Published in final edited form as:

J Appl Behav Anal. 2016 June ; 49(2): 294–307. doi:10.1002/jaba.290.

A Sorting-to-Matching Method to Teach Compound Matching to Sample

Rachel S. Farber,

E. K. Shriver Center, University of Massachusetts Medical School; Department of Psychology, Western New England University

William V. Dube, and

E. K. Shriver Center, University of Massachusetts Medical School; Department of Psychology, Western New England University

Chata A. Dickson

Autism Curriculum Encyclopedia, New England Center for Children; Department of Psychology, Western New England University

Abstract

Individuals with developmental disabilities may fail to attend to multiple features in compound stimuli (e.g., arrays of pictures, letters within words) with detrimental effects on learning. Participants were 5 children with autism spectrum disorders who had low to intermediate accuracy scores (35% to 84%) on a computer-presented compound matching task. Sample stimuli were pairs of icons (e.g., chair-tree), the correct comparison was identical to the sample, and each incorrect comparison had one icon in common with the sample (e.g., chair-sun, airplane-tree). A 5-step tabletop sorting-to-matching training procedure was used to teach compound matching. The first step was sorting 3 single pictures; subsequent steps gradually changed the task into compound matching. If progress stalled, tasks were modified temporarily to prompt observing behavior. Following the tabletop training, participants were retested on the compound matching task; accuracy improved to at least 95% for all children. This procedure illustrates one way to improve attending to multiple features of compound stimuli.

Keywords

autism spectrum disorders; compound matching; matching to sample; sorting; sorting to matching; stimulus overselectivity

Matching to sample is a widely used procedure in applied behavior analysis, including discrete trial teaching approaches in special education. One type of matching task presents compound stimuli as samples. For example, if a child were asked to select the picture that

Correspondence concerning this article should be addressed to Rachel Farber, Shriver Laboratory, New England Center for Children, 33 Turnpike Road, Southborough, MA 01772, ; Email: rachel.farber@umassmed.edu; or W. V. Dube, University of Massachusetts Medical School, 55 Lake Ave. North S3-301, Worcester, MA 01655, ; Email: william.dube@umassmed.edu

Some of the data were presented in a poster at the Berkshire Association for Behavior Analysis and Therapy 2014 Annual Conference; we thank Drs. Kathleen Dyer and Timothy Vollmer for their constructive comments.

matched the printed phrase “blue shirt” from an array that included pictures of a blue shirt, blue hat, and red shirt, then stimulus control by both elements of the cue “blue shirt” as a compound would be necessary for accurate performance. Stimulus control restricted to only one of the elements (“blue” or “shirt”) would lead to errors on some trials. Responding to a restricted number of elements of compound stimuli as opposed to all of the relevant elements has been referred to as stimulus overselectivity or restricted stimulus control (Dube, 2009). Stimulus overselectivity was identified as a learning problem in children with autism spectrum disorders (ASDs) or intellectual disabilities over 30 years ago by Lovaas and colleagues (reviewed in Lovaas, Koegel, & Schreibman, 1979) and remains an active area of research (recent reviews include Brown & Bebko, 2012; Ploog, 2010).

Multiple-cue training is a promising approach for interventions to reduce or prevent stimulus overselectivity with compound stimuli. In multiple-cue training, the discriminative stimuli are compound stimuli and the training trials are arranged so that consistently correct responses require stimulus control by more than one stimulus. For example, in three early studies with simple visual discriminations, participants were trained to select the compound stimulus AB on every trial and reject the incorrect alternatives AC and A alone (Allen & Fuqua, 1985; Koegel & Schreibman, 1977; Schreibman, Charlop, & Koegel, 1982). A variation of this approach was used in a fourth study (Burke & Cerniglia, 1990) for a matching-to-sample task with compound verbal cues similar to the blue shirt example described above. In all of the four studies described above, children who were overselective on initial assessments improved at least to some extent after exposure to multiple-cue training with differential reinforcement (i.e., “trial and error” training).

Dube and McIlvane (1999) used a similar approach to eliminate stimulus overselectivity in a visual matching-to-sample task with two sample stimuli on every trial. The intervention added a compound matching requirement during the sample observation part of each trial. For example, if the sample stimulus on a trial was the compound AB, then the participant selected the identical compound AB from an array that also included AC and DB. As in the previous studies, the compound matching task was introduced with differential reinforcement and the study included only participants who could master the task after trial-and-error training.

Compound identity matching may thus be useful for verifying observation and discrimination of all elements in compound stimuli. It may be particularly useful as part of an intervention for stimulus overselectivity with individuals who have intellectual disabilities. The literature, however, provides little guidance for teaching this task to those unable to learn by trial-and-error training alone. The present study describes a programmed instructional method for teaching compound identity matching that is derived from a sorting-to-matching methodology originally used to teach identity matching to sample with single-element stimuli (Serna, Dube, & McIlvane, 1997). The sorting-to-matching approach was developed when Serna and colleagues observed that some individuals with severe intellectual disabilities, who did not learn to perform computer-presented identity matching after considerable training, were nevertheless able to sort objects into bins on the basis of identity relations (possibly the result of prevocational training).

The sorting version of the matching-to-sample procedure differs from the typical version in two ways. First, in the typical version the sample stimulus location is fixed; in the sorting version the participant may move the sample to different locations during the trial. Second, in the typical version, the participant selects a comparison stimulus by pointing to it (or clicking with a computer mouse, etc.); in the sorting version, the participant selects a comparison stimulus by placing the sample stimulus next to or on top of the selected comparison. For example, in the initial stage of the Serna et al. (1997) procedure, the comparison stimuli (small objects) were presented first within bins. The participant then was handed the sample stimulus (an object identical to one of the comparisons). The correct response was to place the sample object into the bin with the identical comparison. Compared to the typical version, the sorting version may facilitate observing because the participant (a) may observe the sample in order to move it to a new location, (b) may move the sample into close proximity with comparison stimuli to compare them, and (c) previously sorted stimuli may accumulate, resulting in an increased number of stimuli available for observation. Shimizu, Twyman, and Yamamoto (2003) compared typical and sorting versions of matching to sample presented on a computer screen to children with developmental disabilities. The children's accuracy was substantially higher with the sorting version than the matching version.

In subsequent stages of the Serna et al. (1997) sorting-to-matching method, the performance of sorting objects into bins on a tabletop was gradually transformed into computer-presented matching to sample by changing the task requirements over a series of steps: sorting objects on tabletop, matching objects on tabletop, matching two-dimensional visual stimuli on tabletop, changing the plane of the tabletop matching task from horizontal to vertical, and finally matching stimuli on the computer screen. The program was tested with five children; all five were taught to perform accurate matching on the tabletop, and transfer to the computer was successful with four of them. Although the sorting-to-matching approach was successful with individual stimuli, there have been no previous studies using it to teach identity matching with compound stimuli. The present study describes an adaptation of the sorting-to-matching procedure for use with compound stimuli. The methodology is illustrated with data from participants with ASDs and intellectual disabilities who had poor initial accuracy on a compound matching-to-sample task.

Method

Participants and General Methods

Five children diagnosed with ASDs and intellectual disability participated (see Table 1). All five participants attended schools for children with ASDs. These participants were selected for this study because of low or intermediate accuracy (i.e., $M < 85\%$) on a compound matching pretest (details below).

Experimental sessions were conducted at a table in a quiet area of the participant's school. Sessions were scheduled one to five days per week; each session was approximately 10 min in duration, and one to three sessions were conducted per day. The participant sat at a table and the experimenter sat behind and to the side of the participant. The stimuli for test and training conditions were 180 Mayer-Johnson picture communication symbols (Mayer-

Johnson, 2008). The stimuli for a generalized compound matching test were 180 black-and-white arbitrary forms generated for research purposes and unlikely to be familiar to participants (for examples see Dube & McIlvane, 1999; Johnson, Meleshkevich, & Dube, 2014). The stimuli measured approximately 1.5 cm by 1.5 cm and were displayed on a white background.

Prior to the experimental sessions, participants were taught to exchange poker-chip tokens for preferred items (edibles, leisure activities, money, etc.). The experimenter delivered a token for each correct response across all sessions and exchanged tokens after each session.

Computer-Presented Conditions

For computer-presented conditions, a 38.1 cm touchscreen monitor (Elo Touch Solutions model 1515L) was placed on the table in front of the participant. The touchscreen monitor was connected to a computer running software that presented all stimuli and recorded all responses.

All computer-presented conditions used matching-to-sample procedures. Each session consisted of 18 trials. A trial began with the presentation of a sample stimulus in the center of the monitor screen. A single response to the sample produced three comparisons on the bottom (single-stimulus pretest) or top (compound pretest, posttest, and generalized matching conditions) of the screen. A touch to the correct comparison was followed by a 2-s animated stars display, a computer-generated melody, and a token delivered by the experimenter. A touch to an incorrect comparison was followed by a 2-s black screen. Each trial was followed by a 3-s intertrial interval with a white screen.

All computer-presented sessions used a trial-unique stimulus presentation procedure in which different stimuli appeared on every trial. For each session, the computer software drew the stimuli for each trial at random and without replacement from the pool of 180 stimuli.

Single-stimulus identity matching pretest—A delayed matching-to-sample task was used as a screening test for accurate identity matching with single-icon stimuli. When the participant touched the sample stimulus, it disappeared and the comparisons were presented immediately (0-s delayed matching). The correct comparison was identical to the sample, and the incorrect comparisons were not identical. Participants continued to the compound matching pretest if accuracy was at least 89% for one session; all five participants met this criterion in one session.

Compound matching pretest—Figure 1 shows an example of a compound matching trial. At the start of each trial two sample stimuli appeared side-by-side in the center of the screen. When the participant touched the sample display area, the comparison array appeared at the top of the screen and the sample stimuli continued to be displayed (i.e., simultaneous matching to sample). The comparison array consisted of three stimulus pairs. The correct comparison was identical to the sample. Each of the incorrect comparisons included one stimulus identical to a sample stimulus and one stimulus different from both of the sample stimuli. For one incorrect comparison the left stimulus was identical to the left

sample stimulus, and for the other incorrect comparison the right stimulus was identical to the right sample stimulus. For example, if the sample was dragon-paddles, the correct comparison would be dragon-paddles, and the incorrect comparisons might be dragon-cherries and lighthouse-paddles (see Figure 1).

The duration of the pretest condition was arranged as a nonconcurrent multiple-baseline design across participants. Participants were assigned six, eight, or ten pretest sessions. If accuracy was 89% or greater for three consecutive sessions, participation was discontinued.

Compound matching posttest—After tabletop training (described below) was completed, participants received a compound matching posttest. The posttest procedure was the same as the pretest. The mastery criterion was six consecutive sessions with at least 89% accuracy.

Generalized compound identity matching test—Additional sessions were conducted to evaluate generalized identity matching with novel compound stimuli. The trial procedure and session characteristics were the same as the posttest, except that the stimuli were drawn from the pool of 180 black-and-white arbitrary forms.

Tabletop Training

For tabletop conditions, the experimenter recorded correct and incorrect responses on a paper data sheet. Interobserver agreement and procedural integrity were calculated for at least one session for each participant on each of the tabletop steps. For some tabletop sessions, an independent observer also scored responses on a duplicate data sheet; other tabletop sessions were recorded by a digital video camera and an independent observer scored from the videos. Interobserver agreement was calculated by dividing the number of agreements between the experimenter and the independent observer by the sum of agreements plus disagreements and converting the result to a percentage. The mean interobserver agreement for all participants was 99.8% (range, 98.8% to 100%). For procedural integrity, the independent observer scored whether the experimenter followed the procedure accurately on each trial: the prescribed sample was presented, the correct comparison was in the prescribed location, and the correct consequence was delivered. Procedural integrity was calculated by dividing the number of trials implemented accurately by the total number of trials and converting the result to a percentage. The mean procedural integrity for all participants was 98.8% (range, 97.6% to 100%).

The tabletop training sequence included five steps, four with a sorting procedure and a fifth with a matching-to-sample procedure. Table 2 summarizes the procedural differences among the five steps. For all tabletop training steps, a correct response was followed by verbal praise and a token delivered by the experimenter. An incorrect response was followed by the presentation of the next trial; there was no formal correction procedure. Each comparison position was correct equally often. Each session consisted of 18 trials.

Tabletop training Steps 1–4 were sorting tasks (see Figure 2). The steps differed with respect to stimulus type (single vs. compound), the sample position after the sorting response, and the number of different stimuli per session (see Table 2). The stimuli were printed on white

paper and at the same size as the computer display (1.5 cm by 1.5 cm). The paper with single stimuli was trimmed to approximately 2.8 cm by 2.8 cm, and compound pairs of stimuli to approximately 2.8 cm by 5.7 cm. The trimmed stimuli were laminated with thin layers of clear plastic and small bits of Velcro attached to the back of each one. The stimulus display area was a laminated letter-size sheet of white paper (21.6 cm by 27.9 cm) presented in landscape orientation with three evenly spaced strips of Velcro (each approximately 20 cm in length). Before the session began, a different comparison stimulus was placed at the top of each Velcro strip and the experimenter modeled a correct response. A trial began when the experimenter handed the sample to the participant and delivered the verbal cue "Put with." The correct response was placing the sample on the Velcro strip below the identical comparison. An incorrect response was placing the sample below one of the nonidentical comparisons. If the participant did not respond to the verbal cue within 3 s, the experimenter repeated the verbal cue. If the participant did not respond following the second verbal cue, the trial was discontinued and the next trial was presented; this was recorded as an incorrect response.

Step 1—The purpose of Step 1 was to introduce the sorting task and to verify accurate sorting with single stimuli. Stimuli were three single-stimulus samples and three-single stimulus comparisons identical to the samples. The comparisons at the top of the Velcro strips remained in place throughout the session. There were six copies of each sample stimulus, one for each of the 18 trials. The order of sample presentation was random with the restrictions that each sample stimulus was presented equally often and no sample was presented on more than three consecutive trials. Following a correct response, the sample remained in place below the identical comparison (and below any correctly sorted samples from previous trials) for the remainder of the session. Following an incorrect response, the experimenter removed the sample from the display.

Step 2—The purpose of Step 2 was to introduce the compound stimuli and to verify accurate sorting with a small set of compound stimuli. The procedure was the same as Step 1, except the sample and comparison stimuli were compound pairs. As in Step 1, one set of three comparison stimuli was used for an entire session and these stimuli did not change position from trial to trial. A different set of stimuli was used for each session. The composition of the comparison array was similar to that of the computer-presented compound matching procedure in that two of the comparisons had the same left-side stimulus and two of the comparisons had the same right-side stimulus. Thus, one of the comparisons had one stimulus in common with each of the other comparisons; the other two comparisons had no stimuli in common with each other (see the comparison array in Figure 2, Step 2).

Step 3—The purpose of Step 3 was to begin transforming the sorting task to more closely resemble matching to sample by removing the sorted samples immediately following each trial. The procedure was the same as Step 2, except the experimenter removed the sample stimulus after each trial. Thus, at the start of each trial, only the three comparisons were on the display.

Step 4—The purpose of Step 4 was to introduce the trial-unique stimulus presentation procedure used in the computer-presented compound matching. The procedure was the same as Step 3 with two exceptions. First, stimulus presentation was trial-unique; the experimenter removed the sample and comparison stimuli after each trial and replaced them with a different set of comparison stimuli for the next trial. No stimulus appeared on more than one trial within a session. Because each comparison array appeared for only one trial, this step differed from Steps 1–3 in that two of the comparisons on each trial were never the correct comparison within the current session. Second, both of the incorrect comparisons on each trial included one stimulus identical to a sample stimulus and one stimulus different from both of the sample stimuli (as in computer-presented compound matching).

The criterion to complete Step 1 was one session with at least 89% accuracy. The criterion for Steps 2, 3, and 4 was three consecutive sessions with at least 89% accuracy. If accuracy was lower than 89% for three consecutive sessions, the current training step was temporarily modified to include a prompted scanning procedure.

Prompted scanning—The prompted scanning procedure was designed to increase the probability that the participant would observe the sample and comparison stimuli before responding. At the beginning of each trial the experimenter placed a laminated sheet of white paper with no Velcro strips beneath the comparison array, covering the Velcro on the display and any samples from previous trials. The experimenter then placed the sample stimulus at the bottom center of this blank sheet of paper. During the first six trials of each prompted scanning session, the experimenter physically guided the participant's hand to slide the sample to a position directly below the left, then center, and then right comparison, pausing for 1 s at each of the three comparisons (see Figure 3). The experimenter extended the pause if needed until the participant's eyes were oriented towards the sample and comparison for 1 s. The experimenter then removed the white sheet of paper, handed the sample to the participant and stated the cue "Put with." The remainder of the trial procedure was the same as the current training step.

After the first six trials, the experimenter no longer physically guided the participant to move the sample. At any point in the session, however, if the participant did not move the sample below each comparison, pause for 1 s, and orient his or her eyes towards the sample and comparisons, the experimenter resumed physical guidance for two additional trials. The criterion to discontinue the prompted scanning modification and return to the unmodified procedure for the current training step was three consecutive sessions with at least 89% accuracy across all trials in the session, regardless of whether the prompted scanning procedure required physical guidance. Independent scanning was not required.

Step 5: Tabletop matching to sample—The purpose of Step 5 was to complete the transformation of sorting to matching by changing the response requirement from moving stimuli to merely touching them, as in the computer-presented format. Step 5 of the tabletop training procedure was a matching-to-sample task with a trial-unique stimulus presentation. The task displays were printed sheets of paper with a compound sample in the center and three compound comparisons at the top (as in the computer-presented pretest). The displays were presented upright and attached to the touchscreen monitor. Each trial started with the

sample stimuli displayed and the comparison stimuli covered by a white paper flap. After the participant touched the sample, the experimenter uncovered the comparison array. A touch to the correct comparison was followed by verbal praise and a token; a touch to an incorrect comparison ended the trial. Two practice trials were presented before each session. On these practice trials, the experimenter manually prompted the participant to touch the sample and then touch the correct comparison (results of practice trials were not included in data analyses). The criterion to advance to the computer-presented compound matching posttest was three consecutive sessions with at least 89% accuracy.

Results

Compound Matching Pretest

The closed circles in the leftmost portions of the plots in Figure 4 show compound matching pretest accuracy scores (note y-axis range varies across plots). Mean accuracy scores were low for four participants: B86, 35% (range, 17% to 50%); B65, 54% (44% to 61%); B89, 52% (44% to 67%); and B68, 49% (33% to 72%). Participant B15's mean accuracy was higher than the other four participants (84%), but his performance was variable over 10 sessions (67% to 94%), and he did not meet the pretest termination criterion of three consecutive sessions with at least 89% accuracy.

Tabletop Training

Accuracy for the tabletop training is shown by the triangles in the center portions of Figure 4. The closed triangles show accuracy on unmodified Steps 1 through 5, and the open inverted triangles show accuracy with the prompted scanning procedure. With two exceptions, accuracy scores were high and participants met the criteria to advance from step to step in the minimum number of sessions.

The first exception was Participant B65 on Step 2, when compound stimuli were introduced (see second graph of Figure 4). His accuracy scores fell from 78% to 61% over the first three sessions. When the prompted scanning procedure was applied to Step 2, accuracy was variable in the first three sessions (50%, 94%, and 67%), but increased in the following three sessions to at least 89%. When Step 2 resumed without prompted scanning, B65 met the criterion to advance to Step 3 in the first three sessions and completed the rest of the tabletop training program in the minimum number of required sessions.

The second exception was Participant B68 on Step 4, when the trial-unique stimulus procedure was introduced for sorting compound stimuli. Accuracy scores were 28% to 39% in the first three sessions. The prompted scanning modification for Step 4 was immediately effective, with at least 89% accuracy in the first three sessions. When Step 4 resumed without prompted scanning, B68 immediately met the criterion to advance to Step 5 and then completed the tabletop training in three additional sessions.

Compound Matching Posttest

Closed circles in the right portions of Figure 4 show accuracy on the compound matching posttest. All five participants immediately met the mastery criterion with at least 89%

accuracy for six consecutive sessions. Mean posttest accuracy ranged from 95% for Participant B15 to 99% for Participants B86, B89, and B68. Pretest-posttest improvements in mean accuracy were large (increases of 43 to 64 percentage points) for all participants except B15 (increase of 11 percentage points) because his mean pretest accuracy was relatively high. Across-session variability in accuracy during the posttest was less than the pretest for each of the five participants.

Generalized Compound Identity Matching Test

For three participants, the generalized matching test with novel stimuli was conducted within two months of the posttest ($M = 13$ days; range, 0 to 36). For participants B86 and B15 this test could not be conducted until 4 and 12 months, respectively, after the posttest due to a scheduling conflict at another testing site. Because of this gap, B86 and B15 each received two additional posttest sessions immediately prior to the generalized matching test (last two closed circles in Fig. 4). The results of these tests verified continued criterion-level compound matching accuracy (89%) with the stimulus set used for training.

Open circles in the rightmost portion of each plot in Figure 4 show accuracy scores for the generalized compound identity matching test. Participants B86, B65, and B89 immediately met the mastery criterion of at least 89% accuracy for six consecutive sessions. Mean accuracy scores ranged from 95% for B86 to 99% for B89. Participant B15's accuracy scores ranged from 78% to 89% for the first four sessions, but then met the mastery criterion during the next six sessions with a mean of 93%. Participant B68's accuracy score was 67% in the first test session, but then improved to a mean of 97% over the next six sessions.

Discussion

Five participants with ASDs and intellectual disabilities had high accuracy scores on a computer-presented identity matching task with the single-stimulus Mayer-Johnson communication symbols but low or intermediate accuracy with a compound matching version of the task. After exposure to a tabletop sorting-to-matching training program, all participants displayed high accuracy on the computer-presented compound matching task with the stimulus set used for training. Three participants also had immediately high accuracy with unfamiliar black-and-white arbitrary forms.

The current study illustrates a method for establishing generalized compound identity matching. Following the model provided by Serna et al. (1997), our training procedure began with a sorting task and gradually transformed it into generalized compound matching. High accuracy on compound matching tasks requires discrimination of all of the elements of a complex or multi-element stimulus. Teachers and practitioners may use this skill as part of a strategy for teaching effective responding under the control of complex stimuli relevant to an instructional goal, such as the discrimination of printed words consisting of multiple letters (Yoo & Saunders, 2014).

We designed the tabletop training program by analyzing the individual component skills required for successful compound matching. Accurate performance on each step provided a recent reinforcement history for component skills that were likely behavioral prerequisites

for the next step. The high accuracy scores throughout almost all of the training verified that each participant performed the component skill(s) required for each program step, including effective observing behavior. Three participants (B86, B89, and B15) completed the tabletop training program in the minimum number of required sessions. In contrast, accuracy fell for two participants at one point in the program: B65 when compound stimuli were introduced and B68 when the trial-unique stimulus procedure was introduced. In both cases, exposure to the prompted scanning procedure was sufficient to recover high accuracy. We designed the prompted scanning procedure to encourage more effective observing by prompting participants to put the sample in close proximity with each comparison stimulus, and requiring that the participants look at the stimuli. The results were consistent with an interpretation that the procedure was effective because it improved observing behavior. In future research, an eye-tracking apparatus may be useful to provide quantitative data to inform this interpretation.

Differential consequences for correct and incorrect responses were provided throughout the study, including the posttests for compound and generalized compound identity matching. However, the specific stimuli presented on each trial varied, making it highly unlikely that the accurate performance on these tests was due to a recent reinforcement history for matching specific stimulus compounds. With the trial-unique stimulus presentation procedure, a pool of 180 stimuli was used and stimuli for each trial within a session were drawn from this pool at random. Therefore, it seems most likely that participants in this study acquired a generalized repertoire of compound identity matching. High accuracy on the posttests shows stimulus control by the identity relation between the sample and correct comparison stimuli (Dube, McIlvane, & Green, 1992). High accuracy in the first session of the generalized compound matching test provides further support that generalized compound matching had been established with black-and-white arbitrary forms (the generalized compound matching condition) for three participants, B86, B65, and B89.

Accuracy on the generalized compound identity matching tests was initially low for Participants B15 and B68. One interpretation of this outcome is that, for these two participants, the training program with the Mayer-Johnson communication symbols had produced stimulus control primarily by the color differences among the stimuli. With the trial-unique stimulus presentation procedure, stimulus control by color alone would be sufficient for a correct response on almost every trial; the exception would be the very few trials on which the color(s) of the non-matching stimulus within an incorrect comparison pair was identical to the corresponding component stimulus within the sample pair (and on trials like this there would still be a 50% chance of a correct response). If this interpretation is correct, the initially poor performance on the generalized identity matching test with black-and-white arbitrary forms may have been due to the sudden absence of color differences among the comparison stimuli, and the subsequent increase in accuracy due to a shift in stimulus control from color to shape.

Although the tabletop training procedure established generalized compound identity matching with all five participants with few errors, the study was not designed to show that all of the components of the procedure were necessary. Perhaps a procedure with fewer training steps or a less stringent criterion for advancing from one step to the next would have

been just as effective and more efficient. The consistently high accuracy scores throughout the training program for three subjects could be taken to indicate that some of the training steps were not necessary, or that fewer sessions could have been programmed for each step. One approach to improving efficiency of the training procedure in future research is to conduct a component analysis by inserting a posttest probe after completion of each training step. Posttest probes following each training step could allow the experimenter to identify those steps of the sorting-to-matching program required for a given participant. Data from multiple participants may suggest which training steps, if any, could be eliminated. It is also possible that the prompted scanning procedure alone may have been sufficient to establish compound matching for some participants. Finally, it is possible that tabletop training was not necessary. Tabletop training was conducted in the current study for three reasons: (a) evaluation of the teaching procedure could be completed (and modified if necessary) more quickly with a tabletop procedure than with a computer-presented format that would require additional software, (b) computer-presented sorting would add new and possibly complex response requirements, and (c) the participants had extensive experience with tabletop sorting and matching procedures, and we thought this experience may facilitate acquisition of the matching task. Individuals who had not previously learned to sort cards on a tabletop would not be good candidates for this type of instruction; any such individuals would fail Step 1 of tabletop training. In future research, each of the training steps, including prompted scanning, could be programmed in a computer-presented format.

A computer-based program of instruction that provides the necessary and sufficient training to establish complex discrimination could be useful to educators and practitioners seeking to teach these skills. Use of computer-delivered instruction is increasing in special education programs (for reviews, see Pennington, 2010; Weng, Maeda, & Bouck, 2014). Ultimately, an automated, effective program of instruction could be more efficient or economical than a teacher-led tabletop procedure for certain instructional goals that do not require social interaction. Such a program optimally would include (a) careful assessment of an individual student's current repertoire, (b) adequate analysis of the components required for the terminal repertoire, (c) effective procedures for teaching and verifying these component skills, and (d) empirically validated algorithms for progressing through training steps, and returning to previous steps or branching to remedial steps, as needed. With today's computer processing capabilities and research base in discrimination learning and behavioral education we have access to the tools we would need to realize Skinner's (1954) vision for the teaching machine, where classroom instruction is largely automated, and educators are available to focus on troubleshooting problems of learning and teaching skills that require a live instructor. Even as technology allows for instruction to be increasingly automated, however, tabletop instruction will continue to be an important medium in special education. Teachers using this format can quickly modify and individualize curriculum when lags in learning occur.

Acknowledgments

Research and manuscript preparation was supported by the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development under award numbers R01HD062582 and P30HD004147. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of

Health. We also thank Eileen Grant, Marlana Mueller, and Katherine Nolan for assistance with data collection and analysis, and Ben Wallace and Dr. Christophe Gerard for computer software.

References

- Allen KD, Fuqua RW. Eliminating selective stimulus control: A comparison of two procedures for teaching mentally retarded children to respond to compound stimuli. *Journal of Experimental Child Psychology*. 1985; 39:55–71. [PubMed: 3989462]
- Brown SM, Bebko JM. Generalization, overselectivity, and discrimination in the autism phenotype: A review. *Research in Autism Spectrum Disorders*. 2012; 6:733–740.
- Burke JC, Cerniglia L. Stimulus complexity and autistic children's responsivity: Assessing and training a pivotal behavior. *Journal of Autism and Developmental Disorders*. 1990; 20:233–253. [PubMed: 2347822]
- Dube, WV. Stimulus overselectivity in discrimination learning. In: Reed, P., editor. *Behavioral theories and interventions for autism*. New York: Nova Science Publishers; 2009. p. 23–46.
- Dube WV, McIlvane WJ. Reduction of stimulus overselectivity with nonverbal differential observing responses. *Journal of Applied Behavior Analysis*. 1999; 32:25–33. [PubMed: 10201101]
- Dube WV, McIlvane WJ, Green G. An analysis of generalized identity matching-to-sample test procedures. *The Psychological Record*. 1992; 42:17–28.
- Johnson C, Meleshkevich O, Dube WV. Merging separately established stimulus classes with outcome-specific reinforcement. *Journal of the Experimental Analysis of Behavior*. 2014; 101:38–50. [PubMed: 24248538]
- Koegel RL, Schreibman L. Teaching autistic children to respond to simultaneous multiple cues. *Journal of Experimental Child Psychology*. 1977; 24:299–311. [PubMed: 915433]
- Lovaas OI, Koegel RL, Schreibman L. Stimulus overselectivity in autism: A review of research. *Psychological Bulletin*. 1979; 86:1236–1254. [PubMed: 515280]
- Mayer-Johnson. *Picture communication symbols: Boardmaker version 6* [Computer software]. Solana Beach, CA: Mayer-Johnson; 2008.
- Pennington RC. Computer-assisted instruction for teaching academic skills to students with autism spectrum disorders: A review of literature. *Focus on Autism and Other Developmental Disabilities*. 2010; 25:239–248.
- Ploog BO. Stimulus overselectivity four decades later: A review of the literature and its implications for current research in autism spectrum disorder. *Journal of Autism and Developmental Disorders*. 2010; 40:1332–1349. [PubMed: 20238154]
- Schreibman L, Charlop MH, Koegel RL. Teaching autistic children to use extra-stimulus prompts. *Journal of Experimental Child Psychology*. 1982; 33:475–491. [PubMed: 7097156]
- Serna RW, Dube WV, McIlvane WJ. Assessing same/different judgments in individuals with severe intellectual disabilities: A status report. *Research in Developmental Disabilities*. 1997; 18:343–368. [PubMed: 9292929]
- Shimizu H, Twyman JS, Yamamoto J. Computer-based sorting-to-matching in identity matching for young children with developmental disabilities. *Research in Developmental Disabilities*. 2003; 24:183–194. [PubMed: 12742387]
- Skinner BF. The science of learning and the art of teaching. *Harvard Educational Review*. 1954; 24:86–97.
- Weng P, Maeda Y, Bouck EC. Effectiveness of cognitive skills-based computer-assisted instruction for students with disabilities: A synthesis. *Remedial and Special Education*. 2014; 35:167–180.
- Yoo JH, Saunders KJ. The discrimination of printed words by prereading children. *European Journal of Behavior Analysis*. 2014; 15:123–135. [PubMed: 25620886]

Computer-presented Compound Matching

Figure 1.
Example trial for computer-presented compound matching pretest and posttest (stimuli not drawn to scale).

STEP 1

STEP 2

STEP 3

STEP 4

Figure 2.

Tabletop training display examples for Steps 1–4. For Steps 1 and 2, the figure shows the display after correct responses on four trials. For Steps 3 and 4, the figure shows displays for four successive trials and a correct response on the fourth trial.

Prompted Scanning

Figure 3.

Prompted scanning modification for tabletop training. The dotted lines show the path on which the participant slid the sample stimulus, and “PAUSE” shows the locations under the comparisons for 1-s pauses.

Figure 4.

Accuracy scores for successive sessions. Closed and open circles depict computer-presented conditions with color symbols or arbitrary forms, respectively. Closed triangles and open inverted triangles depict tabletop training steps unmodified or with prompted scanning (PS), respectively.

Table 1

Participant Description

Participant	Sex	CA	MAE	ADOS	DAS-II	Verbal Behavior
B86	M	14	4.75	Autism	37	1–3 word vocal mands
B65	M	14	2.25	Autism	30	1-word vocal mands
B89	M	12	6.5	Autism	60	Full vocal sentences: mands, tacts, intraverbals
B15	M	13	7.92	ASD	51	Full vocal sentences: mands, tacts, intraverbals
B68	F	15	< 2 (untestable)	Autism	32	Vocal approximation, full sentences with AAC: mands, tacts, intraverbals

Note. M = Male, F = Female, CA = chronological age in years, MAE = PPVT 4 mental-age-equivalent in years, ADOS = diagnostic category based on Autism Diagnostic Observation Schedule scores in the communication and social interaction domains, DAS-II = Differential Abilities Scales II; General Conceptual Ability Score (a standardized score).

Table 2

Summary of Tabletop Training Procedures

Step	Stimuli	After Sorted	# of Stimuli	Procedure
1	Single	Remained	3	Sorting
2	Compound	Remained	3	Sorting
3	Compound	Removed	3	Sorting
4	Compound	Removed	54	Sorting
5	Compound	N/A	54	Matching

Note. *After Sorted* = position of sample stimuli after sorting response, either remained on the display or removed from the display by the experimenter. *# of Stimuli* = number of different stimuli within each session, including incorrect comparison compounds for trial-unique procedures.