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MATRIX TRAINING OF PRELITERACY SKILLS WITH PRESCHOOLERS WITH AUTISM

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Matrix training is a generative approach to instruction in which words are arranged in a matrix so that some multiword phrases are taught and others emerge without direct teaching. We taught 4 preschoolers with autism to follow instructions to perform action–picture combinations (e.g., circle the pepper, underline the deer). Each matrix contained 6 actions on 1 axis and 6 pictures on the other axis. We used most-to-least prompting to train the instructions along the diagonal of each matrix and probed the untrained combinations. For 2 participants, untrained responding emerged after the minimum amount of training. The other 2 participants required further training before untrained combinations emerged. At the end of the study, 3 of the 4 participants performed the trained actions with previously known pictures, letters, and numbers. This study demonstrated that matrix training is an efficient approach to teaching language and literacy skills to children with autism.

Key words: letter identification, matrix training, number identification, picture identification, recombinative generalization

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Children with autism often exhibit delays in the acquisition of language (Eikeseth & Hayward, 2009; Rapin, 2006) and literacy skills (Mirenda, 2003). Educational approaches to increasing language often involve direct training of listener and speaker repertoires (Lovaas, 1987; Sundberg & Partington, 1998). In the area of literacy, many children with autism exhibit delays in reading and basic readiness skills used to maximize academic achievement, such as writing (Katims & Pierce, 1995; Nation, Clarke, Wright, & Williams, 2006). With the No Child Left Behind Act (2001) holding students with autism to grade-level standards, researchers must continue to identify effective techniques for teaching literacy skills to students with autism (Yell, Drasgow, & Lowrey, 2005). One approach is to target the reading and writing behaviors that precede literacy development, such as looking at books, listening to others read books, constructing stories from pictures and writings, scribbling, and writing (Koppenhaver & Erickson, 2003; Teale & Sulzby, 1986). Although most of this research has focused on adolescents with autism, Denton and West (2002) found preschool children with letter-naming skills and letter knowledge performed better on measures of phonological awareness and word reading in first grade than did children without letter knowledge. There is clearly, however, a dearth of research on methods of teaching literacy skills to young children with autism.

Although interventions that target language and literacy skills with children with autism have been effective, it is difficult for educational programs to address all the individual skills required for children with language delays to meet the standards of their same-age peers (Mackay, Kotlarchyk, & Stromer, 1997). One method to address this problem is generative instruction, which allows educators to directly teach one set of skills so that others emerge without direct teaching (Johnson & Layng,

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1992; Layng, Twyman, & Stikeleather, 2004; Rehfeldt & Barnes-Holmes, 2009; Sidman, 1994). Matrix training, one form of generative instruction, has been used to teach listener skills and labeling with multicomponent phrases, such as learning to label color–object combinations with children with mental retardation (Goldstein & Mousetis, 1989; Karlan et al., 1982; Remington, Watson, & Light, 1990; Striefel et al., 1978). For example, a 2 $\times$ 2 matrix can be arranged with two colors on one axis and two objects on the other axis, resulting in four color–object combinations. If two of the four combinations are trained, the other two may emerge without direct training. For example, if a child is taught to label "red car" and "blue boat," the responses "blue car" and "red boat" may emerge without direct training. Goldstein (1983a) termed this outcome *recombinative generalization*, because the constituents of trained combinations are arranged in new combinations based on environmental requirements. Arranging targets in a matrix and teaching along the diagonal of the matrix allows efficient instruction, in that skills are learned without direct teaching.

Goldstein, Angelo, and Mousetis (1987) evaluated matrix training with three individuals with severe mental retardation. They targeted labeling and instruction following, and arranged both known and unknown words in matrices. In the submatrices with known words, Goldstein et al. taught one combination and probed the untrained combinations. Once the participants met the performance criterion with known words, training commenced with unknown words. All correct responses during probes received reinforcement, and corrective feedback was not provided. Results suggested that training one combination of known words readily produced responding with the new combinations with the known words. Results also showed that training one combination with previously unknown words produced correct responding to the other unknown word combinations. Goldstein et al. noted that 94% to 98% of the learning was untrained.

Two studies have examined matrix training specifically with children on the autism spectrum. Kinney, Vedora, and Stromer (2003) taught generative spelling using video modeling to a first-grade girl. In the video, an adult modeled spelling a word on a large sheet of paper with videos as rewards. In Phase 1, the participant learned to spell 15 words with video modeling. Phase 2 revealed that she did not exhibit recombinative generalization based on the words learned in Phase 1. In Phase 3, she was taught to spell five words and spelled four other words without training. In Phase 4, she was taught to spell nine words and learned 18 words by recombining initial consonants and word endings. This study extended the research on matrix training and video modeling to teach generative spelling to a child with autism.

In another study, Dauphin, Kinney, and Stromer (2004) used video-based activity schedules and matrix training to teach sociodramatic play to a 3-year-old boy with autism spectrum and attention deficit hyperactivity disorders. In Phase 1, the participant was taught to follow video-based activity schedules, say four-word phrases (e.g., "Dinosaur, want to run?"), and perform object–action combinations (e.g., "Bear have a bite," "Rabbit take a drink") across the diagonals of 3 $\times$ 3 matrices. Ten sessions of most-to-least prompting were effective in producing 21 of the 28 novel phrases and four of the six novel actions. In a follow-up phase, training of new object–action combinations was similar to the first phase, but Dauphin et al. tested responses using pictures rather than videos. The participant performed most of the untrained combinations.

The purpose of the current study was to extend the literature in two ways, first to evaluate matrix training with children with autism (Dauphin et al., 2004; Kinney et al., 2003) and second to extend the research to focus on the early literacy skills of writing and identifying letters and numbers. In addition, whereas least-to-most prompting was employed in most previous matrix-training studies, most-to-least prompting was used in the current study to promote errorless learning (Massey & Wheeler, 2000; Touchette & Howard, 1984).

METHOD

Participants

We recruited preschool children who had a diagnosis of autism; significant delays in instruction following, writing skills, picture identification, and labeling; and mild or no challenging behavior. Four children (4 to 5 years old) participated. All four could make simple requests, identify letters, and identify numbers under 20. Matt was a Caucasian boy with a full-scale IQ of 91 on the Leiter International Performance Scale—Revised (Leiter-R; Roid & Miller, 1995). On the Battelle Developmental Inventory (BDI; Newborg, Stock, Wnek, Guidubaldi, & Svinicki, 1994), his age equivalent was 21 to 22 months in the receptive, expressive, and total communication subdomains. At the time of the study, he spoke in one- to two-word sentences when prompted. He exhibited delays in responding to greetings and to his name, taking turns with peers, identifying objects and pictures, and answering yes–no questions. Rex was a Caucasian boy whose full-scale IQ on the Leiter-R was 106. On the BDI, he scored in the 30- to 31-month age equivalent on the receptive communication subtest, 43 months on the expressive communication subtest, and 36 months on the total communication subtest. He spoke in complex sentences but exhibited delays with conversation and pragmatic aspects of language. At the time of the study, his individualized education program goals were to increase his discrimination and classification skills, prewriting and other fine-motor skills, and conversation skills.

Trey was an African American boy with a full-scale IQ of 81. On the BDI, his age equivalents were 21 to 22 months, 14 months, and 16 months on the receptive, expressive, and total communication subdomains, respectively. He spoke in one- to two-word sentences when prompted and often needed many reminders to comply with simple instructions. When he was given instructions that broke routines, he often whined and cried. At the time of the study, Trey's educational goals included requesting assistance, following one- to two-step verbal directions, requesting reinforcers, and tracing letters. Nina was a Caucasian girl with a full-scale IQ of 82. She scored in the 17 to 18 months, 27 months, and 22 months age equivalents on the receptive, expressive, and total communication subdomains of the BDI, respectively. She spoke in five-word sentences and was echolalic. Her educational goals were to complete writing tasks (e.g., make shapes, trace letters), request reinforcers, take turns with adults, use a picture schedule to make smooth transitions, and follow one-step verbal directives.

Setting and Materials

The study took place at a private inclusive preschool for children with autism spectrum disorders. We conducted sessions in a small private room in the school (8 m by 5 m). The experimenter sat with each participant at a small table next to a video camera. Materials were a cup with utensils (pencil, highlighter, stamp, scissors, pen), a timer, toys (books, sensory toys, toy cars, bubbles, balloons), and three types of probe sheets (21.6 cm by 28 cm with color photographs that were 3 cm by 3 cm). The types of probe sheets included (a) pictures in the primary matrices (six target photographs and six distracter photographs arranged in three rows), (b) previously known pictures (six photographs arranged in two rows), and (c) previously known letters and numbers (16 large-print letters and numbers arranged in four rows). We prepared three versions of each type of sheet to vary the order of pictures for each trial. The photographs used in training (see below) were the same size and style as those in the probe sheets.

Dependent Variable

The dependent variable was percentage of correct instruction following in each probe session, defined as performing the action with the picture, letter, or number that matched the spoken words from the experimenter (e.g., underline the pepper, stamp the deer) within 5 s of the instruction. Instruction following was further defined as diagonal trained and nondiagonal untrained. *Diagonal trained* refers to responses that were either targeted for training (i.e., on the diagonal of the matrix) or directly trained (i.e., if more cells other than those on the diagonal were trained). *Nondiagonal untrained* refers to responses that were not targeted for training (i.e., not on the diagonal) or responses that were never trained (i.e., if other cells other than those on the diagonal were trained).

Interobserver Agreement

The experimenter trained graduate students in special education and applied behavior analysis on the definition and measurement of the dependent variable. The observers independently scored instruction following from videotapes across phases and tiers in 29%, 30%, 31%, and 30% of sessions for Matt, Rex, Trey, and Nina, respectively. Interobserver agreement of the probes of performing actions with previously known pictures, letters, and numbers was measured in 50%, 25%, and 75% of sessions for Matt, Rex, and Trey, respectively (these probes were not conducted with Nina). Agreement was defined as both observers scoring the response as being correct or incorrect and diagonal trained or nondiagonal untrained. Interobserver agreement was calculated by dividing the number of agreements by the sum of the agreements and disagreements and converting the ratio to a percentage. Mean agreement was 100% for Matt and Trey. Mean agreement for Rex was 100% in the baseline and maintenance phases and 86% (range, 0% to 100%) in the training phase. Mean agreement for Nina was 100% in baseline and maintenance and 99% (range, 92% to 100%) in the training phase. In the probes of actions with previously known pictures, letters, and numbers, agreement was 100% for Trey and Rex and 94% for Matt.

Design

A multiple probe design across behaviors was employed (Cooper, Heron, & Heward, 2007). For each participant, there were four tiers of the multiple probe design corresponding to the four submatrices in the matrix targeted for each participant (Figure 1). That is, the bold lines in Figure 1 separate Submatrices 1 through 4 assigned to Tiers 1 through 4 in the multiple probe design. The three phases were baseline, training, and maintenance. A probe session occurred each time the experimenter met with a participant. In baseline and maintenance, only a probe session occurred. In training, a training session followed the probe session in which the experimenter trained the cells along the diagonal of the matrix in accordance with the multiple probe design.

The following criteria were applied to the design: Following baseline, training occurred if responding was less than 90% correct on diagonal trained instructions in the probe. Once performance was at 90% correct or higher on one probe of diagonal trained instructions, we administered probes of nondiagonal untrained instructions. Following three sessions of 90% correct or higher on diagonal trained instructions and 50% correct or higher on nondiagonal untrained instructions, we conducted a series of baseline sessions in the next submatrix to ensure that the participant's responding was stable. Following three consecutive sessions of 90% correct or higher on diagonal trained instructions and less than 50% correct on nondiagonal untrained instructions, we trained a new cell from the submatrix. We initially selected a new cell randomly. If a few extra cells were trained and untrained responding still did not exceed criterion, we selected new cells for training based on a high

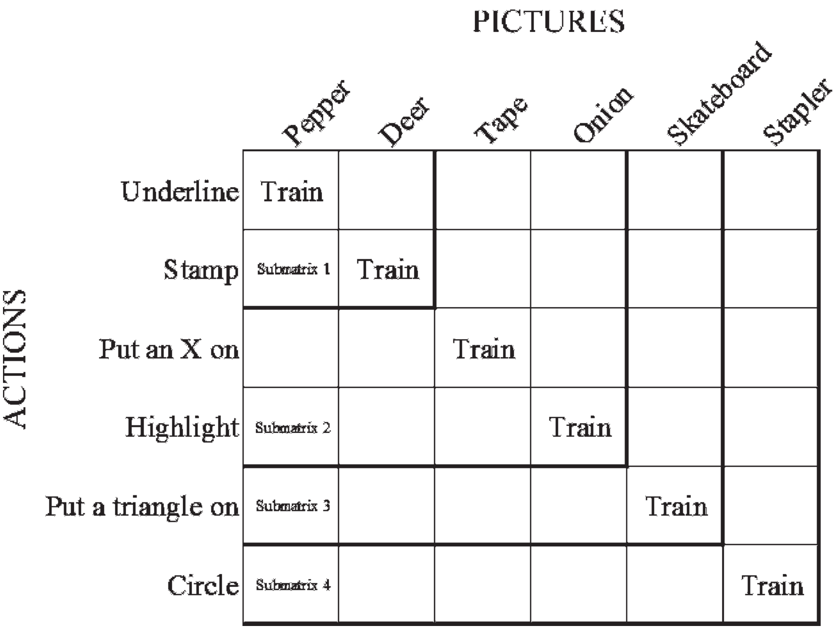

Figure 1. Action–picture matrix used for Matt, Trey, and Nina. Bold lines separate each submatrix, and each submatrix was assigned to a tier in the multiple probe design.

probability of their promoting untrained instruction following. For example, in Submatrix 2 (Figure 1), if we trained three cells with the action, "put an X on," and we trained only one cell with "highlight," we trained a new "highlight" cell. We probed two other 6 × 6 matrices at the beginning and end of the study. One matrix contained the same actions as the primary matrix with previously known pictures (e.g., animals and foods). The other matrix contained the same actions as the primary matrix with randomly selected, previously known letters and numbers (S, V, P, 4, 7, 9).

Procedure

The experimenter met with each participant once or twice per day, 5 days per week, for 10 to 30 min each meeting.

Preassessment. We conducted informal interviews with the participants' teachers to identify potential reinforcers and target skills. Potential reinforcers were enthusiastic praise, books, and preferred toys. Access to these items for 20 s to 40 s was used to reinforce compliance and correct responding during preassessments, warm-ups, probes, and training.

We conducted five 15-min preassessment sessions over the course of 5 days with each participant to identify actions, pictures, letters, and numbers to use in the study. First, the experimenter tested 13 actions by presenting the letter A on a sheet of paper and the cup of utensils and saying, "[action] on the A" (e.g., "circle the A," "stamp the A"). Second, the experimenter tested 30 pictures by presenting several sheets of paper with 12 different randomly distributed pictures on each paper and asking each participant, "Where is the [picture]?" Third, the experimenter tested receptive discrimination of letters and numbers by presenting four letters or numbers at a time and asking the participant to select a letter or number (e.g., "point to the 3"). We tested all the letters and numbers up to 20. Correct and incorrect responses did not produce feedback. If the participant did not make a response within 5 s, the experimenter repeated the instruction. If the participant did not make a response within another 5 s, the experimenter made a neutral statement (e.g., "okay") and delivered the next instruction. After every four to six trials, the experimenter presented known instructions (e.g., "clap your hands," "touch your head"), and compliance produced a choice of preferred items (e.g., books, toys).

The preassessment criterion to identify unknown actions was zero of three trials correct. Criterion to identify unknown pictures was zero of three presentations correct or less than 20% correct on at least six presentations. Criterion to identify distracter pictures was 75% correct or less on at least four presentations or 0% correct on two presentations. Criterion to identify known pictures, letters, and numbers was 100% correct in at least three presentations. As a result of this preassessment, five sets of targets were identified: unknown actions, unknown pictures, distracter pictures (to be presented on primary probe sheets with target pictures), known pictures (to be tested in a matrix at the beginning and end of the study), and known letters and numbers (to be tested in a matrix at the beginning and end of the study). Figure 1 is the primary matrix used by Matt, Trey, and Nina. Based on his performances on preassessments, Rex's matrix had "put a sun on" and "put a check on" instead of "stamp" and "circle." In addition, Rex's pictures were "onion," "anchor," "potato," "lettuce," "stapler," and "spinach."

Probes. A probe session occurred first during each meeting with a participant. Each probe session began with a warm-up in which the experimenter presented two to three known instructions (e.g., "touch your nose," "clap your hands"), and compliance resulted in a preferred item or choice of preferred items. In each probe trial, the experimenter presented a sheet of paper with six target pictures from the matrix, six distracter pictures, and the cup with utensils. The experimenter used three versions of the probe sheets so that the order of pictures was different for each trial. The order of instructions was also randomized, but diagonal trained instructions occurred before nondiagonal untrained instructions. After the warm-up, the experimenter presented each instruction to perform an action–picture combination in the form, "get ready, [action] the [picture]" with exaggerated and elongated inflection on the action and picture. Correct responses produced a choice of preferred items. Incorrect responses resulted in the presentation of the next trial with no feedback. If there was no response after 5 s, the experimenter repeated the instruction. If there was no response following another 5 s, the experimenter presented the next instruction. Following four to six consecutive incorrect responses or no responses, the experimenter presented two to three known instructions (e.g., "touch your head," "stomp your feet") and a preferred item contingent on compliance.

Training. In the training phase, a training session immediately followed the probe session. Each training session lasted 11 to 13 min and consisted of 20 to 40 trials. A training trial consisted of presenting the pictures, the utensils, giving the instruction, providing prompts, providing the opportunity for the participant to make a response, reinforcing correct responses, and re-presenting instructions and prompts contingent on errors (more details below). Each session started with the experimenter presenting two to three known instructions (e.g., "touch your tummy," "touch your ears") and a choice of preferred items contingent on compliance. Each training trial began with the presentation of the cup with utensils, a picture or pictures, and an instruction, "get ready, [action] the [object]" with elongated and exaggerated inflection on the action and picture. When training a new action–picture combination, the experimenter showed the picture alone and provided model and physical prompts to perform the action. According to the following seven steps, the experimenter gradually added distracters and faded prompts. Four correct responses at each step were required to proceed to the next step. In Step 1, the experimenter showed a picture alone, presented the instruction, modeled the response, re-presented the instruction, and physically guided the response. Step 2 was the same but the experimenter did not present the physical prompt. In Step 3, the experimenter presented a distracter picture with the target picture. Step 4 was the same as Step 3, but the experimenter only used a point prompt. In Step 5, the experimenter added a second distracter and did not use the point prompt. The experimenter used Step 6 only when a participant was learning two new instructions, as in Submatrices 1 and 2. In this step, the experimenter presented two new pictures with one distracter picture and alternated between the two target instructions. In Step 7, the experimenter presented the probe sheet (i.e., 12 pictures), and training occurred with the two target instructions. The training session ended when the participant correctly responded to the new action–picture combinations in Step 7 or when 13 min had passed.

In training sessions, the experimenter reinforced all prompted and unprompted responses. If at any step the participant did not respond within 5 s or performed an incorrect response, the experimenter immediately re-presented the instruction and presented the prompt from the previous step in the sequence (e.g., a model prompt after an error with a point prompt). A correct response with a prompt following an error was reinforced in Steps 1 through 3. In Steps 4 through 7, the experimenter did not reinforce a correct prompted response following an error. The experimenter re-presented the instruction without the prompt and then reinforced a correct response. After a participant progressed through Steps 1 through 7 for a particular action–picture combination, subsequent training sessions were slightly different. First, all training trials occurred with the probe sheet (i.e., 12 pictures were presented). Second, if a participant was incorrect on a particular instruction in the probe session, the experimenter presented a model prompt in the first training trial for that instruction.

We made procedural modifications for Rex, Trey, and Nina. For Rex, the general procedures were ineffective in establishing triangles and suns. We placed dots on the trained pictures for Rex to connect, and given correct responding, we faded the intensity of the dots in two phases across two sessions. We made three modifications for Trey. First, Trey resisted physical prompts, and they were not used. Second, because his underlines were too long, we placed dots under the pictures for him to connect. Third, when he was given an untrained instruction, he reached for the correct utensil and then pointed to the correct picture. When he reached for a utensil in the probes of Sessions 46 through 48, the experimenter pointed to it and said, "yes, [action] the [picture]."

We made seven modifications for Nina: three in the error-correction procedures, three in separating the components of the instructions, and one in the feedback for correct responses. These seven modifications were added and removed across training sessions as the experimenter attempted to bring her responding under stimulus control of the instructions. First, in Sessions 8 and 9, the experimenter presented known instructions (e.g., "give me five," "touch your head") between prompted, correct, unreinforced responses and unprompted, correct, reinforced responses. Second, in Sessions 8, 10, 11, 40, 43, 44, 45, 48, 49, and 54, the experimenter presented training trials with the same picture but different actions in fast alternation without reinforcement until Nina was correct with two different actions in two consecutive trials. Third, in Sessions 10, 22, 44, and 45, the experimenter said, "with which one do you [action]?" and reinforcement was contingent on selecting the utensil that matched the action. Fourth, in Sessions 11, 38, and 44, the experimenter gave Nina descriptive feedback following correct performances (e.g., "that's right, you stamped the deer"). Fifth, in

Sessions 12, 45, 46, and 47, the experimenter separated instructions according to this procedure: The experimenter said the action, Nina selected the utensil, the experimenter said the name of the picture, and Nina performed the action–picture combination. Sixth, in Sessions 38, 40, and 43, the experimenter did not reinforce prompted responses following errors and then re-presented the instruction with a preferred item delivered contingent on a correct response. Seventh, in Sessions 55 through 58, the experimenter presented a picture of a car (previously known) alone and prompted and reinforced the four actions from Submatrices 1 and 2 with the car.

Procedural Integrity

For measurement of procedural integrity, *correctly implemented training steps* was defined as following the scripted set of procedures according to Steps 1 through 7 in the Procedure. For example, in Step 1 (below), the experimenter presented the picture alone, gave the instruction, modeled the action response, said "you do it," presented a clean picture and the instruction, physically guided the response, and praised and delivered a reinforcer contingent on a correct response. Observers also measured correctly implemented steps in the probe, defined as the experimenter following the script for conducting probe sessions. This involved doing warm-up instructions, presenting the probe sheet with the correct instruction, reinforcing correct responses, and presenting known instructions following four to six incorrect responses. A second observer independently measured the integrity of the training and probe procedures in 22% to 24% of randomly selected probe and training sessions across participants. Integrity was calculated by dividing the correctly implemented steps by the sum of correctly and incorrectly implemented steps and converting the ratio to a percentage. Mean integrity was 95% for Matt and 99% for Rex, Trey, and Nina (range across participants, 91% to 100%). Mean integrity of implementing the probe procedures as described was 94% (range, 94% to 100%) across participants, phases, and submatrices, with the exception of a mean of 50% integrity (range, 0% to 100%) for Submatrix 3 of training for Rex. This score of 0% occurred when the observers measured only two responses in a session, and there was disagreement on these two responses.

Social Validity

After the study, data on social validity were collected from seven respondents: Rex's teacher, Nina's teacher, the participants' speech–language pathologist, the principal of the school, Matt's and Rex's mothers, and a kindergarten teacher. The experimenter explained the procedures and outcomes of the study, and the respondents watched 1- to 2-min video clips of probes at the beginning and end of the study as well as the training procedures. The respondents completed a questionnaire with seven questions, asking about the procedures using a 7-point Likert scale (e.g., How much do you like the teaching procedures? How confident are you that the procedures would be effective? How likely would you be to use matrix training?). Seven additional questions asked respondents to rate their agreement with statements about the outcomes on a 7-point Likert scale (e.g., the student learned language skills, the student learned preacademic skills, the student is more prepared for kindergarten, the teaching strategies were more efficient than typical teaching strategies, based on the outcomes I would recommend the teaching strategies). We also asked open-ended questions regarding strengths and weaknesses of the procedures and outcomes. The respondents rated the procedures a mean of 5.9 and outcomes a mean of 6.1, where 1 was *don't agree* or *unacceptable* and 7 was *strongly agree* or *acceptable*. A frequently noted concern was the transferability of the teaching procedures and matrix strategy from a one-on-one setting to a classroom situation.

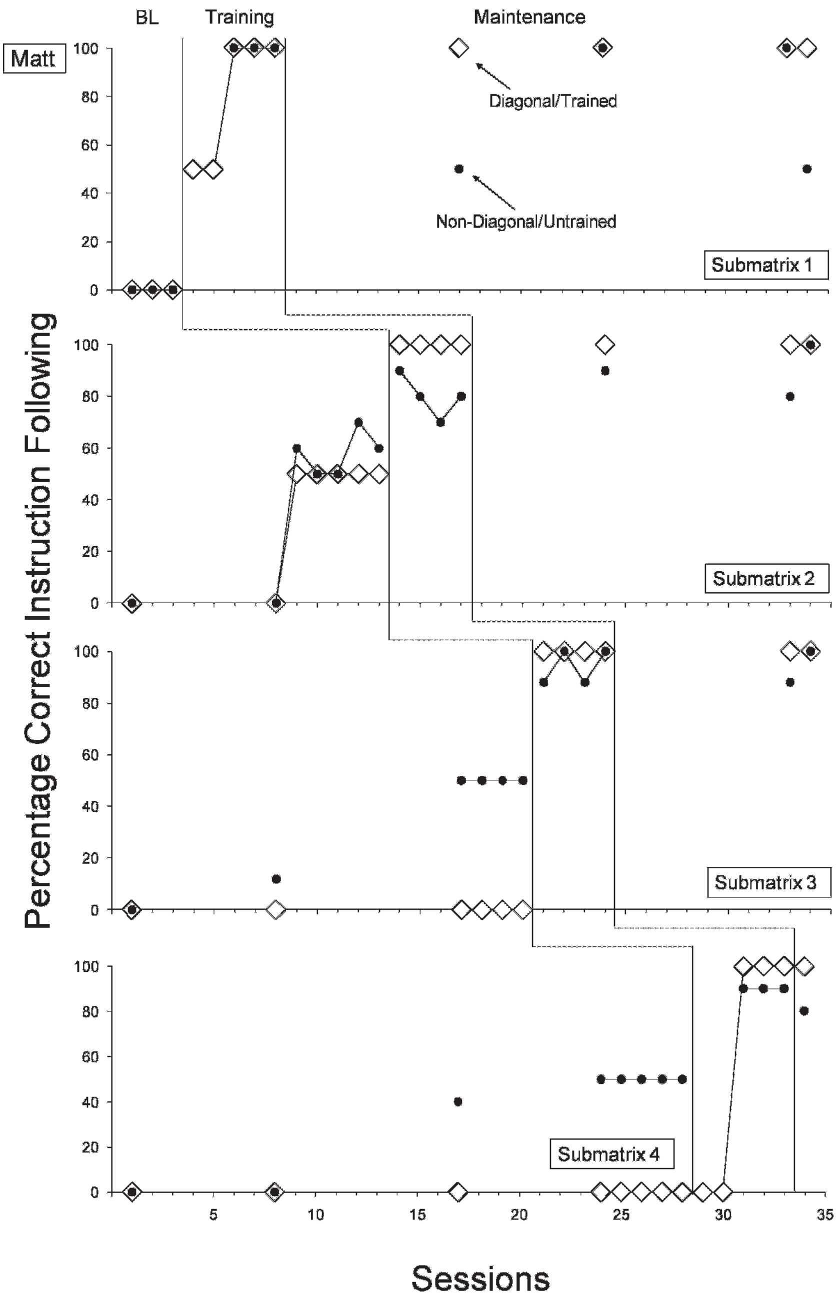

Figure 2. Matt's percentage of correct diagonal trained and nondiagonal untrained instruction following across the 36 instructions in the matrix.

RESULTS

Data for correct instruction following in the probes are displayed in Figures 2 through 5. Matt was 0% correct in baseline in Submatrix (S) 1 and near 50% correct in S2 through S4 (Figure 2). Training consistently produced 100% correct responding to diagonal trained instructions and 70% to 100% correct respond-

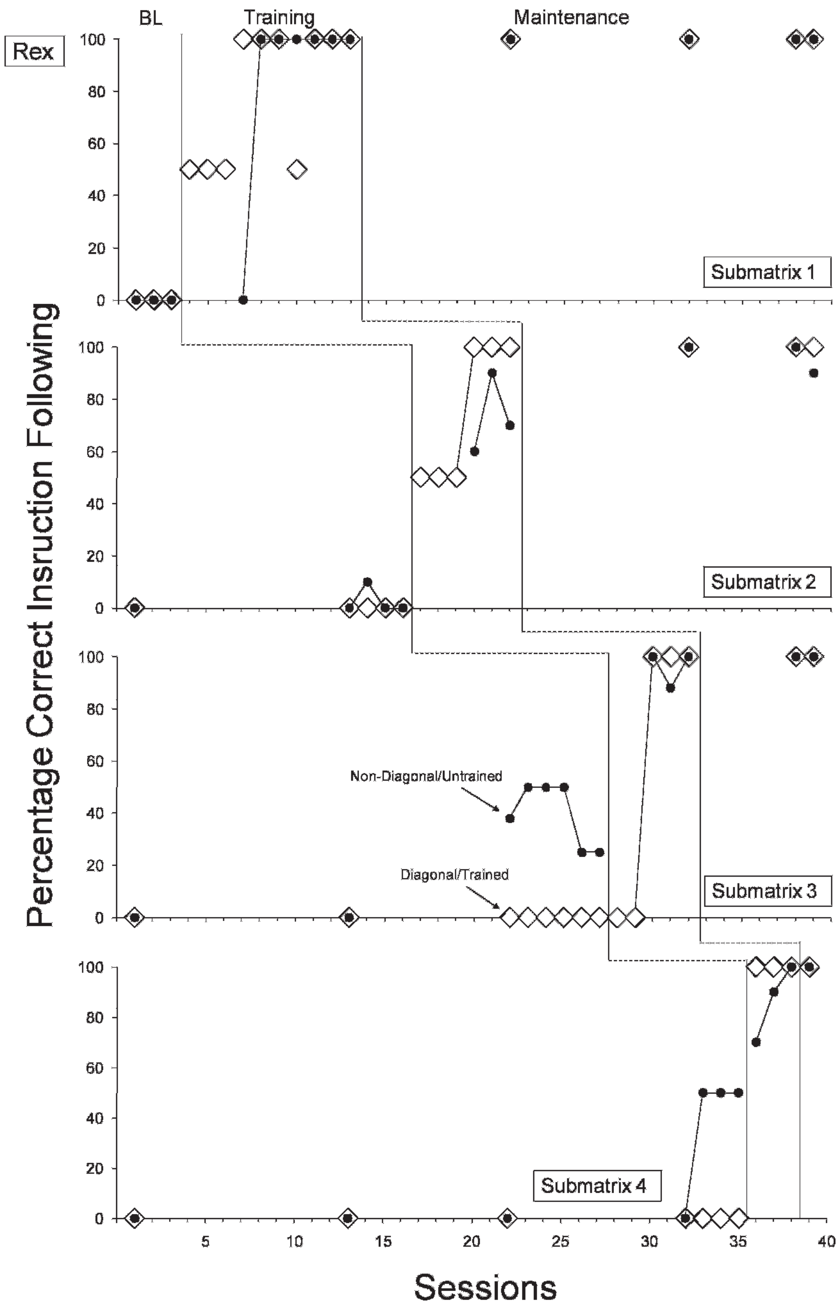

Figure 3. Rex's percentage of correct diagonal trained and nondiagonal untrained instruction following across the 36 instructions in the matrix.

ing to nondiagonal untrained instructions. Maintenance of responding was 80% to 100%, with the exception of two probes of nondiagonal untrained instructions in S1 at 50% correct. Results for Rex (Figure 3) were similar to Matt's. Rex's baseline responding was at or near 0% in S1 and S2, 0% for diagonal instructions in S3 and S4, and near 50% for nondiagonal instructions in S3 and S4. He required a few more training sessions than Matt

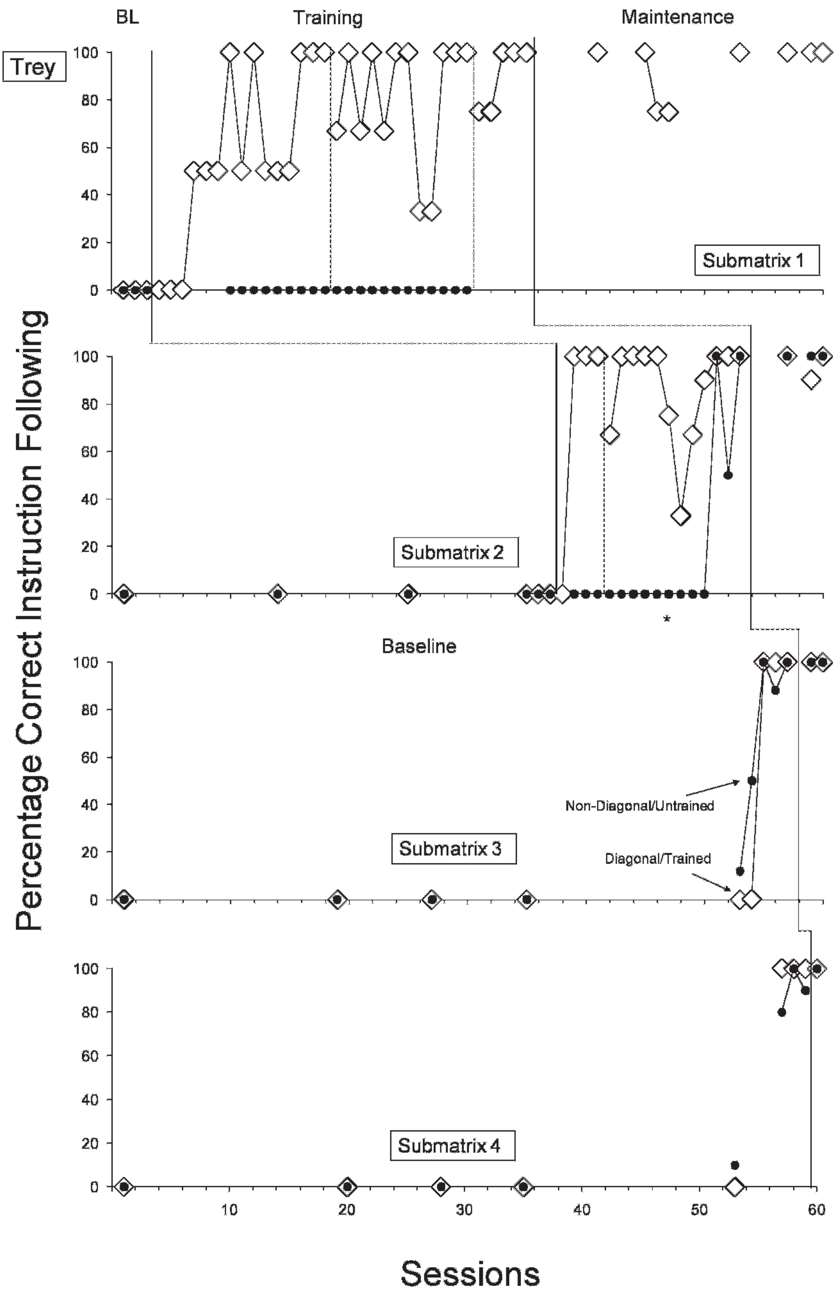

Figure 4. Trey's percentage of correct diagonal trained and nondiagonal untrained instruction following across the 36 instructions in the matrix. Vertical dotted lines indicate that a new cell was trained. The asterisk indicates when a procedural modification was implemented.

to meet criterion in S1 and S2. Maintenance was 100% correct in all but one session.

Trey was 0% correct in baseline in S1 and S2 (Figure 4). He received training on all four instructions from S1 and was 0% correct on nondiagonal untrained instructions. In S2, he met criterion on the two diagonal instructions but his behavior did not generalize, so he was

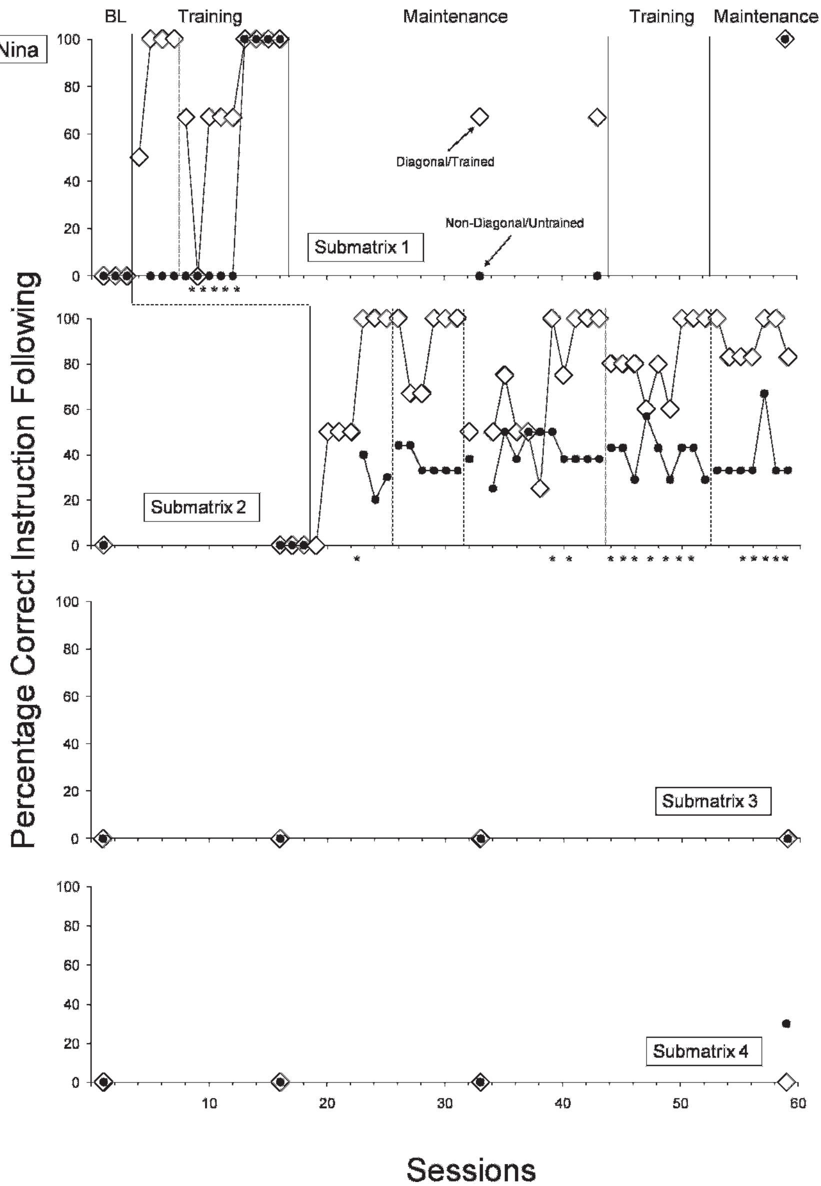

Figure 5. Nina's percentage of correct diagonal trained and nondiagonal untrained instruction following across the 36 instructions in the matrix. Vertical dotted lines indicate that a new cell was trained. Asterisks indicate when procedural modifications were implemented.

trained on an additional instruction ("highlight deer," represented by a dotted line on the graph). After meeting criterion on those three instructions, the third procedural modification (i.e., pointing to the correct utensil and saying, "yes, [action] the [picture]") was employed. This resulted in an initial decrease and then increase in correct responding to the trained instructions (Sessions 46 through 51). After 10 instructions received training as part of the modification (four were reinforced only once), the two untrained instructions were 100% correct. Following these performances, Trey's responding to all instructions in S3 and S4

Table 1
Correct Trained and Untrained Responding, Percentages of Learning Without Direct Training, and Percentage Correct on Untrained Cells

	Primary matrix		Matrix with known pictures		Matrix with known letters and numbers			
	Trained correct	Untrained correct	Trained correct	Untrained correct	Trained correct	Untrained correct	% learning without direct training	% correct on untrained cells
Matt	6	30	0	30	0	33	94	91
Rex	6	30	0	35	0	34	94	97
Trey	14	22	0	35	0	32	86	95

increased to between 80% and 100% correct without training. Responding was maintained at 70% to 100% correct.

For Nina, baseline responding was 0% correct in S1 and S2 (Figure 5). She followed one untrained instruction after training on three instructions in S1. In S2, she met criterion on five trained instructions, and untrained responding was 20% to 50% correct. In S2, criterion was not met for proceeding to a new submatrix. Because the untrained response in S1 was not maintained, it was retrained followed by 100% correct responding to all instructions in S1 in the maintenance condition. Responding in S3 and S4 remained at 0% correct, with the exception of the final probe in S4.

In the two additional 6 × 6 matrices of actions with previously known pictures and actions with previously known letters and numbers, Matt, Rex, and Trey were 0% correct prior to training. At the end of the study, Matt, Rex, and Trey were 83%, 97%, and 94% correct on the probes of actions with previously known pictures and 92%, 94%, and 89% correct on the probes of actions with letters and numbers, respectively. We did not conduct the probes with Nina because she did not complete the primary matrix.

In terms of overall learning, Matt and Rex were directly trained on six instructions (i.e., on the diagonal) and were probed on 102 untrained instructions. Matt responded correctly to 93 untrained instructions. This represents 94% of learning without direct training and 91% correct on untrained instructions (Table 1). Rex followed 99 untrained instructions correctly, representing 94% of learning without direct training and 97% correct on untrained instructions. Trey received training on 14 instructions and followed 89 instructions without direct training. This represents 86% of learning without direct training and 95% correct on untrained instructions.

DISCUSSION

Arranging actions, pictures, letters, and numbers in matrices and training a subset of the action–picture instructions consistently produced untrained instruction following with three of four preschoolers with autism. These results are consistent with previous research that demonstrated recombinative generalization with instruction following (Goldstein et al., 1987; Goldstein & Brown, 1989; Goldstein & Mousetis, 1989; Mineo & Goldstein, 1990; Nigam, Schlosser, & Lloyd, 2006; Striefel et al., 1978), labeling (Dauphin et al., 2004; Goldstein, 1983b; Karlan et al., 1982; Light, Watson, & Remington, 1990; Remington et al., 1990), reading (de Souza et al., 2009; Mueller, Olmi, & Saunders, 2000; Saunders, O'Donnell, Vaidya, & Williams, 2003), and spelling (de Rose, de Souza, & Hanna, 1996; Hanna, de Souza, de Rose, & Fonseca, 2004; Melchiori, de Souza, & de Rose, 2000). The results extend the literature by demonstrating recombinative generalization with preschoolers with autism and by targeting writing and picture-selection skills. Because the participants emitted writing skills in novel ways with letters and numbers, the results add to the relatively small literature on teaching literacy skills to children with autism (Koppenhaver & Erickson, 2003; Teale & Sulzby, 1986).

The largest benefit of matrix training is its efficiency, which comes primarily from training on only the diagonal of the matrix. Goldstein (1983a) recommended training on more than the diagonal when the individual components are unknown. This recommendation was not supported by Matt's and Rex's data, in that these two participants received training on the diagonal only. However, the recommendation was supported by Trey's and Nina's data, in that these participants required training on more than the diagonal before untrained responding emerged. For Matt, Rex, and Trey, 94%, 94%, and 86% of learning occurred without direct training, respectively. These results are consistent with Goldstein (1983b), Goldstein et al. (1987), and Goldstein and Mousetis (1989) in which untrained responding accounted for 56% to 75%, 94% to 98%, and 95% to 98% of learning, respectively.

Untrained instruction following can be explained in terms of establishing stimulus control of each component of the instruction over responding. The two components of the instruction exerted control in a specific order in the following way: The action portion of the instruction evoked selection of a particular utensil, the picture portion of the instruction evoked selection of a particular picture, and the action portion of the instruction evoked the production of a particular action. Once stimulus control was established with trained instructions, the terms in the instruction could be substituted with other trained terms to control novel action–picture responding. Matt and Rex came under control of instructions with novel combinations with relative ease, whereas Trey and Nina required extensive training for novel arrangements of terms in the instruction to exert control. Matrix training may be effective in producing generalized outcomes by sharing features with general case programming (Stokes & Baer, 1977), the technique of exposing an individual to all the types of stimuli encountered in a generalization setting. Diagonal training provides exposure to all stimuli encountered in generalization probes.

It is not clear why the four participants responded differently to matrix training. One limitation of the study was the absence of preassessment data on each child's ability to follow two-step instructions; this information could identify responders and nonresponders to training two-part instructions. Anecdotally, Rex readily followed complex instructions and Matt, Trey, and Nina often needed many prompts to comply with one-step instructions. When presented with an untrained instruction, Trey exhibited rigid responding in that he often reached for but did not grasp a writing utensil and then pointed to the picture. It was not until he was trained with many exemplars in the procedural modification that he performed untrained responses. Nina did not meet criterion on untrained responding in Tier 2 and did not complete training, a clear limitation of the study. Time constraints with the school did not allow further training. Nina's errors were often performing the trained action with a picture when instructed to perform a different action with the picture. For example, after correct responding to "put X on tape" and "highlight onion" (trained), she highlighted the onion when instructed to "put X on onion." Responding appeared to come more under the control of the picture portion of the instruction than the action portion, possibly because the picture portion was in closer proximity to the response. This learning problem is similar to stimulus blocking (Fields, 1979; Partington, Sundberg, Newhouse, & Spengler, 1994) and overselectivity (Dickson, Deutsch, Wang, & Dube, 2006; Lovaas, Koegel, & Schreibman, 1979), in which a child with autism focuses on irrelevant features of a stimulus. This error pattern was the rationale for the procedural modifications of having Nina first respond to the action (by selecting the utensil) and then respond to the picture as well as quickly alternating between trials with different actions with the same picture.

The correct baseline responding by Matt, Rex, and Trey was another limitation of the study, and three sources are possible. First, in S2, S3, and S4, the participants may have selected the correct picture through learning by exclusion (Ferrari, de Rose, & McIlvane, 1993). That is, they may have selected pictures other than those previously trained (e.g., in S1) and other than the distracter pictures, which they correctly selected on some preassessment trials. Second, whereas in early probes Trey pointed to the same picture when presented untrained instructions, in S3 and S4 he pointed to a variety of different pictures, and reinforcement may have facilitated stimulus control. The contingent reinforcement in the probes is one possible limitation of the study. Matrix training studies have been mixed in terms of programming contingent reinforcement in probes (Goldstein et al., 1987; Hanna et al., 2004; Saunders et al., 2003; Striefel et al., 1978). Striefel et al. argued that reinforced trial-and-error responding is a stringent control condition more closely approximating natural conditions than a probe condition with extinction for correct responding. A third explanation for baseline responding is that after the participants learned to respond correctly to instructions in the form of "do an action on a picture," the training may have brought to strength repertoires that were too weak to be detected in preassessments or prior baseline probes. For example, before the study Trey could not draw a circle, but he could receptively identify a circle. After training with drawing particular shapes on pictures, he was able to draw a circle on pictures without direct training.

Future research should address the limitations and further our knowledge of matrix training. Nina's data suggest the need to examine techniques for developing complex verbal stimulus control, and there is limited research in this area. General strategies include within-stimulus prompting in which each component of a verbal stimulus is more salient (Summers, Rincover, & Feldman, 1993; Wolfe & Cuvo, 1978) and requiring a differential observing response to each component of the verbal stimulus (Dube & McIlvane, 1999; Walpole, Roscoe, & Dube, 2007). These studies primarily used visual stimuli, and more research is needed in applying these techniques to vocal verbal stimuli. Researchers should evaluate verbal stimulus control by manipulating the order of words in two-component instructions, because responding may be restricted to the second component with some learners. Strategies for reducing baseline responding in future matrix-training studies include the use of more stringent preassessment criteria for unknown responses and not reinforcing probed responses. Nonsense variables could be used to minimize learning during baseline and would allow further analysis of the stimulus control properties of matrix training. In terms of other repertoires, matrices could incorporate letters and words with the same actions used in this study as well as letters and words on the vertical axis and prepositions on the horizontal axis (e.g., "write *bed* under the box," "write *shoe* next to the box"). This could be reversed so that participants touch "under *bed*" and "next to *shoe*." Matrix training has been evaluated solely with instruction following, labeling, and reading. It could be extrapolated to requesting or manding by having participants request reinforcers with adjectives (e.g., "I want the red candy," "I want the blue truck"). Conversation-type repertoires (i.e., intraverbals; Skinner, 1957) could be analyzed with matrix training with participants responding to two-component phrases (e.g., "What is a red food?" "What is a yellow drink?"). Finally, especially because it was a concern of the respondents in the social validity assessment, future researchers should examine training teachers and early intensive behavior intervention therapists to arrange teaching targets in matrices to promote efficient teaching.

The current research has practical implications for both students and teachers. Preschool students taught the skills trained in this study would likely be prepared for elementary school worksheets, such as those requiring students to "circle all the As," "put a triangle on all the Bs," and so on. Further, a respondent on the social validity questionnaire suggested that the skills addressed in this study are important for standardized testing. Providing young children with the skills (e.g., writing, discrimination) required to complete standardized testing could help to improve their test-taking repertoires and test scores. For teachers, matrix training offers a highly efficient teaching strategy on which teachers and therapists should capitalize. Teachers and therapists who work with children with autism often have an abundant number of skills they need to target. Arranging skills in matrices with two or more types of words taught simultaneously and programming learning to emerge without direct teaching must occur to help children with autism gain the language and literacy skills needed to succeed.

REFERENCES

Cooper, J. O., Heron, T. E., & Heward, W. L. (2007). *Applied behavior analysis* (2nd ed.). Upper Saddle River, NJ: Pearson.

Dauphin, M., Kinney, E. M., & Stromer, R. (2004). Using video-enhanced activity schedules and matrix training to teach sociodramatic play to a child with autism. *Journal of Positive Behavior Interventions*, *6*, 238–250.

Denton, K., & West, J. (2002). *Children's reading and mathematics achievement in kindergarten and first grade*. Washington, DC: U.S. Department of Education, National Center for Education Statistics.

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.

de Souza, D. G., de Rose, J. C., Faleiros, T. C., Bortoloti, R., Hanna, E. S., & McIlvane, W. J. (2009). Teaching generative reading via recombination of minimal textual units: A legacy of verbal behavior to children in Brazil. *International Journal of Psychology and Psychological Therapy*, *9*, 19–44.

Dickson, C. A., Deutsch, C. K., Wang, S. S., & Dube, W. V. (2006). Matching-to-sample assessment of stimulus overselectivity in students with intellectual disabilities. *American Journal on Mental Retardation*, *111*, 447–453.

Dube, W. V., & McIlvane, W. J. (1999). Reduction of stimulus overselectivity with nonverbal differential observing responses. *Journal of Applied Behavior Analysis*, *32*, 25–33.

Eikeseth, S., & Hayward, D. W. (2009). The discrimination of object names and object sounds in children with autism: A procedure for teaching verbal comprehension. *Journal of Applied Behavior Analysis*, *42*, 807–812.

Ferrari, C., de Rose, J. C., & McIlvane, W. J. (1993). Exclusion vs. selection training of auditory-visual conditional relations. *Journal of Experimental Child Psychology*, *56*, 49–63.

Fields, L. (1979). Acquisition of stimulus control while introducing new stimuli in fading. *Journal of the Experimental Analysis of Behavior*, *32*, 121–127.

Goldstein, H. (1983a). Recombinative generalization: Relationships between environmental conditions and the linguistic repertoires of language learners. *Analysis & Intervention in Developmental Disabilities*, *3*, 279–293.

Goldstein, H. (1983b). Training generative repertoires within agent-action-object miniature linguistic systems with children. *Journal of Speech and Hearing Research*, *26*, 76–89.

Goldstein, H., Angelo, D., & Mousetis, L. (1987). Acquisition and extension of syntactic repertoires by severely mentally retarded youth. *Research in Developmental Disabilities*, *8*, 549–574.

Goldstein, H., & Brown, W. H. (1989). Observational learning of receptive and expressive language by handicapped preschool children. *Education & Treatment of Children*, *12*, 5–37.

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.

Hanna, E. S., de Souza, D. G., de Rose, J. C., & Fonseca, M. (2004). Effects of delayed constructed-response identity matching on spelling of dictated words. *Journal of Applied Behavior Analysis*, *37*, 223–227.

Johnson, K. R., & Layng, T. V. J. (1992). Breaking the structuralist barrier: Literacy and numeracy with fluency. *American Psychologist*, *47*, 1475–1490.

Karlan, G. R., Brenn-White, B., Lentz, A., Hodur, P., Egger, D., & Frankoff, D. (1982). Establishing generalized, productive verb-noun phrase usage in a manual language system with moderately handicapped children. *Journal of Speech & Hearing Disorders*, *47*, 31–42.

Katims, D. S., & Pierce, P. L. (1995). Literacy-rich environments and the transition of young children with special needs. *Topics in Early Childhood Special Education*, *15*, 219–234.

Kinney, E. M., Vedora, J., & Stromer, R. (2003). Computer-presented video models to teach generative spelling to a child with an autism spectrum disorder. *Journal of Positive Behavior Interventions*, *5*, 22–29.

Koppenhaver, D. A., & Erickson, K. A. (2003). Natural emergent literacy supports for preschoolers with autism and severe communication impairments. *Topics in Language Disorders*, *23*, 283–292.

Layng, T. V. J., Twyman, J. S., & Stikeleather, G. (2004). Engineering discovery learning: The contingency adduction of some precursors of textual responding in a beginning reading program. *The Analysis of Verbal Behavior*, *20*, 99–109.

Light, P., Watson, J., & Remington, B. (1990). Beyond the single sign: The significance of sign order in a matrix-based approach to teaching productive sign combinations. *Mental Handicap Research*, *3*, 161–178.

Lovaas, O. I. (1987). Behavioral treatment and normal educational and intellectual functioning in young autistic children. *Journal of Consulting and Clinical Psychology*, *55*, 3–9.

Lovaas, O. I., Koegel, R. L., & Schreibman, L. (1979). Stimulus overselectivity in autism: A review of research. *Psychological Bulletin*, *86*, 1236–1254.

Mackay, H. A., Kotlarchyk, B. J., & Stromer, R. (1997). Stimulus classes, stimulus sequences, and generative behavior. In D. M. Baer & E. M. Pinkston (Eds.), *Environment and behavior* (pp. 124–137). Boulder, CO: Westview Press.

Massey, N. G., & Wheeler, J. J. (2000). Acquisition and generalization of activity schedules and their effects on task engagement in a young child with autism in an inclusive pre-school classroom. *Education and Training in Mental Retardation and Developmental Disabilities*, *35*(3), 326–335.

Melchiori, L. E., de Souza, D. G., & de Rose, J. C. (2000). Reading, equivalence, and recombination of units: A replication with students with different learning histories. *Journal of Applied Behavior Analysis*, *33*, 97–100.

Mineo, B. A., & Goldstein, H. (1990). Generalized learning of receptive and expressive action-object responses by language-delayed preschoolers. *Journal of Speech & Hearing Disorders*, *55*, 665–678.

Mirenda, P. (2003). "He's not really a reader …" Perspectives on supporting literacy development in individuals with autism. *Topics in Language Disorders*, *23*, 271–282.

Mueller, M. M., Olmi, D. J., & Saunders, K. J. (2000). Recombinative generalization of within-syllable units in prereading children. *Journal of Applied Behavior Analysis*, *33*, 515–531.

Nation, K., Clarke, P., Wright, B., & Williams, C. (2006). Patterns of reading ability in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *36*, 911–919.

Newborg, J., Stock, J. R., Wnek, L., Guidubaldi, J., & Svinicki, J. (1994). *Battelle Developmental Inventory*. Itasca, IL: Riverside.

Nigam, R., Schlosser, R. W., & Lloyd, L. L. (2006). Concomitant use of the matrix strategy and the mand-model procedure in teaching graphic symbol combinations. *AAC: Augmentative and Alternative Communication*, *22*, 160–177.

No Child Left Behind Act of 2001, 20 U.S.C. 70 § 6301 *et seq*. (2002).

Partington, J. W., Sundberg, M. L., Newhouse, L., & Spengler, S. M. (1994). Overcoming an autistic child's failure to acquire a tact repertoire. *Journal of Applied Behavior Analysis*, *27*, 733–734.

Rapin, I. (2006). Language and communication: Clinical assessment and differential diagnosis. In R. Tuchman & I. Rapin (Eds.), *Autism: A neurological disorder of early brain development* (pp. 51–67). London: Mac Keith Press.

Rehfeldt, R. A., & Barnes-Holmes, Y. (2009). *Derived relational responding applications for learners with autism and other developmental disabilities: A progressive guide to change*. Oakland, CA: New Harbinger.

Remington, B., Watson, J., & Light, P. (1990). Beyond the single sign: A matrix-based approach to teaching productive sign combinations. *Mental Handicap Research*, *3*, 33–50.

Roid, G. H., & Miller, L. J. (1995). *Leiter International Performance Scale—Revised*. Wood Dale, IL: Stoelting.

Saunders, K. J., O'Donnell, J., Vaidya, M., & Williams, D. C. (2003). Recombinative generalization of within-syllable units in nonreading adults with mental retardation. *Journal of Applied Behavior Analysis*, *36*, 95–99.

Sidman, M. (1994). *Stimulus equivalence: A research story*. Boston: Authors Cooperative.

Skinner, B. F. (1957). *Verbal behavior*. Englewood Cliffs, NJ: Prentice Hall.

Stokes, T., & Baer, D. (1977). An implicit technology of generalization. *Journal of Applied Behavior Analysis*, *10*, 349–367.

Striefel, S., Wetherby, B., & Karlan, G. (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 foundations for improvement* (pp. 267–326). Washington, DC: American Association on Mental Deficiency.

Summers, J. A., Rincover, A., & Feldman, M. A. (1993). Comparison of extra- and within-stimulus prompting to teach prepositional discriminations to preschool children with developmental disabilities. *Journal of Behavioral Education*, *3*, 287–298.

Sundberg, M. L., & Partington, J. W. (1998). *Teaching language to children with autism or other developmental disabilities*. Pleasant Hill, CA: Behavior Analysts, Inc.

Teale, W. H., & Sulzby, E. (1986). *Emergent literacy: Writing and reading*. Norwood, NJ: Ablex.

Touchette, P. E., & Howard, J. S. (1984). Errorless learning: Reinforcement contingencies and stimulus control transfer in delayed prompting. *Journal of Applied Behavior Analysis*, *17*, 175–188.

Walpole, C. W., Roscoe, E. M., & Dube, W. V. (2007). Use of a differential observing response to expand restricted stimulus control. *Journal of Applied Behavior Analysis*, *40*, 707–712.

Wolfe, V. F., & Cuvo, A. J. (1978). Effects of within-stimulus and extra-stimulus prompting on letter discrimination by mentally retarded persons. *American Journal of Mental Deficiency*, *3*, 297–303.

Yell, M. L., Drasgow, E., & Lowrey, K. A. (2005). No child left behind and students with autism spectrum disorders. *Focus on Autism and other Developmental Disabilities*, *20*, 130–139.

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