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TRANSFER OF A CONDITIONAL ORDERING RESPONSE THROUGH CONDITIONAL EQUIVALENCE CLASSES

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Eight adult humans were taught conditional discriminations in a matching-to-sample format that led to the formation of two four-member equivalence classes. When subjects were taught to select one comparison stimulus from each class in a set order, they then ordered all other members of the equivalence classes without explicit training. When the ordering response itself was brought under conditional control, conditional sequencing also transferred to all other members of the two equivalence classes. When the conditional discriminations in the matching-to-sample task were brought under higher order conditional control, the eight stimulus members were arranged into four conditional equivalence classes. Both ordering and conditional ordering transferred to all members of the four conditional equivalence classes; for some subjects this occurred without a typical test for equivalence. One hundred twenty untrained sequences emerged from eight trained sequences for all subjects. Transfer of functions through equivalence classes may contribute to a behavior-analytic approach to semantics and generative grammar.

Key words: conditional equivalence classes, stimulus equivalence, transfer of function, second-order conditional discriminations, adults

A functional analysis of verbal behavior (e.g., Skinner, 1957) examines the conditions under which verbal responses occur and the consequences they produce. Advocates of a structural approach (e.g., Chomsky, 1959, 1972) have rejected this account for its purported inadequacy in dealing with issues such as meaning and the generative nature of language. According to cognitive theories, meaning is something communicated by an utterance. Words are symbols that "stand for" or "refer to" things through the cognitive representations they create. In contrast, a behavioral conceptualization (e.g., Skinner, 1957, 1974) holds that a word "refers to" or "means" something to the extent that a stimulus (the "referent") exerts discriminative control over it. Thus, the concept of stimulus control, as developed in the three-term contingency that defines an operant, replaces the notion of reference.

The second controversial issue involves the ability of verbal humans to generate novel utterances of such formal diversity that traditional principles of learning seem insufficient to explain them. This has led cognitive theorists (e.g., Chomsky, 1965) to postulate that language emerges from a universal and species-specific deep-structure component that is part of the biological endowment of humans. According to this view, a limited set of deep-structure rules determines the meaning of utterances which, through the application of transformational rules, can be expressed in a virtually limitless set of sentences with different surface structures. A behavioral perspective has traditionally offered an alternative account, proposing that the notion of stimulus control is also applicable to more complex responses termed sentences. Responses evoked by a situation are basically nongrammatical. They are grouped or ordered through the effects of complex discriminative stimuli, termed autoclitics, that have an effect upon the listener, including the speaker himself (Skinner, 1957, chap. 13).

Upon closer examination, the interpretation in terms of stimulus control appears somewhat dissatisfying as an account of meaning and the generation of novel utterances, as the following examples will illustrate. First, the notion of stimulus control does not seem to capture the essence of what cognitivists mean by word–referent relations. Imagine that a pigeon is trained to peck a key with the word "food" when shown a picture of grain. The word "food" might then be said to "mean" grain. But the bird will not, without further training,

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peck the picture of grain when shown the word "food." Reversibility between stimuli in a conditional discrimination procedure does not emerge when symbolic matching is established with nonhumans (Holmes, 1979; Sidman, Rauzin, Lazar, Cunningham, Tailby, & Carrigan, 1982).[1] Yet in the verbal behavior of humans this reversibility between a word and its referent readily occurs, and is considered one of the properties of symbolic behavior (Catania, 1984; Hayes, 1986). Second, it also seems dissatisfying to explain the grammatical sequencing of more complex utterances exclusively in terms of the traditional concept of stimulus control. Although the grouping of words may occur through the effects of autoclitics, it still would be necessary to explain how the speaker generalizes from previous sentences to novel ones (Robinson, 1977). What are the functional classes through which previous training in word order transfers to new instances?

A more promising behavioral approach to some of the issues involved in an analysis of meaning and syntax is provided by the recent work on stimulus equivalence (e.g., Lazar, 1977; Lazar & Kotlarchyk, 1986; Sidman, 1971; Sidman & Tailby, 1982). Equivalence relations resemble more traditional interpretations of reference and involve a type of stimulus control that is not readily encompassed by a three-term contingency. In humans, training consistent relations within a set of stimuli frequently leads to additional relations emerging without training: The stimuli involved in the set become functionally substitutable and reveal relations of reflexivity, symmetry, and transitivity (Sidman & Tailby, 1982). The properties that define equivalence relations are behaviorally specifiable. If a conditional-discrimination procedure has generated not just conditional discriminations (if A, then B; if B, then C) but true equivalence relations, reflexivity can be demonstrated by generalized identity matching (if A, then A); symmetry is shown by a functional interchangeability between samples and comparison stimuli (if B, then A; if C, then B); and transitivity is demonstrated through the emergence of a new relation between stimuli not previously paired in the conditional-discrimination procedure (if A, then C; if C, then A). To illustrate, a child may be taught to point to the picture of a dog when hearing the word "dog" (A-B), and to the written word DOG when shown the picture of a dog (B-C). Without further training, she may then say "dog" when shown the picture (B-A), point to the picture when shown the written word DOG (C-B), say "dog" when shown the written word (C-A), and point to the written word when hearing "dog" (A-C). One might say that all three stimuli (spoken word, written word, and picture) are bidirectionally related to each other and have become under some circumstances functionally substitutable.

Such bidirectional relations among stimuli may provide a basis for referential meaning: The word is a symbol for the referent and the referent is the meaning of the word because both are members of the same equivalence class. In this sense, stimulus equivalence transforms nonlinguistic conditional discriminations into semantic process (Sidman, 1986).

Stimulus equivalence can only begin to provide an adequate model of referential meaning, however, if equivalence classes can be brought, as classes, into other relationships such as those of conditional control. For example, the meaning of a word can change depending on context. One cannot comprehend the word "bat" unambiguously unless one knows the context in which it is emitted ("flying mammals" vs. "baseball game"). To date, the development of conditional equivalence classes from second-order matching-to-sample training has not been demonstrated. One purpose of the present study, therefore, was to determine whether higher order equivalence relations are readily established in humans.

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[1] Recently, McIntire, Cleary, and Thompson (1987) apparently found evidence for stimulus equivalence in nonhumans. However, their analysis is open to an alternative interpretation. The authors trained a characteristic response (a "name") to each stimulus in a set and claimed to discover emergent reflexivity, symmetry, and transitivity. They also, however, inadvertently trained the animal to select each stimulus in the class, given that the name had just been given. By explicitly reinforcing all possible combinations of object-name and name-object, all possible object-object relations will necessarily emerge as an uncomplicated sequence of conditional discriminations. For example, if an animal turned on an orange light by touching stimuli x, y, or z, and was also trained to pick only x, y, or z in the presence of an orange light, the animal will naturally be able to go from any one of the three stimuli to any other. If x is the sample, and z and p are the comparison stimuli, the animal would respond to x and thus turn on an orange light and now pick z over p because of the explicit reinforcement history for selecting z given an orange light. This example captures precisely the experimental arrangement used by McIntire et al.

Previous research suggests that stimulus equivalence may also play a role in the acquisition of simple syntactic relations. Lazar (1977) trained 3 adult subjects to point sequentially (first to one, then to the other) to each member of four pairs of symbols (A1-A2, B1-B2, C1-C2, D1-D2). In a matching-to-sample procedure these same stimuli were then used as samples with two new pairs (E1-E2, F1-F2) serving as comparison stimuli. During a test phase without reinforcement, Lazar then interspersed the new pairs among the previously trained pairs. One subject showed an immediate transfer of the sequential response to the E and F stimulus pairs, 1 subject required remedial training, and another subject performed at chance level despite remedial training. Lazar and Kotlarchyk (1986) showed the transfer of a conditional sequence response through two equivalence classes. Six-year-old children received matching-to-sample training with a single-sample procedure (i.e., one pair of stimuli serving as samples and a number of different stimulus pairs as comparison stimuli). Then they were presented with test trials for symmetry and transitivity without reinforcement. Once equivalence was demonstrated, Lazar and Kotlarchyk trained a conditional sequence response (the direction of which was controlled by auditory signals) to the stimulus pair that previously had served as samples in the conditional discrimination procedure. In a test without reinforcement, the transfer of this conditional ordering response to stimuli that previously had functioned as comparison stimuli was demonstrated.

These studies suggest that a transfer of simple and conditional response sequences from trained to untrained members of equivalence classes is possible. In both studies, however, the transfer of a sequential response occurred from a sample to a comparison stimulus that had been directly established through reinforcement. Although such a transfer may logically require symmetry, the role of transitivity was not assessed. Further, both studies examined transfer of functions after equivalence tests had been performed. It is not clear whether transfer of sequential responding would have occurred with the equivalence tests themselves. Therefore, a second purpose of the present study was to examine the transfer of simple and conditional sequencing when such transfer required all the defining characteristics of equivalence classes, and to see whether such transfer could occur without a prior equivalence test per se.

If equivalence classes play a role in the generalization of sequential responses, a transfer of sequencing via simple equivalence classes may bear on rudimentary grammatical relations. In human language, meaning often depends on the position a word assumes in a sentence. Words with the same formal properties may have different functions depending on their relation to other words in a sentence. For example, the utterances "red light" and "light red" are composed of the same words, but differ in meaning. Therefore, if we wish to incorporate the effects of context into our model, then it needs to be shown that a sequential response will transfer through conditional equivalence classes. This question was also examined in the present study.

METHOD

Subjects

By means of in-class announcements, 10 college undergraduates, both male and female, were recruited for this study. They were paid for participation ($4.00 per hour regardless of performance) and received no additional course credit. Subjects were randomly assigned to one of two experiments. Two subjects did not continue after completing Phase 1 and were dropped from the study. Four subjects each completed Experiments 1 and 2.

Apparatus and Materials

Subjects were seated at a table in a small experimental room with a color TV monitor and a metal box with two buttons in front of them. Stimulus presentation and the recording of responses and response latencies were controlled by a computer located in an adjacent room. The stimuli were eight nonsense symbols resembling Greek letters (see Figure 1). Each was approximately 2.5 in. in diameter when presented on the monitor. For matching-to-sample tasks, the sample appeared in the center at the top of the screen, with the comparison stimuli to the left and right at the bottom. For sequence tasks, two symbols were presented simultaneously to the left and right on the screen.

General Experimental Sequence

Experiments 1 and 2 differed in their training sequences (Phases 1 through 3). Each be-

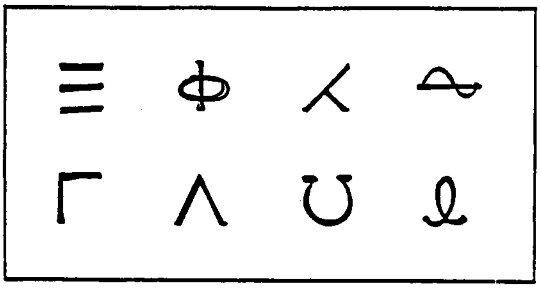


Fig. 1. The stimuli used in both experiments.

gan with an identical Phase 1 consisting of matching-to-sample training and the transfer of a sequence response from trained to untrained members of two equivalence classes. They differed in Phase 2 in that in Experiment 1 the equivalence classes established in Phase 1 were brought under conditional control, whereas in Experiment 2 the sequence response was brought under conditional control. Phase 3 was again identical for both experiments, combining conditional control over the equivalence classes with conditional control over the sequence response. The sequence of all tasks in both experiments is shown in the Appendix.

The training and test sequences in each phase consisted of six parts and were basically identical for all three phases in both experiments. The only difference was that in Phase 1 simple conditional discriminations and a simple sequential response were trained, whereas in Phases 2 and 3 higher order conditional control was added. Because the linkage of the six parts of each phase was complex, the reader should refer to the diagram in Figure 2. The basic logic of the study was to train the conditional discriminations and sequencing response, and then test for transfer of the sequencing. If this transfer did not occur, actual tests for equivalence were added, first with a subset of the stimuli and then, if necessary, with all of the stimuli. When an equivalence test was passed, transfer of sequencing was once again examined.

General Procedure

All subjects were trained and tested individually in several sessions, each lasting approximately 40 to 60 min, until they completed the experiment. At the beginning, they received the following written instructions:

> When the experiment begins, the screen in front of you will show symbols. On some tasks, you will see three symbols: one at the top and two at the bottom of the screen. You have to figure out which of those at the bottom goes with the one at the top. Choose the left or the right symbol and register your choice by pressing the corresponding button on the box in front of you.
>
> On other tasks, you will see only two symbols on the screen. You have to figure out which goes first, which goes second. Depending on your choice, you will then press the buttons in sequence (left-right or right-left).
>
> For some tasks, the computer will tell you whether your answers are correct or wrong, but on other tasks no feedback is provided. All the tasks are interrelated and you can solve those without feedback by paying attention during those where feedback is provided.
>
> If you have any questions, please ask them now. The experimenter is not allowed to answer questions once the experiment has started.

Once the experiment had started, there was no further contact between subject and experimenter. However, additional brief instructions were presented on the monitor before each part of a given phase. For matching-to-sample tasks they read, "Which symbol at the bottom goes with the one at the top?" and for the sequence tasks, "Which symbol comes first, which comes second?"

All tasks were programmed so that sets of stimuli were presented at random with the restriction that the same set would not appear twice in a row. The individual parts of each phase were separated by 30- to 90-s breaks for data storage, during which subjects remained seated. Sessions ended when subjects had completed one or sometimes two of the three phases (depending on how quickly they proceeded with the task) and were resumed within the next 1 or 2 days, until the experiment was completed. Only Subject 8 required a break within one phase, as will be explained below.

EXPERIMENT 1

Procedure

During Phase 1, all subjects were trained in a set of conditional discriminations using a matching-to-sample procedure. The stimuli appeared on green background. On each trial, the sample (A1 or A2) was presented at the top of the screen, followed 2 s later by the addition of the two comparison stimuli (B1-B2, C1-C2, or D1-D2) at the bottom. In the

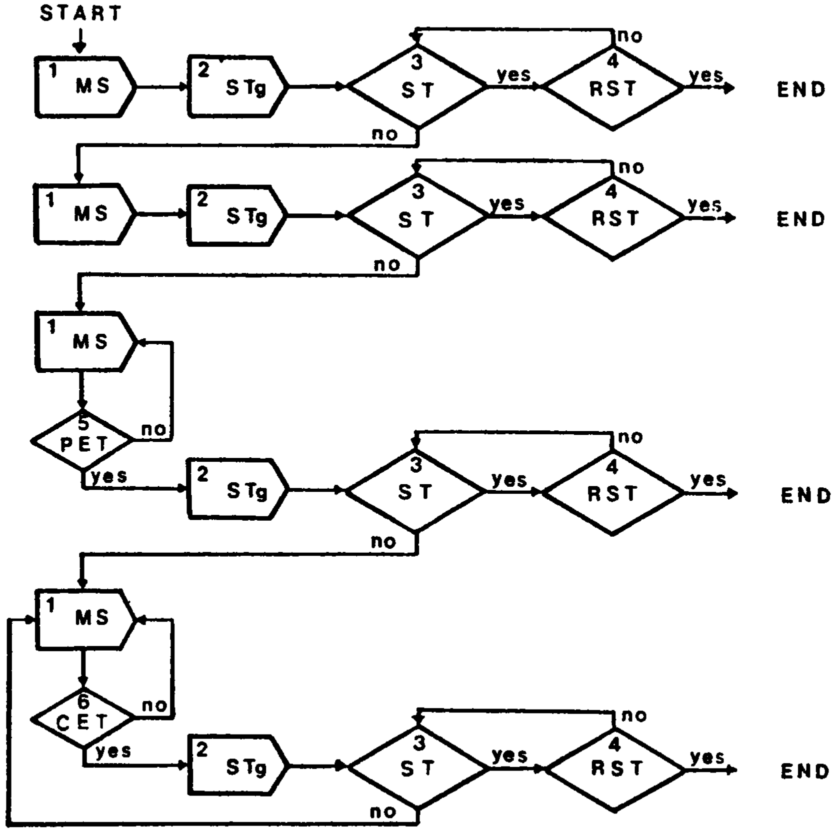


Fig. 2. A flow chart of the sequence of procedural parts within each phase. MS, matching-to-sample; STg, sequence training; ST, Sequence Test; RST, Random Sequence Test; PET, Partial Equivalence Test; and CET, Complete Equivalence Test. The number of each part is shown inside the symbol for each.

presence of sample A1, choices of the comparison stimulus B1, C1, or D1 were reinforced; in the presence of sample A2, choices of B2, C2, or D2 were reinforced. Subjects responded by pressing either one of two buttons mounted on the box in front of the screen. A response removed the stimulus display from the screen and was immediately followed by written feedback ("Correct! *X* points" where *X* was the total points earned in the session, or "Wrong! 0 points"). After a 2-s intertrial interval, the next set of stimuli appeared on the screen. The points were not interchangeable for money or other rewards, and were meant to be functionally equivalent to saying "Good." Training continued until the criterion was reached (see Appendix for all task criteria).

After completion of the matching-to-sample training (Part 1), a sequential response was trained (Part 2). The B1-B2 stimuli, which had served as one of the three sets of comparison stimuli for the conditional discriminations, were presented simultaneously (their respective spatial positions were alternated randomly across trials). Responding to these stimuli by pressing the two buttons in sequence B1-B2 (whether left-right or right-left) resulted in "Correct! *X* points." Pressing in the inverse sequence resulted in "Wrong!"

After reaching the training criterion for the sequence response to B1-B2, a Sequence Test without feedback (Part 3) was presented. This test required sequential responding to randomly presented stimulus pairs (A1-A2, B1-B2, C1-C2, and D1-D2). Responding to the "1s" first and "2s" second indicated that two equivalence classes (A1, B1, C1, D1 and A2, B2, C2, D2) had emerged, because it was implausible that the sequence response could transfer from trained to untrained stimuli other than via symmetry and transitivity. In all phases of both experiments, successful completion of the Sequence Test was followed by a Random Sequence Test (Part 4) that presented the "1s" and "2s" in random combinations (e.g., A1-C2, D1-B2) to assess whether the functions "first" and "second" had transferred independently of the specific stimulus combinations originally presented during matching to sample (e.g., C1-C2).

If the Sequence Test (Part 3) criterion was not reached, Parts 1, 2, and 3 were repeated. If the subjects again failed the Sequence Test, it was assumed that equivalence classes had not emerged. Therefore, subjects were retrained in the underlying conditional discriminations (Part 1) and then received a Partial Equivalence Test (Part 5). On this test, the A, B, and D stimuli served both sample and comparison roles, and subjects received no feedback on their performance. Training (Part 1) and testing (Part 5) continued until equivalence relations had emerged. The purpose of the Partial Equivalence Test (Part 5) was to examine whether the sequence response would transfer to all stimuli on the next Sequence Test, even though the C stimuli had not been included in the test for equivalence. Because the Cs had up to this point (either in training or testing) never been presented together with the training stimuli (B1-B2), successful transfer eliminates possible explanations other than equivalence. The relation between the B and C stimuli must be derived, which excludes transfer due to stimulus compounding or any other direct process. If subjects failed the Sequence Test (Part 3) following a successful completion of the Partial Equivalence Test (Part 5), the underlying conditional discriminations were retrained (Part 1), and a Complete Equivalence Test including all stimuli (Part 6) was presented. Parts 1 and 6 were alternated until equivalence classes had emerged. The sequence response was then retrained (Part 2) and a Sequence Test (Part 3) presented. If necessary, Parts 1, 6, 2, and 3 were repeated until transfer was shown. A Random Sequence Test (Part 4) concluded Phase 1.

In Phase 2, subjects were trained in second-order conditional discriminations. On a green background, all relations remained the same as in Part 1 of Phase 1. On a red background, two of the comparison stimulus pairs (C1-C2, D1-D2) switched classes: with A1 as the sample, choices of B1, C2, or D2 were reinforced; with A2 as the sample, choices of B2, C1, or D1 were reinforced. This allowed for the development of four conditional equivalence classes: on a green background, A1, B1, C1, D1 and A2, B2, C2, D2; on a red background, A1, B1, C2, D2, and A2, B2, C1, D1. In Part 2, the same sequential response was then retrained by reinforcing responding first to B1, then to B2, regardless of the spatial position of the stimuli or the background color, which alternated randomly across trials. In the subsequent Sequence Test (Part 3), transfer of the stimulus functions "first" and "second" to the remaining members of four conditional equivalence classes was tested. To illustrate, on green background the correct response sequences were A1-A2, B1-B2, C1-C2, and D1-D2; on red background, the correct sequences were A1-A2, B1-B2, C2-C1, and D2-D1, given that the C and D stimuli had switched class membership. If subjects failed this test, the same recursive training and testing procedures as described in Phase 1 (and displayed in Figure 2) were followed.

Finally, in Phase 3 the response sequence itself was brought under the conditional control of a high- and a low-pitched tone. Subjects were first retrained in the second-order conditional discriminations (Part 1), and then received training in a conditional sequential response to the B stimuli. Regardless of the background color or the spatial position of the stimuli, in the presence of Tone 1 selecting first B1, then B2 was reinforced; in the presence of Tone 2, selecting first B2, then B1 was reinforced. In Part 3, transfer of the conditional sequence response throughout four conditional equivalence classes was tested. To illustrate, with green background and in the presence of Tone 1, the correct sequences were A1-A2, B1-B2, C1-C2, D1-D2, whereas in the presence of Tone 2 the inverse sequences were correct (A2-A1, B2-B1, C2-C1, D2-D1). With red background and in the presence of Tone 1, the correct sequences were A1-A2, B1-B2, C2-C1, D2-D1, whereas in the presence of Tone 2 the inverse sequences were correct (A2-A1, B2-B1, C1-C2, D1-D2). In Part 4, on each trial a "first" and a "second" stimulus were presented in randomly assembled combinations, with background color indicating class membership and tone determining the direction of the sequential response. If subjects failed a sequence test, remedial training and test sequences were presented in the same order as described in the previous phases. They were repeated until subjects met criterion in Parts 3 and 4.

EXPERIMENT 2

Procedure

Phase 1 was identical to Phase 1 in Experiment 1. Subjects were trained in a set of conditional discriminations (Part 1), learned a sequential response to the B stimuli (Part 2), and then were tested for the transfer of the sequence response to the A1-A2, C1-C2, and D1-D2 stimulus pairs (Part 3) and random combinations of a "first" and a "second" stimulus (Part 4). Remedial training and testing occurred in the sequence described above.

In Phase 2, the conditional discriminations established in Phase 1 were retrained (Part 1) and the sequence response conditioned to the B stimuli was brought under conditional control (Part 2). When Tone 1 was present, selecting first B1, then B2 was reinforced; when Tone 2 was present, the inverse response sequence (B2-B1) was reinforced. All stimuli were presented on green background. A Sequence Test (Part 3) examined the transfer of this conditional sequential response to the A, C, and D stimuli. Transfer was demonstrated if in the presence of Tone 1 subjects responded sequentially in the order A1-A2, B1-B2, C1-C2, and D1-D2, and in the presence of Tone 2 they responded in the inverse order (A2-A1, B2-B1, C2-C1, and D2-D1). The training and testing parts corresponded to those of the other phases described in Experiment 1. Remedial training and testing continued until subjects reached the criterion for completing Phase 2 by mastering the Sequence and Random Sequence Test (Parts 3 and 4).

Phase 3 established the basis for transfer of a conditional sequence response via four conditional equivalence classes. Subjects were trained in second-order conditional discriminations (Part 1), retrained in the conditional sequence response to B1-B2 (Part 2) that had already been established in Phase 2, and then tested for its transfer throughout four conditional equivalence classes in a Sequence (Part 3) and Random Sequence Test (Part 4).

Although Phase 3 was identical in Experiments 1 and 2, subjects entered this phase with different histories. In Phase 2, subjects in Experiment 1 were trained in second-order conditional discriminations (from which conditional equivalence classes were expected to emerge), whereas subjects in Experiment 2 were taught a conditional sequence response. The purpose of varying the training sequences in Phase 2 was to analyze possible barriers that might prevent the emergence of the terminal behavior in Phase 3. If the training sequence mattered greatly, the relevance of the present studies to semantics and syntax would be questionable because it is implausible that verbal behavior is acquired in a strictly sequential fashion. Instead, the processes involved are undoubtedly very complex, interact dynamically, and are probably not dependent on particular training sequences. Therefore, a demonstration that functionally identical, complex response patterns (Phase 3) can emerge from different histories would increase the plausibility of the proposed account.

RESULTS

The results for all subjects from Experiment 1 are presented in Figure 3, and those for subjects in Experiment 2 are presented in Figure 4. Throughout the description of results, responses that contribute to meeting testing or training criteria will somewhat arbitrarily be defined as "correct," and responses that do not contribute to the criteria being met will be defined as "incorrect" or "errors." This entails some danger in terms of assuming the validity of our predictions as measures of "correctness" but no other convention seems to facilitate communication.

EXPERIMENT 1

In Experiment 1 we examined the transfer of sequential responding through equivalence classes (Phase 1), then through conditional equivalence classes (Phase 2), and then of conditional sequential responding through conditional equivalence classes (Phase 3). All 4 subjects showed the transfer of the sequence response in all three phases.

Subject 1. As shown in Figure 3, this subject demonstrated the transfer of a sequential response from trained to untrained stimuli without any specific equivalence test in all three

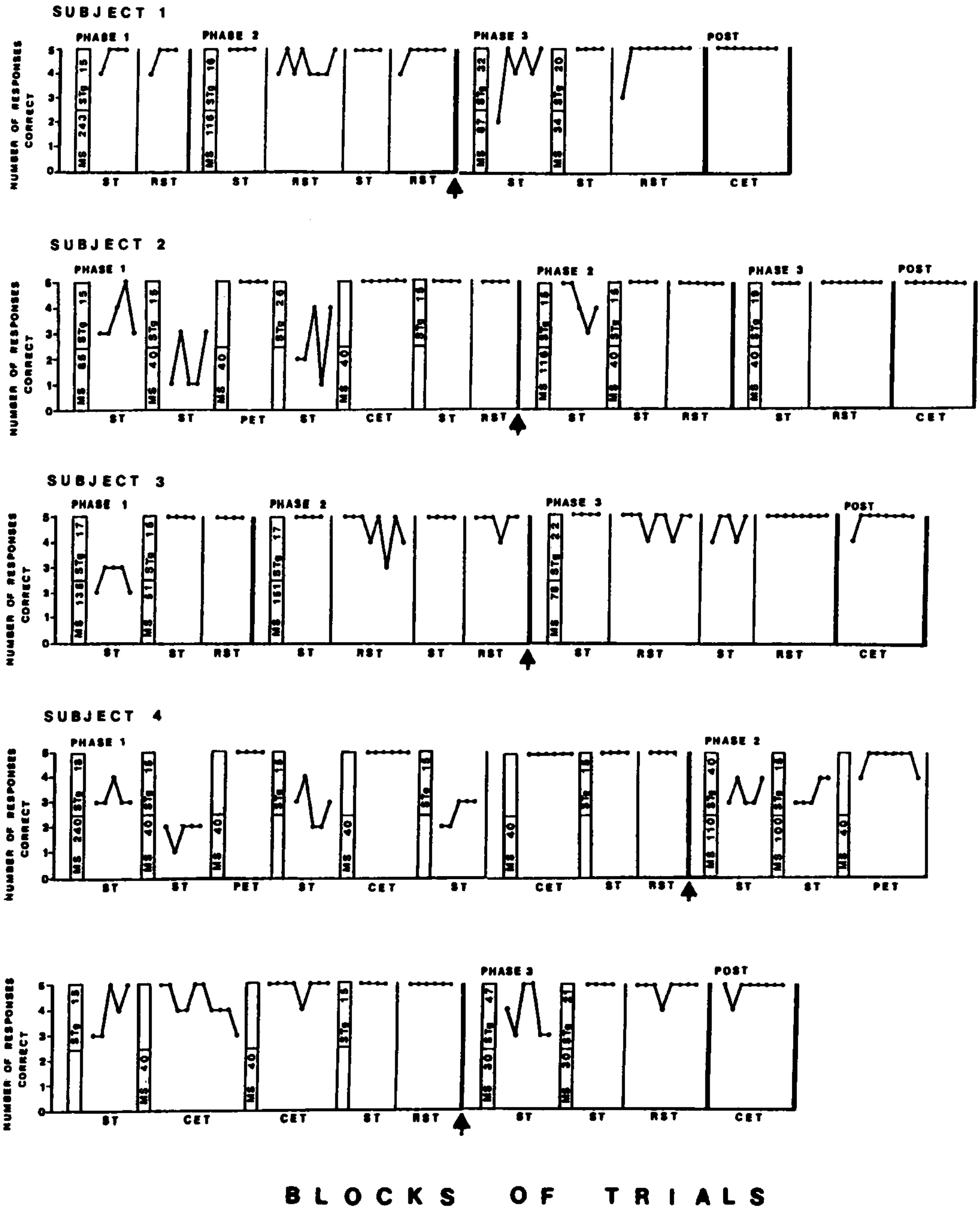


Fig. 3. Performances of Subjects 1, 2, 3, and 4 in each phase of Experiment 1. The phases show the transfer of a sequence response through two equivalence classes (Phase 1) and four conditional equivalence classes (Phase 2), and of a conditional sequence response through four conditional equivalence classes (Phase 3). The vertical bars represent training trials with reinforcement. MS, number of matching-to-sample training trials; STg, sequence response training trials. The frequency polygons represent test trials without reinforcement, with each dot representing five trials. ST, Sequence Test; RST, Random Sequence Test; PET, Partial Equivalence Test; CET, Complete Equivalence Test. POST designates a post hoc conditional equivalence test after completion of Phase 3. Arrows on the abscissa mark the session breaks.

phases of the experiment. In Phase 1, after matching-to-sample training and acquisition of a sequential response to the B stimuli, her performance on a subsequent Sequence and Random Sequence Test (with 19 of 20 consecutive trials correct on both tests) indicated that the functions "first" and "second" had spread without training from B1-B2 to the other members of two equivalence classes that emerged from matching-to-sample training.

In Phase 2, when the conditional discriminations established in Phase 1 were brought under second-order control, she immediately showed a transfer of the sequential response throughout four conditional equivalence classes on the Sequence Test. She failed to reach criterion on the Random Sequence Test, but when both tests were presented a second time she completed them successfully (with 20 of 20 and 29 of 30 trials correct, respectively).

Finally, in Phase 3 sequential responding itself was brought under conditional control of two tones. On the first test, the subject failed to show a transfer of the conditional sequence response. However, after retraining she completed a second presentation of the Sequence Test successfully (20 of 20 trials correct) and also met the criterion on the following Random Sequence Test (40 of 40 trials correct within 45 presentations).

Because the presence of conditional equivalence relations had not been tested specifically, the subject received a post hoc conditional equivalence test (without reinforcement). She completed it without errors. Her performance supported the conclusion that the previously observed transfer of function was caused by stimulus equivalence and not by possible experimental artifacts. This was also corroborated by anecdotal evidence. When interviewed after the experiment, she stated that "groups of symbols went together because they were related to the ones at the top."

Subject 2. As is shown in Figure 3, for Subject 2 the sequence response transferred from trained to untrained stimuli following testing for equivalence relations. In Phase 1, after the conditional discriminations and the sequential response to B1-B2 had been trained, the subject failed two Sequence Tests (separated by retraining trials). After further remedial training, he received a Partial Equivalence Test, which he passed without errors, yet failed the following Sequence Test again. After mastering the Complete Equivalence Test, he passed the next Sequence Test and also the Random Sequence Test without further difficulty (both with 20 of 20 trials correct).

In Phase 2, which introduced the second-order conditional discriminations, the subject barely missed the criterion for the first Sequence Test. After repeating the training and test sequence, he performed without errors on the Sequence and Random Sequence Test (20 of 20 and 30 of 30 trials correct, respectively). The sequential response had transferred throughout four conditional equivalence classes, although the presence of these classes had not been tested explicitly.

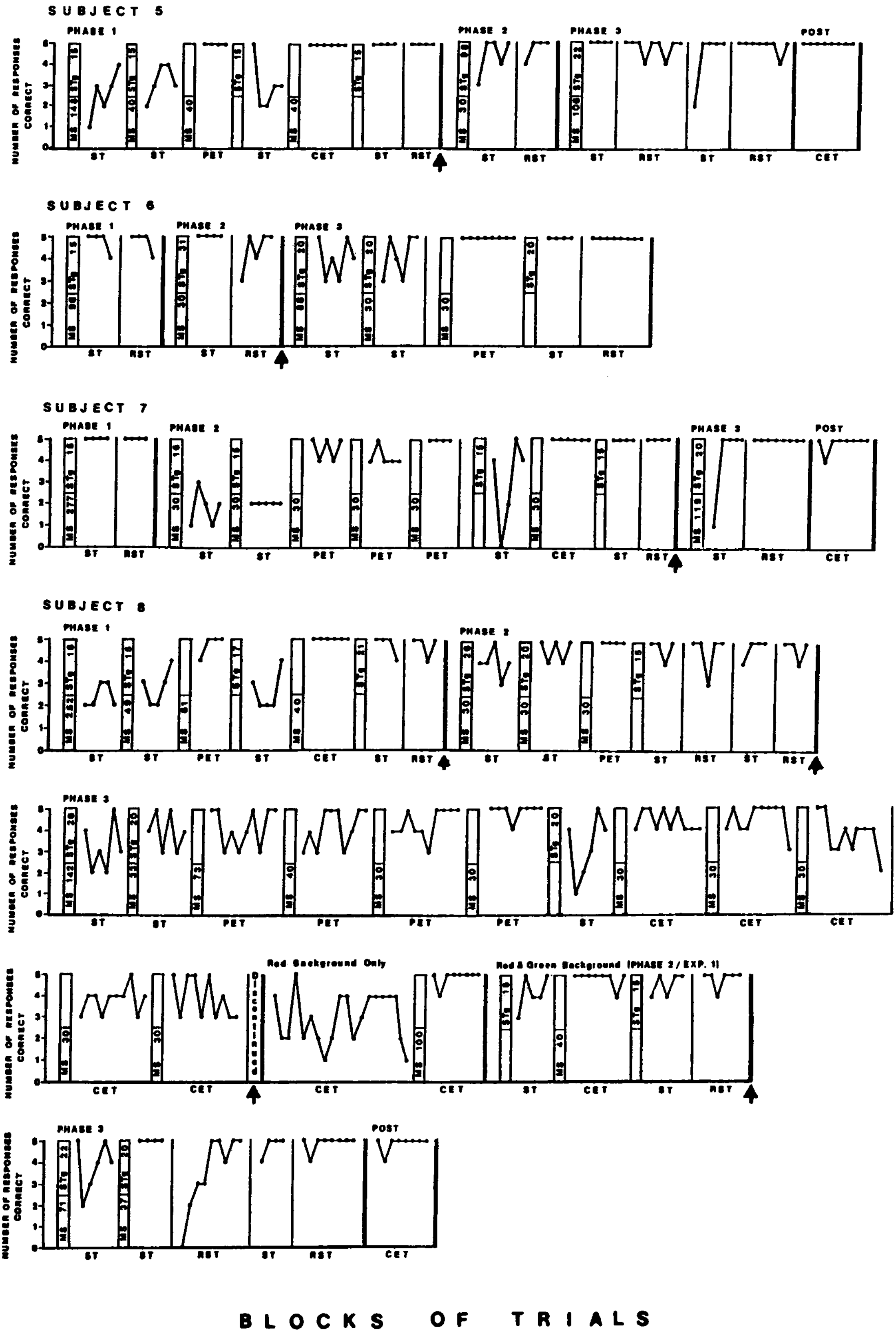
In Phase 3, after bringing the sequence response itself under second-order control, Subject 2 showed error-free performance on both the Sequence and Random Sequence Test (20 of 20 and 40 of 40 trials correct, respectively). He also completed 40 trials of a post hoc conditional equivalence test without errors.

Subject 3. As with Subject 1, this subject completed the experiment without a prior equivalence test (see Figure 3). In Phase 1, he failed the first Sequence Test. After retraining, he mastered this test and also performed without errors on the Random Sequence Test.

In Phase 2, after learning the second-order conditional discriminations, he immediately passed the Sequence Test but failed the Random Sequence Test because of several incorrect responses on sequences involving transitivity. When both tests were repeated, he met criterion (20 of 20 and 29 of 30 trials correct, respectively).

In Phase 3, when the sequential response itself was brought under conditional control, the subject showed an immediate transfer on the first Sequence Test, but failed the Random Sequence Test. This may have been caused by the stringent test criterion, allowing the subject only one mistake in 40 consecutive trials within a limit of 45 presentations. He responded correctly on 43 of the 45 trials, but made two mistakes on the last 40 trials. On a second presentation of the Sequence and Random Sequence Test, he met criterion on both. In 25 trials he scored 19 of 20 correct on the last 20 trials of the Sequence Test, and had 40 of 40 trials correct on the Random Sequence Test. He also passed a post hoc conditional equivalence test with 39 of 40 trials correct.

Subject 4. In comparison with the other 3


SUBJECT 5
PHASE 1
PHASE 2
PHASE 3
POST
SUBJECT 6
SUBJECT 7
SUBJECT 8
Red Background Only
Red & Green Background (PHASE 2 / EXP. 1)
NUMBER OF RESPONSES CORRECT
ST
RST
PET
CET
BLOCKS OF TRIALS

subjects in Experiment 1, Subject 4 had greater difficulty completing the experiment (see Figure 3). In Phase 1, no transfer of the sequential response was observed on the first two Sequence Tests (separated by retraining). After remedial training in the underlying conditional discriminations, she passed the Partial Equivalence Test, but again failed the following Sequence Test. After more remedial training, she passed a Complete Equivalence Test, thus demonstrating that equivalence relations had formed, yet she responded in nearly a random fashion on the next Sequence Test. It appeared that the subject to this point in the experiment had failed to discriminate the relationship between the matching to sample and sequence tasks. However, after retraining and error-free performance on a second Complete Equivalence Test, she completed both the Sequence and Random Sequence Test with 20 of 20 trials correct.

In Phase 2, her performance showed a similar pattern. After training in second-order conditional discriminations and the sequence response, she failed the first Sequence Test. After retraining, she failed this test a second time. After remedial training in the underlying conditional discriminations, she passed the Partial Equivalence Test but again failed the next Sequence Test. When retrained and given a Complete Equivalence Test, it became apparent that conditional equivalence relations had not emerged among all stimuli. On red background the subject responded incorrectly to all C-D and D-C relations. After more remedial training in the underlying second-order conditional discriminations, she passed the Complete Equivalence Test. Once four conditional equivalence classes had formed, a transfer of control occurred on the next test. The subject completed both the Sequence and Random Sequence Test without error (20 of 20 and 30 of 30 trials correct, respectively).

During Phase 3, she failed the first Sequence Test, possibly due to difficulties in discriminating the auditory signals that now determined the directionality of the sequential response. During remedial training, her difficulty in discriminating the tones became apparent when she made seven mistakes in 21 training trials (with reinforcement) on the conditional sequence response to the B stimuli. Once the discrimination was established, she mastered the Sequence and Random Sequence Test (20 of 20 and 39 of 40 trials correct, respectively). She also met criterion on a post hoc conditional equivalence test (39 of 40 trials correct).

EXPERIMENT 2

In Experiment 2, after simple equivalence was established (Phase 1), conditional sequence training occurred in Phase 2 and conditional matching-to-sample training occurred in Phase 3, reversing the order used in Experiment 1. All 4 subjects reached criterion in the three phases of this experiment, although 2 did so only after a specific equivalence test, and 1 of these required extensive retraining sequences. Thus, as in Experiment 1, the intersubject variability was substantial; Subjects 6 and 7 completed the whole sequence without appreciable difficulty.

Subject 5. This subject (see Figure 4) was tested for equivalence relations among all stimuli before she mastered the Sequence and Random Sequence Test in Phase 1. After training in the conditional discriminations and the sequence response to B1-B2, she failed two Sequence Tests (separated by remedial training). After retraining on the underlying conditional discriminations, she passed the Partial Equivalence Test, but again failed the next Sequence Test. After more remedial training, she mastered the Complete Equivalence Test and subsequently also passed the Sequence and Random Sequence Test (20 of 20 trials correct on both).

In Phase 2, she was retrained in matching to sample and then learned a conditional se-

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Fig. 4. Performances of Subjects 5, 6, 7, and 8 in each phase of Experiment 2. The phases show the transfer of a sequence response (Phase 1) and a conditional sequence response (Phase 2) through two equivalence classes, and of a conditional sequence response through four conditional equivalence classes (Phase 3). Vertical bars represent training trials with reinforcement. MS, number of matching-to-sample training trials; STg, sequence response training trials. The frequency polygons represent test trials (without reinforcement), with each dot representing five trials. ST, Sequence Test; RST, Random Sequence Test; PET, Partial Equivalence Test; CET, Complete Equivalence Test. POST designates a post hoc conditional equivalence test after completion of Phase 3. Arrows on the abscissa mark the session breaks.

quence response to the B stimuli. Because of a mild hearing impairment this was particularly difficult for her and required 98 training trials. Once the auditory discrimination was established, she solved both the Sequence (19 of 20 trials correct within 25 presentations) and Random Sequence Test (19 of 20 trials correct).

In Phase 3, after training in the second-order conditional discriminations, she immediately passed the Sequence Test (20 of 20 trials correct), and barely missed the criterion for the Random Sequence Test. On a second presentation, she met criterion on both tests (20 of 20 trials correct within 25 presentations on the Sequence Test and 39 of 40 trials correct on the Random Sequence Test). She also performed without errors on a post hoc conditional equivalence test.

Subject 6. This subject completed Phases 1 and 2 without an equivalence test (see Figure 4). In Phase 1, after training in the conditional discriminations and the sequence response, he immediately showed a transfer of control on the Sequence and Random Sequence Test (19 of 20 trials correct on both tests).

In Phase 2, which added conditional control to the sequence response, his performance was similar. After completing training, he reached criterion on the first Sequence Test (20 of 20 trials correct) and met criterion on the Random Sequence Test within the limits of 25 trial presentations (19 of 20 trials correct).

In Phase 3, after training in the second-order conditional discriminations and retraining in the conditional sequence response, he failed the first two Sequence Tests (separated by remedial training). After retraining in the underlying second-order conditional discriminations, he completed the Partial Equivalence Test without errors, was retrained in the sequential response, and then met criterion on the Sequence and on the Random Sequence Test (20 of 20 and 40 of 40 trials correct, respectively). Because of a failure in the electronic equipment, Subject 6 did not receive a post hoc conditional equivalence test.

Subject 7. This subject (see Figure 4) completed Phase 1 without an equivalence test. After the necessary training trials in matching to sample and sequential responding to B1-B2, she immediately passed the Sequence and Random Sequence Test without errors.

In Phase 2, when the conditional sequence response to the B stimuli was added, she failed two presentations of the Sequence Test (separated by remedial training). After retraining in the underlying conditional discriminations, she also failed the next two Partial Equivalence Tests (separated by remedial training) before meeting criterion on its third presentation. After retraining of the sequential response to B1-B2, she failed the next Sequence Test again. After more remedial training, she performed without errors on the Complete Equivalence Test, and then also mastered the Sequence and Random Sequence Test (20 of 20 trials correct on both).

In Phase 3, she received training in the second-order conditional discriminations and retraining in the conditional sequence response. She showed an immediate transfer of control on the first Sequence Test despite four mistakes on the first five trials, and also passed the Random Sequence Test (40 of 40 trials correct). She met criterion on a post hoc conditional equivalence test (39 of 40 trials correct).

Subject 8. Although this subject's performance in Phases 1 and 2 was comparable to that of other subjects, he had considerable problems with Phase 3, and had difficulty completing the experiment (see Figure 4). In Phase 1, after training, he failed two Sequence Tests (separated by retraining trials). After retraining in the underlying conditional discriminations, he met criterion on the Partial Equivalence Test, was retrained in the sequence response, but again failed the Sequence Test. After more remedial training, he passed the Complete Equivalence Test and then also mastered the Sequence and Random Sequence Test (19 of 20 trials correct on both).

In Phase 2, when the conditional sequence response was added, he failed the first Sequence Test and after retraining just missed criterion on the second Sequence Test by one trial. After remedial training in the underlying conditional discriminations, he passed the Partial Equivalence Test and then completed the Sequence Test (19 of 20 trials correct), but failed the criterion for the Random Sequence Test by one trial. On a second presentation of the Sequence and Random Sequence Test, he met criterion on both (19 of 20 trials correct).

In Phase 3, after training in the second-order conditional discriminations and retraining in the conditional sequence response, he failed two Sequence Tests (separated by remedial training). He was retrained in the second-order conditional discriminations and failed three Partial Equivalence Tests (separated by retraining trials) before he completed it on its fourth presentation (39 of 40 trials correct). He again failed the next Sequence Test, and after remedial training received the Complete Equivalence Test. He failed five presentations of this test (separated by remedial training) almost exclusively due to mistakes involving transitive relations on red background.

It was unlikely that conditional equivalence would emerge. Therefore, a change in the experimental protocol was introduced. Because most errors occurred on relations involving the red background, the green background was eliminated and all training and test trials were presented on red only. First the subject received a Complete Equivalence Test with 100 matching-to-sample test trials (without reinforcement). When equivalence relations did not emerge, he received 100 trials (with reinforcement) of conditional discrimination training until these relations were established reliably. He then passed a Complete Equivalence Test with 39 of 40 trials correct. Now the red and green background colors (randomly varying across trials) were reintroduced, and a simple sequence response to the B stimuli was trained (similar to Phase 2 of Experiment 1). He failed the first Sequence Test and received remedial training in the underlying second-order conditional discriminations. He then passed a complete conditional equivalence test and subsequently also solved the Sequence (19 of 20 trials correct within 25 presentations) and Random Sequence Test (29 of 30 trials correct). Now Phase 3 was reintroduced. The subject was retrained in the underlying second-order conditional discriminations and the conditional sequence response. He failed the first Sequence Test, possibly because of difficulty in discriminating the tones signaling the directionality of the sequential response. After retraining, he passed the Sequence Test without error (20 of 20 trials correct) and failed the Random Sequence Test (because he "got confused with the tones," as he stated after the experiment). He then passed both tests on a second presentation (19 of 20 and 39 of 40 trials correct, respectively). A final presentation of a post hoc conditional equivalence test demonstrated once more that four conditional equivalence classes had formed.

Reaction Time Measures

Fields, Verhave, and Fath (1984) have suggested that the "associative distance" between stimuli in equivalence classes may be understood in terms of the number of stimulus "nodes" between the stimuli. This may be examined by calculating subjects' response latencies from the time the comparison stimuli were presented until a comparison stimulus was selected. Latencies were analyzed for all trials in both the equivalence tests and the sequence tests, depending on whether the stimulus relations were trained or emerged from symmetry or from transitivity.

The average response latencies across all (partial and complete) equivalence tests across all 8 subjects were 1.92, 2.89, and 4.55 s for trained, symmetrical, and transitive relations, respectively. Following a statistically significant overall ANOVA, $F(2, 23) = 4.46$, $p < .002$, a post hoc Newman–Keuls test showed that the reaction times for trained relations were significantly shorter than those for transitive relations ($p < .05$), whereas the difference between trained and symmetrical relations was not statistically significant.

The average reaction times across all sequence tests were 1.93 s for responses to the trained B stimuli, 2.73 s for responses to the A stimuli involving symmetry, and 3.66 s for responses to the C or D stimuli involving transitivity. Relations from the random sequence tests involving "mixed" stimulus pairs were not analyzed because these trials do not fall cleanly into the three categories. Following a statistically significant overall ANOVA, $F(2, 23) = 8.21$, $p < .002$, a post hoc Newman–Keuls test indicated that the reaction times to trained and symmetrical response sequences did not differ statistically from each other, although both were significantly shorter than those to transitive relations ($p < .05$).

DISCUSSION

Results from both experiments have shown that a sequential response trained to a given stimulus pair can transfer, without additional training, to other stimuli in equivalence classes. When the sequential response is itself brought under conditional control, these conditional stimuli will also control sequential responding to members of the relevant equivalence classes that have not been involved in sequence training. In addition, it has been shown that equivalence classes themselves can come under second-order conditional control and that sequential responding will transfer in an orderly way to the members of the conditional equivalence classes for which it has not been explicitly trained. Finally, these experiments have shown that these various sources of control can all converge to produce sequential behavior.

Transfer of the response sequence to untrained stimuli almost always occurred when the formation of equivalence or conditional equivalence classes was demonstrated. That is, although most subjects (i.e., 2, 4, 5, 7, and 8) failed sequence tests and sometimes also equivalence tests at some point in the study, once they passed a Complete Equivalence Test a transfer of the sequence response occurred on the very next Sequence Test. The only exception to this was Subject 4, who passed two Complete Equivalence Tests before the transfer occurred. Hence, it appears that transfer of functions from one arbitrary stimulus to others is highly likely once equivalence classes have formed.

Subjects 1 and 3 completed the entire experiment without passing a specific equivalence test. Thus, the emergence of equivalence classes and transfer of functions through them do not require equivalence tests as usually administered. It has been argued that equivalence testing establishes a context that may contribute to the formation of equivalence classes themselves (Devany, Hayes, & Nelson, 1986; Hayes, in press; Sidman, 1986). The sequence tests, however, may be thought of as another kind of equivalence test, and their administration may have contributed to the emergence of equivalence. These tests required symmetry and transitivity relations to occur and may have established a context similar to tests in the matching-to-sample format, which traditionally have been used to demonstrate equivalence. It is, of course, also possible that equivalence had already emerged during conditional discrimination training for these subjects. Whichever is correct, transfer of functions may provide an alternative method for assessing the presence of stimulus equivalence (Hayes, Brownstein, Devany, Kohlenberg, & Shelby, in press). This might be helpful in an analysis of the role of testing itself in stimulus-class formation.

The present study used recursive training and testing procedures, which could themselves have served as discriminative stimuli for alternative response strategies. Recursive training procedures per se are unlikely as an explanation for the present results, however, for two reasons. First, subjects were not told that an earlier phase was being repeated. Because the normal sequence of phases was unknown to the subjects, only in exceptional cases in which the amount of retraining was substantial (e.g., Subjects 4 and 8) would the repetition be likely to serve as a cue. Some subjects went through the entire experiment with only one or two retraining periods (Subjects 1, 3, and 6). Second, the Sequence Test and especially the Random Sequence Test entail a large number of possible response sequences. For example, in Phase 3 the Random Sequence Test permits 16 different sets of stimuli (four different "1s" combined all possible ways with four different "2s") in each of two background colors, for a total of 32 different sets of stimuli. Each set can be arranged spatially in two different ways, and in the presence of two different tones, for 128 different combinations of stimuli, background colors, tones, and spatial positions. The mere fact of retraining could not provide enough corrective feedback to generate correct responses in such a large set of problems if the correct answers had to be learned on the basis of retraining alone. If we assume that stimulus equivalence is already available as one alternative response strategy, however, then it is plausible that retraining could help to shift the basis of responding from other stimulus dimensions (e.g., similarity in form) to stimulus equivalence. As noted above, a similar role has been implicated for the equivalence test itself. Whether repeated testing encouraged subjects to respond in terms of stimulus equivalence is not known, but it would not threaten the central finding of the study if it did because such an effect assumes the same psychological process (i.e., equivalence) the findings themselves reveal.

The performance of Subject 8 warrants additional discussion. Given the difficulty he had in completing the experiment, he was interviewed extensively and reported that he had approached the second-order conditional discriminations with a "strategy" when he noted that the C and D stimulus pairs had "switched place." With sample A1, he continued to focus on the comparisons C1 or D1, and with sample A2, on C2 or D2, but on red background he deliberately "chose the other one" (i.e., C2 or D2 in the presence of sample A1, and C1 or D1 with sample A2). This strategy worked during acquisition but failed in testing. On red background, with a C stimulus as sample and the D stimuli as comparisons, he chose "the other one" of the comparisons he would have responded to on green background. He related C1 with D2, D1 with C2, and so on, but his strategy was flawed because C1/D1 and C2/D2 continued to be members of the same classes on red background, even though the classes were composed of different stimuli (A1/B1/C2/D2 and A2/B2/C1/D1). He did not discriminate these relations until he received 100 massed training trials on red background only.

If one agrees with Sidman's (1986) argument that equivalence relations are semantic in nature, the demonstrated transfer of a sequence response may parallel the emergence of simple two-word utterances in a child who, after having learned several concepts (e.g., colors, food, clothing, toys), can generate a considerable number of combinations from probably very few trained instances. If the assumption is correct that verbal concepts originate from the participation of verbal stimuli in equivalence or other relational classes, the emergence of new, untrained combinations of elements of these classes seems to lose its mysterious quality. The generation of such untrained symbol combinations can be explained from a behavior-analytic perspective in terms of the ability of humans to respond on the basis of arbitrary relations among events, an appropriate training history with regard to such relations, and transfer of functions through the relational classes this history generates (Hayes, in press).

One contribution of the present research is the empirical demonstration that conditional equivalence relations can emerge from second-order conditional discriminations and that a function acquired by one stimulus transfers to all conditional equivalence class members without direct training. If we accept that equivalence relations closely parallel word–referent relations, then the conditional control of equivalence classes may bear on how "the same word can mean different things," depending on the context in which it occurs.

Establishing second-order control over equivalence relations, in addition to creating flexibility in meaning, may also have implications for syntax. The untrained transfer of a sequential response through four conditional equivalence classes demonstrated that response sequences to topographically identical symbols need not be invariant. Depending on the class membership of the symbols, sequences can be ordered in different ways and mean different things. For linguistic development, these findings may parallel one way in which novel utterances are generated and ordered in different ways without direct training.

Another way in which the environment can determine the ordering of response sequences was demonstrated by the transfer of conditional sequential responding from trained to untrained members of equivalence classes. This might be yet another way in which flexible word order can originate. Perhaps similar processes underlie syntactic relations which linguists have termed active and passive voice: The word order is inverted, yet the meaning of an utterance is conserved.

Finally, in the third phase of both experiments it was demonstrated that different sources of control can combine to generate elaborate forms of sequential responding under complex environmental control. From only eight trained sequences (i.e., Green, Tone 1: B1-B2; Green, Tone 2: B2-B1; Red, Tone 1: B1-B2; Red, Tone 2: B2-B1; and each of the four sequences in each of two spatial arrangements), a total of 120 additional response sequences emerged without direct training due to the transfer of these trained instances to other stimuli in the conditional equivalence classes. From this training history the following 15 untrained sequences emerged under green background in the presence of Tone 1: A1-A2, C1-C2, D1-D2, A1-B2, A1-C2, A1-D2, B1-A2, B1-C2, B1-D2, C1-A2, C1-B2, C1-D2, D1-A2, D1-B2, and D1-C2. Under green background and Tone 2, the same sequences emerged in the inverse order. Under red background and Tone 1, the sequences emerging from B1-B2 were A1-A2, C2-C1, D2-D1, A1-B2, A1-C1, A1-D1, B1-A2, B1-C1, B1-D1, C2-A2, C2-B2, C2-D1, D2-A2, D2-B2, and D2-C1, and under Tone 2 these sequences emerged in the inverse order. Finally, all 60 untrained sequences were responded to successfully in each of the two possible spatial arrangements.

To date it is impossible to determine whether the emergence of syntactic relations is in fact controlled by processes similar to those shown in the present study. One justifiable criticism might be that the data were obtained from adult subjects. It could be argued that the transfer of the sequence response under the specified conditions occurred precisely because adult subjects already have very proficient language skills and other sophisticated behavioral repertoires that facilitated their performance on the experimental tasks. This possibility cannot yet be ruled out. The ability to form equivalence relations has been demonstrated in very small children, some as young as 2 years of age (e.g., Devany et al., 1986), indicating that elaborate language skills are not a prerequisite for equivalence class formation. It may be, however, that transfer of responses through equivalence classes requires a long history of abstract verbal reasoning. A replication of this study with small children as subjects would clarify the issue. If adult repertoires proved essential, it would then be important to discover precisely how the more elaborate verbal repertoires lead to effects such as these.

Another related criticism may be that the present study used instructions to help establish the ordering response and the original matching-to-sample performance (e.g., "which symbol comes first, which comes second?"). It is possible that establishing performance in this way helped contribute to the results obtained. At present, the roles of particular training histories and instructions in the equivalence class phenomenon are not well understood. These raise complicated issues—complicated in part because there are no adequate behavior-analytic theories of instructional control itself. Indeed, this work on stimulus equivalence is meant to help develop such theories. It is illegitimate to "explain" findings on the basis of instructional control if the process of instructional control itself cannot be specified. In addition, direct shaping procedures themselves can create difficulties. For example, a common procedure has been to establish matching to sample by reinforcing identity matching in a preexperimental phase. When such pretraining is not used, some subjects trained in a conditional equivalence class procedure show resultant symmetry and transitivity but no reflexivity (Steele, 1987). Thus, one of the "defining characteristics" of equivalence may under some conditions be an artifact of noninstructional pretraining. At the present time, it seems best simply to delineate the experimental procedures carefully and to be fully aware of the need to examine this issue theoretically and experimentally.

The present data suggest a possible basis for the occurrence of extremely elaborate forms of control over novel behavior in adult verbal humans. For example, the present results might suggest that clients who have a traumatic experience with a given event could generalize to other events based purely on verbal or other equivalence classes. To take a speculative clinical example, an individual who had had a bad experience of feeling trapped in a relationship may also feel panic about being trapped in a shopping mall and develop agoraphobia. Such effects could explain the odd forms of generalization commonly reported by clinicians.

Because children master language rapidly despite its complexity, the principles of learning are considered by some to be insufficient to account for language acquisition. Chomsky (1965), for example, has postulated that language emerges from a universal and species-specific deep-structure component that is part of the biological endowment of humans: "Learning is only a matter of filling in details within a structure that is innate" (Chomsky, 1965, p. 39). If language development is considered to be tied to the training of particular equivalence relations, then the present experiments may serve as a possible learning-based model for the acquisition and untrained transfer of syntactic relations. Although language is undoubtedly a very complex behavioral phenomenon, it seems to emerge from a combination of units that initially are very small and simple (i.e., individual words, then two-word utterances, and gradually longer and more complex units). The present research has shown that the environment can establish rather sophisticated control over sequential responses to symbols and that from few trained instances a very large and flexible number of untrained sequences can arise. It is possible that further experimental analyses within the framework of stimulus equivalence and related phenomena may help elucidate some of the processes that characterize verbal behavior.

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APPENDIX

Training and Test Sequences

Experiment 1, Phase 1

Part 1

Equivalence Training (with reinforcement); matching to sample

If A1, then B1, C1, or D1

If A2, then B2, C2, or D2

Training criterion: 29 of 30 consecutive trials correct

Part 2

Sequence Training (with reinforcement)

B1 → B2 (regardless of their spatial position)

Training criterion: 14 of 15 consecutive trials correct

Part 3

Sequence Test (without reinforcement)

A1 → A2; B1 → B2; C1 → C2; D1 → D2

Test criterion: 19 of 20 consecutive trials correct or a maximum of 25 trials

Part 4

Random Sequence Test (without reinforcement)

e.g., A1 → D2; B1 → C2; C1 → A2; D1 → B2; etc.

Test criterion: 19 of 20 consecutive trials correct or a maximum of 25 trials

Part 5

Partial Equivalence Test (without reinforcement); matching to sample with A, B, and D stimuli serving sample and comparison role.

Test criterion: 19 of 20 consecutive trials correct or a maximum of 25 trials

(Note that not all subjects underwent this test)

Part 6

Complete Equivalence Test (without reinforcement); matching to sample with all stimuli serving sample and comparison role.

Test criterion: 29 of 30 consecutive trials correct or a maximum of 35 trials

(Note that not all subjects underwent this test)

Experiment 1, Phase 2

Part 1

Conditional Equivalence Training (with reinforcement); second-order matching-to-sample procedure with background color (red vs. green) serving as second-order stimulus.

If Green and if A1, then B1, C1, or D1

If Green and if A2, then B2, C2, or D2

If Red and if A1, then B1, C2, or D2

If Red and if A2, then B2, C1, or D1

Training criterion: 39 of 40 consecutive trials correct

Part 2

Sequence Training (with reinforcement) on randomly varying background across trials

Green: B1 → B2

Red: B1 → B2

Training criterion: 14 of 15 consecutive trials correct

Part 3

Sequence Test (without reinforcement) on randomly varying background across trials

Green: A1 → A2; B1 → B2; C1 → C2; D1 → D2

Red: A1 → A2; B1 → B2; C2 → C1; D2 → D1

Test criterion: 19 of 20 consecutive trials correct or a maximum of 25 trials

Part 4

Random Sequence Test (without reinforcement) on randomly varying background across trials

Green: A1 → D2; B1 → C2; C1 → A2; D1 → C2; etc.

Red: A1 → D1; B1 → C1; C2 → A2; D2 → C1; etc.

Test criterion: 29 of 30 consecutive trials correct or a maximum of 40 trials

Parts 5 and 6

Conditional Equivalence Tests (without reinforcement), identical to those of Phase 1, Parts 5 and 6, but with randomly varying background across trials.
(Note that not all subjects underwent these tests)

Experiment 1, Phase 3

Part 1

Conditional Equivalence Training (with reinforcement); identical to that in Phase 2, Part 1

Part 2

Second-Order Sequence Training (with reinforcement) on randomly varying background across trials

Tone 1, Green: B1 → B2

Tone 1, Red: B1 → B2

Tone 2, Green: B2 → B1

Tone 2, Red: B2 → B1

Training criterion: 19 of 20 consecutive trials correct

Part 3

Second-Order Sequence Test (without reinforcement) on randomly varying background across trials

Tone 1, Green: A1 → A2; B1 → B2; C1 → C2; D1 → D2

Tone 1, Red: A1 → A2; B1 → B2; C2 → C1; D2 → D1

Tone 2, Green: A2 → A1; B2 → B1; C2 → C1; D2 → D1

Tone 2, Red: A2 → A1; B2 → B1; C1 → C2; D1 → D2

Test criterion: 19 of 20 consecutive trials correct or a maximum of 30 trials

Part 4

Second-Order Random Sequence Test (without reinforcement) on randomly varying background across trials

Tone 1, Green: A1 → C2; B1 → D2; C1 → A2; etc.

Tone 1, Red: A1 → C1; B1 → D1; C2 → A2; etc.

Tone 2, Green: C2 → A1; D2 → B1; A2 → C1; etc.

Tone 2, Red: C1 → A1; D1 → B1; A2 → C2; etc.

Test criterion: 39 of 40 consecutive trials correct or a maximum of 45 trials

Parts 5 and 6

Conditional Equivalence Tests (without reinforcement), identical to those of Phase 2, Parts 5 and 6
(Note that not all subjects underwent these tests)

Experiment 2, Phase 1

Identical to Phase 1, Experiment 1

Experiment 2, Phase 2

Part 1
Equivalence Training (with reinforcement), identical to Phase 1, Part 1

Part 2
Second-Order Sequence Training (with reinforcement) with randomly varying tones across trials
Tone 1: B1 → B2
Tone 2: B2 → B1
Training criterion: 14 of 15 consecutive trials correct

Part 3
Second-Order Sequence Test (without reinforcement) with randomly varying tones across trials
Tone 1: A1 → A2; B1 → B2; C1 → C2; D1 → D2
Tone 2: A2 → A1; B2 → B1; C2 → C1; D2 → D1
Test criterion: 19 of 20 consecutive trials correct or a maximum of 25 trials

Part 4
Second-Order Random Sequence Test (without reinforcement) with randomly varying tones across trials
Tone 1: A1 → C2; B1 → D2; etc.
Tone 2: C2 → A1; D2 → B1; etc.
Test criterion: 19 of 20 consecutive trials correct or a maximum of 25 trials

Parts 5 and 6
Identical to those of Phase 1, Parts 5 and 6

Experiment 2, Phase 3

Identical to Experiment 1, Phase 3