Recombinative Generalization of Tacts Through Matrix Training with Individuals with Autism Spectrum Disorder

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Abstract Foss (*Journal of Experimental Psychology*, 76, 450–459, 1968a; *Journal of Experimental Psychology*, 77, 341–344, 1968b) compared overlap and non-overlap instruction to promote recombinative response generalization using a matrix training procedure. In the present study, we used a similar set of procedures to teach tacting of kitchen items and prepositions (i.e., relational autoclitics) to three females ages 13–20, diagnosed with autism spectrum disorder. We taught some kitchen items/prepositions as tacts (e.g., “the strainer is to the right of the box”) according to a non-overlap instructional sequence. Subsequently, we taught more combinations in an overlap instructional sequence. Each training procedure was followed by probes of untrained relations. Two participants demonstrated recombinative generalization of untrained combinations following the first non-overlap phase, while the third participant demonstrated some response generalization of untrained relations after a few additional training sequences. All three participants demonstrated generalized tacting of object components while two participants showed generalized tacting of preposition components.

Keywords Autism · Generalization · Matrix training · Prepositions · Relational autoclitics · Tacts

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Acquisition of communication skills is a high priority for individuals with autism. They may, however, require comprehensive and time-consuming instruction across a variety of skill domains. As a result, service providers must often prioritize skills when planning the sequence and scope of intervention. Therefore, instructional efficiency is an important consideration when selecting teaching procedures. Two important factors that contribute to instructional efficiency are the rate of acquisition and generalization. It is therefore relevant to identify teaching procedures that produce generalization while maintaining an acceptable rate of acquisition.

Generalization increases instructional efficiency because it eliminates the need to explicitly teach some responses (response generalization) or eliminates the need to teach the same response across multiple antecedent conditions (stimulus generalization). Stokes and Baer (1977) identified several procedures to promote generalization. A key element to programming for generalization is the use of multiple exemplars (Baer 1981; Stokes & Baer). Despite the potential for increased efficiency, the use of multiple exemplars can be time consuming if a large number of exemplars need to be taught before generalization occurs. It is therefore important to find procedures that may reduce the number of exemplars required to produce generalization or otherwise maximize the efficiency of multiple-exemplar training.

Alessi (1987) discussed a form of generalization in terms of “minimal response repertoires” (e.g., minimal echoic and textual repertoires). As an example, an individual might be able to transcribe all possible English words (a universal set) after being taught to transcribe the 26 letters of the alphabet (a generative set). This outcome involves the recombination of previously mastered responses each of which is under specific stimulus control. Thus, this type of generalization has been referred to as recombinative generalization. Goldstein (1983a) defined recombinative generalization as “differential responding to novel combinations of stimulus components that have been included previously in other stimulus contexts” (p. 280).

Matrix training is an approach that has been frequently used to produce recombinative generalization. Matrix training involves the use of a matrix as an instructional planning technique for the purposes of generating a set of untrained response combinations (i.e., responses consisting of at least two distinct components). In general terms, matrix training involves direct teaching of a subset of combinations followed by probes of untrained combinations. Students demonstrate recombinative generalization if they emit untrained response recombinations when novel (i.e., untrained) stimulus combinations are presented (Goldstein 1983). As an example of recombinative generalization, a child may be taught to emit the tacts “red circle” and “yellow triangle” in the presence of those specifically colored shapes. If the child is able to tact “yellow circle” or “red triangle” as a result of this history, recombinative generalization has occurred. Often, matrix training does not involve teaching of individual components (e.g., shapes, colors), but rather the combination as a whole (e.g., “yellow circle,” “red triangle”).

Many previous studies on matrix training involved individuals with intellectual disabilities (Goldstein et al. 1987; Goldstein and Brown 1989; Goldstein and Moussetis 1989; Karlan et al. 1982; Light et al. 1990; Remington et al. 1990; Striefel and Wetherby 1973; Striefel et al. 1976, 1978). In some studies, the target responses were listener responses (Striefel and Wetherby 1973; Striefel et al. 1976, 1978) while others focused on tacts (Karlan et al. 1982; Light et al. 1990; Remington et al. 1990).

Additionally, Goldstein et al. (1987), Goldstein and Brown (1989), and Goldstein and Mousetis (1989) studied both tacts and listener responses and some elements of cross-modal transfer. Others have applied matrix training to teaching prepositions (Goldstein et al. 1987; Goldstein and Brown 1989; Goldstein and Mousetis 1989; Light et al. 1990). Matrix training studies including individuals with autism have focused on generative spelling (Kinney et al. 2003; Tanji and Noro 2011), sociodramatic play and the use of video enhancements (Dauphin et al. 2004), and listener responses (Axe and Sainato 2010).

Most previous matrix training studies employed a *non-overlap* (NOV) and/or an *overlap* (OV) procedure (in some form or another) as described in Foss (1968a, b). Foss presented slides of colored shapes paired with the auditory presentation of two-component (color and form) unfamiliar combinations to undergraduate students (e.g., “zin tep” represented “red circle”). The participants then tacted the color and form components. Following each response, the experimenter stated the correct response, regardless of whether the participant’s response was correct or incorrect. For one group of participants, the experimenters used a NOV training sequence in which four combinations that constituted the diagonal of the 4×4 matrix were trained (Fig. 1). In another group, experimenters conducted an OV training sequence in which the same combinations were trained, plus four additional combinations, so that the trained combinations formed a stepwise pattern down the diagonal of the matrix. All programmed combinations were trained simultaneously.

Foss (1968b) measured recombinative generalization and number of trials to mastery, thus investigating the instructional efficiency of the NOV and OV procedures. The primary difference between the sequences was that in the NOV sequence, each component was only paired with one other component, whereas in the overlap sequence, each component was presented twice, paired with a different component the second time (Fig. 1). The overlap sequence thus required the participants to

	Circle	Triangle	Square	Heart	Star	Club
Red	NOV OV	OV				
Yellow		NOV OV	OV			
Blue			NOV OV	OV		
Green				NOV OV		
Grey					NOVII	
Violet						NOVII

Fig. 1 Adaptation of the matrix used by Foss (1968a, b). *NOV* indicates stimuli trained in non-overlap training (down the diagonal of the matrix), *OV* indicates the combinations trained in the overlap training sequence (a stepwise pattern), and *NOVII* indicates the items that were trained in a non-overlap or diagonal pattern without later being trained in an overlap pattern

discriminate between color and shape stimuli in order to respond correctly. Results indicated that the NOV group did not demonstrate recombinative response generalization with untrained combinations while the OV group showed some generalized responding.

Subsequent studies have produced varied conclusions about whether or not a non-overlap procedure is sufficient to produce recombinative generalization if the components of the matrix are previously unknown. In most cases, researchers have trained at least some overlapping stimuli even if they primarily used a non-overlap sequence (Goldstein et al. 1987; Goldstein and Brown 1989; Striefel et al. 1976, 1978). In other cases, researchers have conducted matrix training with an overlap procedure or known components before using a non-overlap procedure (Foss 1968a; Goldstein et al. 1987; Kinney et al. 2003), or used a non-overlap procedure with one of the sets of components already known (Goldstein and Brown 1989). Additionally, Foss (1968a), Striefel and Wetherby (1973), and Striefel et al. (1978) did not find non-overlap training to be successful in producing recombinative generalization. Furthermore, in a review of the matrix training literature up to that point in time, Goldstein (1983a) suggested that overlap sequencing might be needed to achieve recombinative generalization if there is no history with the components of the matrix. Interestingly, a non-overlap procedure was effective in producing recombinative generalization in three of four participants with autism for listener responses with action-picture combinations (Axe and Sainato 2010) and with one participant with autism with sociodramatic play (Dauphin et al. 2004). Thus, the available literature indicates that overlap training is necessary in some cases but not others.

The purpose of the current study was to extend research on matrix training of tacts and prepositions with individuals with autism by replicating some of the sequencing of the Foss (1968a, b) matrix combined with some procedural elements similar to the Axe and Sainato (2010) and Dauphin et al. (2004) studies (e.g., most to least prompting, teaching one combination at a time, probes in between training sessions, incorporating maintenance sessions). We sought to determine if training tact responses of objects and prepositions in combination (e.g., “strainer above box”) using non-overlap and overlap matrix training procedures would result in recombinative generalization. We also evaluated whether tacting the components individually (e.g., strainer, tongs, whisk, or under, above, to the right) would emerge.

Method

Participants and Setting

Three students in a residential program at a school for children with autism and related disabilities participated in this study. Experimenters selected these participants because they were identified by teachers or behavioral clinicians as (1) demonstrating at least some untrained intraverbal responses, (2) demonstrating minimal correct prepositions (i.e., relational autoclitics), and (3) individuals who would benefit from autoclitic instruction. Jessie was a 20-year-old female diagnosed with an autism spectrum disorder. She communicated vocally using complete or fragmented sentences with frequent pronoun reversals (e.g., stating “you” when really making an “I” statement).

Allie was a 19-year-old female diagnosed with an autism spectrum disorder. Allie communicated vocally, frequently using single-word mands or fragmented sentences with frequent pronoun reversals. Gale was a 13-year-old female diagnosed with pervasive developmental disorder (PDD-NOS) and a mood disorder. Gale expressed herself vocally using complete sentences, usually with correct use of syntax and pronouns. Experimenters conducted all sessions in the participants' classrooms or residences in an environment free of distractions. Sessions were conducted up to 4 days a week, one to two times per day, with one to ten blocks of nine trials per session.

Materials

To teach spatial prepositions, we used kitchen objects and boxes. The kitchen objects included a strainer, a melon baller, tongs, a whisk, a grater, and a peeler. All the objects were mostly uniform black or white plastic and/or stainless steel. The boxes were made of cardboard and measured either 20.3 cm × 15.2 cm × 11.4 cm or 20.3 cm × 18.4 cm × 7.7 cm. Plastic kitchen bowls and paper napkins were used as stimuli for distracter trials during some maintenance sessions. Paper or plastic cups were used during preposition probes in order to assess mastery of prepositions.

Dependent Variable and Measurement

The dependent variable was the percentage of correct tacts of untrained object-preposition combinations or components (objects, prepositions) during probes. For combinations, a correct response was defined as the participant correctly tacting the object and preposition in the correct sentence order (e.g., "strainer above box" or "strainer above," not "above strainer") within 10 s of the presentation of the stimuli and the cue "tell me about it." The participant did not need to say "box" following the preposition for the response to be counted as correct. For components, a correct response was defined as a participant tacting the object within 10 s when asked, "What is it?" (e.g., "strainer"), or the preposition when asked, "Where is it?" (e.g., "above" or "above box"). For prepositions, the participant did not need to say "box" following the preposition for the response to be counted as correct. Researchers collected primary data using paper (structured data sheets) and pencil. The trial began with presentation of the visual stimulus and auditory cue and ended when the client responded or after 10 s of no response. Percentage of correct tacts of untrained combinations was calculated out of the possible remaining untrained combinations within the matrix relevant to each training condition. During training, the number of possible remaining untrained combinations decreased from one condition to the next. Thus, there were fewer opportunities for generalization as additional training was conducted.

Interobserver Agreement

Teachers from the school where the students received instruction served as secondary data collectors and did so simultaneously and independently. This occurred during a minimum of 33.3 % of sessions in each condition and with each participant. The mean interobserver agreement for Jessie was 100 % in baseline/probes, 98.6 % (range 77–

100 %) in training, and 100 % in maintenance. The mean interobserver agreement for Allie was 99.5 % (range 91.6–100 %) in baseline/probes, 99.5 % (range 89.9–100 %) in training, and 98.8 % (range 91.6–100 %) in maintenance. The mean interobserver agreement for Gale was 100 % in baseline/probes, 99.7 % (range 89.9–100 %) in training, and 100 % in maintenance.

Procedures

Experimental Design and Sequence We used a nonconcurrent multiple-probe design across participants to evaluate the effects of matrix training on the acquisition of spatial prepositions. Experimenters taught tacting of kitchen objects with prepositions (i.e., relational autoclitics) by placing kitchen utensils in different positions around a box (e.g., “strainer above box”). The three primary training sequences used for two participants were outlined by a 6×6 matrix to create 36 possible combinations of kitchen objects and prepositions (see Fig. 2).

Prior to the experiment, we conducted an eight-item paired stimulus edible preference assessment (Fisher et al. 1992) to identify reinforcers for each participant. We then

	Under	Above	Left	Right	Front	Behind
Strainer	NOV: TR1 H/V: TR (1.5)	OV: TR5 H/V: TR (6)	H/V: TR11 (7)	H/V: TR12 (8)	NOVII: Probe	NOVII: Probe
Baller	H/V: TR9 (2)	NOV: TR2	OV: TR6	RDR: TR16	NOVII: Probe	NOVII: Probe
Tongs	H/V: TR10 (3)	RDR: TR13	NOV: TR3	OV: TR7	NOVII: Probe	NOVII: Probe
Whisk	OV: TR8 H/V: TR (4)	RDR: TR14	RDR: TR15	NOV: TR4	NOVII: Probe	NOVII: Probe
Grater	NOVII: Probe	NOVII: Probe	NOVII: Probe	NOVII: Probe	NOVII: TR9 TR17	NOVII: Probe
Peeler	NOVII: Probe	NOVII: Probe	NOVII: Probe	NOVII: Probe	NOVII: Probe	NOVII: TR10 TR 18

Fig. 2 A matrix showing the experimental conditions and training sequence. *NOV* denotes non-overlap training, *OV* denotes overlap training, and *NOV II* denotes non-overlap training II. The *highlighted abbreviations* (H/V horizontal/vertical, RDR remainder, or *NOV II*) indicate stimuli that were only trained (or only trained in the given pattern) for Jessie. *TR* indicates a stimulus that was explicitly trained during a given condition, and *Probe* indicates it was only probed. The *number following TR* indicates the order in which a combination was trained across the entire study. The *number in parenthesis* during the H/V condition is the order in which that stimulus combination was trained in that specific phase

conducted pre-tests to ensure that the participants could tact and respond as listeners to the box that was to be used in subsequent matrix training. This was followed by baseline phases of tacting of combinations (e.g., “strainer above box”), object components (e.g., “strainer”), and preposition components (e.g., “above”).

Following baseline, we conducted non-overlap (NOV) training involving four combinations (T1 to T4 in Fig. 2) from a 4×4 section of the matrix. When the four combinations were mastered, the experimenter probed for generalized tacts using the eight components (four prepositions and four objects) from the training combinations and the 12 untrained combinations within the 4×4 section of the matrix. We then conducted an overlap (OV) training sequence consisting of four additional combinations (T5–T8 in Fig. 2) from the same 4×4 section of the matrix, followed by probes for generalized responding with the remaining eight untrained combinations and eight components. Next, we conducted additional instructional sequences or retraining of previous instructional sequences (Fig. 2) depending on participant performance. Probes were also conducted following each of these instructional sequences. Finally, participants underwent a *second non-overlap* (NOV II) training sequence involving two combinations (T9 and T10 for Allie and Gale and T17 and T18 for Jessie; see Fig. 2), followed by probes for generalized responding.

Pre-training During baseline, probes, and training, we used a box as a reference point for objects to create prepositions (e.g., “strainer above box”). To ensure that the participants could tact and respond as listeners to the box, we had designed a teaching program consisting of delayed prompting and differential reinforcement. However, all participants demonstrated 100 % correct independent tact and listener responding for the first two sessions; hence, no prompting was necessary.

Baselines and Probes Baseline and probe procedures were identical. We conducted baseline following pre-training and prior to matrix training, whereas probes were conducted upon reaching mastery criterion for a training sequence (NOV, OV, NOV II, etc.) or following completion of a retraining sequence. We conducted baselines/probes for each of the components (kitchen objects and prepositions) and for each possible untrained combination (e.g., “strainer above box”). For object component probes, the experimenter presented the object and asked the participant, “What is it?” For preposition component probes, the experimenter placed an object not used in training with which participants had previously demonstrated tacting (i.e., a cup) in the appropriate relation to the box and asked, “Where is it?” For combination probes, the experimenter presented each possible combination (e.g., strainer above box) and stated, “Tell me about it.”

Responses did not produce reinforcement or any form of correction procedure regardless of accuracy. However, preferred edible items were delivered at the end of each baseline and probe session for participation. Prior to the session, the participants were told that they could earn the edible for completing the session. The edibles delivered following probe sessions were larger than those used during matrix training. The experimenter tested each previously mastered combination prior to a probe session to evaluate maintenance of previously acquired responses. The participant had to demonstrate 100 % accuracy and independence in tacting all the maintenance combinations prior to a probe session; otherwise, the experimenters retrained the

combinations the participant missed before conducting another maintenance session. This procedure continued until participants demonstrated 100 % accuracy and independence in the pre-probe maintenance session.

General Training Procedures During matrix training, stimuli were presented as in baseline. Thus, experimenters trained both the object and the physical relation at once (e.g., for the stimulus “strainer above the box,” the tacts “strainer” and “under” were not trained individually). We conducted at least one block of nine trials per session. Each trial consisted of the presentation of the target combination followed by the cue, “tell me about it,” a prompt when applicable, the participant’s response, and a correction procedure or reinforcement as appropriate. The experimenter employed the following verbal prompting procedure: Step 1: immediate full verbal model (e.g., “strainer under box”); step 2: 2-s delayed full verbal model (e.g., “strainer under box”); step 3: 2-s delayed partial model of the first two sentence parts (e.g., “strainer under ____”); step 4: 2-s delayed partial verbal model of the first sentence part (e.g., “strainer ____”); and step 5: no prompt. The experimenter delivered edible reinforcement (small pieces of the item identified as the most preferred in the preference assessment) for correct prompted responses in step 1, correct prompted or unprompted (i.e., independent) responses in steps 2 to 4, and correct independent responses in step 5. In the event of an incorrect response, the experimenter removed materials and re-presented the trial using step 1 (i.e., the most restrictive prompt) before moving to the next trial. The criterion to advance to the next step was 89 % correct prompted (i.e., responded correctly within 5 s of the prompt) or unprompted in one block of trials. The criteria to move back a step were two consecutive incorrect responses (prompted or unprompted) or three total incorrect responses within a block of trials. The mastery criterion was two consecutive blocks of trials with at least 89 % correct and independent responding. When this occurred, the experimenters trained the next combination (e.g., “T2” in Fig. 2) in the instructional sequence.

We conducted maintenance probes of previously mastered combinations every third training session. We presented each mastered combination three times randomly interspersed with other mastered combinations, varying the order of stimuli each session. Early in the experiment, when the participant had only mastered one to two combinations, we asked the participant to tact plastic kitchen bowls and paper napkins as distracter trials (participants had previously demonstrated tacting of these items). If the participant made two errors on the same target, that target was retrained following mastery of the current target. Maintenance sessions only included previously trained combinations and did not include untrained combinations that emerged in probes.

Participant-Specific Procedures Allie and Gale followed the basic instructional training sequence (NOV followed by OV and then NOV II) with few exceptions. Allie completed retraining for the NOV II sequence because she demonstrated incomplete generalization in the probe following the first round of the NOV II training. Gale did not make progress toward mastering combinations T9 and T10. Therefore, we trained T9 and T10 simultaneously, alternating within the same block of trials. We also used a similar procedure with Jessie during the OV condition.

Like Allie and Gale, Jessie completed NOV and OV training. However, following OV training, she did not demonstrate generalized responding of many of the

combinations within the 4×4 matrix. Therefore, we employed other training procedures in an attempt to increase generalized responding before moving on to the NOV II condition with Jessie. First, we conducted retraining of all previously mastered stimuli in the OV condition, because we hypothesized that increased exposure to training stimuli might result in more generalization. We retrained all previously mastered stimuli beginning on step 2 instead of step 1.

When this failed to produce generalized responding, we implemented *horizontal/vertical training* (H/V), using a procedure somewhat similar to Striefel et al. (1976). In this training sequence, we trained one object component in combination with each of the preposition components (vertical direction in the 4×4 matrix) and then trained one preposition component in combination with each of the object components (horizontal direction across the 4×4 matrix; see Fig. 2). Following the completion of this training sequence, we probed the four remaining untrained combinations. We hypothesized that this procedure could aid in discrimination of objects and prepositions from one another and their placement within a sentence (e.g., the object always preceded the preposition). However, generalized responding did not occur. We then conducted a retraining of H/V stimuli but this did not produce additional generalized responding.

Following this, we conducted *remainder training* (RDR; Fig. 2). Remainder training simply involved training the remaining combinations within the matrix. The experimenter trained two of the four untrained combinations starting with step 2 of the prompting procedure instead of step 1, as Jessie demonstrated some (inconsistent) generalized responding with two of those combinations in probe sessions. Thus, the instructional phases for Jessie were (1) NOV, (2) OV (with retraining), (3) H/V (with retraining), (4) RDR, and (5) NOV II.

Results

Allie

Jessie was the first participant to start and complete the study; nevertheless, we have chosen to describe the procedures and results for Allie and Gale first, because Jessie required more deviations from the original training sequence. Allie's results are displayed in the second panel of Fig. 3. Allie did not demonstrate maintenance of previously mastered combinations during some maintenance sessions. Thus, the number of mastered combinations decreased at certain points where she missed the same combination twice out of three opportunities. Following the initial NOV training sequence, Allie demonstrated generalized tacting of 100 % of objects, 0 % of prepositions, and 75 % of untrained combinations. Following OV training, Allie tacted 100 % of all components and combinations.

Following training of the two combinations within the 6×6 matrix in the NOV II sequence, Allie tacted 100 % of object components, 91.6 % of prepositions, and 77 % of untrained combinations. Following retraining of the NOV II sequence (Fig. 3; sessions 79–88), tacting of objects remained at 100 %, prepositions increased to 100 %, and untrained combinations increased to 88.9 %. Allie required 53 training sessions to complete the protocol.

Fig. 3 The results of training and probe sessions for all participants. Note that *Number of Mastered Combinations* does not include combinations that emerged during generalization probes in previous phases. *NOV* denotes non-overlap training, *OV* denotes overlap training, and *NOV II* denotes non-overlap training II. *H/V* denotes the horizontal/vertical training and *RDR* denotes remainder training

Gale

Gale was the only participant who demonstrated any correct responding for baseline trials (Fig. 3, third panel). She demonstrated correct tacting of prepositions in 16.6 % of opportunities. The prepositions that she tacted correctly during at least one baseline trial included under, in front of, and above. However, correct responding with a single preposition was never consistent enough to merit its exclusion from the study. During some maintenance sessions, maintenance of previously mastered combinations was less than perfect. Thus, the number of mastered combinations decreased at certain points where she missed the same combination twice out of three opportunities. Following the initial NOV training sequence, Gale showed generalized tacting for 100 % of objects,

75 % of prepositions, and 91.6 % of untrained combinations. Following OV training, Gale did not demonstrate a change in generalized responding to component stimuli but generalization of untrained combinations increased to 100 %. Following training of the two combinations in the NOV II sequence, Gale demonstrated generalization of 100 % of all components and untrained combinations. Gale required 78 training sessions to complete the protocol.

Jessie

Overall, Jessie demonstrated some but not complete generalized tacting of untrained combinations (Fig. 3, top panel). Following the initial NOV training sequence, she only demonstrated generalized responding in 16 % of opportunities for object components. Following OV training, tacting of object components increased to 75 % correct, identification of prepositions to 50 % correct, and generalization of untrained combinations to 25 % correct of opportunities. Retraining all of the stimuli from the OV sequence (sessions 66–80) resulted in an increase in identification of object components to 100 % correct, no change in identification of preposition components, and an increase in generalization of untrained combinations to 50 % of opportunities. Interestingly, a second retraining (Fig. 3; sessions 81–95) of the OV sequence resulted in no change to identification of object components but a decrease in both preposition identification (to 0 %) and generalization of untrained combinations (37.5 % of opportunities). Thus, we ceased OV retraining and began implementing horizontal/vertical training. Jessie demonstrated no change in tacting objects or prepositions but showed an increase in generalization of untrained combinations to 50 %. However, it should be noted that she tacted only two of four possible combinations (probes following the OV condition had allowed for eight possible combinations). Retraining of the horizontal/vertical sequence (sessions 128–146) resulted in no change. Remainder training of the rest of the combinations within the 4×4 matrix resulted in no change to generalized tacting of object and preposition components.

Following training of the two combinations within the 6×6 matrix in the NOV II sequence, Jessie tacted object components (including two newly introduced objects) with 83.3 % accuracy and continued to tact preposition components with 0 % accuracy. She demonstrated recombinative generalization of untrained combinations within the 6×6 matrix with 22.2 % accuracy (4/18 combinations). Jessie required 133 total training sessions in order to complete the protocol, due to retraining phases and the need to retrain previously mastered combinations.

Discussion

Results demonstrated that recombinative generalization can occur when teaching tacting of prepositions and objects with individuals with autism using a matrix training procedure. Ultimately, this study, like Axe and Sainato (2010) and Dauphin et al. (2004), found that NOV sequencing was sufficient to produce recombinative generalization for at least some participants (Allie and Gale) even when the participants had not previously acquired the components. These results differ from the other matrix training studies that involved a NOV procedure (Foss 1968a, b; Goldstein et al. 1987;

Goldstein and Brown 1989; Striefel et al. 1976, 1978; Striefel and Wetherby 1973), and run counter to Goldstein's (1983a) assertion that non-overlap training is only successful without overlap if some components are known.

The reasons for the inconsistent results across studies are unclear. One possibility involves differences in teaching procedures (e.g., prompting and prompt fading, error correction procedures, and retraining). Axe and Sainato (2010) noted that most previous matrix studies used least-to-most prompting procedures, which may in part explain the relative ineffectiveness of NOV training. Another possibility is the participants' repertoires entering the study. The fact that Jessie required a greater amount of overlap training and retraining than the other participants might be explained by her having a less advanced repertoire. Prerequisites that were likely to facilitate learning in the current study include echoic repertoire and generalized imitation, basic listener and tact repertoires, auditory discrimination of verbal cues/WH questions, and intraverbal responses to WH questions. A lack of a more formal evaluation of participants' prerequisite repertoires is a limitation of the current study. Future research should examine repertoires prior to initiating training with the goal of identifying the necessary or sufficient skills for recombinative generalization.

It is also worth commenting on the inclusion of horizontal/vertical training and NOV II training. The addition of the horizontal/vertical training sequence for Jessie did not result in a significant increase in generalized responding. It is unclear whether this is indicative of the effectiveness of the procedure in general or just for Jessie in particular.

Results following the NOV II sequence were consistent with the results of the Foss (1968a, b) study in that following OV training, recombinative generalized tacting occurred for two of three participants (Allie and Gale). Generalized tacting occurred for both untrained combinations and components in the 6×6 matrix when only a NOV training sequence was used to introduce two new stimuli of each component type (two new objects, two new prepositions) to create a new set of 18 possible untrained combinations. Additionally, Jessie demonstrated a small amount of generalized tacting of untrained combinations and no generalized tacting of preposition components but did demonstrate generalized tacting of object components.¹ It is important to note that in baseline, Gale demonstrated some correct tacting for the two prepositions used in the 6×6 matrix, which presents a limitation in the experimental control over generalized responding.

We also measured the generalization of tacting of untrained components (objects and prepositions). Instructional efficiency for certain target tasks would be greatly enhanced if, when students learned a set of combinations, they not only demonstrated generalized responding to new combinations but could also tact/respond as listeners to the components. Thus, we conducted probes of components that were not trained individually. Across all participants, generalized responding was initially demonstrated at higher levels with one set of components (objects), than with preposition components or combinations. This may be because objects are more concrete and therefore likely to be more easily discriminable than prepositions. This is demonstrated further by Allie's

¹ Additional results from this study regarding cross-modal transfer were not included due to limited baseline (Allie and Jessie) and probe data (Jessie). Results indicated transfer across modalities to listener responses for Gale and Allie when experimenters trained only tacting for Allie and Gale. Jessie demonstrated response generalization of listener responses for most components and for trained and untrained combinations. For more information, address correspondence to the authors.

results, in which immediate complete generalized tacting of objects occurred following the first NOV training, but the same did not occur for prepositions. Similarly, Gale demonstrated immediate complete generalized tacting of objects following the NOV sequence, but only partial tacting of prepositions. Thus, the current results differ from those of Striefel et al. (1978), where generalization of all components (nouns and verbs) occurred.

Additionally, the current results fail to provide consistent support to the hypothesis that if generalization of untrained combinations occurs, generalization of component stimuli will also occur (Foss 1968b). In some cases, participants demonstrated more generalized responding to untrained combinations than to preposition components. This is interesting because one might assume that mastery of all components would be a prerequisite for generalized tacting of untrained combinations. It is possible that the cues (e.g., “where is it?”) during probes of preposition components did not control behavior to a sufficient extent (i.e., the participants did not understand the task). It might have been helpful to teach them to respond to the cues in advance. Anecdotally, Gale and Jessie would frequently answer the question “where is it?” in the natural environment while Allie generally echoed the question back to the speaker. Light et al. (1990) found that while participants demonstrated recombinative generalized responding, two of four participants did not use correct word order with words that would indicate a preposition. Thus, in the present study, while recombination occurred when tacts of components did not, discrimination of the words that served as tacts for the prepositions may not have emerged.

Some additional limitations should be noted. First, teaching only one combination at a time may have decreased instructional efficiency. Future extensions of this study could include simultaneously teaching multiple stimuli within a training sequence. Second, as stated previously, in some cases where participants did not make progress, more than one combination was successfully taught simultaneously. Thus, the same method of instruction was not consistently used throughout the study. Third, because OV training always preceded NOV training, it is difficult to compare the two sequences. Foss (1968a, b) used a group design, which allowed for direct comparison of NOV and OV. In contrast, the current study involved a single-subject design in which the NOV stimuli were a part of the OV set of stimuli. Thus, it would not be possible to have the OV condition precede an NOV condition unless using multiple, comparable matrices. That could be a potential future extension of this study. Fourth, because NOV training occurred before OV training, we did not train stimuli that overlapped with one another (e.g., strainer under box from the NOV set and strainer above box from the OV set) following one another as Foss did. Training in this sequence where stimuli that share a component follow each other may have increased generalization. Fifth, we did not conduct an evaluation of generalization of responses to the natural environment (e.g., locating a strainer behind a pot in the cabinet). Finally, it should be noted that the percentages of correct untrained combinations were not directly comparable from phase to phase within participants (particularly for Jessie due to the H/V and RDR phases) because the number of untrained combinations was smaller following each training sequence.

Additional future extensions could consist of training the components of the matrix rather than combinations (Goldstein 1983; Remington et al. 1990) and comparing the instructional efficiency of this procedure with an NOV/OV combination training

procedure. While this may generally be less efficient, it could be more efficient for certain individuals who require training of all possible combinations (e.g., Jessie). A study comparing the NOV/OV procedure with simply teaching all of the combinations within the matrix would evaluate instructional efficiency and whether the trials required to demonstrate generalized responding are fewer than those required to teach all stimuli in the matrix (Baer 1981). Finally, the replication of this procedure with a less complex, more discriminable component in place of prepositions may yield different results, particularly in component probes.

To conclude, the current study demonstrated that a matrix training procedure employing NOV and OV training can produce generalized tacting of combinations as well as preposition and object components when applied to individuals with autism. The results also indicate that the effectiveness and efficiency of this procedure may vary among individuals with autism. Further, a NOV sequence may be sufficient to produce generalized responding, although additional training may be necessary to achieve generalization for some participants. In some cases, simply training all necessary stimuli may be more efficient than programming for generalization with this population. A relevant, albeit difficult endeavor would be to consider which specific prerequisite skills are necessary for generalized responding for a particular response. This could potentially enable the specification of criteria for determining the most efficient instructional method on an individual basis.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

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