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RECOMBINATIVE GENERALIZATION OF WITHIN-SYLLABLE UNITS IN PREREADING CHILDREN

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This study demonstrates recombinative generalization of within-syllable units in prereading children. Three kindergarten children learned to select printed consonant-vowel-consonant words upon hearing the corresponding spoken words. The words were taught in sets; there were six sets, presented consecutively. Within sets, the four words that were taught had overlapping letters, for example, *sat*, *mat*, *sop*, and *sug*. Tests for recombinative generalization determined whether the children selected novel words with the same components as the trained words (e.g., *mop* and *mug*). Two children demonstrated recombinative generalization after one training set, and the 3rd demonstrated it after two training sets. In contrast, 2 other children, who received tests but no training, showed low accuracy across six sets. The 3 experimental children then demonstrated highly accurate printed-word-to-picture matching, and named the majority of the printed words. These findings are a promising step in the development of a computerized instructional technology for reading.

DESCRIPTORS: recombinative generalization, reading, arbitrary matching to sample, children

Estimates of the proportion of the U.S. population with reading difficulties range from 20% to 40% (Good, Simmons, & Smith, 1998; Stedman & Kaestle, 1987). Kameenui (1996) estimated that one in six children in Grades 1 through 3 have reading difficulties. Reading is a complex skill with numerous interrelated and interacting elements. As Adams (1990) noted, however, "unless the processes involved in individual word recognition operate properly, nothing else in the system can either" (p. 3). When these foundational word naming[1] processes are operating properly, words that are composed of new combinations of previously learned letters and sounds are named the first time they are seen.

The demonstration of novel recombinations of previously established linguistic units has been termed *recombinative generalization* (H. Goldstein, 1993). The recombinative generalization literature has shown that persons taught to respond to several different complex stimuli that contain overlapping units come to respond appropriately to different combinations of the same units (H.

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[1] We will use the phrase *word naming* to refer to seeing a printed word and saying the word. In so doing, we avoid using the comprehensive term *reading* for this single component of reading.

Goldstein, 1993; H. Goldstein & Mousetis, 1989; J. Goldstein, 1984; Romski & Ruder, 1984; Striefel, Wetherby, & Karlan, 1976, 1978). In the aforementioned studies, the recombined units are discrete, whole words. For example, a child might be taught to name several objects: a red square, a red cross, and a green square. Then, without additional training, the child may name a green cross. This procedure has been called *matrix training* because, taken together, the trained and tested word combinations form a matrix (H. Goldstein & Mousetis, 1989). This matrix training approach ensures exposure to all of the units involved in recombinative generalization.

Novel word naming requires the recombination of units that are smaller than individual words. Historically, teachers and researchers have recognized two levels of within-word units: syllables and phonemes. English-speaking children recognize that words can be broken into syllables before they recognize that syllables can be broken into phonemes (e.g., Treiman & Zukowski, 1996). For example, in studies by Byrne and Fielding-Barnsley (e.g., 1989) the majority of English-speaking kindergartners showed some ability to recombine syllables. de Rose, de Souza, and Hanna (1996) showed that some Brazilian children who were beginning readers were able to read novel two-syllable Portuguese words given that previously learned words contained the component syllables. The structure of the Portuguese language makes syllable recombination largely sufficient for novel word decoding.

In learning to read novel English words, the skill of recombining within-syllable units is critical. In English-speaking children this skill typically develops later than the skill of recombining syllables (e.g., Treiman, 1992). The literature nonetheless contains some evidence that beginning readers can recombine within-syllable units. Goswami (1986, 1990) showed that teaching a "cue word" enabled some children to read a novel word "by analogy" to the cue word. For example, after learning to read the cue word *beak*, children read the test word *peak* because *beak* and *peak* have the component *eak* in common. The reading gains shown in these studies were very small, however, particularly in prereading kindergarten children. It is important to note, however, that these studies did not expose participants to all of the subsyllable components of the test words. For example, in the example just mentioned, the study did not present a cue word for the initial consonant sound of *peak*.

Our first major goal was to determine whether a matrix training strategy could be used to demonstrate recombinative generalization of within-syllable units. To ask this question, we used matching-to-sample (MTS) procedures in which participants were required to select, from among four printed words, the word that corresponded to a spoken-word sample. First, participants were taught to select words that contained all of the components of generalization-test words. Next, tests determined whether participants correctly selected the generalization words. For example, subjects were taught to select *mat*, *sat*, *sop*, and *sug*. Tests then determined whether subjects selected the generalization words *mop* and *mug*.

Our subsyllable units were onsets and rimes. The term *onset* refers to the initial consonant sounds in a syllable, and the term *rime* refers to the vowel and subsequent consonants. For example, in the word *sat*, *s* is the onset and *at* is the rime. We chose onset and rime units because of recent studies showing that children perceive onset and rime units within syllables earlier than they perceive individual phonemes within syllables (e.g., Goswami & Bryant, 1992; Treiman, 1992; Treiman & Zukowski, 1996; Wise, Olson, & Treiman, 1990).

A second goal was to determine whether, after showing high accuracy with the MTS procedures, additional reading skills would emerge. Studies in the area of stimulus equivalence relations suggest that, once an individual can select both a picture and a printed word upon hearing the corresponding spoken word, he or she will also select the picture upon seeing the printed word—a rudimentary form of comprehension (Joyce & Wolking, 1989; Sidman, 1971; Sidman & Cresson, 1973; Sidman, Cresson, & Willson-Morris, 1974). The present study presented such comprehension tests. In addition to testing rudimentary comprehension, we also asked whether our children would name the printed words. The 4 participants in Sidman's studies, who were adults with mental retardation, named 55% to 90% of 20 one-syllable words after learning relations between spoken words and printed words and relations between printed words and pictures.

In summary, the present study asked whether nonreading kindergarten children demonstrate recombinative generalization of within-syllable units by correctly selecting novel consonant-vowel-consonant (CVC) words after they have learned to select different words that have the same components. In addition, the study determined whether the word selection task promotes printed-word naming and comprehension.

GENERAL METHOD

Participants

Five typically developing kindergartners attending a public elementary school in southern Mississippi participated. All but one (Bea) were boys. All participants were identified by their teacher as being in the "low reading group."All scored in the average range on the Kaufman Brief Intelligence Test (Kaufman & Kaufman, 1990). On the Woodcock–Johnson Tests of Achievement—Revised (Woodcock & Johnson, 1989/1990), reading levels ranged from K.5 to K.7. On the letter-word identification subtest, each participant named eight of the nine letters sampled. Three of the participants (Lance, Jay, and Carl) named one printed word (*dog*) but did not name other two- and three-letter words presented. The other 2 participants, Mac and Bea, named no real words. None of the participants named any of the three-, four-, and five-letter nonsense words presented in the Word Attack Subtest (e.g., *dee*, *ap*, *bim*, *nan*).

Apparatus

Sessions were conducted in a small room in the children's school. Participants sat in front of a Macintosh computer with a touch-sensitive monitor (Troll Touch®). The experimenter sat behind and to the right of the participant. Session events were controlled by software written by Dube (1991). Visual stimuli could be presented in five touch-sensitive zones, one located in the center of the screen and one in each of the four corners. Printed stimuli were 1.5 cm lowercase black letters. Spoken-word stimuli (recorded male voice) were presented by the computer's internal speaker.

General Procedure

Matching-to-sample sessions. Almost every session in the study involved MTS procedures (the exception was word-naming sessions). Almost all MTS sessions had 60 trials; exceptions will be noted. In each trial, participants were required to select, from among two or more choice stimuli, the stimulus that corresponded to a sample stimulus. In some sessions the sample stimulus was a printed word, and in some sessions the sample was a spoken word. When the sample stimulus was printed, trials began with the presentation of the sample stimulus in the center of the screen. Touching the sample produced two to four choice stimuli in the corners of the screen (the sample remained on the screen). When the sample stimulus was a spoken word, trials began when a black square appeared in the center of the screen, and the spoken word was presented. Touching the square was followed by the removal of the square and the presentation of the choice stimuli. The spoken word was repeated every 2 s until the participant touched one of the choice stimuli.

Following a correct selection, the computer presented a 1-s display of flashing black-and-white stars accompanied by a series of computer-generated chimes. In addition, the experimenter placed a ticket into a cup located to the participant's right. The children traded their tickets for three pieces of candy at the end of each day's sessions. Following an incorrect response, the screen turned black for 3 s and a 0.5-s computer-generated buzz sounded. Either form of feedback was followed by a 3-s intertrial interval, during which the screen was blank. Touching the blank screen reinstated the 3-s interval. Unless noted otherwise, at least two different sample stimuli were presented equally often in a session quasirandomly, with the restriction that each stimulus did not appear as a sample on more than three consecutive trials. The correct choice did not appear in the same position on more than three consecutive trials.

In sessions designated as "no feedback," responses produced only the intertrial interval (i.e., there was no feedback for correct or incorrect responses). Before the start of the session, the child was told, "This time you will not get tickets during the session. The computer will count how many you got right, and you will get your candy after the session for the ones you got right." The children were given the three pieces of candy after the day's sessions regardless of performance.

MTS test sessions all had the following characteristics. They began with 20 trials of previously mastered relations. As has become customary in the literature on emergent stimulus control, we will call these baseline relations. Given at least 90% accuracy in these 20 trials, the program branched automatically so that the next 40 trials included a mixture of baseline and test trials. The number of test trials will be mentioned when describing specific conditions. If there was less than 90% accuracy in the first 20 (baseline) trials, the rest of the session consisted only of previously mastered trials. All trials in test sessions had no feedback.

Word-naming test sessions. In word-naming test sessions, which also had no feedback, a single printed word was presented in the center of the screen on each trial. The experimenter transcribed the participant's first utterance, then cleared the screen and presented the next trial. The session was audiotaped for later verification.

Overview of Phases

Figure 1 shows the specific procedures and order of conditions for the experimental and control groups. Procedures that were omitted for the control participants are shown in gray. For expository purposes, the study is divided into four phases. We will present additional method along with the results for each phase. The phases were Phase 1: pretraining; Phase 2: comprehensive pretests of word naming and spoken-to-printed-word MTS; Phase 3: individual word sets: pretests, training, and posttests; and Phase 4: cumulative word-naming and comprehension tests.

The dependent measures of primary interest were the participants' accuracies on three tasks. The first two, spoken-to-printed-word MTS with all of the generalization words to be used in the study and printed-word naming for both directly trained and generalization words, were pretested in Phase 2. In addition, performance on these tasks was tested at the beginning and end of each individual word set during Phase 3 (involving only the words in the current set). Cu-

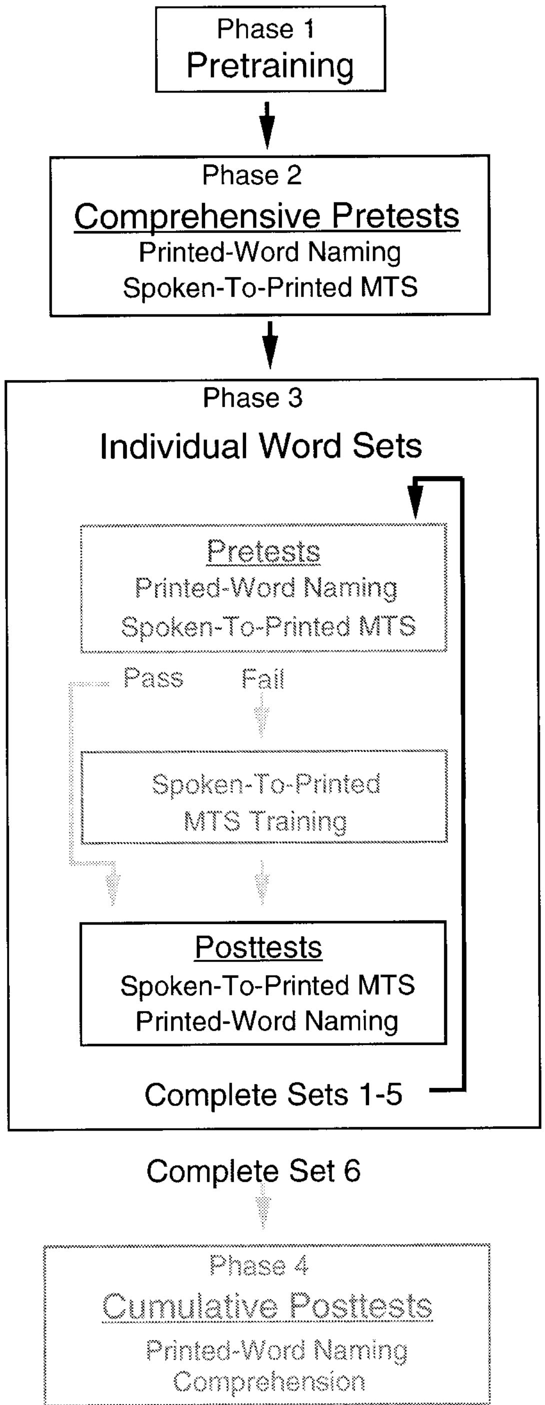

Figure 1. Flow chart showing conditions for the experimental and control participants. The conditions that were omitted for the control participants are shown in gray.

mulative word-naming tests were given at the end of the study (Phase 4). The third task, printed-word-to-photo MTS (i.e., comprehension), involving all trained and generalization words that could be pictured, was not presented until Phase 4.

Three participants, Lance, Jay, and Bea, received all training and testing components of all phases. These procedures allowed within-participant comparisons of pre- and posttest measures. Because these procedures did not rule out extraexperimental experience as a cause of high accuracy, 2 control participants (Mac and Carl) experienced Phases 1 and 2 and the individual word-set posttests for Phase 3. That is, they received pretraining and all tests given in Phases 2 and 3, but they did not receive training with the individual word sets (i.e., in Phase 3).

Phase 1: Pretraining

Method

After presenting several sessions designed to familiarize the children with the laboratory routine and MTS session operation (see the Appendix), we presented four pretraining sessions. These were designed to ensure that failure on pretests could not be attributed to a lack of familiarity with the specific stimuli and discrimination requirements involved.

Spoken-to-printed-word MTS with different onsets. Our experimental task would involve discrimination based on *both* onset and rime along with recombination of these two components. For this initial study, we wanted to select participants who would not have great difficulty learning the spoken-to-printed-word relations to be taught in the study (i.e., who showed at least minimal evidence of stimulus control by an auditory sample over an onset letter). We thus presented a spoken-to-printed-word MTS task that forced a discrimination based solely on the first letter of spoken and printed words. This was a two-

Table 1
Word Sets

Set	Training				Testing: Generalization		Testing: Distracters	
1	mat	sat	sop	sug	mop	mug	sop	sug
2	mug	sug	sot	sap	mot	map	sot	sap
3	map	sap	sum	set	mum	met	sum	set
4	pat	mat	mop	mug	pop	pug	mop	mug
5	pug	mug	mot	map	pot	pap	mot	map
6	pap	map	mum	met	pum	pet	mum	met

Note. Words used in final comprehension test are underlined. Test trials had four choices, but words in the distracter column never appeared as samples.

choice task; one of the following 12 pairs of printed words was presented as the choice array on each trial: *sad-mad*, *set-met*, *sail-mail*, *sob-mob*, *seal-meal*, *sat-mat*, *six-mix*, *sap-map*, *sow-mow*, *sud-mud*, *sop-mop*, *sin-min*. Within each word pair, each word served as the spoken sample (and thus as the correct printed-word choice) on approximately half of the trials. If accuracy did not reach 90% within five sessions, the child's participation was discontinued.

Auditory discrimination. This two-choice task ensured that participants could discriminate spoken CVC words that differed by either onset or rime, as would be required in the study. The 20 spoken words were presented in quasirandom order as samples, and the choices were two photos. The correct choice was the photo that corresponded to the spoken word, and the incorrect choice was always the photo corresponding to the other member of the word pair. Five word pairs differed in onset only (*hot-pot, rat-pat, sat-mat, set-met,* and *sop-mop*), and five word pairs differed in rime only (*hop-hug, pop-pug, rot-rum, sap-sum,* and *map-mum*).

Printed-word identity matching. This task ensured discrimination of printed CVC words based on both onset and rime. It was also the first to present four choice stimuli. This was an identity MTS task with printed-word samples and printed-word choices; the participant was required to select the printed word that was identical to the sample. Each word from the generalization words and distracters columns in Table 1 was presented at least once as a sample. The choice stimuli on each trial were printed generalization and distracter words from the same word set as the sample. For example, if *mop* were the sample, then *mop*, *mug*, *sop*, and *sug* were choice stimuli.

Printed-word identity matching without feedback. These sessions were identical to the previous printed-word MTS sessions. They were presented to prepare the children for tests (without feedback) to be presented in Phase 2.

Results

With two exceptions, all 5 participants met the 90% accuracy criterion on each pretraining task in one or two sessions. Jay required four sessions of spoken-to-printed-word matching, and Lance required three sessions to meet criterion on printed-word identity matching without feedback. Taken together, these tasks ensured that subsequent pretests were not compromised by (a) the novelty of the apparatus and procedures, (b) a failure to discriminate the spoken- or printed-word stimuli involved, or (c) a lack of experience responding in the absence of feedback. In addition, the spoken-to-printed-word sessions ensured that the participants had some experience with sound–symbol correspondence.

Phase 2: Comprehensive Pretests of Word Naming and Spoken-to-Printed-Word MTS

Method

From this point onward, a total of 21 words were used. As shown in Table 1, the 21 words were arranged into six different word sets. There were six words in each word set. A word set contained all possible combinations of two onsets and three rimes. Within each set, four words were designated as training words, and two words were generalization words. Generalization words were recombinations of the onsets and rimes included in the training words. Note that words serving as generalization words could serve as training words in subsequent sets.

Two pretests were given. First, we presented a word-naming test session. The test included all 21 printed words, presented once each. Second, we presented at least two MTS pretest sessions with spoken-word samples and printed-word choice stimuli. These determined whether the participants already selected the printed generalization words upon hearing them spoken. In each test session, each of the 12 generalization words was presented as a sample once. There were four choice stimuli on each trial. These included the other generalization word for the set, and the two distracter words. For example, when *mop* was the sample, *mop*, *mug*, *sop*, and *sug* were presented as choices. In these MTS tests, it was not possible to select the correct printed word based exclusively on either onset or rime. To ensure that participants experienced some success in the session, test trials were intermixed with baseline trials that had spoken-word samples and four photo choice stimuli.

Results and Discussion

The first panel of Figure 2 shows, for experimental and control participants, accuracy on the comprehensive pretests of spoken-to-printed-word MTS for the generalization words. Overall test-trial accuracy ranged between 21% and 63%. Mean accuracy on baseline (spoken-word-to-picture) trials ranged from 90% to 100%. Different response patterns were shown across participants. For Lance and Carl, errors almost always involved selecting the printed word with the same onset as the spoken sample. That is, they rejected the two printed words with an onset that differed from the sample. Thus they exhibited discrimination based on onset but not on rime. Bea usually excluded the one choice stimulus that had no letters in common with the spoken sample, distributing her incorrect choices across words that had at least one component in common with the sample (i.e., sometimes the same rime and sometimes the same onset). For Jay and Mac, responses showed no consistent relationship to the sample stimulus.

For the comprehensive reading pretest, Figure 3 shows that none of the experimental participants read any of the study words; this was also true of the control participants.

In summary, none of the participants showed high accuracy on the MTS task with the 12 generalization words. Moreover, none of the participants correctly named any of the 21 printed words used in the study. Thus, these children's very limited word-recognition skills have been documented in three ways: by these pretests, by their teacher's evaluation, and by standardized testing.

Phase 3: Individual Word Sets: Pretests, Training, and Posttests

Method

Word sets were presented in the order shown in Table 1. Training and testing followed the same sequence of steps for each word set, as shown in Figure 1. Pretests and word-selection training were omitted for the 2 control participants, who received only the

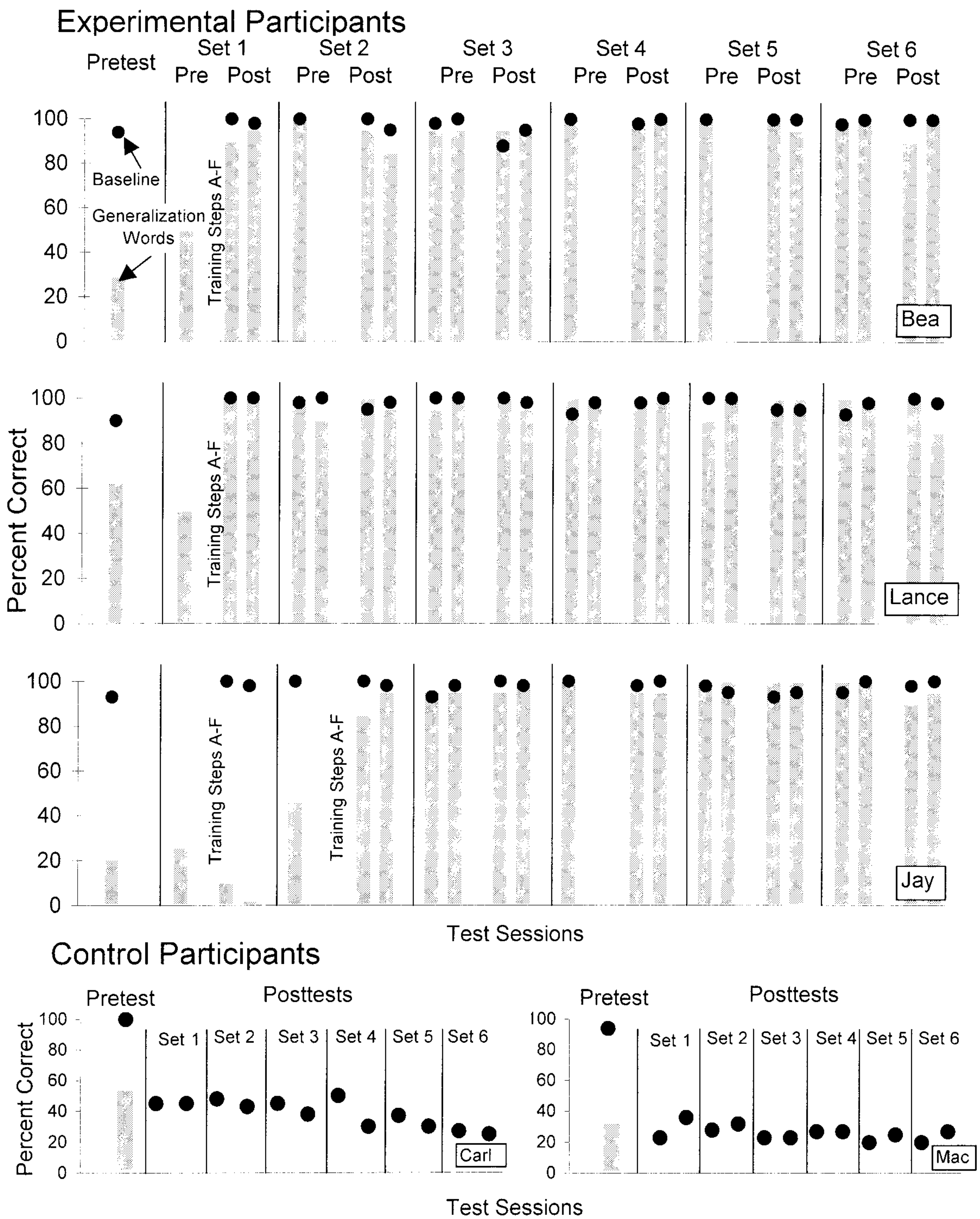

Figure 2. Accuracy from the MTS test sessions for all participants. Generalization test word data are shown as gray bars. The dots represent baseline accuracy. Samples were spoken words, and choices were the corresponding printed words in all test sessions with one exception. In the comprehensive pretest, samples were spoken words, and the choices were pictures. Each bar represents data from the 20 test trials that were intermixed into one session. For the comprehensive pretest, however, test sessions had 10 test trials. Thus the bars represent the average from two sessions.

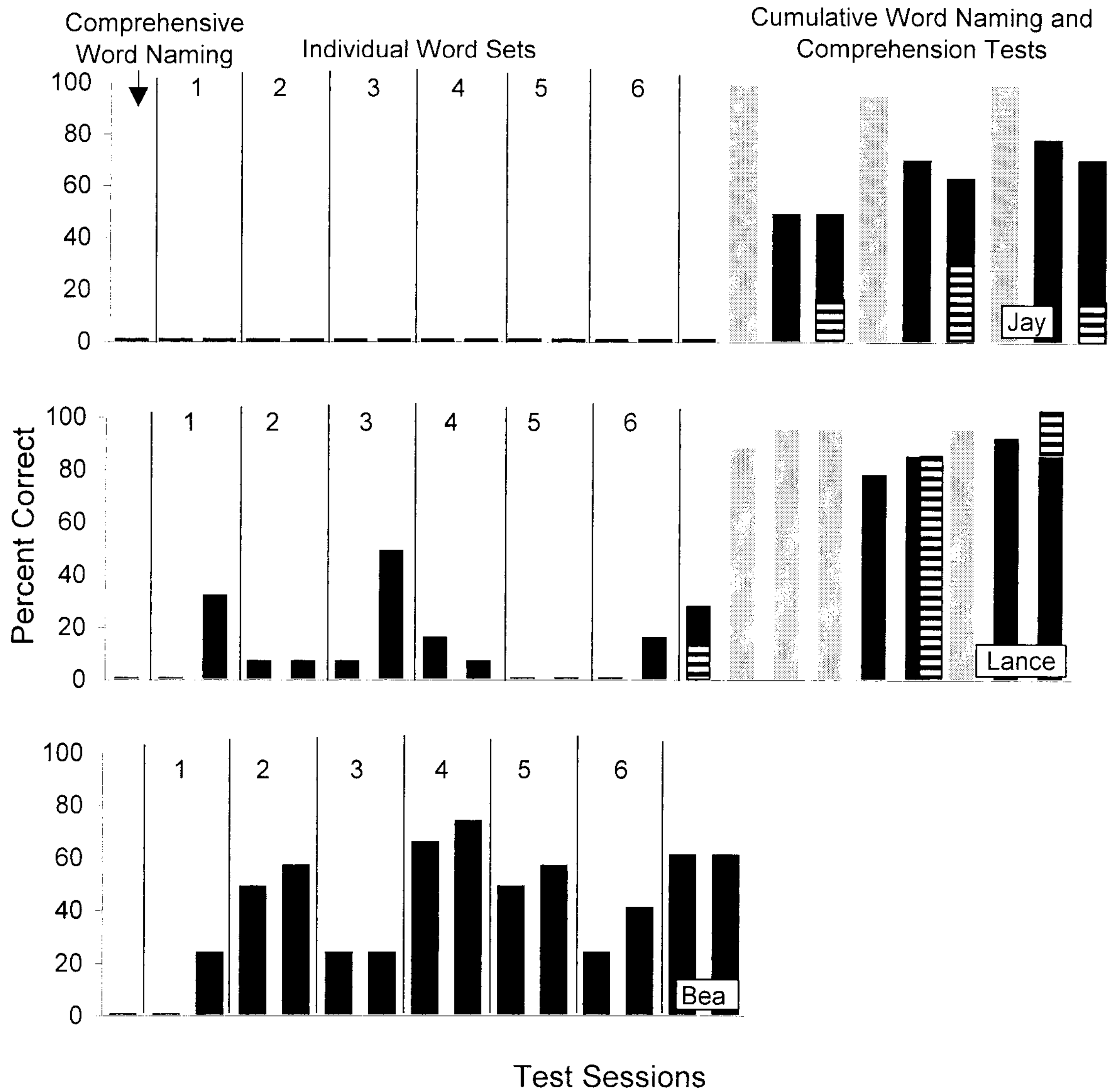

Figure 3. Word-naming and comprehension test accuracy for the experimental participants. Gray bars show comprehension posttest accuracy. For the comprehensive word-naming test sessions, black bars show accuracy on the 14 words used in the comprehension test sessions, and striped bars show accuracy on the other seven words (the additional seven words were presented in half of the test sessions).

posttests for each word set. For the control participants, the amount of time between posttests (i.e., from one set to the next) approximated the time that elapsed between posttests for the 3 experimental participants.

Pretests. The 12-trial word-naming tests presented each of the six words in the set twice, without feedback. This pretest was omitted for Set 1; Set 1 data were taken from the comprehensive word-naming pretest.

The generalization-word MTS pretests were without feedback. Baseline trials used the training words from the immediately preceding word set. There were 20 generalization test trials; each of the two spoken generalization words from the current word set appeared 10 times as a sample. The four choices on each trial were the generalization words and the distracters from the current word set. Given accuracy of 100% for one session or at least 90% for two consecutive sessions, participants moved directly to the posttest phase for that word set (to be described below). Otherwise, they were moved into the spoken-to-printed-word MTS training phase. Posttests were presented despite high pretest accuracy because, although the generalization words were the same in the pre- and posttests, pretest sessions used training words from the previous set as baseline. We wanted to ensure high accuracy with all of the training words in the current set before moving on.

Spoken-to-printed-word MTS training. These sessions involved the four printed words that were designated as training words for the current set. Participants were taught to select each printed word upon hearing the corresponding spoken-word sample. At the beginning of training, there were two samples and two choice stimuli. The number of different sample (and choice) stimuli increased to four across five teaching steps.

Step A included the two training words that had different onsets but the same rime. For example, Step A for Word Set 1 included *mat* and *sat*. After four consecutive correct trials, the program automatically presented Step B.

All Step B trials had the same sample: the third training word in the set (e.g., *sop* for Word Set 1). The first three words in the set were choice stimuli on each trial (e.g., *mat*, *sat*, and *sop*). After four consecutive correct trials, the program automatically presented Step C. In Step C, the first three words were presented quasirandomly as spoken samples and, as in Step B, all three words were used as choice stimuli. For example, *mat*, *sat*, and *sop* each functioned as spoken-word samples and printed-word choices. Given 9 of 10 correct trials, the program automatically presented Step D.

Step D trials all had the same sample: the fourth training word in the set. All four training words were choices. After four consecutive correct trials, the program automatically presented Step E. In Step E, all four spoken words were presented quasirandomly as samples, and all four printed words were choice stimuli. The criterion for moving to Step F was one full Step E session with at least 90% accuracy for each word.

Step F sessions were the same as Step E, except that feedback was withheld. This was done to prepare participants for test sessions, which had no feedback. The criterion for moving to the posttests was two consecutive sessions with at least 90% accuracy.

Posttests. The generalization-word MTS posttest differed from the pretests in that the baseline words were the training words from the current set. There were 20 test trials, 10 with each sample. Given low accuracy across two test sessions, testing was discontinued.

The reading posttests were identical to the reading pretests. They were always presented at least a day after the MTS posttests.

Results

The top three panels of Figure 2 show, for the experimental participants, accuracy on the baseline and generalization-word trials in the MTS pre- and posttests for each individual word set. Pretest accuracy for Set 1 generalization words (extracted from the comprehensive pretests) ranged from 20% to 50%. The number of 60-trial sessions required for Set 1 MTS training (Steps A through F) was four, six, and six for Bea, Lance, and Jay, respectively (training data are not shown). Bea and Lance showed high accuracy on the Set 1 posttest. In each subsequent word set, these 2 participants showed high accuracy in MTS pretest sessions, thus meeting the criterion for advancement from the pretests directly to the MTS posttests, and posttest accuracy was always high. For Jay, Set 1 training did not increase accuracy on the generalization words. His high error rate reflected selection of the choice with the same rime sound as the test word presented (e.g., if the test word was *mug*, Jay often selected *sug*). Jay's pretest accuracy for Set 2 was 46%. He met the training criterion in three sessions, and posttest accuracy averaged 90%. For all subsequent word sets, both pretest and posttest accuracy was high. The bottom panel of Figure 2 shows data for the individual word sets for the control participants. These participants received posttests only. Note that, because test trials were not presented unless accuracy on the first 20 baseline (training word) trials was at least 90%, these sessions contained only training-word trials.

Figure 3 shows, for the experimental participants, naming accuracy for the six printed words in each set both before and after exposure to MTS training and testing for each word set. For Bea, word-naming accuracy improved substantially after exposure to MTS training in Word Sets 1 and 2. Beginning with Set 3, word-naming accuracy was at least 30% in all tests. In contrast, Jay named no words and Lance named few words during the individual word-set conditions. Control participants read no words correctly across all tests.

Phase 4: Cumulative Word Naming and Comprehension

Method and Results

These final tests were given after a participant completed all six of the word sets. Data are presented in Figure 3. The first printed-word naming sessions presented all 21 words once each. Bea's word naming accuracy was 62% across two test sessions. For all but one of her errors, she produced the correct beginning and ending consonant, but not the correct vowel (e.g., seeing *pit* and saying *pet*). In contrast, Jay and Lance named few words correctly. For Lance, almost all errors involved an absence of stimulus control by the vowel. In about half of these errors, he named a whole word with a different vowel sound (e.g., seeing *pit* and saying *pet*); in the other half he produced a sequence of the first vowel plus schwa sound and the final vowel plus schwa sound (e.g., *puh tuh* for *pot*). Jay produced only the name of the final consonant letter.

Tests for comprehension incorporated aspects of the methods used in prior studies of equivalence relations and emergent word naming. For example, in Sidman (1971), the participants (a) selected printed words upon hearing them spoken, (b) selected pictures that corresponded to the spoken words, and (c) named the pictures. After these three performances were demonstrated, participants were also able to select corresponding photos given the printed words as samples—a rudimentary test of comprehension of the printed words. In contrast to Sidman's study, training in Phases 1 to 3 included only selecting printed words upon hearing them spoken. In Phase 4, we asked whether our participants would select photos that matched printed-word samples. Further, we asked whether this addition to the participants' repertoires would promote high accuracy on the word-naming tests. Jay and Lance participated.

The first comprehension test was given after the first cumulative word-naming test. Subsequently, comprehension test sessions were intermixed with word-naming test sessions. Comprehension tests involved the 14 words underlined in Table 1 (the other seven words could not be pictured). Samples were printed words, and the choices were four photos. Before the comprehension tests, the 14 photos were presented in spoken-word-to-photo MTS with feedback sessions until accuracy was at least 90%. There were two differently configured 28-trial comprehension test sessions. In each session, all of the

14 words that could be pictured appeared as a sample twice and as a choice eight times.

For comprehension sessions, choice stimuli were grouped differently than in previous MTS sessions. Moreover, across the two test-session configurations, each distracter grouping for a sample was different. Approximately three of the four times each sample was presented, however, the distracters included at least one word with the same onset (so choices could not be made based on onset sound alone). Also, 12 trials included a distracter with overlap in the rime (e.g., *map* as a distracter for *mop*; *pop* as a distracter for *pot*).

Figure 3 shows high accuracy on the comprehension tests for both participants. The final word-naming test presented all 14 words that could be pictured once per session. In addition, half of the reading test sessions also included the seven words that could not be pictured (which were not included in the comprehension tests). Not shown are data from the spoken-word-to-photo sessions, which preceded each comprehension test (except that this session was erroneously omitted before Lance's first test). Accuracy was always at least 90% in the spoken-word-to-photo sessions, and high accuracy was shown in all comprehension tests.

After comprehension testing, the number of printed words named correctly increased. By the end of the study, both Jay and Lance named the majority of the 14 words that had appeared in the comprehension test, and Lance also read the majority of the seven untested words. For Jay, word-naming errors in the final two tests were equally divided between (a) producing the correct beginning and ending consonant, but with an incorrect vowel sound; or (b) producing a word that began with the correct consonant but had a different rime. Lance made only three errors across the final two test sessions; the errors involved saying words with either the correct onset and the incorrect rime or vice versa.

DISCUSSION

On pretests, these kindergarten children showed low accuracy when required to select, from among a set of closely related words, printed words that corresponded to spoken words. Moreover, none of the participants named any of the printed words. After learning to select printed words that contained onset and rime components of generalization words, all 3 experimental participants correctly selected generalization words. For 2 participants, generalization was shown in the first word set, and the 3rd showed generalization in the second set. In contrast, 2 control children showed low accuracy on the task throughout the study, providing additional evidence that the high accuracy shown by the experimental children was due to the training procedures.

These results provide a strong demonstration of recombinative generalization of within-syllable units. Previous studies demonstrated small but positive effects of training children to name a single-syllable printed word with a component that overlapped with a test word (e.g., train *beak*, test *peak*; Goswami, 1986). The present outcome suggests that recombination can be programmed by ensuring that the trained words incorporate *all* of the test-word components. Matrix training procedures provide an excellent means for ensuring this programming.

In previous studies that have shown full recombination, the recombined units were discrete whole words (e.g., green square) or syllables (de Rose et al., 1996). The extension of recombinative generalization to within-syllable units is significant for both application and theory. For application, the significance is that within-syllable units are crucial to decoding English words (e.g., Snow, Burns, & Griffin, 1998). The significance to theory is that individual phoneme sounds within a syllable overlap one another (i.e., coarticulation; Liberman & Liberman, 1990). Thus, demonstrations of within-syllable recombination provide an especially interesting example of the notion that minimal units that have not been presented independently can develop from larger units (Skinner, 1957).

Beginning with pretests for Set 2 for Bea and Lance and Set 3 for Jay, the children correctly selected new words that contained rime units that had not yet been trained. These outcomes probably reflect recombination within the rimes contained in previously presented sets. Within the rime, however, the number of functional units could not be determined by our procedures. One possibility is that the outcome reflected recombination of both phonemes within the rime (i.e., the middle vowel sound and the final consonant sound). For example, the baseline and test words in Set 1 were *mat*, *sat*, *sop*, *sug*, *mop*, and *mug* (see Table 1). After demonstrating highly accurate responding with these words, Bea and Lance correctly selected words with the rime units *ot* and *ap* (in Set 2), an outcome that could result from recombination of the phonemes within the Set 1 rimes (*at* and *op*).

The second possibility is that the consonant and only one letter of the rime exerted stimulus control. It would be possible to make correct selections based on the onset along with one letter of the rime because rimes differed from one another by both letters (see Birnie-Selwyn & Guerin, 1997; Ehri, 1992). The nature of errors in word-naming tests corroborate this suggestion. For both Bea and Lance, errors involved either misnaming or omitting the middle vowel. To determine conclusively whether or not both letters in the rime controlled selection in the MTS task, tests would have to require selection among choice stimuli with overlap in the rime units, such as *mat*, *map*, *mot*, and *mop*. Our research program is currently incorporating such overlap.

Another ambiguity occurs in interpreting the correct selections of words with the onset letter *p* in Set 4 MTS pretests. It is possible that the initial high accuracy with these words was based on experience with *p* in the ending-letter position (in the first three sets). Another possibility is that exclusion of the two distracters with *m* and *s* onsets contributed to correct selections. If so, correct selections reflected a combination of exclusion (onset) and recombination (the rimes in Sets 4, 5, and 6 had been presented with a different consonant in the first three sets). Note that exclusion *from m* and *s* would require strong positive stimulus control *by m* and *s*—a desirable outcome from a practical standpoint.

These ambiguities notwithstanding, the rapidity with which the children became accurate with the MTS training and generalization procedures is noteworthy. Prior to the study, their lack of skills involving printed words was documented by their teacher, standardized tests, and our pretests. We selected children, however, who rapidly learned to select printed CVC words that differed only in onset (i.e., the first pretraining task). Also, the children may have had unmeasured skills that influenced outcome. It is thought that important precursors of printed-word recognition occur before formal instruction, and much current research is directed at identifying those skills (e.g., Blachman, 1997). The characteristics of our participants, combined with the incomplete stimulus control analysis that was discussed above, leave open the question of whether these procedures will produce different results with less skilled participants. Current work is directed at this issue.

Although the structure of the MTS tests did not permit precise interpretation of the stimulus control involved, the high accuracy shown on comprehension tests (word samples with photo choices) and on the final word-naming tests suggests that, for the majority of the words, all three letters ultimately controlled responding. Comprehension test trials presented a single printed word as the sample, and choice stimulus groupings were different each time a particular printed word was presented. Thus, correct choices did not depend on exclusion of particular words. Further, in some test trials, distracters differed from the sample only *within* the rime unit (e.g., *mop* vs. *map*). Such closely related choice words had not previously been presented; they provided particularly good evidence of control by whole words.

The percentage of words read correctly was ultimately similar to that of earlier studies that used equivalence-based procedures to teach sight words (Joyce & Wolking, 1989; Sidman, 1971; Sidman & Cresson, 1973; & Sidman et al., 1974). The present demonstration of emergent reading adds to the literature in two ways. First, the study's design revealed large increases in accurate word naming (for Jay and Lance) after the comprehension tests were given, suggesting a facilitative effect. In Sidman's studies, testing order did not permit this observation. Second, the present study demonstrated comprehension and naming of printed words that participants learned to select through recombinative generalization. Moreover, the present study provided more convincing evidence of stimulus control by the whole word, as opposed to a single letter. In Sidman's studies, the 20 words had only 10 different onsets, and six words did not share an onset with any other word. Thus, many words could be read correctly given control by their first letter only, a prevalent strategy for beginning readers (Ehri, 1992). In the present study, there were only three different onsets among the 21 words, and there was relatively more overlap of component letters in general, thus precluding control by a single letter of the word.

Although the comprehension tests appeared to increase word-naming accuracy, this study did not isolate the reason for this increase. There are at least three potentially important features. First, comprehension tests presented each printed word alone on the screen, as also occurred in the reading tests (i.e., a successive discrimination; Saunders & Spradlin, 1993). Second, comprehension tests presented choice-stimulus groupings that were different from those used in the MTS sessions (as described above), possibly enhancing discrimination of the printed-word components. Third, selecting photos in the presence of spoken words may have promoted sight-word naming for some of the words. The latter seems most likely for Jay, whose final accuracy on words that had not been presented in the comprehension tests was lower than for words that had been presented in the comprehension tests.

Taken together, the current findings bode well for the potential use of computerized MTS procedures for teaching rudimentary reading skills. If computerized selection-based tasks like ours help promote decoding, time spent interacting with a teacher could be reserved for reading connected text and other more meaning-based reading activities. In addition, computerized procedures might be especially appealing to nonreading adults (including those with cognitive disabilities) because of the individualization and independence that they allow. Such procedures may also hold special promise for individuals whose speech disabilities interfere with production-based teaching. Finally, computerized instruction would promote treatment integrity, that is, the degree to which a planned intervention is implemented as designed (Gresham, 1989). Often, procedures that are effective in research settings lose their effectiveness due to variation in implementation. Effective computerized instructional programming is relatively free of treatment integrity failures.

Sidman (1993) pointed out the potential

of MTS teaching procedures for reading instruction nearly 3 decades ago, and he has more recently suggested the addition of decoding to these procedures. Only recently have recombinative generalization procedures been combined with stimulus equivalence procedures (e.g., de Rose et al., 1996) to more thoroughly model rudimentary reading. The present study is the first to incorporate within-syllable units of recombination, which are crucial to learning to read English. Further development of the decoding component will broaden the applicability of these procedures to computerized reading instruction.

REFERENCES

Adams, M. J. (1990). *Beginning to read: Thinking and learning about print.* Cambridge, MA: The MIT Press.

Birnie-Selwyn, B., & Guerin, B. (1997). Teaching children to spell: Decreasing consonant cluster errors by eliminating selective stimulus control. *Journal of Applied Behavior Analysis, 30,* 69–91.

Blachman, B. (Ed.). (1997). *Foundations of reading acquisition and dyslexia: Implications for early intervention.* Mahwah, NJ: Erlbaum.

Byrne, B., & Fielding-Barnsley, R. (1989). Phonemic awareness and letter knowledge in the child's acquisition of the alphabetic principle. *Journal of Educational Psychology, 81,* 313–321.

de Rose, J. C., de Souza, D. G., & Hanna, E. S. (1996). Teaching reading and spelling: Exclusion and stimulus equivalence. *Journal of Applied Behavior Analysis, 29,* 451–469.

Dube, W. V. (1991). Computer software for stimulus control research with Macintosh computers. *Experimental Analysis of Human Behavior Bulletin, 9(2),* 28–30.

Ehri, L. C. (1992). Reconceptualizing the development of sight word reading and its relationship to recoding. In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 107–143). Hillsdale, NJ: Erlbaum.

Goldstein, H. (1993). Structuring environmental input to facilitate generalized language learning by children with mental retardation. In A. P. Kaiser & D. B. Gray (Eds.), *Enhancing children's communication: Research foundations for intervention* (Vol. 2, pp. 317–334). Baltimore: Paul H. Brookes.

Goldstein, H., & Mousetis, L. (1989). Generalized language learning by children with severe mental retardation: Effects of peers' expressive modeling. *Journal of Applied Behavior Analysis, 22,* 245–259.

Goldstein, J. (1984). Effects of modeling and corrected practice on generative language learning of preschool children. *Journal of Speech and Hearing Disorders, 49,* 389–398.

Good, R. H., Simmons, D. C., & Smith, S. B. (1998). Effective academic interventions in the United States: Evaluating and enhancing the acquisition of early reading skills. *School Psychology Review, 27,* 45–56.

Goswami, U. (1986). Children's use of analogy in learning to read: A developmental study. *Journal of Experimental Child Psychology, 42,* 73–83.

Goswami, U. (1990). Phonological priming and orthographic analogies in reading. *Journal of Experimental Child Psychology, 49,* 323–340.

Goswami, U., & Bryant, P. (1992). Rhyme, analogy, and children's reading. In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 49–63). Hillsdale, NJ: Erlbaum.

Gresham, F. M. (1989). Assessment of treatment integrity in school consultation and prereferral intervention. *School Psychology Review, 18,* 37–50.

Joyce, B. G., & Wolking, W. D. (1989). Stimulus equivalence: An approach for teaching beginning reading skills to young children. *Education and Treatment of Children, 12,* 109–122.

Kameenui, E. J. (Ed.). (1996). *Learning to read/reading to learn: Helping children with learning disabilities to succeed information kit* (Technical Report). Eugene, OR: National Center to Improve the Tools of Educators.

Kaufman, A. S., & Kaufman, N. L. (1990). *Kaufman brief intelligence test, examiner's manual.* Circle Pines, MN: American Guidance Service.

Liberman, I. Y., & Liberman, A. M. (1990). Whole language vs. code emphasis: Underlying assumptions and their implications for reading instruction. *Annals of Dyslexia, 40,* 51–76.

Romski, M., & Ruder, K. F. (1984). Effects of speech and speech and sign instruction on oral language learning and generalization of action + object combinations by Down's syndrome children. *Journal of Speech and Hearing Disorders, 49,* 293–302.

Saunders, K. J., & Spradlin, J. E. (1993). Conditional discrimination in mentally retarded subjects: Programming acquisition and learning set. *Journal of the Experimental Analysis of Behavior, 60,* 571–585.

Sidman, M. (1971). Reading and auditory-visual equivalences. *Journal of Speech and Hearing Research, 14,* 5–13.

Sidman, M. (1993). Stimulus equivalence in and out of the laboratory. In A. Brekstad & G. Svedsäter (Eds.), *Proceedings from the 21st annual congress of the European Association for Behavior Therapy, Oslo, Norway, September, 1991* (pp. 93–114). Slependen, Norway: Norwegian Association for Behavior Analysis.

Sidman, M., & Cresson, O., Jr. (1973). Reading and crossmodal transfer of stimulus equivalences in severe retardation. *American Journal of Mental Deficiency, 77,* 515–523.

Sidman, M., Cresson, O., Jr., & Willson-Morris, M. (1974). Acquisition of matching to sample via mediated transfer. *Journal of the Experimental Analysis of Behavior, 22,* 261–273.

Skinner, B. F. (1957). *Verbal behavior.* New York: Appleton-Century-Crofts.

Snow, C. E., Burns, M. S., & Griffin, P. (Eds.). (1998). *Preventing reading difficulties in young children.* Washington, DC: National Academy Press.

Stedman, L., & Kaestle, C. (1987). Literacy and reading performance in the United States, from 1880 to the present. *Reading Research Quarterly, 22,* 8–46.

Striefel, S., Wetherby, B., & Karlan, G. R. (1976). Establishing generalized verb-noun instruction-following skills in retarded children. *Journal of Experimental Child Psychology, 22,* 247–260.

Striefel, S., Wetherby, B., & Karlan, G. R. (1978). Developing generalized instruction-following behavior in severely retarded people. In C. E. Meyers (Ed.), *Quality of life in severely and profoundly mentally retarded people: Research foundation for improvement* (pp. 267–326). Washington, DC: American Association on Mental Deficiency.

Treiman, R. (1992). The role of intrasyllabic units in learning to read and spell. In P. B. Gough, L. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 65–106). Hillsdale, NJ: Erlbaum.

Treiman, R., & Zukowski, A. (1996). Children's sensitivity to syllables, onsets, rimes, and phonemes. *Journal of Experimental Child Psychology, 61,* 193–215.

Wise, B. W., Olson, R. K., & Treiman, R. (1990). Subsyllabic units in computerized reading instruction: Onset-rime vs. postvowel segmentation. *Journal of Experimental Child Psychology, 49,* 1–19.

Woodcock, R. W., & Johnson, M. B. (1989/1990). *Woodcock-Johnson psycho-educational battery—revised.* Itasca, IL: Riverside Publishing.

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APPENDIX

Familiarization Training

We presented three tasks, all with differential reinforcement, to familiarize the children with the apparatus, matching-to-sample procedures, the reinforcement delivery and exchange procedures, and the kinds of discriminations involved. We describe these only briefly; further details can be obtained from the authors. All three tasks involved selecting one of two choice stimuli conditionally upon the presence of a randomly presented sample stimulus, and all three tasks were presented until accuracy was at least 90% in one 60-trial session. The tasks required the participants (a) to select either the choice letter *m* or the letter *s*, depending on which was identical to the sample; (b) to select familiar pictures upon hearing corresponding spoken words; and (c) to select the three-letter printed word that was identical to the printed-word sample. In the latter task, the two words that were presented as choices differed only in onset letter (e.g., *sat* and *mat*), and there were 20 different word pairs.

STUDY QUESTIONS

1. Define and provide an example of recombinative generalization.

2. What are onset and rime, and why was the distinction between these two units important in the current study?

3. Describe how the matching-to-sample (MTS) trials were conducted with printed versus spoken words as sample stimuli.

4. What stimuli comprised a word set in Phase 2, and to what extent did stimuli presented during the MTS pretest appear to influence participants' responding?

5. Describe the general purpose of training during Phase 3 and the sequence of testing and training procedures that was used.

6. Summarize the performances during Phase 3 posttests following spoken-to-printed-word MTS training.

7. How was experimental control demonstrated over the acquisition of spoken-to-printed-word MTS?

8. Describe data presented in Figure 3. How did the authors explain these results in their discussion?

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