A WITHIN-SUBJECT COMPARISON OF STIMULUS EQUIVALENCE TRAINING

STRUCTURES

Medea Rawls, B.S.

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APPROVED:

Manish Vaidya, Major Professor
Janet Ellis, Committee Member
Sigrid Glenn, Committee Member
Richard Smith, Chair of the Department of
Behavior Analysis
David W. Hartman, Dean of the School of
Community Service
Sandra L. Terrell, Dean of the Robert B.
Toulouse School of Graduate Studies
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Training structures have been defined as the order and arrangement of baseline conditional discriminations within stimulus equivalence training. The three training structures most often used are, linear (trains A:B and B:C discrimination), many-to-one (trains B:A and C:A discriminations), and one-to-many (trains A:B and A:C discriminations). Each training structure trains a different set of simultaneous and successive discriminations that are then needed in the test for derived relations (symmetry, reflexivity, transitivity, and symmetrical transitivity). The present experiment seeks to extend the research on stimulus equivalence training structures by using a within-subject design and adult human subjects. Three sets of 9 arbitrary stimuli were trained concurrently each with a different training structure. From the beginning, training and testing trials were intermixed. The likelihood of producing stimulus equivalence formation was equal across structures.
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Stimulus equivalence refers to the observation that training a few overlapping conditional relations results in the emergence of a number of other conditional relations among the stimuli without direct training (Sidman, 1971). For example, having learned to select a stimulus (B) conditionally upon the presence of another stimulus (A), the subject will reliably select A conditionally upon the presence of B. Further, having learned to select a third stimulus (C) in the presence of B, the subject will now reliably select not only B given C, but also A given C and C given A. A set of stimuli for which the above description is accurate is called an equivalence class and is said to be characterized by reflexive, symmetric and transitive conditional relations among stimuli (Sidman & Tailby, 1982). In terms of basic procedural requirements for this definition, an equivalence class requires at least 3 stimuli, directly trained conditional relations in which some stimuli are common to 2 or more relations, and a testing context in which the directly trained functions of the stimuli can be reversed and recombined in probe trials (Fields, Verhave & Fath, 1984; Saunders & Green, 1999; Sidman & Tailby, 1982).

There are at least 3 different ways to train overlapping conditional relations such that the requirements described above are satisfied. Each of these is referred to as a “training structure” (Fields, Verhave, & Fath, 1984). In a training arrangement referred to as linear (Saunders & Green, 1999), a subject is taught a conditional discrimination relating A to B (given A1, pick B1 not B2 and given A2, pick B2 not B1) and another
conditional discrimination relating B to C. Given a linear training structure, the symmetric nature of the relation is assessed by B-A and C-B trials. Transitivity is assessed by presenting A-C trials and equivalence (or combined control by symmetric and transitive relations) is assessed by presenting C-A trials (see top panel in Figure 1).

In a training arrangement called *many-to-one* (MTO or comparison as node), a subject is taught B-A and C-A conditional discriminations. Given a MTO training structure, symmetry is assessed by presenting A-B and A-C trials. Transitive and equivalence relations (see definition above) are not as easily distinguishable with this training structure and, therefore, are generally assessed together via presentations of B-C and C-B trials (see lower left panel in Figure 1). Finally, in a training arrangement called *one-to-many* (OTM or sample as node), a subject is taught A-B and A-C conditional discriminations. Given OTM training structure, symmetry is assessed by presenting B-A and C-A trials. As with the MTO training structure, transitive and equivalence are difficult to distinguish and transitive and equivalent relations are assessed by presenting B-C and C-B trials (see lower right panel in Figure 1).

If the requirements for equivalence class formation (described above) are the only behavioral prerequisites, the structure of training trials should not make a difference in the likelihood of equivalence class formation since all 3 of the training structures involve establishing 2 overlapping conditional discriminations and testing for the derivation of 4 untrained conditional discriminations. Alternatively, it is possible that the different training structures may be differentially effective in establishing the behavioral prerequisites required for accurate performance on the probe trials. Saunders, Saunders, Williams, and Spradlin (1993) suggested that researchers had not
paid much attention to the functional differences between the 3 training structures, because most stimulus equivalence experiments employ typically developing college students as subjects who are likely, given rich verbal and social histories, to show equivalence class formation regardless of the particular structure used during training.

On what basis might one expect the training structure to make a difference in the outcome of probe trials? Researchers have pointed out that conditional discrimination performances are built out of more simple discriminations (Carter & Eckerman, 1975). For example, acquiring a conditional discrimination requires successive discrimination of the sample stimuli (which change from trial to trial) and simultaneous discrimination of the comparison stimuli, which appear together in the comparison arrays. With respect to these basic discriminations, Saunders and Green (1999) suggest that the different training structures may influence outcomes on probe trials by training more or fewer of the behavioral prerequisites necessary for highly accurate performance on the test trials. Their account will be described in some detail next.

As described above, some of the behavioral prerequisites necessary for accurate performance on probe trials are successive and simultaneous discriminations of the stimuli involved in the study. Saunders and Green (1999) point out that the 3 most commonly used training structures (linear, MTO and OTM) establish a different number of successive and simultaneous discriminations among the stimuli. For example, the linear training structure (A-B and B-C) establishes successive discrimination of stimuli in set A, simultaneous discrimination of the stimuli in set C, and both successive and simultaneous discrimination of the stimuli in set B. Symmetry probes based on the linear training structure (B-A and C-B) require simultaneous and successive
discrimination of set B stimuli, the simultaneous discrimination of set A stimuli and the successive discrimination of set C stimuli. Similarly, transitivity probes require successive discrimination of set A stimuli and simultaneous discrimination of set C stimuli. Tests for equivalence reverse these simple discrimination requirements. Of these, the linear training structure establishes some prerequisites (such as successive discrimination of set A and set B stimuli and simultaneous discrimination of set B and set C stimuli) but fails to establish others (such as the simultaneous discrimination of set A stimuli and the successive discrimination of set C stimuli) required during the probe trials.

Along similar lines, the MTO training structure (B-A and C-A) establishes successive discrimination of stimuli in sets B and C and simultaneous discrimination of stimuli in set A. Symmetry probes then require successive discrimination of set A stimuli and simultaneous discrimination of stimuli in sets B and C. Equivalence probes require both successive and simultaneous discrimination of stimuli in sets B and C. As with the linear training structure, the MTO training structure directly establishes some but not all of the simple discriminations necessary for accurate performance on probe trials. The same analysis applies to the OTM training structure with minor differences.

Important to note is that symmetry probes from all 3 training structures explicitly require simple discriminations that were not directly trained because, by definition, assessing symmetry involves assessing the extent to which the directly trained stimulus functions have become reversible. Because of this, it also follows that performance on the symmetry trials will not allow one to see the influence of training structure on derived relations (for reasons described immediately above). Performance on equivalence
probes, in which the properties of symmetry and transitivity are assessed in combination (Sidman & Tailby, 1982), are not constrained in this manner. For example, equivalence probes in the linear training structure (C-A) require successive discrimination of set C stimuli and simultaneous discrimination of set A stimuli (neither of which were established during training trials). Equivalence probes in the MTO and OTM training structures are difficult to specify as being B-C or C-B. This difficulty notwithstanding, the MTO training structure (B-A and C-A) involves successive discrimination of set B and set C stimuli (which is a partial requirement of the equivalence probe regardless of how it is defined), but fails to establish the simultaneous discrimination of stimuli in either of those sets (which is the other requirement on equivalence probes). Similarly, the OTM training structure (A-B and A-C) establishes the simultaneous discrimination of set B and set C stimuli (which is a partial requirement in the equivalence probes), but fails to establish successive discriminations of the stimuli in those sets (which is the other requirement on equivalence probes). Taken together, these analyses suggest that the MTO and OTM training structures should be more productive in generating equivalence than the linear training structure (Saunders & Green, 1999). Further analyses led Saunders and Green (1999) to suggest that the MTO training structure should be most effective and the linear training structure the least effective in generating equivalence-consistent choices on probe trials.

These analyses have been borne out in some studies. For example, several studies have shown that the linear training structure is the least effective training method (Arntzen & Holth, 1997; Buffington, Fields, & Adams, 1997; Saunders, Saunders, Williams, & Spradlin, 1993). The results with respect to OTM and MTO are
mixed. For example, Saunders, Drake, and Spradlin (1999) compared the likelihood of equivalence class formation in preschool children. Six of 11 children learned baseline relations in an OTM training structure while the other 5 subjects learned the baseline relations in a MTO training structure. Results on probe trials indicated that subjects who had learned the baseline relations under the MTO training structure were much more likely to show equivalence class formation relative to those who had learned the baseline relations in the OTM training structure (see also Spradlin & Saunders (1986) for similar results). However, Arntzen and Holth (1997) reported a higher likelihood of equivalence class formation following training with the OTM training structure than with MTO training structure.

These experiments have been conducted primarily as group designs using a two-choice match-to-sample procedure, raising some doubt about the confidence with which differences in training structures alone could be responsible for the observed differences. Arntzen and Holth (2000) investigated the effect of training structure in a single-subject design. Subjects were exposed to all 3 training structures sequentially and tested for equivalence after training with each structure. Across 3 experiments, Arntzen and Holth (2000) reported that equivalence-consistent choices were more likely following an OTM training structure than following a MTO training structure. In addition, they found that the linear training structure was the least effective in producing equivalence-consistent choices on probe trials.

The Arntzen and Holth (2000) study represents an important advance in the tools with which the interaction between training structure and equivalence class formation is studied. However, their use of a sequential design, in which training and testing was
carried out with one structure before exposure to the next, may have been problematic. In effect, subjects’ performance could improve across the different phases simply as a function of extra practice with the task and thus, mask functional differences or similarities in the effects of the sequential training structures.

The current experiment sought to extend the research on the role of training structures in the likelihood of equivalence class formation by using a within-subject experimental design to compare the effects of 3 different training structures (linear, MTO, and OTM) on acquisition of baseline relations and the emergence of equivalence-consistent choices. During each session subjects were exposed to one block of training and testing trials for each of 3 training structures. The likelihood of equivalence class formation and the number of trials to acquisition of the baseline relations were compared across training structures.
CHAPTER 2

METHOD

Subjects

Six undergraduate students from the University of North Texas participated in this experiment (4 males and 2 females). Participants were recruited through an advertisement placed in the University of North Texas campus newspaper. The number of sessions each subject participated in ranged from 2 to 17 depending on the subject’s performance. Average duration of each session was 26.18 min, ranging from 24.02-30.40 min across subjects. Subjects were paid $1.50 each session plus $0.01 for each correct response on the training trials, for a maximum of $2.58 each session. Subjects also received a bonus, ranging from $10.00 to $12.00, for completing the experiment. Total payments across the 6 subjects ranged from $3.00 to $52.15 and average pay rate per hour was $7.50.

Setting & Apparatus

Sessions were conducted in a small room in the Department of Behavior Analysis at the University of North Texas. The room contained a table, chair, and a Macintosh PowerBook G3 ® computer (www.apple.com) with a 12.1 in. display and a 12.1 in. Troll Touch ® touchscreen adapter (www.trolltouch.com). A custom written software package (MTS version 11.6.7, Dube & Hiris, 1991) was used to present stimuli, manage contingencies, and collect data.
Stimuli consisted of 27 arbitrary figures composed of curved and straight lines presented on a white screen (see Figure 2).

General Procedures

Minimal instructions were given to the subjects at the beginning of each session. The instructions were, “Images will appear on the monitor. It is your job to figure out how best to respond using the touchscreen. Sometimes you will receive feedback and sometimes you will not. Just try to respond the best you can. There is a correct answer for every trial.” Subject 1 was given detailed instructions during sessions 12 and 13 because accuracy on the trained trials remained below 50%. These instructions were the same as the above instructions with the addition of, “The task involves figuring out which stimuli go with each other. The trials with feedback can be used to figure out how to respond on trials without feedback. Good luck.”

Sessions consisted of 3 blocks of 108 trials, 36 of which were training trials and 72 testing trials, totaling 324 trials per session. Nine stimuli were assigned to each block. Each block trained the overlapping baseline relations in a different way: linear, one-to-many (OTM), and many-to-one (MTO). The order of the blocks and trials within the blocks were randomized across sessions. The training and testing trials were intermixed within the blocks so that emergence of equivalence-like responding could be compared to acquisition of the baseline relations and across training structures. Training trials were those in which the experimenter-designated correct response produced the word “correct” on the screen with an audible chime. Incorrect responses on training trials and all responses on testing trials produced no consequence. During Phase 1, correct responding on the baseline trials was reinforced on CRF (continuous
reinforcement) schedule. Once the subject’s performance reached 90% accuracy on
the training trials for all 3 training structures across 2 consecutive sessions, the subjects
moved to Phase 2 wherein the feedback schedule delivered for correct responses on
baseline trials was changed to VR2 (variable ratio 2). This phase continued until
equivalence formation occurred for all 3 blocks, or until no improvements in
performance were seen. During phase 2 responding on the testing trials continued to
produce no consequence. See Figure 3 for diagram of stimulus relations in the 3
training structures.

Training

The training trials sought to establish 3 sets of 6 conditional discriminations.
Each set was trained using a different training structure. The 6 trained conditional
discriminations in the linear training structure set were A1:B1, A2:B2, A3:B3, B1:C1,
B2:C2, and B3:C3. In the OTM training structure set the 6 trained conditional
discriminations were A1:B1, A2:B2, A3:B3, A1:C1, A2:C2, and A3:C3. In the MTO
training structure set the 6 trained conditional discriminations were B1:A1, B2:A2,
B3:A3, C1:A1, C2:A2, and C3:A3. Each trial type for all 3 sets was presented 6 times
per session, equaling 36 training trials per block and 108 training trials per session.
This training established the prerequisite skills to test for the emergence of responding
that comprise equivalence class formation (i.e. symmetry, reflexivity, transitivity, and
symmetrical transitivity).

Each trial began with the presentation of the sample stimulus in the center of the
screen. Touching the sample stimulus produced 3 comparison stimuli on the right, left,
and above the sample stimulus. If the participant touched the experimenter-designated
correct stimulus, the screen was cleared and the word “correct” appeared in the middle of the screen for 1 s along with an audible chime. If the participant touched either of the 2 incorrect stimuli the screen cleared. Both consequences were followed by a 1.5 s ITI (intertrial interval). See Figure 4 for a diagram of trial presentation. During phase 1, correct responses on the training trials were reinforced on a CRF schedule. Phase 1 concluded when performance was at or above 90% accuracy for all 3 training structure sets across 2 consecutive sessions. During phase 2, correct responses on the training trials were reinforced on a VR2 schedule. Phase 2 concluded when equivalence-like responding occurred, or no improvement in performance was seen.

Testing

Testing trials were presented in the same manner as the training trials except there was no programmed consequence for responses other than the 1.5 s ITI. There were 12 testing trial types per training structure and each was presented 6 times per session, equaling 72 testing trials per block and 216 testing trials per session. The total number of trials per session (trained and tested trials) equaled 324. These trials tested for the emergence of conditional discriminations that define equivalence formation. For the linear training structure, the tested trials included: A1:C1, A2:C2, A3:C3, B1:A1, B2:A2, B3:A3, C1:A1, C2:A2, C3:A3, C1:B1, C2:B2, and C3:B3. The tested trials for the OTM training structure set included: B1:A1, B2:A2, B3:A3, B1:C1, B2:C2, B3:C3, C1:A1, C2:A2, C3:A3, C1:B1, C2:B2, and C3:B3. The tested trials for the MTO training structure set included: A1:B1, A2:B2, A3:B3, A1:C1, A2:C2, A3:C3, B1:C1, B2:C2, B3:C3, C1:B1, C2:B2, and C3:B3.
RESULTS

Two of the 6 subjects did not complete the experiment. S1 participated in 10 sessions during which accuracy on training trials did not exceed 52.78%. During sessions 11 and 12 detailed instructions were provided to S1 without improvements in responding. At this point, S1’s participation in the experiment was terminated. S2 participated in 2 sessions before withdrawing from the experiment. Therefore, no further mention will be made of these 2 data sets.

Training

A criterion of 8 consecutive correct responses on each trial type (A1-B1, A2-B2, A3-B3, etc.) was used to define acquisition of the training and testing trials. This criterion was used to compare acquisition across subjects and training structures and was chosen because the probability of making 8 consecutive correct responses by chance was very low. Visual inspection also suggested that this criterion was appropriate in that performances were rarely inaccurate after the subject had responded correctly on 8 consecutive trials. Table 1 presents the average number of trials to criterion on training (and testing) trials for each training structure across the 4 subjects. Acquisition of the linear training trials for S4 (A1-B1, A2-B2, A3-B3, B1-C1, B2-C2, and B3-C3) will be used as an example. For trial type A1-B1, S4 made 8 consecutive correct responses on trials 8-15, so the number of trials up to the first of these 8 correct responses, 7 trials, would be counted as the trials to criterion. The number of trials to
criterion for trial type A2-B2 was 37 (since trials 38-45 were correct) and 0 for trial type A3-B3 (since trials 1-8 were correct). The number of trials to criterion for trial type B1-C1 was 43 trials, B2-C2 was 29 trials, and B3-C3 was 55 trials. Table 1 presents the average number of trials to acquisition for these 6 conditional relations across training structures, so for linear training trials the average number of trials to criterion would equal 28.50 (7+37+0+43+29+55/ 6= 28.50 trials).

One training structure did not prove to be superior to the other training structures with respect to the training trials. Two subjects (S3 & S4) acquired the baseline conditional relations under the one-to-many (OTM) training structure faster than under the many-to-one (MTO) or linear training structures. One subject (S5) met criterion on the linear trials first and another subject (S6) met criterion on the MTO trials first. The average number of training trials to criterion for S3 was 17.67 trials for linear, 18.33 trials for MTO, and 15.50 trials for OTM. S4 met the acquisition criterion after 28.50 trials for linear, 24.17 trials for MTO, and 15.83 trials for OTM. The average number of trials to acquisition for the linear training structure for S5 was 20.50 trials, 26.33 trials for MTO, and 24.83 trials for OTM. S6 met the acquisition criterion after 23.83 trials for linear, 6.17 trials for MTO, and 21.33 trials for OTM. For all 4 subjects, responding on the training trials was not significantly disrupted when moving from Phase 1, during which correct responding was on a CRF schedule, to Phase 2 in which correct responding was on a VR2 schedule.

Figure 5 depicts training performance for S3, S4, S5, and S6. The left graphs of Figure 5 show the average percent of correct trials across sessions for linear training trials A1:B1, A2:B2, A3:B3 (open circles), MTO training trials B1:A1, B2:A2, B3:A3
(closed squares), and OTM training trials A1:B1, A2:B2, A3:B3 (X). The right graphs of Figure 5 show the average percent correct responding across sessions for linear training trials B1:C1, B2:C2, B3:C3 (open circles), MTO training trials C1:A1, C2:A2, C3:A3 (closed squares), and OTM training trials A1:C1, A2:C2, A3:C3 (X).

The top left and right graphs of Figure 5 show that S3 completed 13 sessions overall and met the accuracy criterion of phase 1 during session 7. The top left graph shows that acquisition across the 3 training structures progressed at relatively the same rate. MTO reached 100% accuracy during session 5 and linear during session 6. Responding on the OTM trials lagged slightly behind the linear and MTO trials and reached 100% accuracy during session 8. The top right graph of Figure 5 shows that the OTM trials reached 100% accuracy during session 4 and during session 6 all training structure trials types were at 100% accuracy.

The second row of graphs of Figure 5 shows that S4 completed phase 1 during session 11 and completed the experiment in 17 sessions. The left graph shows that acquisition progressed at relatively the same rate for the OTM trials and linear trials, but progressed slightly slower for the MTO trials. The right graph of Figure 5 shows that acquisition progressed at relatively the same rate for the MTO trials and OTM trials, but responding on the linear trials lagged behind. MTO reached 100% accuracy during session 6, followed by OTM during session 7, and linear did not reach 100% accuracy until session 11.

The third row of graphs of Figure 5 depicts acquisition of the training trials for S5. Phase 1 was completed during session 12 and participation lasted 14 sessions. The left graph shows that acquisition of the training trials progressed at relatively the same
rate for the 3 training structures. The right graph of Figure 5 shows that acquisition of
the MTO training trials lagged behind OTM and linear and responding on the OTM trials
reach 100% accuracy until session 12. MTO and linear reached 100% accuracy during
session 10.

S6 met the accuracy requirement for phase 1 during session 12 and completed
the experiment after 16 sessions. The bottom left graph of Figure 5 shows that
acquisition of the MTO and linear trials progressed at the same rate, but acquisition of
the OTM trials lagged behind. MTO reached 100% accuracy during session 3 and
linear during session 7. OTM reached 100% accuracy during session 8. The bottom
right graph of Figure 5 shows that responding on the MTO trials reached 100%
accuracy by session 4. OTM trials did not reach 100% accuracy until session 9 and
linear did not exceed 94% accuracy.

Symmetry

The same acquisition criterion used to evaluate training was also used to
evaluate symmetry performance. Table 1 presents the average number of trials to
criterion of symmetry performance across the 3 training structures. Symmetry also
encompasses 6 individual trial types (i.e. B1-A1, B2-A2, B3-A3, C1-B1, C2-B2, C3-B3
for linear training structure), so Table 1 is an average of the number of trials to criterion
for all 6 trial types. Three of the 4 subjects demonstrated correct symmetry responding.
Two of the 3 subjects met the acquisition criterion, 8 correct consecutive symmetry
responses, with fewest trials under the linear training structure and 1 subject met
criterion with fewest trials under the OTM training structure. S3 met criterion after 35.50
trials for the linear structure, 45.33 trials for the MTO training structures, and 42.83 trials
for the OTM structure. The average number of trials to criterion for S4 was 30.50 trials for the linear structure, 29.67 trials for the MTO structure, and 17.5 trials for the OTM structure. S5 met criterion after 16.33 trials for the linear trials, 27.83 trials for the MTO structure, and 16.50 trials for the OTM structure.


The top left and right graph of Figure 6 show symmetry performance for S3. The top left graph shows that responding on the OTM trials starts off above the other 2 training structures, but overall acquisition of symmetry performance progressed at relatively the same rate for the 3 training structures. The top right graph shows similar results, responding on the OTM trials starts off above the other 2 training structures, but the 3 training structures progressed at similar rates and all 3 training structures reached 100% correct responding during session 12.

The second row of graphs of Figure 6 depicts symmetry performance for S4. The left graph shows that performance on the OTM trials progressed faster than the other 2 training structures and reached 100% correct responding during session 9. MTO and linear reached 100% correct responding during session 10. The right graph of Figure 6 shows that linear symmetry performance lagged behind MTO and OTM.
OTM reached 100% correct responding during session 6, MTO during session 7, and linear during session 11.

Symmetry performance for S5 is depicted in the third row of graphs of Figure 6. The left graph shows little difference in performance between the 3 training structures. The right graph shows that OTM progressed faster than MTO and linear. OTM reached 100% accuracy during sessions 4. Linear reached 100% accuracy during session 8. Responding on MTO trials lagged behind and did not pass 90% accuracy until session 13 and reached 100% accuracy during session 14.

The bottom left and right graphs of Figure 6 depict symmetry performance for S6. This subject did not show symmetry performance. The bottom left graph shows that responding on the 3 training structures did not exceed 50% accuracy across the 16 sessions and was generally around 30% accuracy for the 3 training structures. The bottom right graph of Figure 6 shows that performance did not exceed 72% accuracy and was generally around 40% accuracy for the 3 training structures. There is no discernable difference in performance among the 3 training structures in either graph.

Transitivity & Equivalence

The acquisition criterion of 8 consecutive correct responses was also employed to evaluate acquisition of transitivity and equivalence performance. Two of the 4 subjects, S3 and S5, demonstrated the transitivity and equivalence relations. Since both subjects showed equivalence formation across all 3 training structures, the acquisition criterion makes it possible to evaluate performance across the 3 training structures at a molecular level. Table 1 shows the average number of trials to acquisition of transitivity and equivalence performance across subjects. Transitivity and
equivalence include 3 trials each, so Table 1 displays the average of these 3 trials. Both subjects met the acquisition criterion on the OTM trials before the MTO and linear trials. S3 acquired the linear transitivity discriminations after an average of 66.67 trials and equivalence after 67.33 trials. MTO B:C (referred to as transitivity in Table 1) and C:B (referred to as equivalence in Table 1) equivalence discriminations were both acquired after an average of 61.00 trials. OTM B:C (referred to as transitivity in Table 1) discriminations met the acquisition criterion after 44.00 trials and the C:B discriminations (referred to as equivalence in Table 1) after 50.67 trials. S5 met the acquisition criterion on the linear transitivity trials after an average of 52.33 trials and 53.33 trials for the equivalence trials. MTO B:C trials were acquired after an average of 61.33 trials and C:B equivalence discriminations were acquired after an average of 47.00 trials. OTM B:C equivalence discriminations met the acquisition criterion after 38.00 trials and the C:B equivalence discriminations after 32.67 trials.

Figure 7 show the average percent correct responding across sessions for transitivity and equivalence performance for S3, S4, S5, and S6. MTO and OTM B-C discriminations will be referred to as transitivity and C-B discriminations will be referred to as equivalence for purposes of clarity. The left graphs depict linear transitivity trials A1:C1, A2:C2, A3:C3 (open circles), MTO transitivity trials B1:C1, B2:C2, B3:C3 (closed squares), and OTM transitivity trials B1:C1, B2:C2, B3:C3 (X). The right graphs of Figure 7 show the average percent correct responding across sessions for linear equivalence trials C1:A1, C2:A2, C3:A3 (open circles), MTO equivalence trials C1:B1, C2:B2, C3:B3 (closed squares), and OTM equivalence trials C1:B1, C2:B2, C3:B3 (X).
Transitivity and equivalence performance for S3 are depicted in the top left and right graphs of Figure 7. In the top left graph, OTM and MTO performance reached 100% accuracy during session 12 and linear performance reached 100% accuracy during session 13. The top right graph shows that the percent of correct responding on the OTM trials was higher than the other 2 training structures for most of session 1 through 10 and reached 100% accuracy during session 13 along with the linear trials. MTO performance reached 100% accuracy during session 12. Transitivity, equivalence, and symmetry occurred at roughly the same time for S3.

The second row of graphs of Figure 7 depicts transitivity and equivalence performance for S4. This subject did not demonstrate equivalence formation for any of the 3 training structures. The left graph shows that responding was highest for the OTM trials for 7 out of the first 9 sessions. Correct responding on the OTM trials during session 10 through 17 remained at 33%. Correct responding on the MTO trials was at 33% from session 10 through 17 as well. Correct responding on the linear trials was at 0% from session 11 through 17. The right graph shows similar results.

The third row of graphs of Figure 7 shows transitivity and equivalence performance for S5. Performance on the OTM trials was above the other 2 training structures for most of sessions 1 through 7. Responding on the linear trials reached 100% accuracy during session 10; responding on the OTM trials reached 100% accuracy during session 12 and responding on the MTO never exceeded 94%. The right graph shows similar results. Symmetry occurred before transitivity and equivalence and transitivity and equivalence occurred at roughly the same time. Also a
lag in MTO symmetry performance lined up with lag in MTO transitivity and equivalence performance.

The bottom left and right graphs of Figure 7 depict transitivity and equivalence performance for S6. This subject did not demonstrate equivalence formation for any of the 3 training structures. The bottom left graph shows that the percent of correct responding was undifferentiated between the 3 training structures and averaged around 35%. The bottom right graph shows similar results.

Summary

One subject (S1) did not learn the baseline conditional discriminations under any of the 3 training structures. The other 4 subjects learned the baseline conditional discriminations across all 3 training structures. The difference in the average number of trials to criterion across the 3 training structures for S3, S4, S5, and S6 ranged from 2.83-17.66 trials. The difference between the average number of trials to criterion for the 3 training structures was small for S3, only 2.83 trials. The difference between the average number of trials to criterion for S5 was also small, 5.83 trials. S4 and S6 had a larger difference between the average number of trials to acquisition for the 3 training structures. The difference for S4 was 12.67 trials and 17.66 trials for S6.

The differences between the 4 subjects in regards to the average number of trials to criterion of the training trials across the 3 training structures could be due to individual differences in subject histories. No one structure led to faster acquisition of the baseline conditional discriminations than the other 2 training structures and each subject that did show acquisition of the training trials did so for all 3 training structures. Similarly, the 1
subject who did not acquire the necessary conditional discriminations during training, failed to acquire them in all 3 training structures.

Three of the 4 subjects (S3, S4, S5) showed positive symmetry performance across all 3 training structures. One subject (S6) did not show symmetry performance on any of the training structures. The difference in the average number of trials to criterion across the 3 training structures for S3, S4, and S5 was relatively small and ranged from 9.83 to 13.00 trials. The difference between the average number of trials to criterion for the 3 training structures was smallest for S3 (9.83 trials), followed by S5 (11.50 trials), and S4 (13.00 trials).

Two of the 4 subjects (S3 and S5) showed positive equivalence formation across all 3 training structures. For the 2 subjects (S4 and S6) that did not show equivalence formation, negative results were shown across all 3 training structures. The difference between the average number of trials to acquisition for the transitivity trials across the 3 training structures was 22.67 trials for S3 and 23.33 trials for S5. The difference between the average numbers of trials to acquisition of the equivalence trials across the 3 training structures was 16.66 trials for S3 and 20.66 trials for S5.

From the data it appears that positive symmetry performance is required to produce positive equivalence performance. The 2 subjects (S3 and S5) that show equivalence formation acquired the symmetry relations before or at the same time as the equivalence relations. This can also been seen in the fact that when MTO symmetry performance for S5 lagged behind OTM and linear, equivalence performance for MTO also lagged behind the other 2 training structures. It also appears that acquiring the symmetry relations does not ensure that the equivalence relations will be
acquired since S4 acquired the symmetry relations, but not the equivalence relations. None of the subjects acquired the equivalence relations without the symmetry relations. One subject (S6) did not acquire the symmetry or the equivalence relations. It is possible that exposing the subjects to the symmetry trials before the equivalence trials may help in producing positive equivalence formation.

The fact that all subjects either acquired or did not acquire the trained, symmetry, or equivalence relations across all 3 training structures could be an indication that there is no difference between the training structures in regards to the probability of producing these conditional discriminations. None of the subjects in this experiment showed acquisition of any of the derived relations for 1 training structure and not another training structure and none of the subjects responded negatively on one derived relation in 1 of the training structures and positively on the same derived relation in another structure.
Since the number of subjects in this experiment was small and only 2 of the 4 subjects showed positive equivalence formation, it is not possible to conclude that any one structure is superior in regards to training, symmetry, or equivalence formation.

Arntzen and Holth’s (2000) within-subject comparison of the training structures exposed subjects to 3 sets of stimuli each trained with a different training structure. In the first group subjects were first exposed to linear, followed by many-to-one (MTO), and lastly one-to-many (OTM) and in the second group the order was MTO, OTM, and linear. The authors concluded that linear was least likely to produce equivalence. The first group of stimuli taught in this experiment might have been less likely to result in positive equivalence responding because it was the first time the subjects had been exposed to a stimulus equivalence experiment; thus, the stimuli that were trained with the following training structures may have been more likely to result in positive equivalence responding because of the previous training.

The current experiment avoided this possible confound by training and testing all 3 sets of stimuli at the same time. Also, the procedures used in this experiment may have contributed to correct responding across all 3 training structures on the training, symmetry, and equivalence trials. In Figure 5 though 8 it appears that when the subjects started responding at or close to 100% accuracy on one structure the other 2 training structures quickly (within a few sessions) jump to 100% accuracy as well. This
may be due to the effects of learning the task in one training structure and thus applying that knowledge to the other training structures. If this is the case, looking at when acquisition criterion was met versus whether equivalence formation occurred may be a better measure for comparing the training structures.

Many of the group designs (Banes, 1992, as cited in Barnes, 1994; Saunders et al., 1988, 1993, 1999; Spradlin & Saunders, 1986) used a 2-choice conditional discrimination. The current experiment used a 3-choice conditional discrimination, thereby decreasing the likelihood of responding being controlled by the negative comparison.

The conclusion of no difference between the training structures is in contrast to the findings of past research (Arntzen & Holth, 1997, 2000; Barnes, 1992, as cited in Barnes, 1994; Saunders et al., 1988, 1993, 1999; Spradlin & Saunders, 1986) and there are several aspects of the experimental design that may have made it less likely that differences in performance across the 3 training structures would be found. First is the use of adult humans as subjects who have long learning histories and verbal repertoires. This is supported by Barnes (1992, as cited in Barnes, 1994) and Saunders et al (1993) who conclude that typically developing adults show equivalence formation irrespective of the structure used. Second is the mixing of training and testing trials from the onset. Exposing the subjects to the training trials and then adding the testing trials after acquisition of the baseline conditional discriminations may help in the investigation of the training structures. Third is the mixing of training structures from the beginning. It is possible that an experimental design similar to Arntzen and Holth (2000) may be better for a within-subject design to investigate the training structures. Lastly, it
is difficult to draw conclusions when only 2 subjects showed positive equivalence formation. Increasing the likelihood of positive equivalence formation would greatly increase the conclusions that can be drawn from these data. One possible modification is to add distinct sample and observing responses.

Further research of the possible differences between the training structures is necessary because various labs use different training structures and different populations when conducting stimulus equivalence research. If one structure is more likely than others to lead to equivalence formation, at least with some populations, comparing results from different labs could be difficult.
Figure 1. Representation of the 3 training structures: linear, one-to-many, and many-to-one. Arrows indicate the baseline conditional discriminations.
Figure 2. Stimuli used in experiment.
LINEAR
Training (CRF/ VR2)
A1:B1, A2:B2, A3:B3,
B1:C1, B2:C2, B3:C3

Each trial presented 6 times

Testing (Ext)
A1:C1, A2:C2, A3:C3,
B1:A1, B2:A2, B3:A3,
C1:A1, C2:A2, C3:A3,
C1:B1, C2:B2, C3:B3

Each trial presented 6 times

MTO
Training (CRF/ VR2)
B1:A1, B2:A2, B3:A3,
C1:A1, C2:A2, C3:A3

Each trial presented 6 times

Testing (Ext)
A1:B1, A2:B2, A3:B3,
A1:C1, A2:C2, A3:C3,
B1:C1, B2:C2, B3:C3,
C1:B1, C2:B2, C3:B3

Each trial presented 6 times

OTM
Training (CRF/ VR2)
A1:B1, A2:B2, A3:B3,
A1:C1, A2:C2, A3:C3

Each trial presented 6 times

Testing (Ext)
B1:A1, B2:A2, B3:A3,
B1:C1, B2:C2, B3:C3,
C1:A1, C2:A2, C3:A3,
C1:B1, C2:B2, C3:B3

Each trial presented 6 times

Figure 3. Each large rectangle (block) depicts the trials presented for a particular training structure during training and testing. All 3 blocks were presented during each session and trials within a block were selected randomly without replacement. Trials were presented 6 times per session, equaling 108 trials per block and 324 trials per session.
Figure 4. Diagram of trial presentation.

Figure 4. Diagram of trial presentation.
Table 1

Average number of trials to acquisition for each trial type for all 4 subjects (defined as 8 consecutive correct responses). Bold numbers represent the best performance by each subject for training, symmetry, transitivity, and equivalence.

<table>
<thead>
<tr>
<th>Training Structure</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linear</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Train</td>
<td>17.67</td>
<td>28.50</td>
<td><strong>20.50</strong></td>
<td>23.83</td>
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<td>30.50</td>
<td><strong>16.33</strong></td>
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<td>52.33</td>
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</tr>
<tr>
<td>Equivalence</td>
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<td></td>
<td>53.33</td>
<td></td>
</tr>
<tr>
<td><strong>MTO</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>24.17</td>
<td>26.33</td>
<td><strong>6.17</strong></td>
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<tr>
<td>Symmetry</td>
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<td>29.67</td>
<td>27.83</td>
<td></td>
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<tr>
<td>Transitivity</td>
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<td></td>
<td>61.33</td>
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<tr>
<td>Equivalence</td>
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</tr>
<tr>
<td><strong>OTM</strong></td>
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<td></td>
</tr>
<tr>
<td>Train</td>
<td><strong>15.50</strong></td>
<td><strong>15.83</strong></td>
<td>24.83</td>
<td>21.33</td>
</tr>
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<td><strong>38.00</strong></td>
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<tr>
<td>Equivalence</td>
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<td></td>
<td>32.67</td>
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</tbody>
</table>
Figure 5. Percent of correct responses per session for training trials for S3, S4, S5, and S6. Open circles represent linear trial types, closed squares represent many-to-one trial types and X represents one-to-many trial types.
Figure 6. Percent of correct responses per session for symmetry trials for S3, S4, S5, and S6. Open circles represent linear trial types, closed squares represent many-to-one trial types and X represents one-to-many trial types.
Figure 7. Percent of correct responses per session for transitivity and equivalence trials for S3, S4, S5, and S6. Open circles represent linear trial types, closed squares represent many-to-one trial types and X represents one-to-many trial types.
REFERENCES


