A Behavior Analytic Analogue of Learning to Use Synonyms, Syntax, and Parts of Speech

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Matching-to-sample and sequence training procedures were used to develop responding to stimulus classes that were considered analogous to 3 aspects of verbal behavior: identifying synonyms and parts of speech, and using syntax. Matching-to-sample procedures were used to train 12 paired associates from among 24 stimuli. These pairs were analogous to synonyms. Then, sequence characteristics were trained to 6 of the stimuli. The result was the formation of 3 classes of 4 stimuli, with the classes controlling a sequence response analogous to a simple ordering syntax: first, second, and third. Matching-to-sample procedures were then used to add 4 stimuli to each class. These stimuli, without explicit sequence training, also began to control the same sequence responding as the other members of their class. Thus, three 8-member functionally equivalent sequence classes were formed. These classes were considered to be analogous to parts of speech. Further testing revealed three 8-member equivalence classes and 512 different sequences of first, second, and third. The study indicated that behavior analytic procedures may be used to produce some generative aspects of verbal behavior related to simple syntax and semantics.

Key words: Generativity, language, matching-to-sample, sequence learning, humans

For over fifty years, behavior analysts have worked to develop a thorough description of verbal behavior (e.g., Catania, 1998; Chase & Parrott, 1986; Hayes & Chase, 1991; Hayes & Hayes, 1992; Peterson, 1978; Salzinger & Feldman, 1973; Skinner, 1957; Wetherby, 1978; Winokor, 1976). This effort has produced a variety of extensive typologies, definitions, and experimental arrangements that, with varying degrees of success, confront the intricacies of verbal behavior. Despite this effort, behavior analytic explanations continue to encounter difficulty as they attempt to explain generative verbal behavior (Chomsky, 1959; Shahan & Chase, 2002). A typical example of generative verbal behavior is the novel use of words and

word combinations to deal with changes in an individual's environment. To illustrate, a child's parent has reinforced saying "green car" in the presence of a green car and "red truck" in the presence of a red truck. If the child continues to make these utterances in the presence of these stimuli, the behavior can be accounted for by direct reinforcement of the behavior and stimulus control. Moreover, stimulus generalization may account for the child saying "green car" in the presence of cars that vary slightly along some dimension, including color and shape. If the child sees a green truck and says, "green truck," however, neither the child's explicit reinforcement history, nor stimulus generalization are sufficient explanations. In order to explain such behavior, alternate concepts such as stimulus and functional equivalence have been developed (Alessi, 1987).

Stimulus Equivalence

The term stimulus equivalence refers to stimulus classes that typically are formed using matching-to-sample (MTS) procedures where a comparison stimulus "B" is matched to a sample stimulus "A," and a comparison stimulus "C" is matched to a sample stimulus "B" (Sidman, 1986). Unreinforced MTS tests are then administered to evaluate whether the subject responds to the emergent relations necessary for stimulus equivalence (Fields,

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Adams, Verhave & Newman, 1990). First, the subject must demonstrate reflexivity by matching each stimulus to itself. Second, the subject must demonstrate symmetry by matching A to B and B to C. Third, the subject must demonstrate transitivity by matching C to A and/or combined transitivity and symmetry, by matching A to C. By training only two relations, a class is formed that contains four new or emergent relations.

Stimulus equivalence classes have also been expanded when a new stimulus is trained to only one member of the class. For example, if a new comparison stimulus, D, is matched to C, and the subject responds to D as being equivalent to A and B without explicitly being taught, the class is expanded (Sidman, Kirk, & Willson-Morris, 1985).

The emergence of untrained relations may be used to explain some of the generative qualities of verbal behavior. For example, if a group of words are part of a class that displays the characteristics of an equivalence class, perhaps the class of words that refer to canine pets (e.g., *dog*, *hound*, *pooch*), and a new word is matched to one of these (e.g., *mutt* is matched to *dog*), the rest of the class (e.g., *hound* and *pooch*) would also be matched to *mutt* without further training. Thus, some of the generative semantic qualities of verbal behavior found in synonyms may be explained by stimulus equivalence.

Functional Equivalence

When two or more stimuli are functionally equivalent, they each control identical responses from an organism. Unlike stimulus equivalence, however, stimuli that are functionally equivalent typically are not taught using MTS procedures nor do they necessarily pass tests for reflexivity, symmetry, and transitivity. The test for functional equivalence is either a transfer of functions test (Goldiamond, 1962) or a reversal test (Vaughan, 1988). The transfer of functions test involves teaching an individual to respond to stimuli A and B with an identical response. Then a new response is trained to one of the stimuli. If the second stimulus is shown to control the new response the stimuli are functionally equivalent and a generative relation has been demonstrated.

The generative qualities of functionally equivalent stimuli suggest that they too may be usefully incorporated into an explanation

for generative verbal behavior. For example, as individuals learn English, using a verb in the third sequence position of the phrase (e.g., "the dog runs, the dog throws, the dog eats") will more likely be reinforced than if they use an adjective in the third position (e.g., "the dog red, the dog fat, the dog good"). In the example, the use of three distinct verbs are reinforced for being used in the third position in the phrase, therefore, it seems plausible that they become a class of functional stimuli (Wetherby, 1978). This can be tested when individuals learn to describe at least one of these words as verbs and then all of them are described as verbs.

Interactions between Stimulus and Functional Equivalence

Stimulus equivalence and functional equivalence classes have been studied together as well (e.g., Barnes, Smeets & Leader, 1996; Dougher, Augustson, Markham, Greenway, & Wulfert, 1994; Ellenwood & Chase, 1990; Layng & Chase, 1999; Lazar, 1977; Mackay, 1985; Roche & Barnes, 1997). For example, Lazar (1977) showed that equivalence relations established through MTS procedures could be used to expand functional classes that were established through a sequence training procedure. Lazar (1977) trained subjects to respond to stimuli in a specific sequential position. He then trained these stimuli as classes using MTS procedures. When tests were administered to evaluate the transfer of the sequence characteristics to stimuli throughout the classes, Lazar found the stimuli that had not undergone explicit sequence training developed the sequence characteristics. Lazar suggested that sequence characteristics of an individual verbal stimulus could be transferred throughout a class if the stimuli in that class were related through stimulus equivalence relations.

Furthermore, if a single member of an established stimulus equivalence class is trained to have a particular function (e.g., being used in a position within a sequence) all of the stimuli in that class will take on that function (Ellenwood & Chase, 1990; MacKay, 1985; Wulfert & Hayes, 1988). For example, Ellenwood and Chase (1990) initially trained three four-member stimulus equivalence classes. Then subjects were trained to respond to two members of each class with a sequence response. Two stimuli forming one class were trained as firsts,

Table 1
Spanish Words Used as Experimental Stimuli

	A	B	C	D
1	gusano	amable	siempre	ademas
2	ciervo	sucio	quien	hace
3	rey	cortesés	comida	lastima
4	lucha	pero	depues	dioses
5	pregunta	estan	todas	miedo
6	hermoso	mundo	entoces	caballo

two from another were seconds, and the two from the last class were thirds. When tests were implemented, the subjects responded to all the members of each class with the same functionally equivalent sequence response. Research also has shown that a variety of procedures for producing relations among stimuli, including respondent elicitation, could be transferred through equivalence classes or pass tests for stimulus equivalence (e.g., Barnes, Smeets & Leader, 1996; Dougher, Augustson, Markham, Greenway, & Wulfert, 1994; Layng & Chase, 1999; Roche & Barnes, 1997).

PURPOSE

Research has indicated that functional and stimulus equivalence procedures can be applied successfully to develop analogs of semantic relations (Imam & Chase, 1988), syntactic classes (Lazar, 1977; Wulfert & Hayes, 1988) and transfer of syntactic characteristics among stimuli (Ellenwood & Chase, 1990). The purpose of current research was to expand the application of functional and stimulus equivalence to synthesize these elements of verbal behavior to produce both large equivalence classes and hundreds of novel sequences of responses. The study specifically used (1) MTS procedures to establish stimulus pairs analogous to synonyms, (2) sequence procedures to teach functionally equivalent orders that were analogous to syntactic relations in simple sentences, and (3) MTS procedures to expand equivalence classes that were analogous to the parts of speech that relate synonyms and syntactic relations. The current study then tested whether all of the stimuli would be used in novel sequences that were analogous to the generative qualities of simple sentences.

METHOD

Subjects

Three female undergraduate psychology majors were selected from a list of potential subjects from those who signed up for the experiment on a recruitment bulletin board in the Department of Psychology at West Virginia University. These three were selected because they were not enrolled currently in a Spanish course and their performance on a pretest met the selection criteria (see pretest procedures described below). Subjects received one dollar for every session they attended, plus one cent in exchange for every point they earned during the research. Subjects were paid for their session attendance every two weeks, however, money earned from accumulating points was not paid until the research was completed.

Setting and Apparatus

The experiment was run in a 2.17 m by 1.75 m laboratory with a table, a chair, and the apparatus. The apparatus consisted of an IBM compatible microcomputer, a color computer monitor, and a computer mouse positioned on the desk in front of the subject. The activities during each session that were controlled by the computer were programmed in Turbo Pascal V.6.0. These activities included: presentation of trials, presentation of feedback, and data collection. Instructions were read to the subject by the attending research assistant.

Twenty-four Spanish words shown in Table 1 were used as stimuli. These words were used arbitrarily in that they ignored their actual Spanish meaning. This was done to neutralize the effects of the subjects' possible previous his-

Table 2
A List of the Experimental Phases of the Research

Phases	Steps in each phase
I. Stimulus Pairs	Stimulus Pair Pretest Stimulus Pair Training Stimulus Pair Test
II. Sequence Positions	Sequence Position Pretest Sequence Position Training Sequence Position Test Sequence Transfer Test
III. Expanded Equivalence Classes	Matching-to-sample Testing Expanded Equivalence Class Training Expanded Equivalence Class Testing
IV. Generative Sequence Positions	Sequence Position Testing

tory with the words. In Table 1 each stimulus is labeled by a letter and a number (e.g., A1, B3, C2, D4). These labels were never shown to the subjects, however, the labels are helpful in discussing the various relations that were trained among the stimuli. Note that stimuli on the same row are all designated by the same number, and that stimuli from the same column are all identified by the same letter.

Throughout the experiment subjects responded by moving a small cursor with a mouse until it touched a stimulus, and then clicked the left mouse button. Clicks occurring when the cursor was outside of a rectangle bordering the stimulus were not registered.

General Procedures

Matching-to-sample. Each matching-to-sample (MTS) trial began with the presentation of four 15mm x 69mm white rectangles. One of the rectangles was presented at the top center and three were presented horizontally across the bottom of the screen. Only when the subject selected the top rectangle were the stimuli presented within the rectangles. Subjects were given as much time as they needed to select a comparison. During training, if their selection was correct (Note: The words *correct* and *incorrect* are used to indicate responding in correspondence with experimenter defined relations among the stimuli shown on Table 1), the computer emitted a high-pitched tone and one

point was added to a counter displayed at the top of the screen. If the selection was incorrect, a low-pitched tone was emitted by the computer and the counter remained unchanged. During testing the subjects did not receive feedback regarding the accuracy of the performance. After the subjects selected a comparison, the stimuli were cleared from the screen. The next trial started when subject again selected the top rectangle.

Sequence training. At the beginning of sequence training sessions, three 15 mm x 69 mm white rectangles were presented horizontally across the center of the monitor screen. The subjects began each trial by clicking on one of the rectangles, which produced the stimuli within the rectangles. The subjects then selected the stimuli sequentially, for example, clicking the right stimulus first, the left stimulus second, and the middle stimulus third. During sequence training, if the subject responded in a correct sequence, regardless of the left-to-right position on the screen, the computer emitted a high-pitched tone and one point was added to the counter display. The left-to-right position of the stimuli was randomly determined. If the subject responded in an incorrect sequence, the computer emitted a low-pitched tone and no points were added to the counter display. During testing, no feedback was provided. After all three stimuli had been selected, the stimuli disappeared from the rectangles. When the subjects clicked on one of the empty rectangles the stimuli for the next trial were presented.

Figure 1. Diagram of stimulus pairs. Arrows depict matching-to-sample training used to develop stimulus pairs.

Experimental Design

A within-subject multiple pretest/post-test design was used for this study. All of the subjects underwent the same order of training and testing. Before each training phase, a pretest was administered to determine whether the subjects could already engage in the behavior to be trained. After training, a post-test identical to the pretest was administered to allow for comparison of the results. This allowed for an assessment of the change in responding produced by the training. In order to proceed beyond each training or post-testing phase, subjects had to attain a mastery criterion that required at least 90% of the responses to be correct. The sequence of testing and training phases is depicted in Table 2. The specific procedures and data for each phase are presented below.

Procedures and Results

Purpose of the stimulus pairs phase. The purpose of first phase of the study was to establish 12 pairs of stimuli that could be considered analogous to synonyms through MTS procedures. These pairs, if successfully taught, would then serve as the basis for teaching and testing the sequence characteristics taught in the second phase of the study as well as one of the relations expanded through stimulus equivalence procedures in the third phase of the study.

Stimulus pairs pretest. Two kinds of relations were tested during the initial pretest: matching each of the 24 verbal stimuli to itself (i.e., reflexivity), and matching the stimulus pairs that we planned to teach during the Stimulus Pairs Training Phase.

Both kinds of relations were tested in a MTS format. Before the first trial of the pretest was presented, the pretest instructions (see Appendix A.1) were read to the subject. Subjects who responded equal to or greater than 90% correct on the 72 trials evaluating the 24 reflexive relations and less than 40% correct on the 36 test trials evaluating responses to the relations we planned to teach in the next phase continued as subjects for the remainder of the research.

Pretest results. The first three subjects who met our criteria were selected. Subject JW responded with 100% accuracy to the reflexive relations and with 39% accuracy to the untrained stimulus pairs. Subject AF responded with 99% accuracy to the reflexive relations and 28% accuracy to the untrained stimulus pairs. Subject CL responded with 99% accuracy to the reflexive relations and 39% accuracy to the untrained stimulus pairs.

Stimulus pair training. At the beginning of the first research phase, subjects were read the Subject Orientation (see Appendix A.2). Upon completion of the orientation, MTS procedures were used to establish 12 pairs of relations from the 24 verbal stimuli (see Figure 1). Each Row 4

Figure 2. Diagram of sequence training. The arrows depict previous stimulus pairs training. The rectangles depict sequence training.

stimulus was matched to the Row 1 stimulus with the corresponding letter. For example, A4 was matched to A1. In like manner, each Row 5 stimulus was matched to its corresponding Row 2 stimulus and each Row 6 stimulus was matched to its corresponding Row 3 stimulus. This pattern of training is represented by the solid arrows in Figure 1.

During training, the sample was always a stimulus from among the Row 1, Row 2 or Row 3 stimuli. The three comparisons were the Row 4, Row 5 and Row 6 stimuli of the same letter (e.g., if the sample was an A, then all three comparisons were A's). The correct comparison was the comparison which corresponded to the sample as described above. The subject was read the MTS Instructions (see Appendix A.3) before the beginning of each training session. During each 36-trial training session each pair was presented three times. After a subject had met a criterion of responding accurately to 90% of the trials for a training session, they were tested on their performance. The test used the same 36-trial MTS format as was used during training except no feedback regarding the accuracy of the subjects' choices was provided.

Stimulus pairs results. Subject JW required seven sessions of training before responding with 90% accuracy to the trained relations. Having met the 90% training criterion she was then presented the test to which she responded with 94% accuracy. Subject AF required four sessions of training before she met the training

criterion. She then responded accurately on 100% of the testing trials. Finally, Subject CL required three training sessions before meeting criterion. She then met the testing criterion with accurate responding on 100% of the test trials.

Additional stimulus pairs testing. Throughout the rest of the research subjects were tested periodically in order to assess responding to the stimulus pairs that were trained. For this purpose, a 72-trial stimulus-pairs test was administered. The subjects were read the MTS Test Instructions (see Appendix A.4) before each of these test sessions began. All three subjects maintained criterion performance throughout the experiment.

Purpose of the sequence position phase. The next phase of the experiment sought to train sequence characteristics analogous to simple syntax using functional equivalence procedures developed by Lazar (1977). A subset of the stimuli trained as stimulus pairs in Phase 1 were trained to have sequence characteristics and then the stimuli that had been trained as a matched pair were tested to see if the sequence characteristics would emerge without direct training.

As shown in Table 2 this phase consisted of four steps. First, a pretest provided a baseline of subjects' sequencing of these stimuli. Second, training procedures were used to teach sequencing to six of the stimuli used in phase one, the stimulus pairs phase. Third, testing of the sequential responding taught assured that

the functions would be maintained under nonreinforced testing conditions. Fourth, transfer testing was used to determine whether the sequential responding would transfer to the stimuli that had been paired with the trained sequence stimuli during the stimulus pairs training of Phase 1.

Sequence position pretest. After the subjects were responding accurately to the 12 stimulus pairs, a sequence position pretest was administered. The sequence pretest provided a baseline measure of the subjects' accuracy in responding to the A1 and B1 stimuli as the first stimuli in a sequence, the A2 and B2 stimuli as seconds, and the A3 and B3 stimuli as thirds (see Figure 2). Each test trial presented randomly one first-position, one second-position, and one third-position stimulus. Before the test session began, each subject was read the Sequence Test Instructions (see Appendix A.5).

Sequence pretest results. All 3 of the subjects scored near or below chance levels on the pretest. Subject JW responded with 36% accuracy, Subject AF with 14% accuracy and Subject CL with 17% accuracy.

Sequence position training. After the sequence pretest was completed, the sequence position training was administered to develop sequential responding to the A1, A2, A3 and B1, B2, B3 stimuli. The training involved 36 trial sessions with each trial displaying either A1, A2, and A3 or B1, B2, and B3. When the subjects pressed the A1 or B1 first, A2 or B2 second, and A3 and B3 third, regardless of the left-to-right position in which they were displayed on the monitor, they were presented feedback indicating *correct*. The left-to-right positions of the stimuli was randomly determined. If subjects responded in any other way they were presented feedback indicating *incorrect*. The mastery criterion for the sequence training was responding with 90% accuracy on a single training session. Each subject was read the Sequence Training Instruction (see Appendix A.6) before every sequence position training session.

Sequence training results. Subject JW required 3 training sessions before meeting the criterion with 100% accurate responding. Subject AF also required 3 sessions before responding with 100% accuracy. Subject CL required 4 training sessions before meeting the mastery criterion by responding with 94.4% accuracy.

Sequence position testing. After the sequence position training was complete, unreinforced tests were implemented to evaluate the success of the training. Each test trial presented randomly one first-position, one second-position, and one third-position stimulus. The Sequence Testing Instructions (see Appendix A.5) were read to the subject before the start of each sequence testing session. The mastery criterion was 90% correct performance for one complete session of 36 trials.

Sequence test results. All 3 of the subjects met the mastery criterion by responding with 100% accuracy during the first test session.

Sequence transfer testing. When the mastery criterion had been met for the sequence test, a new sequence test was administered to investigate whether the sequential responding controlled by A1, B1, A2, B2, A3, and B3 would transfer to the stimuli that had been paired with these stimuli during the stimulus pairs training. For example, would a subject respond to A4 as a first-position stimulus because it was paired to A1, which had been shown to control first-position responding? A test session was implemented that contained 36 trials. Each trial displayed a three-sequence array consisting of either A4 or B4; either A5 or B5; and either A6 or B6. The mastery criterion for this sequence was also 90% correct. Before the beginning of each test session, each subject was read the Sequence Test Instructions again (see Appendix A.5).

Sequence transfer results. Figure 3 shows the results of the sequence transfer tests. As shown in the first three bars, no subject met the mastery criterion for responding to the sequence transfer test. After 21 sessions, 28 sessions, and 26 sessions, respectively, Subjects JW, AF, and CL had not responded with greater than chance accuracy. During these sessions the sequence position test of the trained sequences had been repeated approximately every sixth session and the subjects always responded above mastery level.

When it became apparent that the subjects would not meet the mastery criterion, a new test was implemented that incorporated sequence transfer trials, the original MTS trials, which taught the stimulus pairs, and trained sequence trials. Before the beginning of each test the subjects were read the Special Test Instructions (see Appendix A.7). After subjects had responded to this test for several sessions, it was discontinued as the subjects typically

Figure 3. Percentage of correct trials for the last session of each kind of sequence transfer test for all three subjects.

responded to the trained sequence trials and MTS trials with 100% accuracy, while responding to the sequence transfer trials with less than chance accuracy (see middle bars of Figure 3).

In a final effort to increase the accuracy of the subjects' responding to the sequence transfer trials an additional instruction was introduced to the subjects. The instruction stated "The training that you have received to this point in the research has prepared you to respond correctly to all of the trials in this session, and thus earn all of the money available." After the instructions had been presented, Subject JW performed with 100% accuracy in two sessions, Subject AF performed with 98.8% accuracy in four sessions, and Subject CL performed with 100% accuracy in 4 sessions (see the last three bars of Figure 3).

Additional sequence testing. Throughout the rest of the research additional sequence tests were administered to evaluate whether the sequential responding was maintained. The Sequence Test Instructions (see Appendix A.5) was read to each subject before testing session began. All 3 subjects maintained criterion performance on the Sequence Transfer Test throughout the experiment.

Purpose of matching-to-sample test 1. At this point in the research, the subjects were responding correctly to the relation between each of the 12 stimulus pairs as tested with MTS trials, and three functionally equivalent classes (i.e., A1, B1, A4 and B4 as firsts; A2, B2, A5, and B5 as seconds; and A3, B3, A6, and B6 as thirds) as tested with sequence trials. In order to evaluate whether functional class membership would be extended to MTS performance as has been found in previous research (cf. Mackay, Kotlarchyk, & Stromer, 1997) a test containing 36 MTS trials evaluated whether relations between A1–B1, A4–B4, A2–B2, A5–B5, A3–B3, and A6–B6 had been learned. Examples of these relations are labeled as functional relations in Figure 4. If, for example, the functional relation to be tested was A1–B1, either A1 stimulus would be the sample and the B1, B2, and B3 stimuli would be presented as the comparisons or the B1 stimulus would be the sample and the A1, A2, and A3 stimuli would be presented as the comparisons. The position of the comparisons was varied randomly across trials. Likewise, when A4, A5, or A6 was the sample, B4, B5, and B6 were presented in random order as the comparisons, and when

Figure 4. Diagram depicting the emergent, trained, and functional relations contained for one of the four member classes. Solid arrows indicate trained relations, dashed arrows indicate tested relations.

B4, B5, or B6 was the sample, A4, A5, and A6 were presented randomly as the comparisons. The MTS Instructions were read to the subjects before the testing session began. The mastery criterion was 90% correct for each of the relations tested.

Results of matching-to-sample test 1. Figure 5 shows that all of the subjects met the mastery criterion for MTS Test 1. Subject JW responded accurately to 100% of the trials during the first test session. Subject AF also met the mastery criterion during the first test session by responding with 98.6% accuracy. Subject CL required two test sessions before meeting the mastery criterion by responding with 100% accuracy.

Purpose of matching-to-sample test 2. When subjects met the mastery criterion for the functional relations MTS test, the relations A4–A1 and B4–B1 from the firsts' class, A5–A2 and B5–B2 from the seconds' class, and A6–A3 and B6–B3 from the thirds' class were tested (see Figure 4). These relations were the symmetric relations of the stimulus pairs trained earlier. In order to test whether these relations would also be found in MTS test, subjects were exposed to a MTS test consisting of 36 trials, with each

of the six relations being tested with six test trials. The sample stimulus was always the 4, 5, or 6 stimulus from the stimulus pair being tested. The comparisons were always the 1, 2, and 3 stimuli with the same letter as the comparison. For example, when A4–A1 was being tested, A4 was the sample and A1, A2 and A3 were the comparisons, with A1 being correct. The MTS Instructions were read to the subjects before the testing session began. The mastery criterion was 90% correct for each of the relations tested.

Results of matching-to-sample test 2. Figure 5 shows that all subjects met the mastery criterion. Subject JW and AF responded with 100% accuracy during their initial test sessions, while Subject CL scored with 97% accuracy during her initial test session.

Purpose of matching-to-sample test 3. The final relations tested with a MTS test were A1–B4, B4–A1, B1–A4, and A4–B1 for the firsts' class, A2–B5, B5–A2, B2–A5, and A5–B2 for the seconds' class and A3–B6, B6–A3, B3–A6, and A6–B3 for the thirds' class (see Figure 4). These relations meet the mathematical definition of transitivity or combined transitivity and symmetry, but we hesitated to name them be-

Figure 5. Percentage of correct trials on the final session of the three matching-to-sample tests that tested emergent relations among A and B for all three subjects. Test #1 tested for the functional relations among the stimuli: A1–B1, A4–B4, A2–B2, A5–B5, A3–B3, and A6–B6 stimuli. Test #2 tested symmetric relations among stimuli: A4–A1, B4–B1, A5–A2, B5–B2, A6–A3, B6–B3. Test #3 tested the remaining emergent relations: A1–B4, B4–A1, B1–A4, A4–B1, A2–B5, B5–A2, B2–A5, A5–B2, A3–B6, B6–A3, B3–A6, A6–B3. Subject AF did not receive Test #3 due to experimenter error.

cause one of the relations is derived not trained directly. When the sample was an A1, A2, or A3 stimulus, then the B4, B5, and B6 stimuli were randomly presented as the comparisons. When the sample was a B1, B2, or B3 stimulus, the A4, A5, and A6 stimuli were randomly presented as the comparisons. When the sample was an A4, A5, or A6 stimulus, the B1, B2, and B3 stimuli were randomly presented as the comparisons. When the sample was B4, B5, or B6 stimulus, the A1, A2 and A3 stimuli were randomly presented as the comparisons. Each of these 12 relations was tested with 6 trials, producing a test containing 72 test trials. The MTS Instructions were read to the subjects before the testing session began. The mastery criterion was 90% correct for each of the relations tested.

Results of matching-to-sample test 3. Figure 5 shows that both Subject JW and Subject CL met the mastery criterion during the first test session by responding with 100% and 98.8% accuracy, respectively. Due to a researcher’s error, Subject AF was not administered this test.

Expanded class training. The purpose of this training was to expand the classes of stimuli that could be considered analogous to words that are the same part of speech. After it had been established that the four member classes existed, MTS training was used to expand the classes by training C1 to B1, C2 to B2, and C3 to B3, and then D1 to C1, D2 to C2 and D3 to C3. When a C stimulus was being matched to a B stimulus, the B stimulus was the sample and the C1, C2, and C3 stimuli were the comparisons. When a D stimulus was being matched to a C stimulus, the C stimulus was the sample and the D1, D2, and D3 stimuli were the comparisons (see Figure 6). The subjects were read the MTS Instructions (see Appendix A.3) before the beginning of each training session. The B–C stimulus relations were trained first, and when the training criterion was met, the C–D stimulus relations were trained. Each relation was presented 12 times, thus, both the B–C and C–D training sessions contained

Figure 6. Diagram of all the training undertaken during the research.

36 trials. The mastery criterion during training was 90% correct for each of the relations being trained within a single session. Sessions were repeated until the training criterion was met.

Results of expanded class training. Subjects JW and CL required one training session to reach mastery level on the B-C relation and two training sessions to reach mastery level on the C-D relation. JW's percent correct during the final training sessions were 94% and 100%, respectively. CL's percent correct during her final training session were 97% and 100%, respectively. AF required two sessions to reach mastery level for the B-C relation and one session to reach mastery for the C-D relation. Her percent correct scores during these final training sessions were 100% and 97%, respectively.

Purpose of 8-member class testing. All training was complete when the B-C and C-D relations had been successfully trained. Therefore, the next phase of the research involved MTS test sessions that evaluated the

emergence of relations that formed three 8-member equivalence classes from among the 24 experimental stimuli.

Each of the 4 test sessions contained 36 trials that tested a portion of the relations constituting the 8-member classes. Before each session the MTS Instructions (see Appendix A.4) were read. Individual test sessions were repeated until the 90% correct criterion was met. Appendix B defines the six emergent relations that were tested within each session, including what the sample and comparisons for the test trials were. The relations being tested within each session were presented in random order. The test sessions were presented in the order in which they are shown in Appendix B.

Results of 8-member class testing. Subjects AF and CL met the mastery criterion for all of the tests. Both subjects had difficulty obtaining mastery on Test 2, but were able to do so after the test was delayed until later in the testing sequence (see Figure 7). Subject JW

Figure 7. Percentage of correct trials on each of the 16 tests constituting the 8-member class testing for two subjects. Each graph depicts one subject's data.

only attained mastery on Tests 1 and 3 after which she began to miss sessions and eventually withdrew from the study.

Purpose of final sequence position testing. The final phase of the research tested whether sequence characteristics had been established with all of the 24 experimental stimuli. A1, B1, C1,

D1, A4, B4, C4, and D4 were tested as firsts; A2, B2, C2, D2, A5, B5, C5, and D5 were tested as seconds; and A3, B3, C3, D3, A6, B6, C6, and D6 were tested as thirds (see Figure 6).

The sequence characteristics among all A and B stimuli had been tested during previous sequence position testing. Thus, the initial tests

Table 3
A List of the Tests Constituting the Final Sequence Position Testing

Test	Stimuli Tested
Test 1	C1, C2, C3, C4, C5 and C6
Test 2	D1, D2, D3, D4, D5 and D6
Test 3	All C and D stimuli
Test 4	All stimuli (i.e., A, B, C and D stimuli)

in this final phase of sequence testing evaluated the sequence characteristics of the C and D stimuli, as shown in Table 3. The sequence characteristics present among C1, C2, C3, C4, C5, and C6 were tested first, and sequence characteristics among D1, D2, D3, D4, D5, and D6 were tested second. When these tests were complete, the third sequence test, which evaluated whether subjects responded accurately to combinations of the C and D stimuli, was implemented. Each of these trials contained one first-position, one second-position and one third-position stimulus, but they were randomly drawn from among all of the C and D stimuli. For example, a trial might consist of C1, C5, and D3, with C1 functioning as the first-position stimulus, with C5 functioning as the second-position stimulus and with D3 functioning as the third-position stimulus. The final test combined one first-position stimulus, one second-position stimulus, and one third-position stimulus, randomly drawn from among all of the experimental stimuli (see Table 3). During each test, the stimuli being tested were presented randomly within each trial. The Sequence Test Instructions (see Appendix A.5) were read to the subject before the start of each test.

Results of final sequence test. Both of the remaining subjects, AF and CL achieved mastery on these tests. AF required only one session to reach mastery on the tests by responding with 100% accuracy during the first session of each. CL required three sessions before responding with 100% accuracy on Test 1, then proceeded to respond with 100% accuracy on her first attempts at the remaining tests.

DISCUSSION

The current study tested the development of relations among verbal stimuli using MTS and sequence training procedures. Subjects were trained to respond to 12 relations between stimu-

lus pairs, two sequences of three stimuli each, and 6 additional stimulus relations. Without further training, these relations interacted to produce three 8-member equivalence classes and 512 sequences resulting from three 8-member functional classes. These results suggest that this training produced behavior that is consistent with emergent syntactic and semantic verbal behavior. The discussion that follows addresses this suggestion and brings up in turn: the model of verbal behavior supported by the data, methodological problems encountered during the study, and implications for future research.

Verbal Analogs to the Relations Trained

The current research was designed to produce a model containing elements that could be considered analogous to how particular components of verbal behavior might be learned. For example, direct training was used to produce analogs to synonyms, syntax, and parts of speech. The 12 stimulus pairs that were initially trained can be considered analogous to 12 synonyms. For example, the A1–A4 relation could be the relation big–large, A2–A5 could be the relation dog–pooch, and A3–A6 could be the relation plays–frolics. The three position sequence characteristics that were trained next could then be considered analogous to a simple declarative syntax (qualifier→subject→predicate). For example, A1→A2→A3 could be the correct syntax big→dog→plays, whereas A3→A2→A1 or plays→dog→big is incorrect. Finally, classes were directly expanded by training stimuli that could be considered analogous the same parts of speech. For example, A2, B2, C2, and D2 could be the class of nouns *dog*, *cat*, *bruin* and *pig* respectively.

In addition to being analogous to some directly trained components of verbal behavior, the model also attempted to produce analogs of some of the generative qualities of verbal

behavior using procedures that resulted in stimulus equivalence and functional equivalence. For example, A1 and B1 were explicitly trained as first-position stimuli (e.g., qualifiers *big* and *little*). Then, without further training, the stimuli that had been paired with these stimuli during the stimulus pairs training, A4 and B4 (e.g., *large* and *small*), controlled similar sequence responding. Furthermore, for the two subjects who completed the study, when C1 (e.g., *obese*) was trained to B1, and D1 (e.g., *fast*) was trained to C1, both C1 and D1 controlled first-position responding too. Then, C4 and D4 (e.g., *fat* and *quick*), the stimuli that had been paired with C1 and D1 in the initial stimulus pairs training also began to control first-position sequence responding (e.g., the synonyms to *obese*, *fast*, *fat* and *quick* also became qualifiers without explicit training) for these subjects. An 8-member sequence class had been formed with A1, A4, B1, B4, C1, C4, D1, and D4 all being responded to as firsts. This eight-member class also could be considered analogous to the parts-of-speech class "adjectives" as was tested with equivalence tests.

Parallel training was undertaken for all of the other stimuli with two other sequence classes and parts of speech classes. The second stimulus class consisted of A2, A5, B2, B5, C2, C5, D2, and D5 (e.g., *dog*, *pooch*, *cat*, *kitty*, *bruin*, *bear*, *pig*, *swine*) and could be considered the subject and nouns class. The third stimulus class consisted of A3, A6, B3, B6, C3, C6, D3, and D6 (e.g., *plays*, *frolics*, *bites*, *chomps*, *hops*, *jumps*, *itches*, and *throws*) and could be considered the predicate and verbs class. Equivalence testing indicated that each of the three sequence classes was also an equivalence class for the two subjects who finished the experiment.

The procedures of this study produced a number of behaviors that may be considered analogous to generative verbal behavior. One set of analogs has been presented here as examples, however, other kinds of verbal behavior, and perhaps other types of behavior, also may be analogous to the relations found in the study. Most importantly, however, the results of this research indicate that behavior analytic procedures can be combined to produce behavior that has often been considered beyond the scope of behavioral principles (Chomsky, 1959).

These findings also lend support to previous conceptual work from our laboratory. Hall and Chase (1991) described the explicit rela-

tions between stimulus equivalence and verbal behavior such as abstraction, autoclitics, and minimal repertoires. Hall and Chase logically demonstrated that some examples of topography-based responding could meet the definition of stimulus equivalence as well as the more familiar selection-based responding found in MTS (Michael, 1985). Examples of topography-based responding would include the sequencing task used in the current research and other functional equivalence classes that demonstrate transfer, such as spelling (Mackay, 1985). Examples of selection-based responding involving equivalence include the MTS tasks of the current research as well as many others in the literature (e.g., Sidman and Tailby, 1982).

Hall and Chase (1991), however, also gave examples of verbal behavior that do not involve equivalence. Specifically verbal behavior that is directly trained, like the abstract tact saying "red" that is controlled by a wavelength of light used during training. Similarly one would exclude other functional classes that are directly trained, but that do not result in symmetric and transitive relations. For example, saying "cat" in the presence of the word *gato*, but not saying "gato" in the presence of the word *cat* does not exemplify equivalence, but can be considered a form of verbal behavior. Many introductory students of second languages find that they can translate the second language into their first language before they can do the opposite. At this point in their language development one might say that they are engaging in verbal behavior even though the behavior is not demonstrating equivalence (although cf., Hayes, Blackledge, & Barnes-Holmes, 2001 for a different definition of verbal behavior). This argument by Hall and Chase focuses on producing evidence to demonstrate equivalence, not assuming that it occurs. Thus, many examples of verbal behavior might have evidence to suggest that they are members of a functional class, but not an equivalence class.

Shahan and Chase (2002) also described the importance of including stimulus and function equivalence in models of complex novel behavior like that found in verbal behavior. The concept of equivalence is needed to account for how direct training of a subset of relations results in the emergence of untrained relations. That stimuli in a class become interchangeable helps explain generalized frames such as "adjectives precede nouns," a sequenc-

ing task, and the substitution of one synonym for another without direct training.

The observations of Hall and Chase (1991) and Shahan and Chase (2002) are similar to those made by others (e.g., Sidman, 2000). These observations have been suggested and supported by a variety of empirical work on stimulus equivalence (e.g., Sidman & Tailby, 1982), relational frames (e.g., Roche & Barnes, 1997), transfer (e.g., Ellis, 1965; Wulfert & Hayes, 1988), and transformation (e.g., Roche & Barnes, 1997). These findings and those of the current research also support other research on verbal behavior, particularly those studies that have been described in the literature on miniature linguistics systems (MLS) (Wetherby, 1978). In fact, MLS provides an alternative way of describing the results obtained here. Like the MLS research, we logically arranged the relations among the stimuli in a matrix. Similar to MLS studies, we systematically trained a subset of these relations so that the subjects would discriminate three groups of stimuli (e.g., nouns, verbs, and qualifiers). We also systematically trained a subset of the stimuli in each group to occur in a particular order. Thus, like MLS studies we brought at least two separate responses under the control of at least two different stimuli (one from each of at least two classes). A key feature of MLS is the equivalence or substitutability of stimuli involved in a variety of classes. The MTS and sequence training in the current study was explicitly designed to produce equivalence.

These conclusions in turn support developments within the stimulus equivalence and functional equivalence literatures suggesting the interplay of responding to stimulus classes. A variety of studies have shown that stimuli involved in stimulus equivalence classes can be expanded through functional equivalence training procedures and vice versa (Barnes, Smeets & Leader, 1996; Dougher, Augustson, Markham, Greenway, & Wulfert, 1994; Layng & Chase, 1999; Roche & Barnes, 1997). In fact, Sidman (1994) suggested that stimulus equivalence and functional equivalence are the same phenomena and Wirth and Chase (2002) have experimentally demonstrated their similarities.

These conclusions concerning the current research are drawn tentatively, however, because not all of the results were decisive. At least four methodological problems hinder the analysis. These problems are addressed below.

Methodological Issues

Problems with sequence transfer. The first phase of the research that tested subjects for transfer of training was unsuccessful until an instruction that informed them that their training had prepared them to respond correctly was provided. While evaluating the reason for the inaccurate responding, we noted that the tests were different than those commonly employed in MTS, stimulus equivalence, and other research. No single difference in our procedures, however, would likely have produced the lack of transfer. For example, although the current research did not employ baseline reviews (Sidman, et al., 1985) nor baseline trials mixed with probe trials (Lazar, 1977; Wulfert & Hayes, 1988), baseline performance, when assessed, was always near 100% correct. Therefore, we are fairly certain that the current results are not due to weaknesses in the baseline performances. Rather it appears that a combination of the differences in testing and training, in particular the sequence of testing and training, may have been responsible.

If subjects responded differently to training and testing, then the pattern of testing and training may have facilitated responding to the sequence transfer test as if it were a pretest. Both pretests and post-tests in this research presented trials with no feedback, no baseline trials, and trials testing untrained or novel relations. The training sessions, however, presented repeated training trials on the same relations that were always followed by feedback. In addition, the pretests all used stimuli that had not been displayed before. The initial phase of the research was a pretest of responding to untrained stimulus pairs and identity relations. Then, accurate responding to the stimulus pairs was trained. This training was followed by a test on those same relations. This pretest, training, and testing cycle was then repeated for the stimuli involved in sequence training. Subjects, therefore, had experienced two cycles of moving from untrained relations, to training those relations, to testing the relations that were developed. When the sequence transfer test trials used stimuli that had not been displayed in a sequence training or testing format, the trials were novel, much like those presented for pretesting. Therefore, the subjects had been provided a history that predicted that the sequence transfer test would be another

pretest. These factors may have interacted such that the initial sequence transfer tests functioned to control behavior identical to the pretests.

The effects of instructions. Although the initial sequence transfer tests may have controlled behavior similar to the pretest, the introduction of the instruction produced accurate responding. Because the instruction merely told the subjects that the training had prepared them to “respond correctly to all of the trials, and thus earn all of the money available,” it is difficult to say how control was obtained. A possible explanation may be that the instruction acted as a “function-altering” (Schlinger & Blakely, 1987) or “contingency-specifying” (Skinner, 1969) stimulus, such that it altered the sequence functions of the stimuli. An alternative explanation is that the instructions functioned as a conditional discriminative stimulus (Catania, 2007).

The instruction presented during the sequence transfer test was likely a function-altering stimulus because it was not related to whether a particular sequence of responses would or would not be reinforced. The same accurate sequence responding that was reinforced after the introduction of the instruction would have been reinforced before the instruction was presented and after the instruction was removed. Furthermore, because the same test conditions were in effect before and after the insertion of the instructions, the multiple stimulus conditions required for a conditional discrimination were not present. As suggested by Andronis (1991), the instructions acted as stimuli that increase the likelihood that a given response topography would be controlled by other stimuli.

Because the instruction only established or strengthened the discriminative control of stimuli (i.e., the sequence characteristics), it seems best to describe it as a function-altering stimulus.

Problems with 8-member equivalence class testing. After all of the training in the study was complete, tests were administered to evaluate whether subjects responded to three 8-member sequence classes (see Figure 7). The first test evaluated the following symmetric relations: C1–B1, C2–B2, C3–B3, D1–C1, D2–C2, and D3–C3. Subject AF met the mastery criterion during the first session and Subject CL met the mastery criterion during the fourth session of the test.

Subject CL’s results were similar to those pro-

duced by other studies of complex MTS. Subjects frequently do not respond accurately to equivalence class relations during their initial testing (Fields, et al., 1990; Sidman, 1992; Spencer & Chase, 1996). Indeed, most frequently, responding to the relations that constitute an equivalence class emerge over the course of several tests, particularly if the classes being tested are large. This gradual emergence of relations or test effect (Sidman, Kirk, & Willson-Morris, 1985) is still the subject of investigation.

The test effect seems to occur because the tests used for the development of equivalence relations also provide the conditions necessary for the observation of the final class. Sidman (1992) suggested that test trials, despite not being followed by feedback, allow for a “winnowing” process to occur. During this process, the subject matches comparisons to samples based on a variety of possible stimulus classes. For example, if the emergence of equivalence relations was being tested using stimuli consisting of nonsense syllables of various lengths, the subject might initially match stimuli based on which stimuli are similar when sounded out. This matching would probably be abandoned, however, after trials were presented in which none of the stimuli had the same sound. The subject then might begin to match the stimuli based on the number of letters each contains. Again, however, this would probably be abandoned when the stimuli consisted of different numbers of letters, or, perhaps, if the comparisons frequently had the same number of letters. Sidman suggested that, eventually, the subject would match the stimuli based on their equivalence class membership and, finding that this was consistent, stick with that strategy.

As was the case with the instruction inserted during the sequence transfer test, one could describe repeated tests of equivalence as “function-altering stimuli.” Like the instructions, the repetition of the tests did not exert discriminative control over the desired behavior, but did, nonetheless, change the function of the trials to eventually control accurate equivalence responding. By altering the function of the test trials the repeated testing finally allows the equivalence relations to control accurate responding by the subject.

Problems with test 2 of the 8-member equivalence tests. A third seemingly anomalous result was the failure of the subjects to respond

to the second test of 8-class membership. This might be understood, however, as an effect of nodality (Fields, et al., 1990, Spencer and Chase, 1996). Specifically, relations with fewer nodes tend to emerge before relations with many nodes. In the current research, the second test for eight-member class membership evaluated six relations: B4–C4, C5–C2, C6–C3, D4–D1, D5–D2, and D6–D3. Three of these relations (B4–C4, C5–C2, and C6–C3) were two node relations (e.g., B4–C4 depends on relations taught to B1 and C1) while the remaining relations were symmetric (i.e., D4–D1, D5–D2, and D6–D3). Over several sessions accurate responding occurred on the symmetric relations, but not on the two node relations. A comparison of these results with the results from Fields et al. suggested that, in the current study, the two node relations would not emerge until after the one node relations had been established. Therefore, the second 8-member class test was abandoned until after the subjects had met the mastery criterion on tests measuring one node relations. When the second test was re-administered, the two subjects who finished the experiment met the mastery criterion during the initial session in which they were tested. CL responded with 100% accuracy and AF responded with 95% accuracy. These results further suggest that the emergence of equivalence relations is related to the number of nodes within the relation (Fields, et al., 1990; Spencer & Chase, 1996).

Problems with Subject JW. Subject JW did not meet the mastery criterion for the second 8-member class test. JW's progress was hindered by her consistently arriving late to and leaving early from sessions. At the time CL and AF were finishing the study, JW had completed only 50% of the 8-member class testing and relations established early in the research began to break down. Attempts to re-establish these relations, although successful, put the subject too far behind schedule to complete the experiment. Subject JW's participation in the research was terminated after the completion of Sequence Test 8. The reasons for her failure to respond similarly to the other participants were not apparent from the observations of the study. Further subjects are needed to test the robustness of the procedures used here to affect stimulus class formation.

Problems with the experimental design. In addition, experimental designs that are more stringent than simple pretest/post-test designs

with 3 subjects are needed to eliminate alternative explanations for the results and to expand the generality of the results. Although pretest/post-test designs with small numbers of subjects are commonplace in stimulus and functional equivalence research, they do not eliminate two compelling alternative explanations. One could hypothesize that any systematic training would have produced the results obtained or that some other method of training would produce better results. One also could suggest that special characteristics of the subjects tested produced the results and the results would not generalize to other subject populations. For example, these college students are likely to have had previous training that specially prepared them to respond to both the MTS procedures and the sequencing procedures.

Implication for Further Research

The results of the current research suggest that several methodological issues must be resolved in order to define the training conditions that produce equivalence classes. Research is needed to isolate the critical components of the tests used to study stimulus equivalence. Similarly, an investigation of the similarities and differences between repeated testing and instructions could help examine the status of function-altering stimuli in determining equivalence classes. In addition, problems with the experimental design suggest that the model should be compared to other training models of verbal behavior. Finally, greater range of subjects, perhaps those that are less verbal than college students, should be included in future experiments.

Further research is also needed to expand the behavior analytic model of verbal behavior. The study developed a model with elements that could be considered analogous to three different parts of speech, adjectives, nouns, and verbs, and the syntactic position of these elements in a simple declarative sentence. The stimuli, however, maintained a membership in only a single class (e.g., C4 was only an adjective used in the first-position). In natural language, however, words may be a member of more than one parts-of-speech class. For example, the word "fat" is an adjective if it modifies a noun (e.g., "The *fat* cat ran"), but is a noun if it refers to a type of body tissue (e.g.,

“Measure the patient’s body *fat*”). Therefore, the model will be more useful if it is expanded to a wider range of verbal behavior. For example, in one context C4 would be a first-position stimulus and a member of the adjectives class, in another it would be a second-position stimulus and a member of the nouns class. Finally, additional experiments are needed with more subjects and more control over alternative explanations. Perhaps the ultimate study would be one with organisms that are completely naïve with respect to verbal behavior.

Conclusion

This research indicates that behavior analytic procedures (e.g., MTS and sequence training) can be combined to account for generative verbal behaviors that cannot be described by referring to physical similarity among stimuli alone. For example, behavior analytic principles were sufficient to produce an untrained sequence of selecting responses (e.g., syntax) that accurately reflected each stimulus’ sequence class membership (e.g., semantics). Furthermore, the success of this model suggests that behavior analysis may eventually be able to comprehensively describe verbal behavior.

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APPENDIXES

APPENDIX A: SUBJECT INSTRUCTIONS

A.1 *Pretest Instructions*

“Please do not touch the mouse until you are instructed to do so. In order for the research to run smoothly you must be aware of certain features of the apparatus. First, this is the computer monitor (researcher pointed to monitor) on which all experimental trials will be presented. When the instructions ask you to respond to the stimuli, you will do so by moving the small yellow rectangle with the mouse until it touches that stimulus, and then pressing the left mouse button (researcher identified the cursor, demonstrated moving it with the mouse, and identified the left mouse button). You will now be presented a number of trials on the monitor. Each trial will display one red rectangle with three green rectangles horizontally positioned below it. Each rectangle will display a Spanish word. After each trial is presented, you must examine the top stimulus and then select which of the three bottom stimuli matches it. When you have selected the matching stimulus, register your choice using the mouse. Choose and select only one stimulus. After you have made your selection the screen will be cleared except for a single rectangle in its center (researcher identified this rectangle). To produce the stimuli for each new trial, select that rectangle with the mouse. Do you have any questions? (If the subject had questions the relevant portion of the instructions were repeated. If the subject had no questions, the researcher continued.) You may now begin the session by selecting the rectangle.”

A.2 *Subject Orientation*

“In order for the research to run smoothly you must be aware of certain features of the apparatus. First, this is the computer monitor on which all experimental trials will be presented. When the instructions ask you to respond to the stimuli, you will do so by moving the small rectangle with the mouse until it touches that stimulus, and then pressing the left mouse button (re-

searcher identified the cursor, demonstrated moving it with the mouse, and identified the left mouse button). You will now be presented a number of trials on the monitor. Each trial will display one red rectangle with three green rectangles horizontally positioned below it. Each rectangle will display a Spanish word. After each trial is presented, you must examine the top stimulus and then select which of the three bottom stimuli matches it. When you have selected the matching stimulus, register your choice using the mouse. Choose and select only one stimulus. If you choose correctly the computer will produce a high-pitched tone and one point will be added to your score. After you have made your selection the screen will be cleared except for a single rectangle in its center (researcher identified this rectangle). To produce the stimuli for each new trial, select that rectangle with the mouse. Do you have any questions? (if the subject had questions the relevant portion of the instructions were repeated. If the subject had no questions, the researcher would continue). You may now begin the session by selecting the rectangle.”

A.3 *Matching-to-sample Instructions*

“A number of trials will now be presented to you on the computer monitor. After each trial is presented, you must examine the top stimulus and then select which of the three bottom stimuli matches it. When you have selected the matching stimulus, register your choice using the mouse. Choose and select only one stimulus. If you choose correctly the computer will produce a high-pitched tone and one point will be added to your score. If your selection is incorrect the computer will produce a low-pitched tone and no points will be added to your score. After you have made your selection the screen will be cleared except for a single rectangle in its center (researcher identified this rectangle). To produce the stimuli for each new trial, select the rectangle with the mouse. Do you have any questions? (if the subject had questions the relevant portion of the instructions were repeated; if the subject had no questions, the researcher would continue). You may now begin the session by selecting the rectangle.”

A.4 *Matching-to-sample Test Instructions*

"You will now be presented a number of trials on the computer monitor. After each trial is presented, you must examine the top stimulus and then select which of the three bottom stimuli matches it. When you have selected the matching stimulus register your choice using the mouse. Choose and select only one stimulus. Correct selections will each be awarded one cent, however, you will not be given feedback regarding when your selections are correct or incorrect. After you have made your selection the screen will be cleared except for a single rectangle in its center. To produce the stimuli for each new trial, select that rectangle with the mouse. Do you have any questions? You may now begin the session by selecting the rectangle."

A.5 *Sequence Test Instructions*

"You will now be presented trials displaying only three stimuli. Your task is to respond to each of the stimuli in the correct sequence. For example, select one stimulus first, another second and so on. You will receive one cent for every time you select the stimuli in the correct sequence, however, you will not be told when your responding is correct or incorrect. As you make your selections for each trial the stimuli will be cleared from the rectangles. To produce the next trial, select one of the empty rectangles with the mouse. Do you have any questions? Thank you, please begin the session by selecting one of the rectangles."

A.6 *Sequence Training Instructions*

"You will now be presented trials displaying three horizontally arranged rectangles, each containing a Spanish word. Your task is to respond to each of the rectangles in the correct order. For example, select one stimulus first, another second and so on. If you select the stimuli in the correct order the computer will produce a high-pitched tone and one point will be added to your

score. If you select the stimuli in the incorrect order the computer will produce a low-pitched tone and no points will be added to your score. As you make your selections for each trial the stimuli will be cleared from the rectangles (researcher identifies the three rectangles). To produce the next trial, select one of the empty rectangles with the mouse. Do you have any questions? (if the subject had questions the relevant portion of the instructions were repeated. If the subject had no questions, the researcher continued). Thank you, please begin the session by selecting one of the rectangles."

A.7 *Special Test Instructions*

"Two different types of trials will now be presented to you on the computer monitor. After some of the trials are presented, you must examine the top stimulus and then select which of the three bottom stimuli matches it. When you have selected the matching stimulus, register your choice using the mouse. If you choose correctly the computer will produce a high-pitched tone and one point will be added to your score. If your selection is incorrect the computer will produce a low-pitched tone and no points will be added to your score. After you have made your selection the screen will be cleared except for a single rectangle in its center. For other trials your task is to respond to each of the three stimuli in the correct sequence. For example, select one stimulus first, another second and so on. You will receive one cent every time you select the stimuli in the correct sequence, however, you will not be told when your responding is correct or incorrect. As you make your selections for each trial the stimuli will be cleared from the rectangles. To produce the stimuli for each new trial, select that rectangle with the mouse. Do you have any questions? (if the subject had questions the relevant portion of the instructions were repeated. If the subject had no questions, the researcher continued). You may now begin the session by selecting the rectangle."

APPENDIX B: EMERGENT RELATIONS TESTED IN EACH OF THE 8-MEMBER CLASS TESTS. SA IS THE SAMPLE, CO IS A COMPARISON ,AND CO+ IS THE CORRECT COMPARISON.

Test	Relations	Sa	Co	Co	Co	Co+
TEST #1	C1-B1	C1	B1	B2	B3	B1
	C2-B2	C2	B1	B2	B3	B2
	C3-B3	C3	B1	B2	B3	B3
	D1-C1	D1	C1	C2	C3	C1
	D2-C2	D2	C1	C2	C3	C2
	D3-C3	D3	C1	C2	C3	C3
TEST #2	B4-C4	B4	C4	C5	C6	C4
	B5-C5	B5	C4	C5	C6	C5
	B6-C6	B6	C4	C5	C6	C6
	C4-C1	C4	C1	C2	C3	C1
	C5-C2	C5	C1	C2	C3	C2
	C6-C3	C6	C1	C2	C3	C3
TEST #3	C4-C1	C4	C1	C2	C3	C1
	C5-C2	C5	C1	C2	C3	C2
	C6-C3	C6	C1	C2	C3	C3
	D4-D1	D4	D1	D2	D3	D1
	D5-D2	D5	D1	D2	D3	D2
	D6-D3	D6	D1	D2	D3	D3
TEST #4	B1-C4	B1	C4	C5	C6	C4
	B2-C5	B2	C4	C5	C6	C5
	B3-C6	B3	C4	C5	C6	C6
	C4-B1	C4	B1	B2	B3	B1
	C5-B2	C5	B1	B2	B3	B2
	C6-B3	C6	B1	B2	B3	B3
TEST #5	B4-C1	B4	C1	C2	C3	C1
	B5-C2	B5	C1	C2	C3	C2
	B6-C3	B6	C1	C2	C3	C3
	C4-D1	C4	D1	D2	D3	D1
	C5-D2	C5	D1	D2	D3	D2
	C6-D3	C6	D1	D2	D3	D3
TEST #6	C1-D4	C1	D4	D5	D6	D4
	C2-D5	C2	D4	D5	D6	D5
	C3-D5	C3	D4	D5	D6	D6
	D4-C1	D4	C1	C2	C3	C1
	D5-C2	D5	C1	C2	C3	C2
	D6-D3	D6	C1	C2	C3	C3

Test	Relations	Sa	Co	Co	Co	Co+
TEST #7	D1-C4	D1	C4	C5	C6	C4
	D2-C5	D2	C4	C5	C6	C5
	D3-C6	D3	C4	C5	C6	C6
	D1-B1	D1	B1	B2	B3	B1
	D2-B2	D2	B1	B2	B3	B2
	D3-B3	D3	B1	B2	B3	B3
TEST # 8	B1-D1	B1	D1	D2	D3	D1
	B2-D2	B2	D1	D2	D3	D2
	B3-D3	B3	D1	D2	D3	D3
	D4-B4	D4	B4	B5	B6	B4
	D5-B5	D5	B4	B5	B6	B5
	D5-B6	D6	B4	B5	B6	B6
TEST #9	A1-C1	A1	C1	C2	C3	C1
	A2-C2	A2	C1	C2	C3	C2
	A3-C3	A3	C1	C2	C3	C3
	C1-A1	C1	A1	A2	A3	A1
	C2-A2	C2	A1	A2	A3	A2
	C3-A3	C3	A1	A2	A3	A3
TEST #10	A4-C4	A4	C4	C5	C6	C4
	A5-C5	A5	C4	C5	C6	C5
	A6-C6	A6	C4	C5	C6	C6
	C4-A4	C4	A4	A5	A6	A4
	C5-A5	C5	A4	A5	A6	A5
	C6-A6	C6	A4	A5	A6	A6
TEST #11	A1-D1	A1	D1	D2	D3	D1
	A2-D2	A2	D1	D2	D3	D2
	A3-D3	A3	D1	D2	D3	D3
	D1-A1	D1	A1	A2	A3	A1
	D2-A2	D2	A1	A2	A3	A2
	D3-A3	D3	A1	A2	A3	A3
TEST # 12	A4-D4	A4	D4	D5	D6	D4
	A5-D5	A5	D4	D5	D6	D5
	A6-D6	A6	D4	D5	D6	D6
	D4-A4	D4	A4	A5	A6	A4
	D5-A5	D5	A4	A5	A6	A5
	D6-A6	D6	A4	A5	A6	A6

APPENDIX B, *cont.*

Test	Relations	Sa	Co	Co	Co	Co+
TEST #13	A1–C4	A1	C4	C5	C6	C4
	A2–C5	A2	C4	C5	C6	C5
	A3–C6	A3	C4	C5	C6	C6
	C4–A1	C4	A1	A2	A3	A1
	C5–A2	C5	A1	A2	A3	A2
	C6–A3	C6	A1	A2	A3	A3
TEST #14	B1–D4	B1	D4	D5	D6	D4
	B2–D5	B2	D4	D5	D6	D5
	B3–D6	B3	D4	D5	D6	D6
	D4–B1	D4	B1	B2	B3	B1
	D5–B2	D5	B1	B2	B3	B2
	D6–B3	D6	B1	B2	B3	B3
TEST #15	A1–D4	A1	D4	D5	D6	D4
	A2–D5	A2	D4	D5	D6	D5
	A3–D6	A3	D4	D5	D6	D6
	D4–A1	D4	A1	A2	A3	A1
	D5–A2	D5	A1	A2	A3	A2
	D6–A3	D6	A1	A2	A3	A3
TEST #16	A4–D1	A4	D1	D2	D3	D1
	A5–D2	A5	D1	D2	D3	D2
	A6–D3	A6	D1	D2	D3	D3
	D1–A4	D1	A4	A5	A6	A4
	D2–A5	D2	A4	A5	A6	A5
	D3–A6	D3	A4	A5	A6	A6