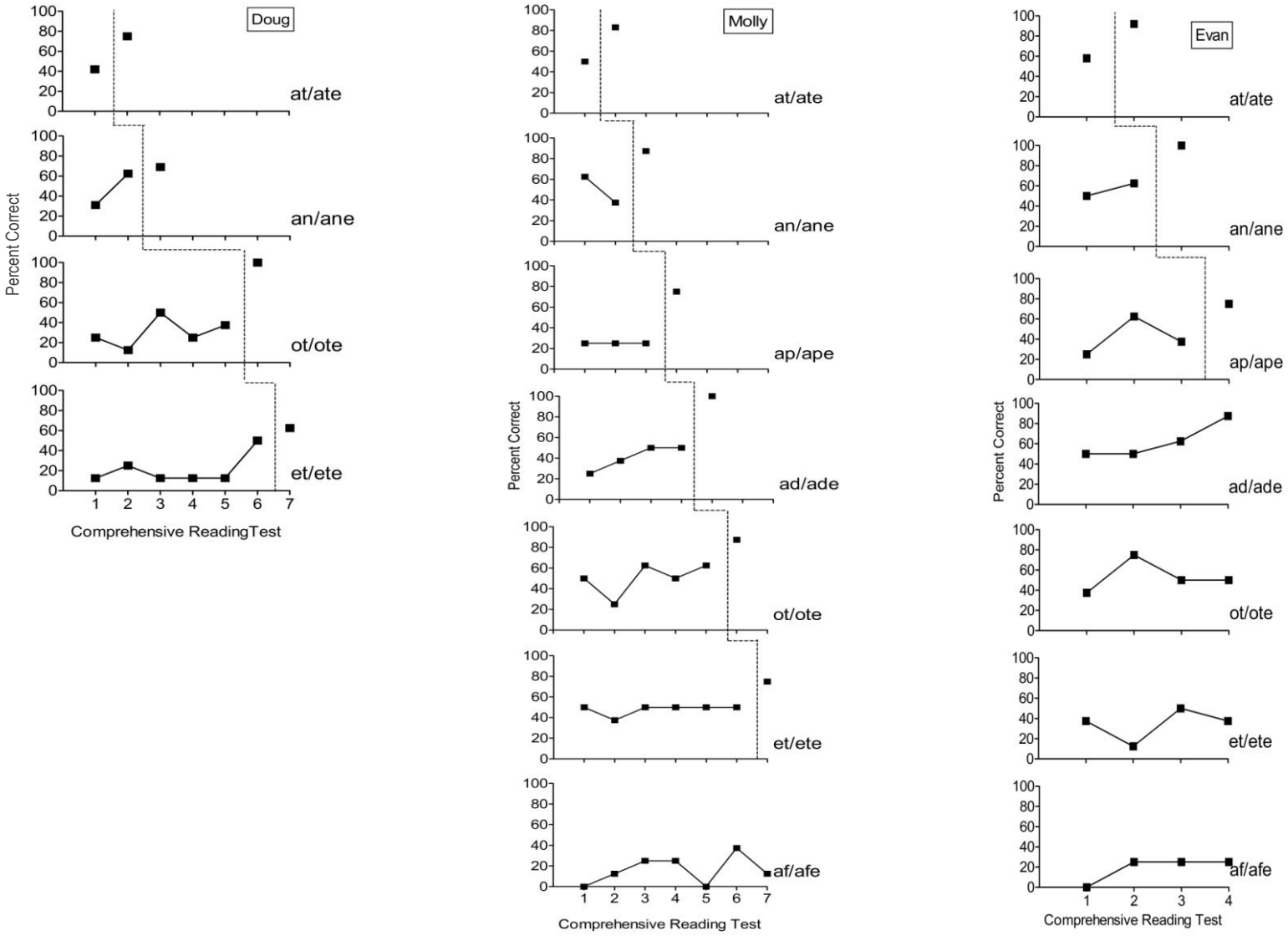

Figure 7. Emergent reading scores, broken into rime sets, for Doug (left), Molly (middle), and Evan (right).

phase-change line reflect accuracy on the same words in the final (cumulative) post-subset reading test that occurred at the end of the rime set (see Figure 4). Only words from the post-subset reading test that were also present in the comprehensive reading test are reflected in data points. Data from the comprehensive tests alone were not used as a measure of emergent reading because any real words missed on the cumulative post-subset reading test were trained before the comprehensive reading test was delivered.

For both Molly and Evan, reading accuracy always increased following construction training. Mean percentages of increase were 34% for Molly (range 12.5-50%) and 27% for Evan (range 10-37.5%). These increases occurred without any direct reading training on that rime set. Emergent reading was only assessed in 4 rime sets for Doug as his comprehensive reading tests did not contain all rime sets present in the study. Some emergent reading was seen in all four of these rime sets; however only two rime sets showed marked improvement (i.e., at/ate and ot/ote).

Figure 8 shows accuracy on written spelling before and after the occurrence of matrix training and testing. The first and last data point for all participants displays accuracy on the full written-spelling test. For Molly and Evan, the intermediate data points are from abbreviated tests including only those words from the just-completed and upcoming rime sets. For example, following completion of matrix training for the at/ate set, only the at/ate (completed) and an/ane (upcoming) from the written-spelling test were administered. Doug was given the full written-spelling test throughout the course of the study.

Emergent written spelling following matrix training and testing was seen in both Molly and Evan. The mean increases in accuracy (from the highest baseline measure to the first emergent writing score) were 46% for Molly (range 25-75%) and 58% for Evan (range 33-75%). These increases were seen in all six of Molly‘s trained sets and all three of Evan‘s trained sets.

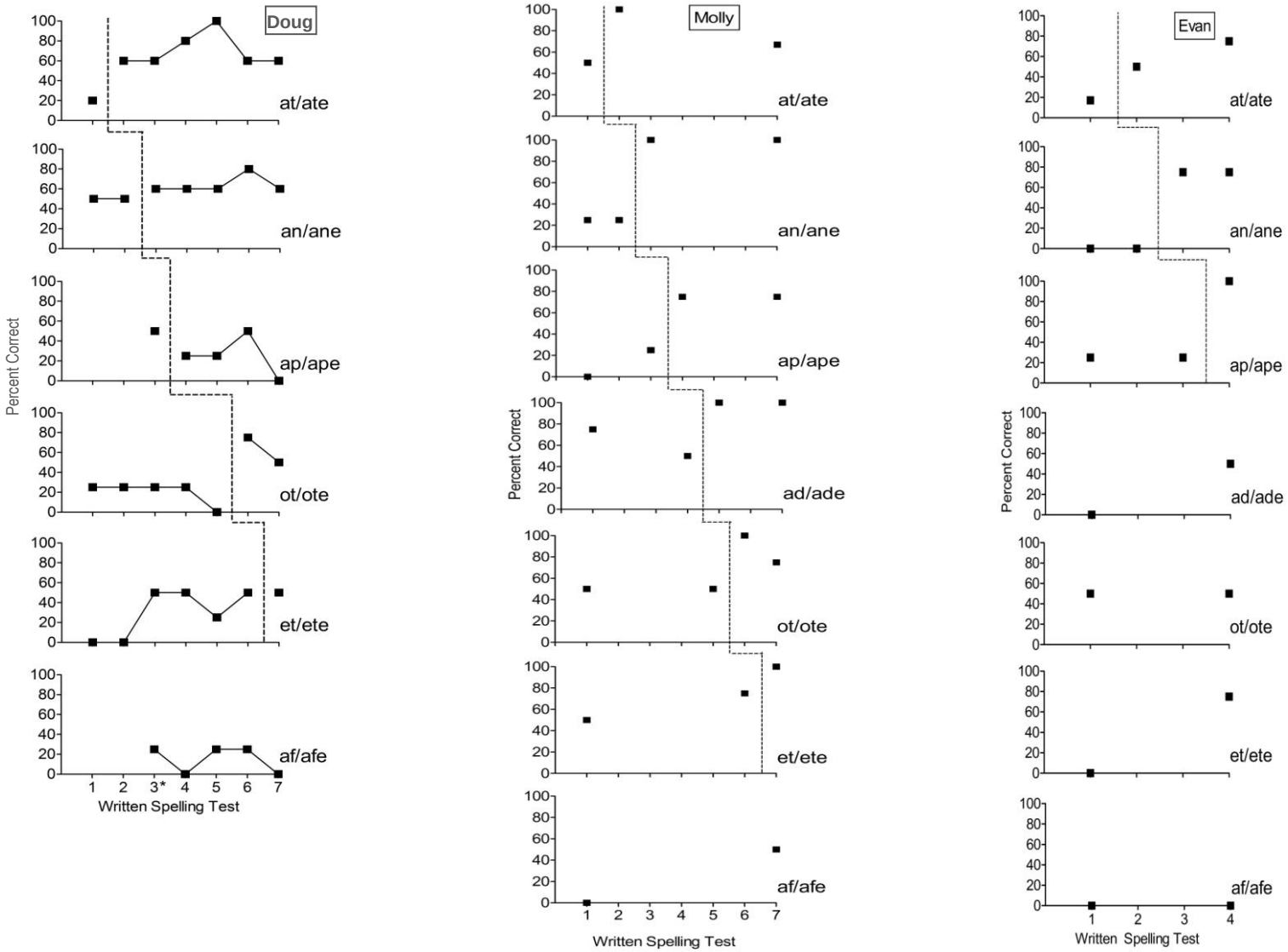

Figure 8. Emergent writing scores, broken into rime sets, for Doug (left), Molly (middle), and Evan (right). The asterisk on Doug's graph indicates where additional spelling words were added.

For Doug, emergent writing was seen in two of six trained sets.

Interobserver Agreement. IOA was calculated on four of the seven comprehensive reading tests (i.e., 57%) for Doug, six of seven (86%) for Molly, and two of four (50%) for Evan. The mean scores were 92% (range 90-95%), 96% (range 92-98%), and 97% (range 95-98%), respectively. For the individual subset reading tests, IOA was assessed for Molly and Evan on every third pre- and post-subset reading test. The mean scores were 99% (range 88-100) and 97% (range 75-100%), respectively. For Doug, IOA was assessed on 84% of the post-subset reading test with a mean IOA score of 97% (range 89-100%).

DISCUSSION

This study sought to extend the literature on recombinative generalization and constructed spelling to include silent-_e‘ words. To our knowledge, this is the first study that addresses this complex word pattern in individuals with ID. Over the course of the study, Doug and Molly learned to construct the 104 words included in the 6 rime sets used in matrix training. Evan learned to construct the 56 words in the 3 rime sets used in Matrix training. Accuracy of these words remained high despite gaps in time where matrix training occurred (i.e., between comprehensive tests). Additionally, during matrix training, all participants demonstrated recombinative generalization to untaught words with the same rimes as taught words. That is, after learning to construct some words within a rime set, participants correctly constructed untrained words in Test 1 or Test 2 (i.e., generalization tests), thus demonstrating phonological awareness. Although generalization was seen within rime sets, it was not seen across rime sets. That is, learning to construct some _a‘-containing rime words (e.g., at/ate) did not result in the correct construction of other _a‘-containing rimes (e.g., an/ane).

There were no systematic improvements in untaught word sets across comprehensive construction tests, suggesting that increases in accuracy following matrix training and testing were the result of that training. The one exception is Molly's et/ete rime set (see Figure 6). One possible explanation is that Molly learned an exclusion-response strategy based on previously demonstrated high accuracy with three of four rimes in the choice pool. More specifically, ot/ote was the rime set that immediately preceded et/ete, and ot/ote served as the foil rimes in the choicepool for et/ete; thus, _ot' and _ote' could be excluded.

Molly also had high, to almost-perfect, accuracy on _et' words in previous comprehensive tests, with errors restricted to _ete' words. By also excluding the rime _et' on _ete' trials, Molly could construct all the words in the et/ete set. This interpretation of exclusion without sample S+ control (i.e., no control by the sample word) is supported by Molly's reading scores. Despite increases in comprehensive construction test accuracy before the et/ete training condition, her reading scores did not improve. That is, Molly didn't learn the relation between spoken _ete' and printed _ete'. In fact, her reading accuracy did not improve until et/ete words were trained on the computer (thus establishing sample S+ control).

What is the generality of these findings? The ultimate goal in research on instructional programming is to predict outcomes at the level of individuals. In pursuit of this goal, we selected participants whose intellectual ability, vocabulary, and existing reading skills were similar. Moreover, the effectiveness of any instructional procedure depends on the match between the existing skills and instruction. It is likely of particular importance that the present participants read sight words at the first-grade level, named letters, and selected onsets with above-chance accuracy in the comprehensive pretest (the latter applied to 2 of 3 participants).

Although it is an empirical question, our working assumption is that these findings would apply to other individuals with similar skills.

Pre-existing skills also (likely) played a role in emergent reading and written spelling. Our participants already read some words, as demonstrated by their Woodcock Word ID and comprehensive reading pretest scores. All participants were also able to print their first and last names. Without these pre-existing skills, it is unlikely that reading and written spelling would have emerged. It may also be important to note that while Doug only demonstrated emergent writing in two of the six trained sets, his writing did improve in ways not reflected in his accuracy scores. Originally, his written spelling contained unnecessary and/or incorrect letters, and he rarely attempt to spell unknown words. Following matrix training, his errors mainly involved reversing letters (e.g., spelling sote as soet).

The generalization within rime sets shown in this study demonstrates phonological awareness, as participants had to correctly discriminate the sounds in the untrained words in order to construct them correctly (i.e., abstract the component sounds). Future studies may examine the use of similar procedures as an alternative to measures of phonological awareness that require following complex verbal instructions. Such procedures may be better suited for individuals with ID. Additionally, the use of a computer with recorded sounds eliminates accidental vocal cuing by the experimenter during delivery (i.e., emphasizing the correct answer). The use of the receptively based computerized construction task may also prove useful in facilitating reading acquisition in young children and individuals with low speech intelligibility, as there is no requirement to sound out words.

As is consistent with recent literature, linking letters with sounds helped to promote phonological awareness and benefited both reading and spelling (see review in NRP, 2000).

Although there is empirical support for linking spelling and reading, the procedures have not yet been widely adopted or explored. In computer-based instruction, the use of letters may be practical for wider audiences (e.g., children and individuals with poor fine-motor skills) as there is no requirement to write letters or words on paper. Instead, a mouse or touchscreen may be used to select letters.

Our long-term goal is to create computerized instructional programming that produces fluent readers. Linking spelling and reading, providing multiple exemplars, using matrix training as a means to promote recombinative generalization, breaking complex words into consistent units (e.g., onsets and rimes), and minimizing errors by customizing programs to the pre-existing skills of the learner are important steps towards this goal. The use of the computer allows for procedural integrity and immediate feedback during learning. Additionally, the use of computerized instruction may free teacher time to focus on more complex skills, such as comprehension.

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List of Appendices

Appendix A

Rimes present in sample words and foil-rime pair comparisons present in the choicepool in comprehensive pretests, training, and testing sessions.

Sample	Foil Comparisons			
	Comp. tests			Matrix training & testing
rime	1 - 2	3-6	7-9	
at/ate	ete/ete	ete/ete	n/a	et/ete
an/ane	at/ate	ap/ape	n/a	ap/ape
ap/ape	n/a	an/ane	n/a	an/ane
ad/ade	n/a	af/afe	n/a	af/afe
ot/ote	at/ate	n/a	et/ete	et/ete
et/ete	at/ate	n/a	ot/ote	ot/ote
af/afe	n/a	ad/ade	n/a	n/a

Sample	Foil Comparisons	
Rime	Comp. tests	Matrix training & testing
at/ate	it/ite	it/ite
an/ane	ap/ape	ap/ape
ap/ape	an/ane	an/ane
ad/ade	af/afe	af/afe
ot/ote	et/ete	et/ete
et/ete	ot/ote	ot/ote
af/afe	ad/ade	n/a

Note: Rimes present in sample words and foil rimes present in the choicepool in comprehensive pretests, training, and testing sessions for Doug (left) and Molly and Evan (right). For comprehensive tests, onsets consisted of the correct comparison and three pseudo-random consonants. In matrix testing (and cumulative practice sessions), onsets consisted of the two consonants present in the exemplar words and two pseudo-random consonants. In matrix training, onsets consisted of the two consonants present in the exemplar words and the two onsets in the upcoming rime set. Consonants that were visually or auditorily similar to the correct comparison were not used as comparisons (e.g., /m/ and /n/, _p‘ and‘q‘).

Appendix B

Word Pairs in the Remaining Matrices

	an	ane
m	man*	mane*^
p	pan*	pane*
l	lan	lane^
g	gan	gane
j	jan*	jane*
t	tan^	tane
f	fan*^	fane*
s	san	sane

	ap	ape
g	gap^	gape
t	tap*	tape*^
c	cap*	cape*^
b	bap	bape
p	pap	pape
f	fap	fape
l	lap*^	lape*
j	jap	jape

	ad	ade
f	fad*	fade*^
s	sad*^	sade*
m	mad*	made*^
t	tad	tade
g	gad	gade
h	had*^	hade*
n	nad	nade
l	lad	lade

	ot	ote
d	dot^	dote
h	hot*	hote*
p	pot*^	pote*
n	not*	note*^
m	mot	mote
t	tot	tote^
s	sot	sote
r	rot*	rote*

	et	ete
t	tet	tete
j	jet*^	jete*
g	get	gete
d	det	dete
l	let*	lete*
r	ret	rete^
v	vet*^	vete*
p	pet*	pete*^

	af	afe
d	daf*	dafe*^
g	gaf	gafe
j	jaf^	jafe
m	maf	mafe
n	naf*	nafe*
r	raf*^	rafe*
s	saf*	safe*^
t	taf	tafe

Note: Words with asterisks (*) are those words that appear in the comprehensive reading test for Molly and Evan. For Doug, the comprehensive reading test consisted of all 24 words from the at/ate set, 10 words from an/ane, 8 from ot/ote, and 8 from et/ete (not marked in the tables). Words with carets (^) are those words that appear in the written-spelling test for Molly and Evan. For Doug, the written-spelling test consisted of five words from at/ate, five from an/ane, and four each from ap/ape, ot/ote, and et/ete (not marked in tables).