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CONSTRUCTED-RESPONSE MATCHING TO SAMPLE AND SPELLING INSTRUCTION

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The development of interactive programmed instruction using a microcomputer as a teaching machine is described. The program applied a constructed-response matching-to-sample procedure to computer-assisted spelling instruction and review. On each trial, subjects were presented with a sample stimulus and a choice pool consisting of 10 individual letters. In initial training, sample stimuli were arrays of letters, and subjects were taught to construct identical arrays by touching the matching letters in the choice pool. After generalized constructed-response identity matching was established, pictures (line drawings) of common objects were presented as samples. At first, correct spelling was prompted by also presenting the printed name to be "copied" via identity matching; then the prompts were faded out. The program was implemented with 2 mentally retarded individuals. Assessment trials determined appropriate words for training. Correct spelling was established via the prompt-fading procedure; training trials were interspersed among baseline trials that reviewed and maintained spelling of previously learned words. As new words were learned, they were added to a cumulative baseline to generate an individualized review and practice battery for each subject.

DESCRIPTORS: matching to sample, computer-assisted instruction, programmed instruction, spelling, special education

A microcomputer was used as a programmed teaching machine in a special education classroom. We describe a computer-based spelling program designed to function as an interactive spelling "workbook." The potential for microcomputer-based teaching systems in special education is widely acknowledged (Ager, 1989; Budoff & Hutten, 1982; Conners, Caruso, & Detterman, 1986; Schmidt, Weinstein, Niemic, & Walberg, 1985–1986). However, the current state of computer-based instructional methodology for those with severe learning problems has prompted observations such as Ager's (1989) that "the field remains one of promise rather than genuine achievement" (p. 2). A major goal of the present article is to provide an example that is firmly grounded in laboratory-derived programmed instructional techniques (Holland, Solomon, Doran, & Frezza, 1976; Sidman & Stoddard, 1966; Terrace, 1963). Because such techniques often provide an effective means to overcome the learning problems of developmentally limited individuals (e.g., Lancioni & Smeets, 1986; Singh & Singh, 1986), their incorporation into computer-based teaching programs may further the development of instructional software for this population.

The program used variants of the matching-to-sample (MTS) procedure. In educational settings, MTS is often used to establish the conditional discriminations prerequisite to adaptive behavior. In MTS, a sample stimulus is displayed along with two or more comparison stimuli; one comparison is defined as correct, conditionally upon the sample. For example, given the printed words CAT, DOG, and BOY as comparisons, the student is taught to select CAT conditionally upon a picture of a cat, DOG upon a picture of a dog, and so forth. Selection is generally accomplished by touching or pointing to a comparison. Perhaps because of this

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modest response requirement, MTS is widely used in the instruction of developmentally disabled individuals. For example, prerequisites for language-related performances have been established by MTS training with spoken words, printed words, and pictures (Sidman, 1971, 1977, 1986; Sidman, Cresson, & Willson-Morris, 1974; Spradlin & Saunders, 1984; Stoddard & McIlvane, 1986).

Recently, the educational potential for MTS has been enhanced by development of constructed-response matching-to-sample (CRMTS) procedures (Mackay & Sidman, 1984). In CRMTS, the correct comparison is "constructed" by selection of its individual components. For example, given a picture of a cat as a sample, the student selects the letters C-A-T from a choice pool consisting of D-T-O-A-G-B-C-Y. Thus, the student not only learns to identify words but also learns to spell them. The CRMTS procedure has been used successfully to teach mentally retarded individuals to spell color names (Mackay, 1985; Mackay & Sidman, 1984) and to assemble various coin combinations equivalent to printed prices (McDonagh, McIlvane, & Stoddard, 1984; Stoddard, Brown, Hurlbert, Manoli, & McIlvane, 1989).

Previous studies of CRMTS were conducted in face-to-face training sessions with a live teacher. Here we demonstrate adaptation of the CRMTS procedure to computer-assisted review and remedial instruction in spelling. Our training goals were to (a) establish generalized identity-matching CRMTS performance, (b) identify words appropriate for spelling instruction and review, and (c) incorporate those words into an expanding CRMTS baseline.

METHOD

Subjects and Setting

Two mentally retarded young men participated. Sam and Rick were 27 and 24 years old, respectively, and achieved Peabody Picture Vocabulary Test (1981 rev.) mental age equivalent scores of 4 years 7 months and 4 years 1 month, respectively. On the Wide Range Achievement Test (1984 rev.) raw scores (and grade equivalents) for the spelling subtest were 23 (beginning first) for Sam and 12 (prefirst) for Rick; reading subtest scores were 27 (prefirst) for Sam and 38 (midfirst) for Rick.

Sessions were conducted 2 to 4 days per week in a classroom at the subjects' day program. Approximately eight other students and a teacher were present and engaged in regular classroom activities. The subject sat facing the apparatus, which was placed on a small table facing one wall of the classroom. The experimenter sat behind and slightly to one side of the subject, so that the subject could not observe the apparatus and experimenter simultaneously.

Apparatus

The apparatus consisted of a portable Apple Macintosh® computer fitted with a touch-sensitive screen (MicroTouch®). The screen (19 by 14 cm) displayed experimental stimuli, and the subject responded to a stimulus by touching it. Responses were automatically recorded and session data saved in disk-based files (Dube & McIlvane, 1989).

Preliminary Training

During preliminary training, the computer display consisted of five white squares (4.5 by 4.5 cm) on a gray background. One square was located in the center of the screen, and the others appeared in the four corners. In initial sessions, subjects learned to look at the computer screen and select a plus sign (+) (2 by 2 cm) that appeared in one of the squares by touching it. Touching the plus (initially modeled by the experimenter) was followed by a flashing screen display, melodic tones, and presentation of a penny; pennies were used to buy food items after the session. While the plus was displayed, touches to blank squares were followed by a 3-s blackout of the screen. These two consequences were programmed to follow responses defined as correct and incorrect, respectively, for the remainder of the study. During the 3-s intertrial interval, all keys were blank and any touches prolonged the ITI for 3 s.

After the response topography was established, subjects were tested for standard (i.e., not constructed-response) identity matching to sample. Each trial began with presentation of the sample stimulus on the center display square. Touching it was followed by presentation of two comparison stimuli on two of the outer squares; the two other squares remained blank. The sample remained present, and further touches to it had no programmed consequences. One comparison, S+, was identical to the sample, and the other, S−, was different. A touch to the square with S+ was defined as correct, and a touch to any of the other three corner squares (S− or a blank) was incorrect. Accurate identity matching was established first with geometric forms as stimuli. Later, uppercase letters of the alphabet were substituted so that discrimination of all letters could be verified.

Identity CRMTS

Subjects also learned to perform a generalized identity-matching version of CRMTS. When presented with novel arrays of letters as samples, they learned to construct arrays identical to the samples by selecting matching letters from a choice pool. The screen display (Figure 1) consisted of three white rectangles on a gray background. The sample display area (8.4 by 4.2 cm) was at the top of the screen, the construction area (8.4 by 2.1 cm) was in the center, and the choice pool area (17.8 by 4.1 cm) was at the bottom. Black uppercase letters, approximately 1.0 by 0.7 cm, were displayed in these areas.

Sessions consisted of 26 to 40 trials. Trials began when a one- to five-letter sample stimulus was displayed (Figure 1A). A touch to the sample produced an array of individual letters in the choice pool area (Figure 1B). As the subject touched choice pool letters that matched the sample in order from left to right, they moved up into the construction area (Figure 1C–F). After the last letter moved up to the construction area, the remaining letters in the choice pool disappeared and the penny consequence (see above) was delivered. If the subject touched a letter in the choice pool that was not in the sample or matched a sample letter in incorrect order, the trial was terminated immediately by the blackout and an error was recorded. No correction procedure was used.

To require continued discrimination of the sample stimulus, a different sample was presented on every trial. Samples were arrays of letters that were not English words (NX, TRS, IKPG, etc.); across trials, all letters of the alphabet appeared equally often in each position. In initial CRMTS sessions, the sample stimulus was a single letter, and the number of letters in the choice pool was increased gradually from two to ten. Then, the number of letters in the sample was increased to two, three, four, and finally five letters.

When two-letter samples were introduced, two procedures were available to prompt matching in left-to-right order:

Flashing prompt. The letter to be selected flashed on and off. In repeating cycles, the letter was displayed for 0.6 s and then disappeared for 0.2 s.

Fading procedure. With the fading procedure, the sample letter to be matched at each point in the trial was displayed in black, and the other letter was faded in over trials by presenting it in graded shades of gray. Figure 2 illustrates the fading steps. Initially, the sample display included only the letter to be matched. That is, prior to the first response, only the left letter was displayed; immediately after the first response, the left letter disappeared and only the right letter was displayed (Figure 2, Step 0). On successive fading steps, the intensity (shade of gray) of the incorrect sample letter increased gradually. At first, in Steps 1 through 4, the left letter remained displayed after its match was selected from the choice pool. Then, in Steps 5 through 8, the left letter was displayed at full intensity (black) for the entire trial and the right letter was gradually introduced at the beginning of the trial. Letters in the choice pool always appeared at full intensity. The program advanced one step following correct responses and backed up one step following errors.

Arbitrary CRMTS

Spelling instruction was conducted with an arbitrary-matching constructed-response procedure. Pictures—line drawings of objects—were displayed on the sample key, and subjects selected the letters that spelled the corresponding name from the choice pool (Figure 3A). The matching procedure is designated as arbitrary because the relationship between pictures and the corresponding printed words

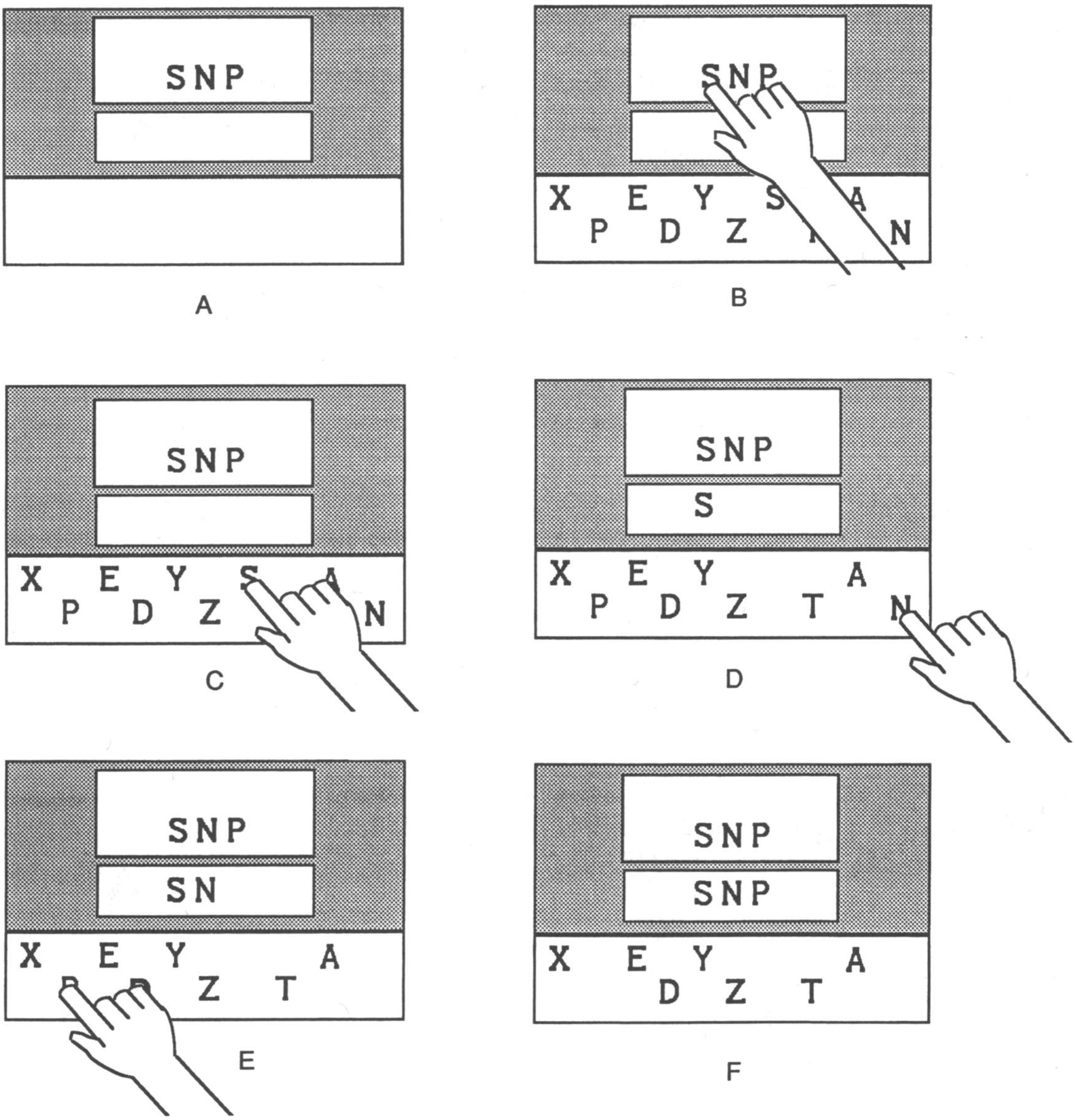

Figure 1. Macintosh video screen display for the identity CRMTS task. A: Trials began with presentation of the sample stimulus. B: A touch to the sample produced the choice pool. C–F: As choice pool letters that matched the sample letters were touched in left-to-right order, they moved up to the construction area.

was not based on physical stimulus features (e.g., identity matching) or point-to-point correspondence between samples and comparisons (e.g., matching printed words to spoken names); rather, correct matches were defined by the prevailing reinforcement contingencies of the verbal community. The pictures were approximately 1.5 by 1.5 cm and are reproduced in Figures 4 and 5. On each CRMTS trial, the incorrect letters in the choice pool always included the initial letters of words presented on other trials. Contingencies for correct and incorrect responses were the same as those for identity CRMTS; response chains were always interrupted immediately following errors.

Assessment. Probe assessments (Kazdin, 1982) were used to determine words appropriate for spelling instruction. For each word, the assessment included nonconstructed arbitrary MTS trials in which

Figure 2. Sample displays for the fading program to teach two-letter sample construction in left-to-right order. At Step 0, only the letter to be matched was displayed. In Steps 1 through 4, the letter on the left was faded in prior to the second response; in Steps 5 through 8, the letter on the right was faded in at the beginning of the trial. See text for details.

the picture was the sample and printed names were the comparisons (Figure 3B) and arbitrary CRMTS trials with picture samples (Figure 3A). Subjects' first two sessions consisted of assessment trials for several words interspersed among identity MTS trials with pictures and words (Figure 3C and 3D); assessments for additional words were interspersed among subsequent sessions in a variant of the multiple probe technique (Barlow & Hersen, 1984). Assessments were brief so that subjects were not forced to make repeated errors (cf. Lancioni & Smeets, 1986; Stoddard & Sidman, 1967). Initial assessments consisted of four arbitrary MTS and two arbitrary CRMTS trials per word; in later sessions assessments consisted of two MTS and two CRMTS trials per word. If a subject made an error on an assessment CRMTS trial, the trial ended at that point, but without the blackout consequence.

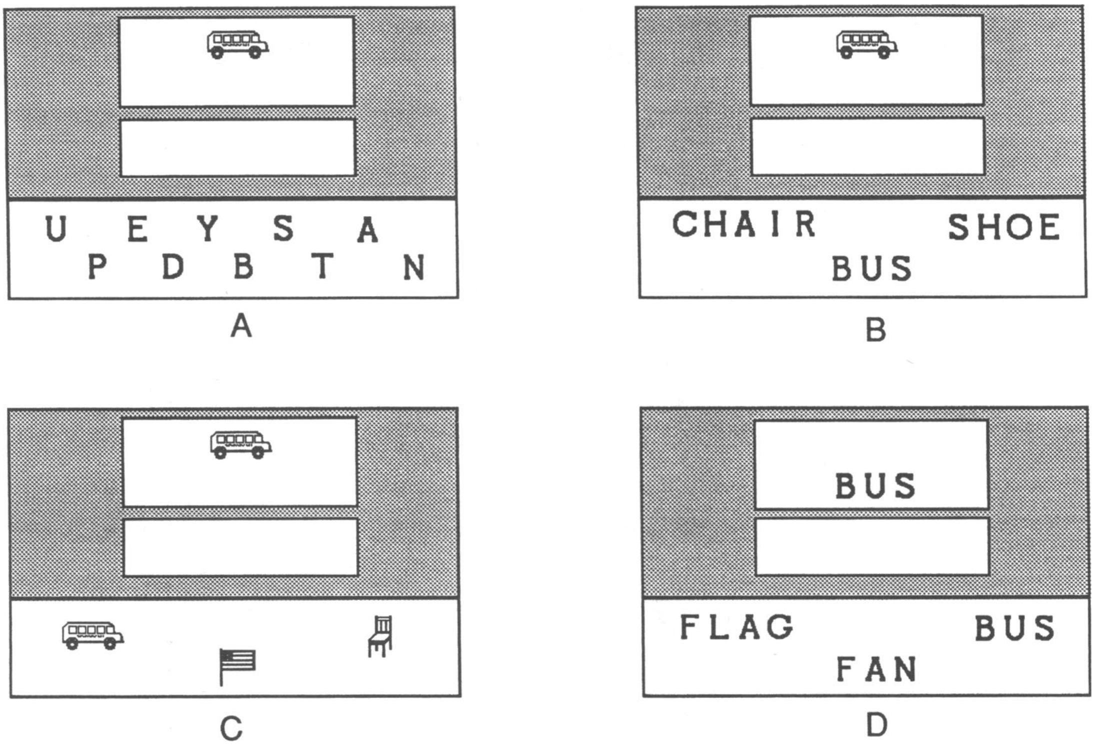

Figure 3. Representative trial displays. A: Arbitrary constructed-response matching to sample (CRMTS); B: Arbitrary matching to sample (MTS) with pictures as samples and printed names as comparisons; C: Identity MTS with pictures; D: Identity MTS with printed names.

Cumulative baseline. Because initial assessments determined that both subjects could spell at least one word correctly, the subjects entered the third session with a performance baseline consisting of arbitrary CRMTS trials with one or more words and identity MTS trials with pictures and words (trial types illustrated in Figure 3A, 3C, and 3D). As sessions progressed, the baseline was expanded via the following cycle: (a) Assessment results identified a new word for training, (b) the subject was taught to spell the word (see below), and (c) the word was added to the cumulative baseline. All sessions included 30 to 40 baseline trials; for example, if the cumulative baseline included five words, each word was presented on six CRMTS trials and one identity MTS trial per session.

Training procedure. For words not spelled correctly on the assessment, a prompting procedure was used for initial CRMTS training. Sessions included approximately 30 to 40 training trials interspersed among an equal number of baseline trials (see Neef, Iwata, & Page, 1977). Correct spelling was prompted by displaying a compound sample consisting of the picture and the printed name; the subject could copy the printed-name prompt as in identity CRMTS. Across subsequent trials, the prompt was gradually faded, beginning with the last letter, then the next-to-last letter, and so forth, until only the picture remained ("vanishing" the prompt, Skinner, 1968). Each letter was eliminated over five fading steps, similar to those shown in the middle column of Figure 2 (sample prior to first response) for Steps 8, 7, 6, 5, and 4. The fading procedure advanced one step following a correct response and backed up one step following an error; when a letter was completely faded out, three consecutive correct responses were required before fading began for the next letter. Training continued until the new word was spelled correctly for at least six consecutive trials without any prompt; that is, the initial letter of the word was completely faded out and only the picture remained as the

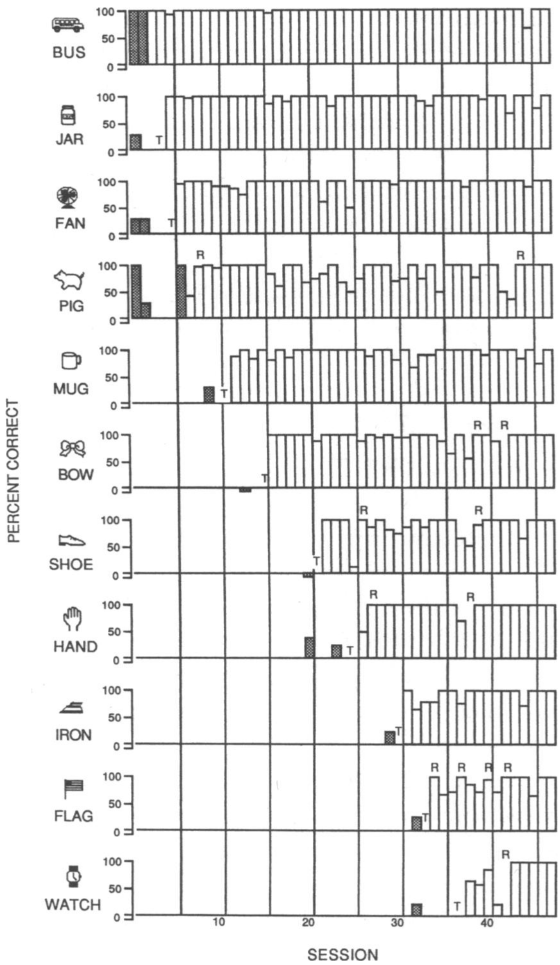

Figure 4. CRMTS accuracy scores for Sam. Assessment and baseline scores are shown as gray and white bars, respectively. Scores are calculated as the percentage of consecutive letters correct; see text for details. A score of 0% is shown below the abscissa. A missing bar indicates a session in which the word was not included in the baseline. "T" indicates training sessions; see Table 2 for details. "R" above a baseline score indicates that review trials preceded the baseline trials.

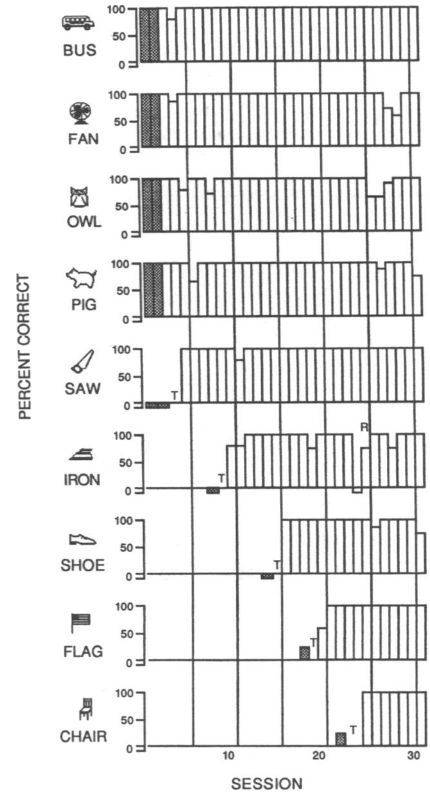

Figure 5. CRMTS accuracy scores for Rick. Assessment and baseline scores are shown as gray and white bars, respectively. Scores are calculated as the percentage of consecutive letters correct; see text for details. A score of 0% is shown below the abscissa. A missing bar indicates a session in which the word was not included in the baseline. "T" indicates training sessions; see Table 2 for details. "R" above a baseline score indicates that review trials preceded the baseline trials.

sample. At that point, the word was added to the cumulative baseline.

Review procedure. If a subject made errors on half or more of the trials for a baseline word in one session, the word was temporarily removed from the baseline and a review was conducted. The review was an abbreviated version of the training procedure. The first trial displayed a compound sample consisting of the printed name and picture. On trials following correct responses, one letter of the printed-name prompt was eliminated without fading, beginning with the last letter (e.g., BUS, BU, B). The procedure backed up (i.e., added a letter) following any errors. The review was complete when the word was spelled correctly for at least three consecutive trials without a prompt. Review trials were interspersed among an equal number of baseline trials.

The review procedure also was used when training required more than one session to complete. The latter session(s) began with a review of letters that had been faded in previous training. For example, if the first training session for SHOE ended after only three letters had been faded, the second

Table 1
Percentage of Trials Correct (and Number of Sessions) for Identity CRMTS with One- to Five-Letter Samples

Subject	Number of letters 1	2	3	4	5
Sam	99 (11)	100 (1)[a]			
		97 (2)	95 (3)	95 (1)	93 (5)
Rick	99 (5)	47 (1)[a]			
		63 (2)			
		91 (4)[b]			
		90 (1)	91 (2)[b]		
			97 (3)	93 (8)	99 (3)

[a] Sessions included trials with the flashing prompt.
[b] Sessions included trials with the fading procedure.

session began with review trials displaying the prompts "SHOE," "SHO," and "SH" before fading resumed with the prompt "S."

RESULTS

Both subjects completed preliminary training requirements within two sessions, and both immediately demonstrated generalized identity MTS with geometric forms and individual letters.

Identity CRMTS

Identity CRMTS training is summarized in Table 1. Both subjects were highly accurate with one-letter samples as choice pool size was increased from two to ten letters.

The flashing cue was used to introduce two-letter samples. Sam's accuracy score was 100% for one session with the cue and 97% for two sessions following abrupt elimination of the cue. Three-, four-, and five-letter arrays were introduced without prompts. The two-letter performance apparently had provided Sam with the necessary prerequisites for CRMTS with longer sample arrays; he completed all sessions with accuracy scores higher than 90%.

For Rick, control of letter selection by the flashing cue was not reliable. He scored 47% correct in his first session with two-letter samples and flashing cues and 63% correct in two subsequent sessions without the flashing. All errors were due to matching the right letter first. When the fading procedure was introduced, it exerted immediate control of letter selection (91% correct). Fading prompts were eliminated over the next three sessions, and Rick scored 90% correct without prompts in his eighth session with two-letter arrays. Three-letter samples were introduced by programming fading Steps 4 through 8 for the third letter. Four- and five-letter arrays were introduced without fading, and his accuracy scores were high throughout (Table 1).

Arbitrary CRMTS

Arbitrary CRMTS scores are shown in Figures 4 and 5. Scores were calculated as the percentage of consecutive letters correct; trials ended immediately following errors. For example, given the picture of the fan, the response "A" would score 0%, "FN" would score 33%, "FAS" would score 67%, and the overall score for those three trials would be 33% (3/9 letters). Assessment scores and baseline scores are shown as gray and white bars, respectively. The points at which training and review were conducted are labeled "T" and "R," respectively, and performance on prompted training and review trials is not included in the scores. For example, Figure 4 shows that Sam's assessment for SHOE was conducted in Session 20 and that he scored 0% correct. SHOE training was conducted in Session 21, and the assessment and training trials were interspersed among baseline trials that included BUS, JAR, FAN, PIG, MUG, and BOW (3 to 4 trials each per session). SHOE was added to the baseline in Session 22, and Sam was 100% correct on all SHOE trials in Sessions 22 through 24. In Session 25, performance on SHOE dropped to 12.5% (one letter correct on two trials). SHOE was reviewed at the start of Session 26; following the review, Sam was 100% correct on unprompted SHOE trials for the remainder of Session 26. Figures 4 and 5 show that Sam's and Rick's cumulative baselines were expanded to include eleven and nine words, respectively.

Assessment. In initial assessments (Sessions 1 and 2), Sam correctly spelled BUS on both CRMTS trials and PIG on one trial (Figure 4), and Rick

Table 2
Assessment and Training Data

	Assessment				Training		
Subject	Word	Session number	MTS (Correct/total)	CRMTS	Session number	Trials	Errors
Sam	BUS	1–2	4/4	BUS, BUS	—[a]		
	JAR	1–2	4/4	JF, S	3–4	49	7
	FAN	1–2	4/4	FO, FW	5	25	2
	PIG	1–2, 6	6/6	PIG, PO, PIG, PIG	—		
	MUG	9	2/2	MA, MG	10–11	36	2
	BOW	13	1/2	W, W	15	29	2
	SHOE	20	0/2	J, H	21	33	1
	HAND	20, 23	4/4	HN, HAE, HS, HU	24–25	52	5
	IRON	29	2/2	IO, O	30	36	2
	FLAG	32	1/2	FA, FA	33	40	4
	WATCH	32	2/2	WH, WH	35–37	86	13
Rick	BUS	1–2	1/2	BUS, BUS	—		
	FAN	1–2	2/2	FAN, FAN	—		
	OWL	1–2	2/2	OWL, OWL	—		
	PIG	1–2	1/2	PIG,PIG	—		
	SAW	1–2	0/2	P, L	4	30	2
	IRON	8	0/2	N, M	9	32	1
	SHOE	14	0/2	H, H	15	31	0
	FLAG	18	2/2	FA, FH	19	34	3
	CHAIR	22	2/2	CHI, CHI	23–24	53	7

[a] Word added to the baseline without training.

correctly spelled BUS, FAN, OWL, and PIG on all trials (Figure 5). The words that were correct on both assessment trials constituted the initial performance baseline. PIG was added to Sam's baseline without training following a retest in Session 6 (Figure 4).

Words were considered appropriate for training if scores on CRMTS assessment trials averaged 33% or lower. Sam's initial assessment identified JAR and FAN for spelling instruction, and Rick's identified SAW. Assessment results in later sessions indicated that the low scores on these words in initial sessions were not due merely to unfamiliarity with the procedures. Even after performance baselines were well established, the assessments continued to identify some words that required instruction. Assessments also identified some words that subjects could spell accurately, but these words were not added to the baseline because of the emphasis on instruction. On assessments, Sam correctly spelled SAW (Sessions 1 and 2), OWL (Session 6), TIE (13), and FORK (29); Rick correctly spelled JAR (1 and 2), MUG (7), HAND (14), WATCH (22), BRUSH (26), and SHIRT (27).

Details of assessment results for words added to the baseline are shown in the left portion of Table 2. Words spelled incorrectly on CRMTS trials were often identified correctly on MTS trials. For example, Sam's results in Session 9 show that he could match the word MUG to the picture of a mug, but that only the first letter M was correct on CRMTS trials.

Training. Training data are shown in the right portion of Table 2; the totals for training trials and number of errors include both fading and criterial trials and, when training required more than one session, review trials at the beginning of the latter session(s). Subjects completed training for most of the words with eight to twelve training trials per letter and with few errors. The exceptions were Sam's training with JAR and WATCH and Rick's training with CHAIR. However, despite initial difficulties with these words, performance following training was immediately accurate for JAR and CHAIR. Figure 4 shows that Sam's baseline performance with WATCH was relatively poor for the first four sessions following training, but then, following a review in Session 42, performance became errorless for five additional sessions (three trials per session).

DISCUSSION

This study demonstrates the application of a constructed-response matching-to-sample procedure to computer-assisted spelling instruction and review. Subjects first learned to perform generalized identity CRMTS. Then, initial assessments showed that both subjects were able to spell at least one word correctly; this performance served as a baseline for further training. Throughout the following sessions, a series of probe assessments identified words that subjects spelled incorrectly. Following training for each word, the word was added to the performance baseline to generate a cumulative, individualized review and practice battery for each subject.

Subjects' successful spelling of previously misspelled words seems to be clearly related to the CRMTS training procedures. Three aspects of the subjects' performance support this conclusion. First, the subjects consistently misspelled some words on assessments despite spelling other words correctly; procedural control was thus ascertained. Second, defective assessment performances were typically followed by at least some errors during training; those errors provide additional evidence that subjects could not spell the words correctly prior to the intervention. Finally, when the CRMTS training procedures were implemented, they were always successful; there were no failures to acquire the correct spelling performances.

Because initial training had established a generalized identity-matching CRMTS performance, correct spelling could be prompted by presenting the printed word to be copied. Successful transfer of stimulus control from the identity-prompt word to a nonidentical picture systematically replicated previous reports with teacher-delivered (i.e., not computer-based) CRMTS methods using cardboard anagram letters (Mackay, 1985; Mackay & Sidman, 1984) and programmed paper-and-pencil workbooks (Mackay & Sidman, 1984). The fading procedure provided sufficient conditions for transfer, although additional controls are needed to demonstrate its necessity. As noted above, subjects generally made a small number of errors during training. It may be possible, therefore, that the fading was superfluous and that repeated CRMTS testing with differential reinforcement would have led to reliably accurate performance (particularly for those words identified correctly on MTS assessment trials). On the other hand, the fading procedure may have prevented a much larger number of errors, errors that could result in failures to learn. In either case, the errors indicate that the current procedure will require revision in order to provide optimal instructional support (see Sidman & Stoddard, 1966).

In the present study, the CRMTS program was used as the sole means of instruction to establish experimental control. Positive results demonstrated that the procedure was sufficient for spelling review and instruction. This outcome suggests further studies to compare CRMTS training with other computer-based spelling programs designed for normally capable students (e.g., Kinney, Stevens, & Schuster, 1988) and traditional classroom methods (e.g., Allred, 1984; Henderson, 1985). Although the relative effectiveness of computer-based CRMTS procedures for teaching new words is of basic interest, we think it likely that, in application, such procedures will be most useful as a supplement to other forms of instruction. An interactive spelling "workbook" such as the CRMTS program could be used to augment the number of available contexts in which spelling behavior is displayed in the classroom. The range of training stimuli could be extended by including CRMTS trials with computer-generated spoken words as auditory sample stimuli.

A CRMTS-based program may make computer-assisted spelling instruction and review available to students whose keyboard proficiency is inadequate for programs that require keyboard input. Further, CRMTS procedures may offer a way to bridge the gap between standard forms of MTS training and use of a keyboard. Progression from the 10-choice CRMTS procedure to the keyboard includes at least three components: (a) increasing the number of choices per trial, (b) standardizing the locations of choice pool letters to match those of the keyboard, and (c) transferring the response from the bottom of the computer screen to a keyboard placed immediately below. Further study will be necessary to determine the feasibility of such an approach.

For mentally retarded students with limited writing skills, CRMTS spelling procedures can provide review and practice in a context independent of instruction in manipulating a pencil. Even for those who write adequately, the computer-assisted program may be used to augment standard paper-and-pencil spelling worksheets and, in fact, offers several advantages over such worksheets. Briefly, some of the advantages are those often cited for programmed instructional methods: The computer supplies immediate and continuous feedback during both correct and incorrect performances, the procedures control observing behavior, and the fading and review procedures program gradual progression from entry-level performance to the target performance (e.g., Holland et al., 1976; Skinner, 1968). Other advantages are those associated with computer-assisted instruction: The content of each subject's cumulative baseline was individualized, the review procedure provided remedial branches as required by the student's performance, and automation promoted optimal use of the teacher's time (e.g., Conners et al., 1986).

Computer-based implementation of programmed instruction requires a system that includes both hardware and software components. The hardware is currently available. Microcomputers with satisfactory graphics capabilities, low-cost speech digitizers and synthesizers, and add-on touchscreens to fit most popular computers have been produced commercially for some time; the price of such equipment has become increasingly more affordable. However, the development of, for example, a computer-based CRMTS package appropriate for classroom use will require considerable additional research, both basic and applied. One way to encourage applied research might be to incorporate the CRMTS and fading procedures into an authoring system designed for use with special needs populations. Authoring systems are modular application programs that can be used by teachers to edit, format, compile, and present instructional software (Becker, 1988; Crowell, 1989). A good authoring system provides a user interface appropriate for the practitioner, editing programs specifically designed for lesson preparation, automated record-keeping and report generation, and so forth. Combining the practical benefits of a software authoring system with the "errorless learning" procedures that have emerged from stimulus-control laboratories (fading, stimulus shaping, etc.) could create a powerful tool for applied research in the special education classroom (see Greer, 1989).

Both computer-based and teacher-delivered implementations of CRMTS address one limitation of standard MTS training with complex stimuli such as printed words—the phenomenon described as "stimulus overselectivity" or "restricted stimulus control" (Bickel, Richmond, Bell, & Brown, 1986; Lovaas, Koegel, & Schreibman, 1979; Lovaas, Schreibman, Koegel, & Rehm, 1971). Restricted stimulus control is shown when only a subset of the elements of a stimulus complex controls its selection. For example, in Sam's initial assessment, on MTS trials with the picture of a fan as the sample and comparisons such as FAN, PIG, and MUG, he correctly selected FAN on four of four trials (see Table 2). However, on (unprompted) CRMTS trials with the same picture, he selected the letters FO and FW. The CRMTS results suggest that correct selections of the complex stimulus FAN on MTS trials were controlled by the first element, F, but not by the second element, A. (A test for such control, not conducted here, would be to present the MTS trials with the comparisons FAN, FUN, and FAT. If control was exerted by the first element only, then selection of each comparison would be equally likely.) In CRMTS, discrimination of all elements of complex comparison stimuli is required and verified on every trial. Future research will determine the extent to which CRMTS will be useful in the assessment and remediation of restricted stimulus control: Is there a relationship between restricted stimulus control and CRMTS accuracy scores? Will restricted stimulus control persist in a training context that also includes CRMTS? Perhaps most important, will programs seeking to expand the breadth of stimulus control (Allen & Fuqua, 1985; Schreibman, Charlop, & Koegel, 1982) be enhanced by the incorporation of CRMTS procedures?

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