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Higher-order control over equivalence classes and response sequences: An experimental analogue of simple syntactical relations

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The University of North Carolina at Greensboro, 1987

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HIGHER-ORDER CONTROL OVER EQUIVALENCE CLASSES AND RESPONSE SEQUENCES: AN EXPERIMENTAL ANALOGUE OF SIMPLE SYNTACTICAL RELATIONS

by

Edelgard Wulfert

A Dissertation submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
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APPROVAL PAGE

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Committee Members

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WULFERT, EDELGARD, Ph.D. Higher-Order Control over Equivalence Classes and Response Sequences: An Experimental Analogue of Simple Syntactical Relations. (1986) Directed by Drs. Steven C. Hayes and Richard L. Shull. Pp. 122

The purpose of the present research was to investigate the emergence of untrained response sequences under complex environmental control. 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 pick 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 in an orderly fashion to all members of the four conditional equivalence classes. For each subject, 64 untrained sequences were shown to have emerged from four trained sequence responses.

Transfer of control through equivalence and conditional equivalence classes may provide the basis of a behavior-analytic model of semantic meaning and generative grammar.

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CHAPTER I

INTRODUCTION

A behavioral approach to the study of language, (e.g., Skinner, 1957) has been rejected as untenable by psycholinguists and cognitive psychologists. For example, one of the foremost critics of a Skinnerian approach, Chomsky (1957) asserted that human language can only be explained by postulating a complex cognitive system that differs qualitatively from the behavior accounted for by an operant approach. "What is necessary, in addition to the concept of behavior and learning, is a concept of what is learned that lies beyond the conceptual limits of behaviorist psychological theory" (Chomsky, 1972, p.72).

The two main issues that underly the controversy between cognitive and behavioral theorists are the symbolic nature and the generative aspect of language. In the following sections, I will briefly outline the divergent positions surrounding this controversy and then propose a behavioral model for the acquisition of some kinds of simple linguistic relations and generative language behavior.

Traditional Theories of Semantics and Syntax

Traditional accounts of human linguistic ability have placed considerable emphasis on the symbolic nature of language. In these accounts words seem to be given special status: They are considered symbols that "refer to" or "stand for" a referent (i.e., an object or event) and are said to convey meaning.

Over the years, a variety of different theories have been proposed to explain how humans come to acquire language. At one time the most widely held view was a "referential theory" that suggested a point-to-point correspondence between words and the objects designated by them. Some scholars contended that word-referent relations were established not unlike conditioned reflexes, without "mental intermediaries" (e.g., Russell, 1940; Watson, 1924). According to this view, a word "meant" something to the extent that a man reacted (within limits) to it as he would have, had he seen the object.

Other theorists, in contrast, held that word meanings serve to divide up the world. These divisions are arbitrary in that the words "red" and "blue", for example, do not correspond to any natural division in physics. Carried further, this perspective would suggest that words are nothing but labels for cognitive categorization processes. They do not refer to objects or events per se, but to our cognitive organization of the world (cf. Lenneberg, 1967, Ch.8).

More recently, these "referential theories" have been replaced by different versions of "atomic" theories which propose that the meaning of a word is determined by a set of semantic features and relational information about the context. One such view suggests that word-referent relations originate from specific perceptual stimulus dimensions such as movement, shape, size, sound, etc. (Clark, 1975). Another view stresses the importance of functional stimulus features. The child is assumed to form cognitive representations of concepts based on his/her interactions with an object and later matches a word to the object (Nelson, 1974).

Although both atomic theories may have some validity, neither has specified the exact conditions giving rise to "symbolic" behavior. Moreover, both conceptualizations are based on diary data and uncontrolled observations and do not prove the hypothesized origins of word meaning. Thus, one thing we need to increase our understanding of symbol-referent relations is an experimental demonstration of the controlling variables that establish these relations.

As meaning does not exclusively depend on simple word-referent relations, but to a large extent on the ways in which individual words are combined into sentences, a second important issue in language development is the generation of syntax. It is well documented that children begin to communicate in one-word utterances, but with time their language gradually unfolds in an ever more elaborate system. What processes are responsible for this phenomenon? A variety of theories have attempted to answer this question.

Traditional behavioral views, for example, stressed the processes of imitation and reinforcement. However, these views soon became unpopular when linguists pointed out that child utterances often differ markedly from syntactically correct adult speech, dismissing imitation as the main mechanism of syntax acquisition. Furthermore, some research showed that parents did not seem to approve or disapprove of child utterances depending on their grammatical correctness, but rather on their truth value (e.g., Brown, Cazden & Bellugi, 1969).

More recently, various cognitive theories have replaced traditional reinforcement accounts. As linguists have observed that early child utterances are relatively fixed in word order (e.g., children place nouns before verbs in sentences designating agent-action relations, but invert the order in action-object relations), some of these theories hold a nativistic view of syntactic development. Chomsky's (1965, 1972) generative trans- formational theory of grammar is an example of this approach. Chomsky has proposed that syntax emerges from a universal and species-specific deep-structure component which is part of the biological endowment of humans. The deep structure of a sentence determines its meaning which can be expressed in a variety of different forms or surface structures, depending on the transformational rules applied to generate them. Thus, from a finite set of deep structure and transformational rules, a virtually limitless set of sentences with different surface structures can be generated.

According to Chomsky, this "generative" aspect of language poses a problem for a behavioral account. A simplified example will illustrate this issue. Suppose a little boy is taught to name different colors and to label his toys. Few linguists would deny that the child may also be taught to combine two words to say "red car". However, when the child is then spontaneously able to say "green ball", "yellow truck", and "black robot", even though these novel combinations were not specifically taught, linguists often conclude that the child's reinforcement history is not responsible and that a behavioral approach is therefore inadequate.

Language acquisition is undoubtedly a complex process. The previous example is an oversimplification, but it may help the reader understand the controversy at issue: How does a child come to utter sentences which quite obviously have not been trained? The purpose of this study was to develop and test a preliminary analysis of the acquisition of meaning and language structure from a behavioral perspective. The project was carried out with linguistically proficient adult subjects. Nevertheless, it might serve as a model for the acquisition of simple symbolic relations in children. As much of this model has build on the conceptual groundwork laid by B. F. Skinner (1957, 1974), it seems useful first briefly to summarize his view on symbol-referent and syntactical relations and then to show how the proposed model can add to his analysis.

Skinner's Account of Symbol-Referent Relations

For Skinner, "meaning" is neither a property of a word or an object nor does it emerge from mental processes; rather, it arises from a history of exposure to contingencies arranged by a verbal community. To illustrate, one might reinforce a rat's bar-presses with food in the presence of a flashing light and another one's with water when the light is steady. The behaviors of both rats are topographically the same, but someone might argue that they differ in meaning (i.e., "food" vs. "water"). Or else, someone might also say that the lights differ in meaning: the flashing light means food and the steady light means water. Yet the meaning is neither in the rats nor in the lights, but in the circumstances that established stimulus control over the bar-presses. Analogously, the traditional terms "symbols" and "referents" will not be found in words but in the circumstances under which words are used by speakers and understood by listeners (Skinner, 1974, Ch.6). In other words, for Skinner an utterance means something to the extent that a stimulus ("referent") exerts conditional control over it.

However, from the perspective of psycholinguistics conditional relations between discriminative stimuli and responses do not seem to capture the essence of what is meant by word-referent relations. Consider the following example: Pigeons can be trained to peck a key with the word "food" on it when shown a picture of grain. But there is no reason to assume that the pigeons - without training - would now peck the picture of grain when shown the word "food". The relation between sample and comparison stimuli cannot simply be reversed. Yet we expect such reversibility when we deal with words and objects, as when a child who has learned to point to the picture of a car when hearing the word "car" can also utter "car" on seeing the picture. In a sense then, conditional discriminations are typically "unidirectional", while word-referent relations seem to be "bidirectional". This reversibility between a word and its referent is a property of symbolic behavior (Catania, 1984).

The bidirectionality in symbolic behavior can be seen in the interplay of speaker and listener functions as well.

For example, a chimpanzee might be taught to select a card with a specific symbol, apparently to "request" a banana. But to date it has not been shown that it will without additional training select a banana from an array of fruits when the trainer shows it the symbol. In a linguistic sense therefore, the chimpanzee does not necessarily "request" a banana any more than a pigeon "requests" food by pecking a key. The chimpanzee's pointing to the symbol has simply been reinforced in the past and recurs under appropriate stimulus conditions. In contrast, a child who requests a banana is typically also able to point to one when asked, "Which of these fruits is a banana?". The word and referent are bidirectionally related. If they are not, we would say that the child "does not understand what a banana is."

From the first day of life, children are exposed to the language they will eventually speak and learn to follow instructions of adults long before they can talk. Developmental researchers using diary data assume that a child who produces a word also comprehends that word (MacDonald, 1983). Because of this implicit bidirectionality a simple conditional discrimination does not seem to be a very satisfying model of symbolic behavior. To illustrate, Pepperberg (1983) trained a parrot to utter "red" or "green" in the presence of objects of the respective colors when asked, "What color is it?", and to utter the appropriate shape names in the presence of objects when asked, "What shape is it?" Although the behavior of the parrot undoubtedly was under conditional control of the questions and object properties, most people would be very uncomfortable with the claim that the parrot possesses language abilities. In lay terms we would say that the parrot did not really "understand" what it was saying. Indeed, this is reflected by the phrase, "He was just parroting back what he was told."

Understanding seems to require more than simple conditional discriminations. In language, the relationship between words and the objects, events or relations they designate is typically bidirectional, which is not characteristic of simple processes of stimulus control. Skinner's explanation of symbol-referent relations as conditional discriminations thus appears incomplete. As we will see below, this bidirectionality between a word and its referent seems to emerge from a particular behavioral process termed stimulus equivalence. Before examining this process, however, let us first turn to Skinner's view on syntax.

Skinner (1957, 1974) has argued that the concept of stimulus control replaces the notion of referent not only for words but also for more complex responses termed sentences. Responses evoked by a situation are basically nongrammatical, but are grouped or ordered through the effects of autoclitics. These autoclitics are complex discriminative stimuli which have an effect upon the listener, including the speaker himself. For example, the tacts "chocolate" and "good" evoked by a given object may come under the control of a relational autoclitic which occasions the ordering of the verbal operant "good chocolate" (Skinner, 1957, Ch.13). The size of verbal operants is flexible and depends on a unitary contingency of reinforcement. Therefore compound expressions such as "The book is on the table" can be ordered through the effects of the relational autoclitic 'is', but can eventually also be emitted as a functional unit without the action of an autoclitic (p. 336).

Another way in which expressions can be ordered is through the effect of partially conditioned autoclitic "frames" that combine with specific responses evoked by a situation. If, for example, a number of responses such as "the boy's shoe", "the boy's hat", etc. has been conditioned, Skinner (1957, Ch.13) supposes that the partial autoclitic frame "the boy's _____" will emerge, which then can be combined with other responses such as "the boy's bicycle". In other words, a frame is strengthened by the relational aspects of the situation, and specific features of the situation strengthen the responses placed into it.

According to Skinner, autoclitic frames also play a role in definitions such as "a _____ is a _____" (e.g., an amphora is a Greek vase with two handles) and translations from one language to another (e.g., pan means bread). Through these definitions or translations, the speaker can acquire new behaviors without direct conditioning, although responding to autoclitic frames is of course based on a long history of verbal conditioning. With his frame notion, Skinner might even to some degree have anticipated a process that seems to lie at the heart of the stimulus equivalence phenomenon. As we will see later, the relational frame notion proposed by Hayes & Brownstein (in press) as the basis of stimulus equivalence bears some resemblance to Skinner's autoclitic frames. However, in contrast to Skinner who seems to assign frames a relatively minor role, these authors view it of central importance in the emergence of meaning and perhaps related language phenomena (e.g., syntax).

In regards to syntax, there are two potential problems with Skinner's autoclitic based account, both related to the so-called generative aspect of language emphasized by psycholinguists.

First, Robinson (1977) has pointed out that it appears dissatisfying to consider the sequence of grammatical categories of words of the entire sentence as an autoclitic. It would still be necessary to explain how the speaker generalizes from previously experienced sentences to novel sentences. In other words, we might justifiably ask how speakers come to order words in a correct syntactical sequence, although they may have never before uttered a similar sentence.

A second issue arises from Skinner's suggestion that novel grammatical utterances based on autoclitic frames arise from many specific training instances. Observations by linguists contradict this claim as parents seem to train word-referent relations, but not series of grammatically correct utterances. On the contrary, children apparently create novel word sequences with little if any training. Braine (1976, p.34), for example, found that his two-year old son combined eight different attributes such as big, little, red, blue with a number of objects such as sand, ball, balloon, and pants to form a large number of untrained combinations, e.g., blue shirt, red pants, red balloon, wet pants, shoe wet, shirt wet, and so on.

As already indicated above, there is a behavioral phenomenon that recently has sparked the interest of the behavioral community. It is termed stimulus equivalence and seems to relate quite closely to the issue of symbolic activity. It may be useful not only to explain so-called word-referent relations but also the untrained transfer of autoclitic frames, relational autoclictics, and so on to novel sentences. The remainder of this paper will focus on the phenomenon of stimulus equivalence and will examine its theoretical underpinnings and the role it might play in language development.

Stimulus Equivalence Paradigm

The behavioral phenomenon of stimulus equivalence was originally described by association psychology. At the beginning of this century, some associationists proposed that two ideas can become linked to each other not only directly, but also indirectly via a third idea common to both (Warren, 1921). This type of "mediated transfer" was first investigated experimentally by Peters (1935). He replaced "ideas" with visual paired associates (nonsense syllables) and demonstrated transitive stimulus control. He as well as Jenkins (1965) showed that groups of subjects who were trained in A-B and B-C relations acquired A-C relations considerably faster than control subjects who only learned the A-C relations.

In 1971, Sidman published an article that generated renewed interest in the issue of stimulus classes. Sidman conducted research with a microencephalic male who pointed to twenty pictures when hearing their spoken names, but was unable to read words or select printed words in response to their spoken names. After training him with a matching-to-sample procedure to select twenty printed words to their dictated names, he matched without additional training printed words to pictures and vice versa, and read the printed words. In other words, he had acquired simple reading comprehension and production skills.

In various studies, Sidman and his colleagues (e.g., Constantine & Sidman, 1975; Sidman & Cresson, 1973; Sidman & Tailby, 1982) showed that training in conditional discriminations may generate another stimulus relation besides conditionality. The stimuli involved in the conditional discriminations become functionally substitutable for each other so that new, untrained relations among them emerge. For example, from training word-picture and word-text relations, untrained text-picture and picture-text relations as well as simple naming (picture-word) and reading (text-word) skills may emerge. Each stimulus is bidirectionally related to the other stimuli, which provides a basis for referential meaning: the words are symbols for the referents, and the referents are the meanings of the words (Sidman et al., 1982). Thus, one might say that stimulus equivalence transforms a conditional discrimination into a semantic process. In Sidman's (1985) view, arbitrary matching to sample is a linguistic performance, which emerges from non-linguistic conditional "if ... then" relations.

We cannot tell whether stimulus equivalence has originated simply by looking at subjects' performance on the underlying conditional discriminations. Additional tests are needed to determine whether a performance involves something more than conditional relations between sample and comparison stimuli (Sidman & Tailby, 1982). Such tests can be derived from the mathematical definition of an equivalence relation which specifies three properties: reflexivity, symmetry, and transitivity.

For a relation to meet the criterion of reflexivity, the individual must show generalized identity matching, i.e., he/she must match novel identical stimuli without training (e.g., A=A, B=B, etc.). This concept of identity is not only a prerequisite for equivalence, but also for the emergence of simple meanings or "semantic correspondences" (Sidman, 1985).

For a relation to be symmetrical, the conditional relation between sample and comparison stimuli must be functionally reversible. A child taught to match the printed word CAT to the picture of a cat must also be able to match the picture to the printed word without training. Therefore, if equivalence has emerged from trained conditional discriminations (e.g., if A, then B), subjects will perform additional conditional dis- criminations (e.g., if B, then A) that have not been explicitly taught (Sidman & Tailby, 1982).

The transitivity of relations is demonstrated if the child responds to two stimuli that have never been directly related to each other after each has been related to a third stimulus (e.g., if A, then B; if B, then C; therefore, if A, then C). To illustrate, a child who has been taught to match the picture of a dog to the spoken word "dog" and the spoken to the written word, must also be able to match the written word to the picture without additional training.

In short, stimulus classes emerging from a matching-to-sample procedure consist of members which semantically correspond to each other. For example, when an equivalence class of the elements "five", "5", "V", and "..." has been established, it is possible to say that the name and the numbers have the same meaning or that they stand for each other. In this sense, equivalence relations between stimuli seem to correspond closely to word-referent relations.

Research Findings

If the formation of equivalence classes is related to "symbolic" activity and if symbolic activity is not just a matter of conditional stimulus control, then training in conditional relations should not always generate stimulus equivalence. As a review of the pertinent animal reseach literature shows, this is what occurs.

For example, to date researchers have not been able to demonstrate equivalence classes in non-humans when given training in the underlying conditional discriminations. While the necessary conditional discriminations have been established in a variety of species such as pigeons (cf. Carter & Werner, 1978), rats (e.g., Lashley, 1935), dolphins (e.g., Herman & Thompson, 1982) and monkeys (e.g., D'Amato , Salmon, & Columbo, 1985; Sidman, Rauzin, Lazar, Cunningham, Tailby & Carrigan, 1982), no study has yet been successful in demonstrating the presence of equivalence relations in non-humans despite extensive training.

To illustrate, Kendall (1983) taught pigeons two conditional discriminations. First they had to peck a left or a right front wall key (both red), depending on whether a signal light was white or amber. Then they learned to peck one of two side wall keys (both green), again depending on the color of the same signal lights. After both conditional discriminations had been established, a test phase for transitivity was introduced. One of the red front wall keys was lit and a peck produced the illumination of both green side wall keys. To receive grain, the pigeons had to peck the side wall key that corresponded to the lit front wall key, based on the previously trained conditional discriminations. This type of problem would have been easily solved by most humans, but none of the pigeons responded above chance level.

In a series of studies, Sidman and his colleagues (1982) attempted to establish equivalence classes in rhesus monkeys and baboons based on hue and line discriminations. Despite extensive training neither symmetry nor transitivity could be established, while equivalence relations emerged without difficulty in 5-year-old children these researchers trained with the same procedure. D'Amato and his colleagues (1985) replicated this research with different visual stimuli, suggesting that the original line discriminations may have been difficult to establish in monkeys. They trained monkeys with arbitrary visual symbols in A-B and B-C relations and found transitivity from A to C in the absence of symmetry. A replication of the same experiment with pigeons as subjects was unsuccessful. D'Amato et al. concluded that the transitive responding of the monkeys may have emerged from classically conditioned associations.

The failure to demonstrate equivalence class formation in non-humans shows that stimulus equivalence is not an automatic result of learning a coordinated set of conditional discriminations. It also makes it more plausible to suggest that stimulus equivalence may be related to linguistic ability. Recent studies lend further support to this notion. Devany, Hayes, & Nelson (in press) have shown the formation of stimulus equivalence in language-able normal and retarded children, some as young as 25 months old. But despite intensive training they failed to establish equivalence relations in language-impaired retarded children matched to the mental ages of the language-able children. Of course, one might argue that the latter differed from the other children in more than just language ability. For example, a severe structural damage might account for both the inability to produce language and the failure to establish equivalence relations. However, a recent study by Lowe and his colleagues (1986) also seems to point to a relation between language and equivalence class formation. These investigators attempted to train two equivalence classes in three groups of children, ages 2-3, 3-4, and 4-5. While all children of the oldest group showed equivalence, only half of those in the second group and only one of the six children in the youngest group did. When those who had failed the equivalence test were trained in labeling the stimuli (e.g., for 'vertical bar' - 'green' saying "up-green"), all of them subsequently demonstrated untrained symmetrical and transitive relations. Lowe concluded that naming the relations may be necessary, though perhaps not sufficient for the formation of stimulus equivalence.

A review of the research literature on equivalence class formation in humans shows that, in contrast to the animal literature, equivalence has been generated from matching-to-sample procedures in normal children and adults (e.g., Lazar, 1977; Sidman & Tailby, 1982) as well as mentally handicapped children and adults (e.g., Devaney et al., in press; Sidman et al., 1974; Spradlin, Cotter & Baxley, 1973; Spradlin & Dixon, 1976). Equivalence classes in humans have been formed with arbitrary and nonarbitrary stimuli, presented in the visual (e.g., Wetherby, Karlan, & Spradlin, 1983) or auditory (e.g., Karlan, 1977) modality or both (e.g., Dixon, 1976). There is some evidence that equivalence class formation has implications for learning to read (e.g., Wultz & Hollis, 1979), for developing premathematical skills (e.g., Gast, VanBiervliet, & Spradlin, 1977), for object concept formation (Dixon & Spradlin, 1976), and for the emergence of simple syntactic relations (Lazar, 1977; Lazar & Kotlarchyk, in press). One recent study has even investigated the role of stimulus class formation in social classifications (Silverman, Anderson, Marshall & Baer, 1982).

In conclusion, stimulus equivalence is a well documented phenomenon in humans that has been demonstrated in children as young as two years of age, but to date has not been found in non-human species. Furthermore, there is at least some preliminary evidence that in humans the phenomenon seems associated with linguistic development, although the generality of this observation remains to be established.

What are the implications of these findings for operant theory? Have we discovered a new principle applicable only to human behavior, and does it limit our theoretical assumptions which have mainly been derived from research with non-humans? The following section of this paper will present two current theoretical viewpoints of stimulus equivalence from an operant perspective, suggesting that the elevation of equivalence to the status of a new principle may not be justified. We will see that it is possible to explain the phenomenon in terms of the already estabished principles of reinforcement and stimulus control, although some special parameters may be required.

Four-Term Contingency vs. Relational Frames

Sidman (1985) who has reintroduced the equivalence phenomenon into the current experimental literature, views stimulus equivalence as a new type of stimulus control that emerges in humans when they are expcsed to conditional discriminations. He considers this control by equivalence as a prerequisite for language and meaning, which traditionally have been the domain of cognitive psychology. This new type of stimulus control can best be explained in terms of a larger unit of analysis or higher-order contingency which fits the framework of operant theory.

In operant theory, the units of analysis are flexible and depend on what is to be accomplished with the analysis. Under some circumstances the appropriate unit might be the two-term contingency (response - consequence), such as when we are interested in the effect of consequences on behavior in a stable, unchanging environment. Under different circumstances the three-term contingency (stimulus - response - consequence) would be a more appropriate unit of analysis because it allows to analyze the two-term contingency in relation to changing environments. In a complex environment, however, different aspects of the situation can vary and the three-term contingency itself can be brought under higher-order control. To accommodate such complex contextual control of which stimulus equivalence is an example, Sidman proposes to expand the units of analysis to four and five-term contingencies. In other words, under appropriate circumstances the stimulus - response - consequence relation would give way to a stimulus - stimulus or even stimulus - stimulus - stimulus - response - consequence relation.

For Sidman, the control exercised by equivalence relations is best conceptualized in terms of a four-term contingency because the structure of such a larger unit of analysis allows us to see that conditional and discriminative control are different stimulus functions: A discriminative stimulus can be identified only by reference to a differential response while a conditional stimulus needs no additional differential behavior to be identified. In Sidman's view it is neither necessary to postulate an intervening response such as a "perceptual response" (Schoenfeld & Cummings, 1963) between the conditional and the discriminative stimulus nor is it justifiable to collapse both stimuli into a compound. Once they have been explicitly related (e.g., as sample and comparison in a conditional discrimination), they can then function independently of each other. This is shown in equivalence tests where each stimulus can now serve a sample or comparison role with elements never previously paired. This substitutability of stimuli seems to resemble closely what linguists mean by word-referent relations: Language-able humans can react to the word as if it were the object, which allows them to behave adaptively in new environments to which they may not have been exposed before.

Finally, by bringing equivalence classes themselves under conditional control, we can demonstrate the ability of the environment to select conditional discriminations from a person's repertoire and to influence the "meanings" that are derived from conditional relations (Sidman, 1985). To illustrate, the word "bat" cannot be comprehended unambiguously unless one knows the context in which it is emitted ("flying mammals" vs. "baseball game"). Thus, by expanding our unit of analysis to a five-term contingency we can represent the context as additional stimulus element that determines the meaning of an utterance.

In summary, for Sidman stimulus equivalence is a matter of stimulus control emerging from conditional discrimination training in humans. He considers it a prerequisite for the emergence of language and meaning and shows that it fits operant theory by an extension of the units of analysis. While simple stimulus control is best analyzed in terms of the three-term contingency, conditional stimulus control involved in equivalence better conforms to a four or (in second-order equivalence) to a five-term contingency.

A second view to conceptualize the bidirectional control exerted by equivalent stimuli has been proposed by Hayes & Brownstein (in press). In contrast to Sidman, these authors have emphasized the control by relations between stimuli instead of the individual stimuli themselves. It has long been known from the transposition literature (e.g., Reese, 1968) that humans and other species can learn to respond to some dimension on which two stimuli differ. In non-humans this relation is typically stimulus-bound in that the stimuli defining the relation in fact differ along some physical dimension such as size, brightness, etc. Humans, in contrast, have the ability to respond to "arbitrary" relations between "arbitrary" stimuli, i.e., relations and stimuli that are determined solely by convention of a verbal community. Probably due to species-specific differences, humans seem to have an increased ability to respond to stimuli indicating a relationship between stimuli, but for this ability to develop a specific history of training is necessary. This history presumably involves training of the kind, "This is a spoon", "This is called a cup", etc. Once the child has learned that something "is the same as" or "means" something, (s)he will then be able to respond to the relation itself: _____ means _____. In other words, what is learned is a "relational frame" that is independent of the specific stimuli placed into it and once acquired can be brought to bear on new stimuli. All arbitrary relations are bidirectional (though not necessarily symmetrical), and several such relations can combine to form a network. From Hayes & Brownstein's perspective, stimulus equivalence is simply a special case of such a network of relational frames. As the environment is capable of selecting particular frames from the individual's repertoire, it can also establish higher-order control over "meanings" by bringing the frames themselves under conditional control.

When comparing Sidman's with Hayes & Brownstein's analysis of the equivalence phenomenon, it appears that Sidman's expansion of the three-term contingency may be unnecessary. From a theoretical perspective both views are certainly tenable as both fit the general framework of operant theory. Sidman's conceptualization may be helpful in analyzing the origin of relations of "sameness". However, beyond that Hayes & Brownstein's analysis has the potential also to explain relations different from stimulus equivalence, e.g., opposites, hierarchical classes among stimuli, etc. Thus, their approach not only appears more parsimonious but also seems to have a broader scope.

Another difference between the two viewpoints is that Sidman considers stimulus equivalence as a prerequisite for language development while from Hayes & Brownstein's perspective language acquisition may be one of the best ways to capitalize on the ability of humans to respond to arbitrary relations. In other words, the experiences to which children are exposed in the natural course of language acquisition may also be the experiences that lead to the development of relational frames, of which stimulus equivalence is only one example. Preliminary evidence (cf. Devany et al., in press; Lowe et al., 1986) suggests that Hayes & Brownstein's view may have greater validity in this respect.

In conclusion, the main point in presenting both theoretical analyses was not to "arbitrate" between different conceptualizations but to show that stimulus equivalence does not invalidate the assumptions made by operant theory in regards to human behavior. However, it should be emphasized that equivalence relations do not conform to the established concept of stimulus control in that they are not just based on unidirectional conditional discriminations. Given their bidirectionality, they seem to involve not a new principle, but certainly some special parameters which require further investigation.

Let us now turn to the possible implications that stimulus equivalence may have for an operant analysis of word-referent relations and syntax.

Implications of Stimulus Equivalence for Word-Referent Relations

At the onset of this paper, I stated the challenge of psycholinguists that behaviorists cannot explain satisfactorily the symbolic and generative nature of language. So far I have attempted to show the usefulness of the stimulus equivalence paradigm in analyzing the origin of meaning because it suggests which kinds of experiences may lead to the formation of symbol-referent relations. While traditional accounts have claimed that the child "associates" symbols with referents without explicating the origin of this "association", the equivalence paradigm shows that it is possible to take a set of unrelated stimuli (i.e., "symbols" and "referents") and establish them as a class through a matching-to-sample procedure. Based on a training history, a number of untrained relations among these stimuli originate so that each stimulus is bidirectionally related to the other or, as traditional accounts would say, each stimulus "stands for" the other. In short, the stimulus equivalence paradigm suggests which kinds of experiences cause bidirectional symbol-referent relations to emerge.

The process involved in stimulus equivalence is probably not limited to classes of word-referent relations where the referent is a single object, event, or property.

The same process is likely also to be at work at a higher level of abstraction, namely when we deal with concepts. The term "concept" simply implies that a group of objects form a class, the members of which are responded to similarly.

We could argue that many organisms besides humans are capable of concept formation. Pigeons, for example, can be taught to respond to pictures of water, trees, distinguish photographs of humans vs. non-humans and show generalization (within the concept) and discrimination (between concepts) based on some physical dimension or property of the stimuli involved. In the case of verbal concepts, however, the stimuli involved are arbitrary as there is no physical similarity between the words "urn" and "vase", for example. This has led some researchers (e.g., Keller & Schoenfeld, 1950) to postulate that generalization to equivalent instances of a verbal concept are mediated. However, the equivalence paradigm shows that it is unnecessary to appeal to mediational processes.

For example, if a child is taught that roses, tulips, and daisies are flowers (s)he may come to treat them equivalently. If the child then learns the label "plant" for one flower, that label may generalize to the whole class. Of course, additional contingencies may also teach the child that roses, tulips and daisies control a common response in one context, but that in a different context their labels may not be freely substitutable (e.g., bulbs); otherwise we would not need different labels (Wetherby et al., 1983). Hayes & Brownstein's (in press) example of hierarchical classes seems to capture the essence of this distinction nicely.

The example above shows that the control acquired by one equivalent stimulus may transfer to the other class members, which greatly economizes teaching. A person will respond appropriately to novel instances of a concept if this instance is linked to any one of the other members. The implications of this process are far from trivial. Much of human behavior trained in a given context and involving verbal stimuli may transfer to novel situations without additional training, simply by teaching (or telling) someone that a novel object "means" or "is the same as" some known word. The novel object will automatically enter the stimulus equivalence class of which the known word is a member, and responses appropriate to the latter will generalize to the novel instance.

Thus, stimulus equivalence appears useful to explain symbol-referent relations in terms of single ("words") as well as complex ("concepts") referents. It helps us analyze the origin of meaning because it suggests which kinds of experiences may lead to the formation of symbol-referent relations.

Implications of Stimulus Equivalence for Syntax

As stated before, one serious challence of psycholinguists (e.g., Chomsky, 1957) has been that behaviorists cannot explain how humans form novel sentences for which apparently no reinforcement history exists. In this section I will attempt to show that the equivalence paradigm may also have implications for the emergence of syntax and the construction of untrained, novel grammatical sequences. For this purpose, three types of manipulations will be discussed below that can lead to the formation of simple response sequences. Together they will suggest ways how the environment can establish sequential behavior similar to simple syntactical relations and how response sequences can generalize to untrained instances.

(1) Transfer of Stimulus Functions via Equivalence

A study by Hayes, Brownstein, Devany, Kohlenberg & Shelby (1985) showed an interesting phenomenon related to stimulus equivalence. These researchers trained subjects in a matching-to-sample procedure and established two three-member equivalence classes (A,B,C and D,E,F). Then a discriminative function was given to one member of each class (e.g., B="wave", E="clap"). The findings showed that this function transferred without additional training to the other class members. Similarly, when the B stimulus was established as a positive reinforcer and the E stimulus as a punisher, the other class members acquired corresponding functions and could be used to shape the behavior of subjects on an unrelated task.

Such untrained transfer of control of a given stimulus function from one equivalent stimulus to other class members also seems to play a role in the formation of syntactical relations, as the following example will illustrate. Suppose a child has been taught two concepts, colors and articles of clothing. If the child now learns via imitation or direct training to combine one element of the first with one element of the second class to form a response sequence (e.g., "red shirt"), these elements will acquire the ordinal properties "first" and "second". Or in Skinner's (1957) terminology, we would say the stimuli will be grouped through the effect of a relational autoclitic. Due to the participation of "red" and "shirt" in equivalence classes, the autoclitic function can be expected to transfer from the trained stimuli to the remaining class members. What is remarkable about such transfer of a function is not only the speed at which it can occur but also the large number of novel combinations it can create. In the example above, the child might "generate" without additional training a considerable number of grammatically correct utterances. For instance, from two six-member classes thirty-six response sequences can emerge after training of just one relation. All these combinations could be considered novel and, as linguists correctly assume, have emerged without direct training.

A study by Lazar (1977) has attempted an empirical demonstration of the transfer of response sequences via stimulus equivalence. He taught three 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), regardless their spatial position. Then he trained them in a matching-to-sample procedure with the same stimuli serving as samples and two new pairs (E1-E2, F1-F2) as comparisons. For example, in the presence of A1 as sample and E1-E2 as comparisons responses to E1 were reinforced, while in the presence of A2 as sample responses to E2 were reinforced. During an unreinforced test phase, Lazar then presented sequence trials of the A,B,C,D pairs, interspersed by the E and F pairs. Two subjects showed a transfer of the sequential response to the E and F stimulus pairs, while one subject performed at chance level.

Unfortunately, Lazar's training procedure does not allow the unambiguous conclusion that the sequence response was transferred via equivalence. Given that the A,B,C,D stimuli not only had acquired ordinal properties, but also had served as samples in the matching-to-sample procedure, the E and F pairs (as comparisons) may have acquired the function "first" and "second" via direct pairing, not stimulus equivalence. For example, a transfer of the sequence response could have occurred because the sample and comparison stimuli formed compounds during training so that during testing a response conditioned to one part of the compound would also have been evoked by the other part. An alternative interpretation is that the sequence response was transferred via symmetry in the absence of transitivity. Remember that humans have a lifelong history of responding symmetrically to symbol-referent relations, which may even be a prerequisite for the initially asynchronous speaker and listener functions to "converge". Once the general frame "If A means B, then B also means A" is learned, no further training in symmetry may be required as from then on it will occur automatically. In short, Lazar's results could have been produced by symmetry alone or by other processes and therefore are no unequivocal demonstration of the transfer of sequential responding via stimulus equivalence.

Pilot data collected for the research project presented below seem to justify the criticism of Lazar's study. Subjects were trained in conditonal discriminations, with A1 or A2 as sample and B, C or D stimulus pairs as comparisons. When without testing for equivalence a sequence response was conditioned to the B-stimuli, several subjects were immediately able to respond sequentially to the A stimuli, yet performed erratically on the C and D stimulus pairs.

Note that during training the A and B stimuli had been presented together, while the C and D stimuli had not previously been paired with the B's. Thus, the transfer of the sequence response from B to A probably occurred in the absence of equivalence.

To conclude, I am proposing that stimulus equivalence may be involved in the transfer of syntactical relations to novel stimuli. However, such transfer has not yet been demonstrated unequivocally. One purpose of the research project presented below was therefore to determine if untrained simple response sequences can be generated via equivalence.

(2) Contextual Control of Equivalence Classes

Stimulus equivalence classes by themselves may be of restricted utility in the analysis of syntactical relations, given that the same word, depending on its "meaning", can occupy different positions in a sentence. The effect of the context which determines word meaning therefore needs to be incorporated into the equivalence relations. This can be accomplished by bringing equivalence classes under contextual control (Sidman, 1985).

Consider, for example, the utterances "red light" vs. "light red". Both consist of the same two words but differ in word order and also in meaning. "Red", in both cases, is a member of the equivalence class "colors", but in the two phrases has different ordinal properties. "Light" is an element of two different equivalence classes, each one associated with different ordinal properties. Though perhaps trivial, this example demonstrates well that words can have multiple class memberships and can be shifted from one class to another, depending on the context. Just consider the word "light": it can be a member of an equivalence class comprising "things that illuminate" (e.g., lights, candles, lamps, sun, moon, etc.) or of a class comprising particular "object properties" (e.g., light, bright, clear, luminous, etc.). It could also belong to a class of particular "actions" (e.g., to light, to set afire, to incinerate, etc), and of yet other classes (e.g., words denoting weight, words denoting cheerfulness, etc.). In each case its class membership can only be determined by the context. As a member of different equivalence classes, it may furthermore have membership in classes with various "structural" properties such as "objects or events", "characteristics of objects", "agents", "actions", etc. Linguists have labeled these classes nouns, adjectives, verbs, adverbs, etc. and have constructed rules which determine the grammatical correctness of a particular sequence. These labels and rules, however, do not add anything to a functional analysis of language as it is true that most speakers can speak correctly and listeners can comprehend without knowing the grammatical categories of words. They may simply have learned to relate a given object property with an object ("red ball") or a given agent with an action ("daddy gone") in particular ways and these relational autoclitics may then have transferred via stimulus equivalence to other instances.

No published study to date has shown whether response sequences can depend on the participation of elements in conditional equivalence classes. The research presented below attempted to provide data on this question. The implications of such a demonstration would be to show that novel response sequences can be generated without explicit training, and that the same symbols can occupy different spatial positions, depending on their participation in conditional equivalence classes.

(3) Conditional Control over Response Sequences

There is yet another way in which the environment can generate syntactical relations: A given response sequence might itself be brought under conditional control and transfer to untrained stimuli via equivalence relations.

Consider the example of an English speaker who in the presence of a red traffic light might utter "red light", whereas a Spanish speaker in the same context would say "luz roja" (literally "light red"). In a different context, an

English speaker's utterance controlled by the color of a beautiful garment might be "light red", while a Spanish speaker under the same stimulus conditions would emit "rojo claro" (literally "red light"). Whether a bilingual speaker will order a response sequence in terms of "property first, object second" (English) or the other way around (Spanish), will depend on the control exerted by a particular audience. This example is not meant to imply that conditional control over word order can only occur by switching from one language to another; it was simply chosen to illustrate a point. A similar argument could be made for active vs. passive voice and other language phenomena which require an inversion of word order, but conserve the meaning of an utterance.

Only one study to date has dealt with second-order control over response sequences (Lazar and Kotlarchyk, in press). However, the attempted transfer of these conditional sequences via equivalence was not demonstrated unequivocally. The authors established two equivalence classes in six-year-olds with a single-sample procedure (cf. Spradlin & Saunders, 1986). Then they trained a conditional sequence response to the sample stimuli and the children were then able to respond without further training in the appropriate order to the stimuli originally presented as comparisons. Unfortunately, this study suffers from the same problem as Lazar's (1977) previous experiment discussed earlier. Given the particular training procedure, the sequence response could have transferred via symmetry, direct pairing, stimulus compounds or other dimensions not synonymous with stimulus equivalence. Thus, it has yet to be demonstrated that conditional sequences can be transferred without explicit training through the participation of stimuli in equivalence classes.

Another purpose of the research project presented below was to examine this question. In addition, it examined the possibility of simultaneous control by conditional sequences <u>and</u> conditional equivalence class membership of the stimuli comprising the sequence as a first approximation to an experimental analysis of complex syntactic relations.

Statement of Purpose

The proposed research project attempted to answer the following four questions:

(1) If the ordinal properties "first" and "second" are conditioned to members of stimulus equivalence classes, will a transfer of control by these properties occur to other class members via symmetry and transitivity? Such a transfer of a simple sequential response would indicate one possible way in which simple grammatical sequences might be generated without explicit training.

(2) If equivalence classes are brought under second-order control, will a sequence response conditioned to equivalent stimuli be transferred to the remaining members of four conditional equivalence classes without additional training? Such contextual control over untrained response sequences could help explain "generative" behaviors and flexible word order in the absence of a direct reinforcement history.

(3) Is it possible to bring ordinal stimulus functions (e.g., "first" and "second") under conditional control and can they, when conditioned to equivalent stimuli, be transferred to other equivalence class members without further training? This could be yet another way in which untrained, flexible response sequences can be generated.

(4) Can second-order stimulus control be brought to bear simultaneously on equivalence classes and on ordinal stimulus functions trained to one member of each of these classes? Will this complex control be transferred via equivalence without additional training? Such an effect would not only show the emergence of sequential responding under complex environmental control, but in addition account for untrained novel response sequences. In the study below, for example, a training history establishing four conditional sequence discriminations could account for a total of sixty-four individual sequence discriminations,

sixty of which had never been explicitly trained.

To conclude, the proposed research project seeks to contribute to an operant analysis of the formation of symbol-referent relations and word sequences within the framework of stimulus equivalence.

CHAPTER II

METHOD

Subjects

Ten college undergraduates of both sexes were solicited through in-class announcements to volunteer for this study. They were offered payment for participating ($ 4.00/hr). Subjects were randomly assigned to one of two experiments. Two subjects did not continue after completing Phase I and were dropped from the study. Eight subjects completed Experiment 1 (n=4) and 2 (n=4), respectively.

General Experimental Design

The project consisted of two experiments, each one comprising three separate phases, with six parts per phase. In each phase, Parts 1 and 2 were training steps (subjects received continuous feedback until their performance met a specified criterion). Parts 3 through 6 were test steps (no feedback was given). The goal set for both experiments was successfully to complete Parts 3 and 4 of each phase.

As the experiments and all training and test sequences were very complex, it will help first to refer to Table 1 which briefly describes the three phases of each experiment and their individual parts. The table shows that each phase consists of two training and four test parts. In the first training step (Part 1), subjects learned a number of conditional discriminations via a matching-to-sample procedure, which served as basis for the formation of equivalence classes. In the other training step (Part 2), a sequence response was taught to two stimuli which in the matching-to-sample task had served as comparisons. Given this training history, it was then examined if the sequence response had transferred to untrained stimuli via equivalence (Parts 3 and 4). If a transfer had not occurred, it was then examined whether equivalence classes had emerged from matching to sample or whether they would emerge during equivalence tests (Parts 5 and 6).

As the linkage of the six parts of each phase was complicated, the reader should refer to the diagram in Figure 1. This diagram shows that each phase began with the training parts (1 and 2), followed by the first sequence test (Part 3). This test assessed whether the sequence response trained to one stimulus pair in Part 2 had transferred via symmetry and transitivity to the other stimuli presented during matching to sample (Part 1). If subjects did not meet the criterion, Parts 1, 2, and 3 were repeated once for the reasons described below. The literature has shown that equivalence frequently is not established during training, but seems to emerge during unreinforced equivalence test trials. Retraining (Parts 1 and 2) and retesting subjects on the sequence test (Part 3) served to examine whether equivalence would emerge not only from tests in a matching-to-sample format, but also from retraining in the underlying conditional discriminations and/or retesting on a task that can only be solved via equivalence (such as the present sequence test, for example).

If subjects failed the sequence test a second time, a partial equivalence test (Part 5) was presented, testing for equivalent relations among only three of the four stimuli in each class. If subjects then solved the following sequence test (Part 3), the control of the sequential response by the stimulus pair excluded from the test unquestionably demonstrated a transfer via equivalence, given that these stimuli had neither during training nor testing ever been presented together with the training stimuli. Only when subjects failed the sequence test again was a complete equivalence test including all stimuli (Part 6) presented.

If at any time during this training and test routine the sequence test (Part 3) was solved, a random sequence test (Part 4) was presented that combined all "first" and "second" stimuli in random pairs. A successful completion of this test concluded the respective phase or - in Phase III -

the experiment.

Experiments 1 and 2 differed in the training sequences, but were expected to lead to the same terminal behavior. Both began with matching-to-sample training and the transfer of a sequence response throughout two equivalence classes (Phase I). During Phase II, in Experiment 1 the equivalence classes established in Phase I were brought under conditional control, while in Experiment 2 the sequence response was brought under second-order control. Phase III was identical for both experiments and combined contextual control over the equivalence classes with second-order control over the sequence response. The diagram presented in Figure 2 shows the general strategies for 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 (manipulanda) in front of them. Stimulus presentation and the recording of responses and response latencies was controlled by a TRS 80 Color Computer (Radio Shack) located in an adjacent experimenter room.

All experimental tasks were programmed in BASIC. The stimulus material (Figure 3) consisted of eight nonsense symbols (resembling Greek letters) of approximately 2 1/2 inches in diameter which were presented on the monitor. For matching-to-sample tasks, the sample appeared in the center at the top of the screen with the comparisons to the left and right at the bottom; for sequence tasks, two symbols were presented to the left and right on the screen (Figure 4). Subjects' responses and response latencies (i.e., the time from the onset of the comparison stimuli in conditional discriminations or the sequence stimuli on sequence tasks to the moment a response occurred on one of the manipulanda) were recorded automatically.

Procedure

All subjects were run individually in several sessions, each lasting approximately 45 to 60 minutes. At the beginning of the first session, subjects were given a sheet with general instructions (Appendix C). During the experiment, the TV monitor presented brief specific instructions before each part of a given phase. For the conditional discriminations, 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?" After each training trial (during Parts 1 and 2 of each phase) the TV monitor gave subjects feedback on their performance ("correct" or "wrong"), while no feedback was given after any test trial (during Parts 3 to 6 of each phase). All tasks were presented in specified sequences as outlined in Figure 1.

Experiment 1

During **Phase I**, all subjects were trained in a matching-to-sample procedure (Part 1). The stimuli appeared on green background. In the presence of sample A1 responses to B1, C1, or D1 were reinforced; in the presence of sample A2 responses to B2, C2, or D2 were reinfored. On each trial, the sample was presented at the top of the screen, followed two seconds later by presentation of the comparison stimuli at the bottom. The time interval between presentations of sample and comparison stimuli served to increase the probability of subjects observing the sample. A press on either one of the buttons removed the stimulus display from the screen, followed by written feedback ("correct - X points" or "wrong - 0 points") and a two-second intertrial interval. Then the next set of stimuli appeared on the screen. Training continued until the criterion was met. (The training and test criteria for all parts and phases are specified in Table 2.)

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 different parts of each phase were separated by 30 to 90 sec breaks for data storage, during which subjects remained seated.

After completion of the matching-to-sample training (Part 1), a sequence task was presented (Part 2). The B1-B2 stimuli, which served as one of the four sets of comparison stimuli for the conditional discriminations were presented simultaneously. Their spatial positions alternated randomly, i.e., B1 left - B2 right or vice versa. Subjects were required to respond to these stimuli by pressing both buttons in sequence (left-right or right-left). Responses first to B1, then to B2 were reinforced ("correct - X points") or else the word "wrong" appeared on the screen.

After meeting the criterion on the sequence task, a sequence test without feedback was presented (Part 3). This test required sequential responding to the A, B, C, and D stimulus pairs (A1-A2, B1-B2, C1-C2, D1-D2). It was assumed that if during the initial matching-to-sample procedure two equivalence classes had formed (A1,B1,C1,D1 and A2,B2,C2,D2), the discriminative functions conditioned to B1 ("first") and B2 ("second") would transfer without training via symmetry from the B to the A stimuli and via symmetry and transitivity from the B to the C and D stimuli. In other words, if subjects in the sequence test (Part 3) responded to all "1's" first and to all "2's" second, their performance was evidence for the formation of two equivalence classes emerging from the matching-to-sample procedure. Successful performance on the following random sequence test (Part 4) which presented the "1's" and "2's" in random combinations (e.g., A1-C2, D1-B2, etc.) furthermore showed that the functions "first" and "second" were not bound to specific stimulus pairings but that each stimulus with the ordinal function "first" exerted control over responding in combination with any stimulus with the ordinal function "second".

As discussed above, it was also examined whether a repetition of the training/test sequence (Parts 1, 2 and 3) served a similar function as an equivalence test if the sequence test (Part 3) was initially failed, but then mastered on its second presentation, although the formation of equivalence relations had not been tested per se. If the sequence test was failed again, a partial equivalence test (Part 5) was presented after retraining in the underlying conditional discriminations. On this test the A, B and D stimuli served both sample and comparison roles, and subjects received no feedback on their performance. The purpose of this test was to examine whether on the following sequence test a transfer of function would occur to all stimuli, although the B and C stimuli had neither during training nor testing ever been presented together. When subjects failed the sequence test again, an equivalence test including all stimuli was presented (Part 6).

When equivalence relations among all stimuli had emerged, it was examined whether subjects now solved the sequence tests in Parts 3 and 4. Successful performance on these tests showed a transfer of function via equivalence throughout two stimulus classes.

In Phase II, subjects in Experiment 1 were trained in second-order conditional discriminations. On green background, all relations remained the same as in Phase I, Part 1. On red background, two of the comparison stimulus pairs (C1-C2, D1-D2) switched classes: with A1 as the sample, responses to B1, C2, or D2 were reinforced; with A2 as the sample, responses to B2, C1, or D1 were reinforced. Then the sequential response to the B stimuli was retrained by reinforcing responding to B1 first, B2 second, regardless the background color or spatial position of the stimuli (Part 2). Thereafter, the transfer of the stimulus functions "first" and "second" to the remaining class members was tested (Part 3). If subjects failed this test, the same training and testing procedures as described in Phase I were followed until four equivalence classes had been established (Green: A1,B1,C1,D1 and A2,B2,C2,D2; Red: A1,B1,C2,D2 and A2,B2,C1,D1). It was tested whether a transfer of the functions "first" and "second" from the B's to the other stimuli had occurred. The purpose of this was to show that response sequences transferred via equivalence are not invariant, i.e., that the same stimulus can occupy the position "first" or "second", depending on the equivalence class of which it is a member.

Finally, in <u>Phase III</u> of Experiment 1 the response sequence conditioned to the B-stimuli was itself brought under conditional control. In the presence of Tone 1, responding first to B1, then to B2 was reinforced, while in the presence of Tone 2, responding first to B2, then to B1 was reinforced, regardless of the background color or spatial positions of the stimuli (Part 2). Training and testing sequences were identical to those in the previous phases and were repeated until subjects met criterion in Parts 3 and 4. Mastering Parts 3 and 4 concluded Experiment 1.

Experiment 2

In Experiment 2, <u>Phase I</u> was identical to that of Experiment 1. (The training and test criteria for all parts and phases of this experiment are specified in Table 3.)

In <u>Phase II</u>, the sequence response conditioned to the B stimuli was brought under conditional control. When Tone 1 was present, responding first to B1, then to B2 was reinforced; with Tone 2 the reverse response sequence was reinforced. Then it was tested if the conditional sequence response had transferred via equivalence to the A, C, and D stimuli. The training and test parts corresponded to those of the other phases previously described in Experiment 1. Training and testing continued until subjects reached the criterion for completing Phase II.

Similar to Phase I, Phase III was also identical in both experiments. However, subjects entered this phase with different histories. Subjects in Experiment 1 had previously learned four conditional equivalence classes to which in Phase III the conditional sequence response was added. In contrast, subjects in Experiment 2 had acquired a conditional sequence response in Phase II, and were now taught twelve second-order conditional discriminations from which the formation of four conditional equivalence classes should emerge. The terminal performance of subjects in both experiments was expected to be identical.

The purpose of varying the training sequences in Part 2 of Experiments 1 and 2 (second-order conditional discriminations vs. second-order sequence response) was to establish at which point a break-down in performance would occur in case subjects would not reach the criterion in Phase III. This information was considered valuable, given that the terminal performance in Phase III was very complex and the components from which it was expected to emerge to date had not been demonstrated experimentally. In addition, another purpose of varying the training sequence was to show that topographically and functionally similar complex response patterns can emerge from different histories.

CHAPTER III

RESULTS

The results for all subjects are presented in Figures 5 to 12. In the upper part of these figures, the reinforced training trials are represented by bars with MS standing for "matching-to-sample training" and STg for "sequence response training", and the numbers after MS and STg representing the number of trials required to meet the training criterion on each task. All test trials are represented as frequency polygons, with each dot representing five trials. The number of correct responses (from 0 to 5) are graphed on the Y-Axis while the number of blocks of five trials for each test are graphed on the X-Axis. The labels below the X-Axis stand for the various tests: ST stands for "sequence test" (testing for sequential responding to the A1-A2, B1-B2, C1-C2 and D1-D2 stimulus pairs); RST stands for "random sequence test" (presenting randomly assembled stimulus pairs with a "1" and a "2" stimulus); ET 1 stands for "partial equivalence test" (excluding the C stimuli); ET 2 stands for "complete equivalence test" (including all possible stimulus presentations).

In the lower part of Figures 5 to 12, the types of errors on the various sequence and equivalence tests are shown in the black histograms. Each bar stands for the percentage of responses correct to trained, symmetrical and transitive relations. For sequence tests, A1-A2 (symmetrical), B1-B2 (trained), C1-C2 and D1-D2 (transitive) relations are designated by the letters "A", "B", "C" and "D", respectively. For random sequence tests, the letter "a" designates sequences involving an A stimulus (symmetry) paired with an A, C or D stimulus; "b" designates relations involving a B stimulus (trained) paired with any other stimulus; and "t" stands for transitive relations involving the C and/or D stimuli.

For equivalence tests, trained relations (A = sample, B/C/D = comparisons) are designated by "L" (learned), symmetrical (the inverse of trained) relations are designated by "S", and transitive relations (involving the B/C/D stimuli) by "T".

Before discussing the results of individual subjects, the reader may first wish to turn to Table 4 which presents a general overview of the results of both experiments.

In Experiment 1, for two of the subjects (50%) the sequence response conditioned to the B stimuli transferred to the remaining members of two equivalence classes without a specific equivalence test, while for two other subjects (50%) a complete equivalence test (ET 2) was required before the transfer occurred. For three subjects (75%) this sequence response also transferred through four conditional equivalence classes without an equivalence test, whereas one subject (25%) required the complete test. Finally, all four subjects (100%) demonstrated the transfer of a conditional sequence response through four cnditional equivalence classes without an equivalence test.

Similarly, in Experiment 2 two subjects (50%) showed the transfer of the sequence response through two equivalence classes without a specific equivalence test, whereas two (50%) required a complete test. The conditional sequence response transferred without such a test for two subjects (50%), after a partial equivalence test for one subject (25%), and after a complete test for one subject (25%). Finally, three subjects (75%) showed the transfer of the conditional sequence response through four conditional equivalence classes without an equivalence test, while one subject (25%) required extensive testing (and, as discussed below, even a change in the experimental protocol) before completing the experiment.

The results of individual subjects in both experiments will be discussed in detail in the following section.

Experiment 1

To recapitulate, in Experiment 1 four subjects were tested for transfer of sequential responding through equivalence classes, then through conditional equivalence classes, and then of conditional sequential responding through conditional equivalence classes. All subjects showed the transfer of the sequence response in all three phases. Two (Subjects # 1 and 3) mastered the sequence and random sequence tests without a previous equivalence test, while the other two subjects (# 2 and 4) mastered them after partial or complete equivalence tests.

<u>Subject # 1.</u> As shown in Figure 5, in Phase I this subject required 243 trials to meet the acquisition criterion for the conditional discrimination training and 15 trials to meet the criterion for the sequence training involving the B stimulus pair. On the following sequence test, which assessed the transfer of the sequence response from the B to the A, C and D stimulus pairs, she reached the test criterion (19 of 20 trials correct) in 20 trials. Similarly, she responded correctly to 19 of 20 trials on the following random sequence test which combined any stimulus designated as "1" randomly with another stimulus designated as "2". Thus, for this subject, sequential responding transferred to all elements of two equivalence classes without specific equivalence testing.

In Phase II, when second-order conditional discriminations were trained, Subject # 1 performed in a similar way. She acquired the second-order conditional discriminations in 116 trials, received 16 trials of retraining on the sequence response to the B stimuli and completed the following sequence test without any errors on 20 consecutive trials. But on the subsequent random sequence test, she made several mistakes and failed to reach criterion. A second presentation of both the sequence and random sequence test then resulted in successful performance with 20 of 20 and 29 of 30 trials correct, respectively.

In Phase III, the sequence response itself was brought under conditional control of two tone signals. The subject required 87 trials of retraining in the second-order conditional discriminations taught in Phase II and learned the conditional sequence response to the B stimuli in 32 trials. On the following sequence test she committed five errors in 30 trials and failed the test criterion. It appeared that these errors were mainly due to a failure to discriminate between the two tones signalling a "forward" or "backwards" sequence. After retraining she completed the experiment by reaching criterion on both the sequence and random sequence test (20 of 20 and 39 of 40 trials correct, respectively).

After Phase III, the subject received a post-hoc conditional equivalence test examining all possible relations. The purpose of this test was to establish that four second-order equivalence classes had emerged from training to support the assumption that the transfer of the sequence response had occurred due to stimulus equivalence and not because of a possible experimental artifact. The subject performed correctly on 40 consecutive test trials. She also said in a post-experimental interview that "groups of symbols went together because they were all related to those on the top".

<u>Subject # 2.</u> For Subject # 2, the sequence response did not transfer without prior testing for equivalence relations from the trained to the untrained stimuli.

As shown in Figure 6, he acquired the conditional discriminations in Phase I in 85 trials and the sequence response in 15 trials, but failed to show a transfer of the sequence response to the other class members on the first sequence test. After retraining he failed this test a second time by responding incorrectly to the C and D stimulus pairs. After errorless retraining on the conditional discriminations he passed 20 consecutive trials of a partial equivalence test (without C's) errorfree, yet failed the next sequence test again due to the same mistakes as before. He was then given a complete equivalence test, which he passed (30 of 30 trials correct). When presented again with the sequence test, he completed it and also the following random sequence test errorfree (20 of 20 trails correct on both tests). Thus it appears that for Subject # 2 a transfer of control from trained to untrained stimuli did not occur until the equivalence relations of the two classes had been explicitly tested.

In Phase II, he reached the training criterion for the second-order conditional discriminations in 116 trials and received 15 trials of retraining in the sequence response. He just missed the criterion for the following sequence test (3 errors in 25 trials), but after retraining mastered the sequence and random sequence test (20 of 20 and 30 of 30 trials correct, respectively). Hence, four conditional equivalence classes had formed without the presentation of an equivalence test.

In Phase III, the subject showed perfect retention of the previously trained second-order conditional discriminations and acquired the conditional sequence response to the B stimulus pair in 19 trials. He then solved the sequence and random sequence test without errors (20 of 20 and 40 of 40 trials correct, respectively).

Because the presence of conditional equivalence relations had never been tested explicitly, Subject # 2 was given a post-hoc test. He completed 40 consecutive trials without mistakes, thus demonstrating that higher-order stimulus equivalence had formed.

Subject # 3. Similar to Subject # 1, this subject completed the experiment without a prior equivalence test (see Figure 7). In Phase I, he reached the acquisition criterion for the conditional discriminations and sequence response training in 135 and 17 trials, respectively. On the following sequence test, he responded correctly to the B and D stimulus pairs and incorrectly to the A and C stimulus pairs. After retraining, the sequence test was presented a second time. He mastered this and the following random sequence test without any errors (20 of 20 trials correct on each test).

In Phase II, he learned the second-order conditional discriminations in 151 trials and received 17 trials of retraining to meet the criterion for the sequence response to B1-B2. He succeeded on the first sequence test (20 of 20 trials correct), but failed the random sequence test due to mistakes on transitive relations. After retraining, he then met the criterion on both the sequence test (20 of 20 trials correct) and the random sequence test (29 of 30 trials corret).

In Phase III, Subject # 3 reacquired the second-order conditional discriminations in 78 trials and learned the conditional sequence response in 22 trials. He immediately passed the following sequence test (20 of 20 trials correct), but failed the random sequence test as in Phase II. This failure appeared to be due mainly to the very stringent criterion which required 39 of 40 consecutive trials correct within a limit of 45 trial presentations. Although the subject scored correctly on 43 of the 45 trials, two mistakes occurred during the last 40 trials. On a second presentation of the sequence and random sequence test, he met criterion on both (19 of 20 and 40 of 40 trials correct, respectively).

As Subject # 3 had not been tested for equivalence, a post-hoc conditional equivalence test was presented without feedback. He reached criterion (39 of 40 consecutive trials correct).

<u>Subject # 4.</u> When compared to the other three subjects in Experiment 1, this subject appeared to have greater difficulties completing the experiment (see Figure 8). In Phase I, she acquired the conditional discriminations in 240 trials and the sequence response to the B stimuli in 18 trials. She failed the first sequence test, responding consistently wrong to the A and C stimulus pairs and making erratic mistakes on the D stimuli. Errorfree performance during retraining on the conditional discriminations and the sequence response indicated that this failure had not been due to deficient acquisition of the trained relations. She failed the sequence test again by responding incorrectly to all A, C and D stimulus pairs. After retraining, she passed the partial equivalence test without mistakes, but failed the sequence test a third time, seemingly because of unsystematic errors. She solved the complete equivalence test without mistakes, thus demonstrating that equivalence relations had formed, yet she continued to respond almost in

a random fashion on the next sequence test. It appeared that Subject # 4 to this point in the experiment had failed to discriminate the relationship between the matching-to-sample and sequence tasks. However, after retraining and errorfree performance on a second complete equivalence test, she then solved the sequence and random sequence test (20 of 20 trials correct on both tests).

In Phase II, her performance showed a similar pattern. She acquired the second-order conditional discriminations in 110 trials and after retraining in the sequence response failed the first sequence test by responding to the C and D stimulus pairs in the same fashion as during Phase I. Apparently, she disregarded the changing background colors which now signalled the class membership of the stimuli. When retrained on the second-order conditional discriminations, it took her 100 trials to reach criterion. An analysis of her errors showed that all mistakes occurred on relations involving the C or D stimuli as comparisons on red background. Apparently the previous learning history established in Phase I continued to exert strong control over her behavior. After retraining, she failed the sequence test again. She solved the partial conditional equivalence test with 39 of 40 trials correct, but failed the sequence test for the third time. After retraining, the complete conditional equivalence test was presented and it became apparent that equivalence had not emerged. On red background, the subject responded incorrectly to all C-D and D-C relations which had not previously been tested; she also made some mistakes on B-D relations. After renewed retraining, the complete conditional equivalence test was presented once more, and now the subject met criterion (39 of 40 trials correct). Once the four conditional equivalence classes had formed, Subject # 4 then completed the sequence and random sequence test without further errors (20 of 20 and 30 of 30 trials correct, respectively).

During Phase III, the subject showed perfect retention of the previously trained second-order conditional discriminations and acquired the conditional sequence response in 47 trials. On the first sequence test she made several unsystematic errors. These may have been due to a failure to discriminate the tones consistently because she performed errorfree on the retraining trials of the second-order conditional discriminations, but made seven mistakes before reaching criterion during retraining of the conditional sequence response. Then she solved both the sequence and random sequence test (20 of 20 and 39 of 40 trials correct, respectively).

She also met criterion on the post-hoc conditional equivalence test (39 of 40 trials correct) which was given to her once more at the end of the experiment, although she had solved a similar test during Phase II.

Experiment 2

It will be recalled that in Experiment 2 the conditional sequence training occurred in Phase II and the conditional matching-to-sample training in Phase III, thus reversing the order of presentation in Experiment 1. All four subjects reached criterion in the three phases of this experiment. Similar to Experiment 1, the intersubject variability was substantial. None of these four subjects completed the entire experiment without ever passing an equivalence test, although Subjects # 6 and 7 finished Phase I without one.

Subject # 5. This subject (see Figure 9) was tested for equivalence relations among all stimuli before she mastered the random sequence test in Phase I. Initially, she acquired the conditional discriminations in 148 trials and the sequence response in 15 trials. She failed the sequence test by responding incorrectly to the A and C stimulus pairs. After retaining, she failed it again, this time due to errors on the C and D stimulus pairs. After retraining, she solved the partial equivalence test (excluding the C's), but again failed the sequence test due to the same errors as before. She was then given a complete equivalence test, which she solved. Subsequently, she also passed the sequence and random sequence test (20 of 20 trials correct on both tests).

In Phase II, a perfect carry-over from Phase I was observed on the conditional discrimination training, but she took 98 trials to acquire the conditional sequence response. Because of a mild hearing impairment it was apparently difficult for her to discriminate the tones controlling he conditional sequence response. However, once this discrimination was established, she had no further difficulties and solved the sequence and random sequence test (both with 19 of 20 trials correct).

In Phase III., she met the training criterion for the second-order conditional discriminations in 106 trials and received 21 trials of retraining in the conditional sequence response. She solved the following sequence test (20 of 20 trials correct), but just missed the criterion for the random sequence test. On a second presentation of both tests, she solved the sequence test with 19 of 20 trials correct and the random sequence test with 39 of 40 trials correct.

As she had completed Phase III without an equivalence test, she was given a post-hoc conditional equivalence test and solved it errorfree (40 of 40 trials correct).

<u>Subject # 6.</u> This subject (see Figure 10) completed Phase I without an equivalence test, requiring 95 trials to reach the training criterion on the conditional discriminations

and 15 trials on the sequence training. He then passed the sequence and random sequence test (19 of 20 trials correct on both).

In Phase II, he immediately met the training criterion for the conditional discriminations established in Phase I, and acquired the conditional sequence response in 31 trials. He also reached criterion on the following sequence test (20 of 20 trials correct) and the random sequence test (19 of 20 trials correct) within the limits of 25 trial presentations. Thus, a transfer of the conditional sequence response had occurred, although equivalence relations had not been explicitly tested either in Phase I or II.

In Phase III, Subject # 6 took 88 trials to acquire the second-order conditional discriminations and received 20 trials of retraining in the conditional sequence response. He then failed the sequence test by responding incorrectly on several C and D stimulus pairs on red background. After retraining, he failed the sequence test for the second time because of mistakes on the D stimulus pairs on red background. He completed a partial equivalence test errorfree (40 of 40 trials correct) and thereafter also solved both the sequence and random sequence test without further mistakes.

Due to a failure in the electronic equipment, Subject # 6 was not given a post-hoc equivalence test. However, as during Phase III the presence of some conditional equivalence relations had been demonstrated (when the subject solved the partial conditional equivalence test), it is justified to assume that second-order equivalence relations had been established.

<u>Subject # 7.</u> This subject (see Figure 11) completed Phase I without an equivalence test. She met the training criterion for the conditional discriminations in 277 trials and for the sequence response to the B stimuli in 15 trials. She then passed the sequence and random sequene test, both with 20 of 20 consecutive trials correct.

In Phase II, after 30 trials of retraining in the conditional discriminations established in Phase I and 16 training trials for the conditional sequence response, she failed the sequence test by responding incorrectly to all C and D stimulus pairs. After retraining, she failed it a second time due to the same mistakes. She also failed the following two partial equivalence tests (excluding the C's) despite errorless retraining on the conditional discriminations between tests. She solved the partial equivalence test on its third presentation, but continued to respond incorrectly to the C and D stimuli on the following sequence test. After retraining, she solved the complete equivalence test errorfree and then also mastered the sequence and random sequence test (both with 20 of 20 trials correct).

In Phase III, the subject acquired the second-order conditional discriminations in 119 trials and received 20 trials of retraining in the conditional sequence response to the B's. She met criterion on the sequence test, despite responding incorrectly on the first five trials. (After the experiment she reported that she "got confused with the tones".) She also passed the random sequence test (40 of 40 trials correct).

As the presence of conditional equivalence classes had not been tested explicitly in Phase III, the subject was given a post-hoc conditional equivalence test. She met criterion with 39 of 40 consecutive trials correct.

Subject # 8. This subject (see Figure 12) had great difficulty solving the experiment. In Phase I, he acquired the conditional discriminations in 252 trials and the sequence response to the B's in 16 trials. He failed the first sequence test and after retraining failed it again, both times because of responding incorrectly to the C and D stimulus pairs. He required 61 trials of retraining in the conditional discriminations to meet the training criterion, solved a partial equivalence test (excluding the C's), but then again failed the sequence test due to errors involving the D stimuli. After retraining, he passed the complete equivalence test and then also mastered the sequence and random sequence test (19 of 20 trials correct on both tests).

In Phase II, after errorfree retraining in the conditional discriminations and 26 trials of conditional sequence response training, he failed the sequence test due to errors involving the A and C stimuli. After retraining, he just missed the sequence test by one trial. He solved the partial equivalence test and then also the sequence test (19 of 20 trials correct), but failed the random sequence test by one trial. When both tests were presented once more, he met criterion with 19 of 20 trials correct.

In Phase III, the subject acquired the second-order conditional discriminations in 142 trials and received 26 trials of retraining in the conditional sequence response. He failed the sequence test due to seemingly unsystematic errors. After retraining, he failed it again, this time by responding incorrectly to the C and D stimulus pairs. During retraining, he continued to make mistakes on the C and D comparisons on red background, requiring 73 trials to meet the training criterion. It was obvious that the previously established history continued to exert strong control over his behavior. He then failed three partial conditional equivalence tests separated by retraining trials, mainly because he responded incorrectly to the B-D/D-B relations on red background. He passed the fourth presentation of this test (39 of 40 trials correct), but failed the following sequence test again by responding incorrectly as before to C and D stimulus pairs on red background. Separated by training trials, he received five complete conditional equivalence tests, but continued to respond incorrectly to relations involving transitivity when the background was red.

When it became apparent that Subject # 8 was not likely to solve the conditional equivalence test, a change in the experimental protocol was introduced. As mistakes occurred almost exclusively on red background, it was decided to train the conditional discriminations on red separately from those on green background. However, given the evidence in the literature that equivalence relations often emerge during testing, he was first given 100 unreinforced trials of a complete equivalence test on red background only. As before, he responded incorrectly to relations involving transitivity and equivalence did not emerge. The subject then received 100 reinforced training trials in conditional discriminations on red background. When then given the equivalence test again, he reached criterion (39 of 40 trials correct). Thus, it was established that equivalence relations had emerged on red background, and the changing background colors were reintroduced. He was now trained in a simple sequence response to the B stimuli with randomly alternating background colors and then given a sequence test without the conditional tone signals (i.e., a test identical to that administered in Experiment 1, Phase II). The subject failed the sequence test, responding incorrectly to four D1-D2 sequences. After retraining in the second-order conditional discriminations, he passed a complete conditional equivalence test (39 of 40 trials correct) and then solved the sequence test (19 of 20 trials correct) and the random sequence test (29 of 30 trials correct), again without conditional sequence cues.

To recapitulate, this subject's training history up to this point had led to the emergence of (a) the transfer of a simple sequence response through two equivalence classes, (b) the transfer of a conditional sequence response through two equivalence classes, and (c) the transfer of a simple sequence response through four conditional equivalence classes. Building on this history, it was expected that he would now master the transfer of a conditional sequence response through four conditional equivalence classes in the next phase.

Phase III of Experiment 2 was reintroduced. The subject was retrained in the second-order conditional discriminations and the conditional sequence response. He failed the first sequence test. After retraining, he solved the sequence test (20 of 20 trials correct), but failed the random sequence test (because he "got confused with the tones", as he stated after the experiment). On a second presentation of the sequence and random sequence tests, he reached criterion on both (19 of 20 and 39 of 40 trials correct, respectively).

A final presentation of a post-hoc conditional equivalence test including all stimuli corroborated that four conditional equivalence classes had formed. Subject # 8 solved this test with 39 of 40 trials correct.

Reaction Time Measures

Subjects' response latencies were analyzed for both the equivalence tests and the sequence tests, depending on whether the stimulus relations were trained, emerged from symmetry or from transitivity.

Equivalence Tests. For each subject the average response latencies across all (partial and complete) equivalence tests were calculated separately for three types of relations: (a) trained relations involving all presentations of A1 or A2 as sample with the B, C or D stimuli as comparisons, (b) symmetrical relations involving all trained relations, but with the sample and comparison roles of the stimuli reversed, and (c) transitive relations involving the B, C or D stimuli.

The average reaction times across all eight subjects were 1.92 sec for trained, 2.89 sec for symmetrical, and 4.55 sec for transitive relations. These response latencies were subjected to a single-factor repeated measures ANOVA, with the within-subjects factor consisting of three levels (trained / symmetrical / transitive relations). An omnibus F test was statistically significant at $p < 0.002$ (F (2,23) = 4.46). To pinpoint which of the three treatment levels differed from each other, a Studentized Newman-Keuls test was applied. This test showed that the average reaction time to trained relations was statistically significantly shorter than to transitive relations (obs.diff. = 2.63 sec; crit.diff. = 2.25 sec; $p < 0.05$). However, neither the difference in reaction times between trained and symmetrical relations (obs.diff. = 0.93 sec; crit.diff. = 1.89 sec) nor between symmetrical and transitive relations (obs.diff. = 1.66 sec; crit.diff. = 1.89 sec) was statistically significant ($p > 0.05$).

Sequence Tests. For the response latencies to the sequence and random sequence tests a similar analysis was carried out. The average reaction times across these tests were calculated for each subject, separate for three types of sequential responses: (a) trained responses to the B stimuli, (b) responses to the A stimuli involving symmetry, and (c) responses to the C or D stimuli involving transitivity. Relations from the random sequence tests involving "mixed" stimulus pairs (e.g., B1-D2 with B1 being trained and D2 involving transitivity) were not included into the analysis.

The average reaction times across all eight subjects on the sequence/random sequence tests were 1.93 sec to trained, 2.73 sec to symmetrical, and 3.66 sec to transitive response sequences. These response latencies were analyzed with a single-factor repeated measures ANOVA, with the three types of sequential responding as a within-subjects factor. The omnibus F test showed a statistically significant effect at $p < 0.002$ (F (2,23) = 8.21). This effect was further analyzed with a Studentized Newman-Keuls test. The test showed that the average reaction times to trained and symmetrical response sequences did not statistically differ from each other (obs.diff. = 0.80 sec; crit.diff. = 0.88 sec; $p > 0.05$), while both were significantly shorter ($p < 0.05$) than the reaction times to transitive relations (trained / transitive: obs.diff. = 1.73 sec, crit.diff. = 1.06 sec; and symmetrical / transitive: obs.diff. = 0.93 sec, crit.diff. = 0.88 sec).

CHAPTER IV

DISCUSSION

The results from both experiments have shown that humans, having acquired a sequential response to a given stimulus pair, will transfer this response without additional training to other stimuli in equivalence classes. Further, when the direction of the sequential response is itself brought under conditional control, these conditional stimuli will also control the directionality of untrained sequential responding to untrained members of the relevant equivalence classes. In addition, it has been shown that it is possible to bring equivalence classes themselves under second-order conditional control and that the sequential response will transfer in an orderly way throughout the untrained members of the conditional equivalence classes. And last but not least, the experiments have shown that these various sources of control can all converge to produce sequential behavior.

Before I will discuss the implications of these findings for the formation of symbol-referent and syntactical relations, let us first inspect the data of individual subjects more closely and let me point out some interesting observations.

Two subjects (# 1 and 3) completed the entire Experiment 1 without passing a specific equivalence test. The presence of four conditional equivalence classes was only demonstrated post-hoc when subjects received 40 unreinforced matching-to-sample trials testing for symmetrical and transitive relations. These findings are important as to date no study has shown the formation of stimulus equivalence in the absence of a specific equivalence test in the usual matching-to-sample format. Since it is highly unlikely that the sequence and random sequence tests were solved unless a transfer of control from trained to untrained stimuli via equivalence relations had occurred, the presence of stimulus equivalence and second-order stimulus equivalence was demonstrated in subjects' performance on these tests. This was confirmed with the successful completion of a post-hoc conditional equivalence test by these subjects.

What are the implications of this finding? Can we say that equivalence relations have formed in the absence of any equivalence test, merely from training in conditional discriminations? Although this is possible, an alternative interpretation exists. As the sequence and random sequence tests could only be solved via equivalence, these tests could have served the same "instructional" function as conventional tests in the matching-to-sample format. In other words, it is still possible that some kind of equivalence test is required as a context for equivalence relations to emerge, although this test need not conform to the usual matching-to-sample format. It might be possible to test this assumption experimentally. Imagine that subjects were trained in the same conditional discriminations as in Phase I of the present experiments and that they were then taught to respond sequentially to the B stimuli: in the presence of Tone 1, a "left-right" sequence would be reinforced, while with Tone 2, a "right-left" sequence would be reinforced, regardless the position of B1 and B2. If then conditional sequence and random sequence tests (identical to those of Phase II in Experiment 2) were presented, we could expect that subjects would order any stimulus pair according to a "forward" or "backwards" tone signal. If subjects were then given a conventional equivalence test, equivalence formation would probably have been disrupted instead of facilitated by the sequence tests, which were completely irrelevant to the emergence of equivalence relations. Such a finding would support the interpretation that the sequence and random sequence tests for some subjects in the present study were functional substitutes for the conventional equivalence tests used in other studies.

A second interesting observation was that the transfer of the sequential response to untrained stimuli virtually always occurred when the formation of equivalence classes or conditional equivalence classes had been demonstrated.

Several subjects (# 2, 4, 5, 7, and 8) in one phase or another failed several sequence tests and sometimes also equivalence tests. But once they passed a complete equivalence test, a transfer of the sequence response occurred on the very next sequence test. This provides evidence that a transfer of control from one arbitrary stimulus to others does not occur in the absence of stimulus equivalence, but almost seems an automatic process when equivalence classes have been established. The performance of Subject # 4 in Phase I was the only exception: she solved two complete equivalence tests correctly before a transfer of the sequential response occurred. An inspection of her errors on the sequence tests showed no systematic pattern, and it is unclear what controlled her responding. It seemed as if she treated the matching-to-sample tasks independently from the sequence tasks and her behavior apparently came under the control of the relationship between them only after the second complete equivalence test. Nevertheless, she did show the transfer of the sequential response. In conclusion, within the limits of the results of the present study the transfer of control through classes of equivalent stimuli is a well established phenomenon.

The performance of Subject # 8 warrants some additional explanations. Given the extraordinary difficulties he had with the conditional equivalence classes in Phase III, after the experiment he was extensively interviewed to discover the possible origin of these difficulties. He reported that he had developed a strategy when the second-order conditional discriminations were introduced, concluding that the C and D stimulus pairs had been "switched around". From then on, he continued to focus on C1/D1 when sample A1 was present (or on C2/D2 when A2 was present), but when the background was red he deliberately <u>avoided</u> the formerly correct response and "chose the other one". This strategy worked during acquisition, but was bound to fail during testing. His performance on the sequence test became inconsistent, as he responded at times in a C2-C1 or D2-D1 sequence on green background and in the reverse sequences on red background and "got confused". On the complete equivalence test, his errors became very consistent because with a C stimulus as sample and the D stimuli as comparisons on red background he continued to "choose the other one" of the comparisons he would have chosen on green background, i.e., he related C1 to D2, D1 to C2, etc. However, the equivalence classes on red background consisted of A1,B1,C2,D2 and A2,B2,C1,D1; hence, responding to D1 in the presence of C1 and to D2 in the presence of C2 as sample was still the correct choice. Reportedly, the subject did not discriminate these relations until he was given 100 massed training trials on red background only and "suddenly realized how the symbols went together". After this "insight" he then performed the first complete conditional equivalence test without errors and solved the following simple sequence and random sequence tests. Once the four conditional equivalence classes had been established, he then also showed a transfer of the conditional sequence response through these four classes.

It appears that the performance of Subject # 8 was a clear case of "self-rule formulation", demonstrating how rules acquired in a different context may come to strength as self-rules during a problem solving task, but instead of helping may actually interfere with the solution. In adult humans, depending on their particular history, such rules may exert powerful control over behavior and prevent the person from contacting contingencies that would lead to successful problem solving.

A further issue I would like to discuss is the observation that stimulus equivalence often appears to be a gradually emerging phenomenon. This was also found in the present research. Although some subjects (e.g., Subjects # 1, 6, and 7) solved the very first sequence test immediately after having been trained to criterion in a set of eight conditional discriminations (thus showing that equivalence relations had formed), most other subjects required several sequence or equivalence tests for stimulus equivalence relations to emerge. Some studies in the literature have also found the immediate presence of equivalence during the first unreinforced test (e.g., Saunders, Wachter, &

Spradlin, 1986), but many others have reported that responding to equivalence relations gradually improves over testing (e.g., Devaney et al., in press) or that repeated blocks of training and test trials are necessary for equivalence classes to form. Whether equivalence emerges immediately or gradually, may largely depend on subjects' history. Above I have attempted to explain why some subjects in the present study may have come to solve the entire experiment without passing a specific equivalence test. What remains to be explained is why for others equivalence classes emerged only after repeated testing. Several explanations might be possible.

First, as an analogy Skinner's (1957) analysis of understanding a difficult paper comes to mind. Initially, a reader may not understand a paper (i.e., (s)he would not emit the same verbal behavior as the author of the paper under comparable circumstances), although each single word may be part of his/her repertoire. However, by reading and rereading the paper several times, intraverbal sequences will be established so that the reader's behavior will gradually be changed in the direction of increased understanding because his/her verbal behavior will now come closer to the writer's (Skinner, 1957, p.278). An analogy could be made in regards to equivalence tests. We could argue that a subject, after matching-to-sample training, on a test is initially presented with novel stimulus combinations. Although each individual symbol is familiar (just as each single word may be in the reader's repertoire), the particular symbol configurations are unfamiliar so that the subject does not "understand" them. Only after repeated presentations of particular stimulus combinations (analogous to rereading a difficult paper) may the necessary discriminations have been established, which then, when existing at considerable strength, lead to correct performance on the equivalence test. This would explain why subjects' performance gradually improves over repeated testing.

An alternative explanation (Devany & Hayes, 1986) is that equivalence relations emerge because humans are likely to have a history of reinforcement for responding consistently to given discriminative stimuli and stimulus equivalence is the only consistent source of control present on every trial. Although responding might initially be controlled by various (mostly irrelevant) sources, the very inconsistency of these sources should lead to a weakening of the response tendencies they control, while control by equivalence relations should come to strength over repeated trials. Once sufficient strength has been attained, we would expect responding to be controlled by the equivalence relations among symbols.

Devany & Hayes (1986) have attempted to find empirical support for their analysis by interspersing irrelevant trials among the trials of an equivalence test. As hypothesized, these irrelevant trials interfered with equivalence class formation. However, this interference did not occur immediately: initially, equivalence classes formed, but deteriorated on subsequent tests when the irrelevant trials were no longer presented. An explanation of this finding still awaits further analysis.

Finally, one could also argue that equivalence emerges gradually because subjects approach equivalence tests in a "hypothesis testing" fashion, gradually eliminating rival hypothesis until a solution is found. This could especially be claimed for the present study where adult college students served as subjects. They not only had sophisticated verbal repertoires but also a history where problem solving through hypothesis testing may have been extensively reinforced. In addition, the performance of Subject # 8 seems to support this notion because he clearly approached at least part of the experiment with a strategy, though an ineffective one. However, it seems unlikely that responding to equivalence relations is generally based on "hypothesis testing" or strategies. After all, the formation of stimulus equivalence has been demonstrated in very small children (cf. Devany et al., in press; Lowe et al., 1986). These children certainly did not have verbal repertoires that allowed them to formulate and test out hypotheses during an equivalence test. Furthermore, as the perfomance of Subject

8 in the present study has shown, formulating complex hypotheses about the relations among stimuli may hinder rather than help the process. This "self-rule formulation" for which humans have a long history of reinforcement, may be controlled by contingencies which under some circumstances lead to insensitivity to other contingencies surrounding a task, thus preventing contact with alternative sources of reinforcement. In conclusion, although some subjects in the present research may have formulated hypotheses about the task, it would be unsatisfying to say that these hypotheses caused the gradual emergence of equivalence classes. If anything, the contingencies responsible for the formulation of these hypotheses may also have been responsible for the gradual formation of the equivalence relations.

Finally, the results from the reaction time data can be interpreted in light of Hayes & Brownstein's (in press) notion that stimulus equivalence emerges from a network of relational frames. The simplest of these would be a frame generated from a history of reinforcement for responding symmetrically to two stimuli. In a sense, this frame would closely parallel the relationship between a word and its referent. At a higher level of complexity, transitive responding could be generated through the combination of at least two symmetrical frames with one stimulus in common. Thus, a referent might be designated by two synonyms, or a concept could involve (at least) two or more instances. One might therefore expect the response latency to relations involving two or more symmetrical frames to be longer than to those based on one frame only. This is what has been found in the average reaction times of the subjects in the present experiment: Subjects responded about equally fast to trained and symmetrical relations, but took significantly longer when transitive relations were involved.

After having discussed in some detail the findings of the present experiments, let us now turn to the implications of this research for a behavioral perspective on language.

The purpose of this research project was twofold. On the one hand, it was designed to address one of the challenges posed by psycholinguists to behaviorists, i.e., that a behavioral approach cannot deal with important linguistic phenomena such as the emergence of syntactical relations and the generation of novel utterances. On the other hand, it was designed to further our understanding of simple verbal phenomena from an operant perspective by extending the research on stimulus equivalence to an area that may play a role in the acquisition of meaning and syntax. If we accept Sidman's (1986) argument that equivalence relations are semantic in nature, the demonstrated transfer of a sequence response through equivalence classes (i.e., Phase I) may parallel the emergence of simple two-word utterances in a child who, after having learned several concepts (e.g., colors, food, clothing, toys, etc.), can generate a considerable number of combinations probably from very few trained instances. If the assumption is correct that verbal concepts originate from the participation of verbal stimuli in equivalence classes, the emergence of new, untrained combinations of elements of these classes seems to lose its mystical quality. The generation of such untrained symbol combinations can be explained from an operant perspective in terms of a particular training history and the increased ability of humans to respond to arbitrary relations.

A significant contribution of the present research is the demonstration of conditional equivalence class formation. No published study to date has provided an empirical demonstration that conditional equivalence relations can emerge from second-order conditional discriminations and that a function acquired by one equivalent stimulus transfers without training to the other class members. Interestingly, five of the eight subjects in this study showed conditional equivalence by their performance on the sequence and random sequence tests without having received an equivalence test, while two required an explicit test in matching-to-sample format. As previously discussed, the only one of the eight subjects who had considerable problems with conditional equivalence relations was Subject # 8 because he approached the task with an ineffectual strategy.

The demonstration of conditional equivalence has important implications for an analysis of "meaning". If we accept that equivalence relations closely parallel word-referent relations, then the conditional control over such relations shows how "the same word can mean different things", depending on the context in which it occurs. It also shows that "meaning" is not something inherent in a symbol (word), but depends on the context that determines the class membership of an equivalent stimulus. A second implication of the present study is that an operant analysis of symbolic behavior possibly can also account for differences in "meaning" of verbal stimuli. By demonstrating that the environment can exert conditional control over the class membership of equivalent stimuli, meaning itself becomes flexible and dependent on the context which selects symbols from one class or another. To illustrate, the word "chaining" probably means something different to a prisoner than to a behavior analyst. The conditional control established over equivalence classes in the present study has attempted to show one possible way how the environment might create such flexibility in the "meaning" of arbitrary stimuli and how individuals might come to emit responses appropriate to particular stimulus conditions.

Establishing second-order control over equivalence relation, besides 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 example, saying "Violet is blind" means something quite different than saying a "blind is violet". The present study has shown that this flexibility in response sequences can be explained by the participation of symbols in conditional equivalence classes. In regards to linguistic development, these findings might 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 bringing these sequences themselves under conditional control. As before, a transfer of conditional sequential responding from trained to untrained members of equivalence classes was shown. This might yet be another way in which flexible word order can originate. Perhaps similar processes underly syntactical relations which linguists have termed active and passive voice: the word order is inverted, yet the meaning of an utterance is preserved.

Last but not least, in the third phase of both experiments it was demonstrated that different sources of control can combine to generate sequential responding under complex environmental control. Most importantly, it was also possible to show that response sequences under complex control can be transferred without training to other stimuli due to their participation in equivalence classes. From only four trained instances a total of sixty-four different response sequences were generated, sixty of which emerged without direct training.

At this moment, it is impossible to say whether the emergence of syntactical relations is in fact controlled by processes similar to those shown in the present research. More research is needed to investigate the implications of stimulus equivalence for the acquisition of language structure.

One justifiable criticism of the present study and the implications I have given its results might be that the data were obtained from adult subjects. Someone might argue that the transfer of the sequence responses under the specified conditions occurred precisely because adult subjects already have very proficient language skills and other sophisticated behavioral repertoires which facilitated their performance on the experimental tasks. This possibility cannot be ruled out, although other experimental findings seem to lend some support to my interpretation. It will be recalled that stimulus equivalence has been shown in children as young as two years of age and that the ability to respond to equivalence relations seems to be associated with linguistic development (e.g., Devany et al., in press; Lowe et al., 1986). However, it is still possible that the transfer of a (conditional) sequence response through simple and conditional equivalence classes requires a behavioral repertoire by far exceeding that of small children. Thus, the adult subjects may have been successfully completed the present experiments because of a long history of solving complex tasks by abstract reasoning. Attempting to demonstrate this effect with adult subjects is nevertheless justifiable for methodological reasons. Because to date it has not been shown in any published study, it makes good sense first to carry out experiments with adult subjects: If these subjects were not able to solve the tasks, it would be fruitless to train small children in this rather complex procedure. As the effect has now been shown in adults, the next step should be to attempt a systematic replication with younger children. An experimental demonstration of a transfer of control via conditional equivalence classes in small children would provide considerable support for the assumption that this phenomenon may play a role in the emergence of syntax.

Summary and Conclusions

The present study investigated the potential implications of stimulus equivalence for the acquisition of meaning and simple syntactical relations. The transfer of a simple and a conditional sequence response through equivalence and conditional equivalence classes was demonstrated. The experiments showed that the environment can establish a 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.

Although language is undoubtedly a very complex behavioral phenomenon, it seems to emerge from initially very small and simple units (individual words, then two-word utterances, and gradually longer and more complex units). The overall findings from the present research suggest that the transfer of control via stimulus equivalence may be implicated in the emergence of word-referent and simple syntactical relations. Further experimental analyses within the framework of stimulus equivalence and relational frames more generally may help elucidate some of the processes that operate in the acquisition of verbal behavior.

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APPENDIX A

TABLES

Table 1

Description of Phases I-III for both Experiments

Experiment 1

Phase I:
(a) Training in conditional discriminations (Part 1)
(b) Training in simple sequence response to B stimuli (Part 2)
(c) Test for transfer of sequence response through two equivalence classes (Parts 3 and 4)
(d) Test for equivalence if transfer of sequence response does not occur (Parts 5 and 6)

Phase II:
(a) Training in second-order conditional discriminations (Part 1)
(b) Training in simple sequence response to B stimuli (Part 2)
(c) Test for transfer of sequence response through four conditional equivalence classes (Parts 3 and 4)
(d) Test for conditional equivalence if transfer of response does not occur (Parts 5 and 6)

Phase III:
(a) Training in second-order conditional discriminations (Part 1)
(b) Training in conditional sequence response to the B stimuli (Part 2)
(c) Test for transfer of conditional sequence response through four conditional equivalence classes (Parts 3 and 4)
(d) Test for conditional equivalence if transfer of conditional sequence response does not occur (Parts 5 and 6)

Table 1 (continued)

Experiment 2

Phase I:

(a) Training in conditional discriminations (Part 1)
(b) Training in sequence response to B stimuli (Part 2)
(c) Test for transfer of sequence response through two equivalence classes (Parts 3 and 4)
(d) Test for equivalence if transfer of sequence response does not occur (Parts 5 and 6)

Phase II:

(a) Training in conditional discriminations (Part 1)
(b) Training in conditional sequence response to the B stimuli (Part 2)
(c) Test for transfer of the conditional sequence response through two equivalence classes (Parts 3 and 4)
(d) Test for equivalence if transfer of conditional sequence response does not occur (Parts 5 and 6)

Phase III:

(a) Training in second-order conditional discriminations (Part 1)
(b) Training in conditional sequence response to the B stimuli (Part 2)
(c) Test for transfer of the conditional sequence response through four conditional equivalence classes (Parts 3 and 4)
(d) Test for conditional equivalence if transfer of conditional sequence response does not occur (Parts 5 and 6)

Table 2

Training and Test Sequences

Experiment 1

<u>Phase I</u>

Part 1
Equivalence Training (with feedback)
Matching-to-sample procedure
(If A1, then B1/C1/D1
If A2, then B2/C2/D2)
Training criterion:
29 of 30 consecutive trials correct

Part 2
Sequence Training (with feedback)
B1--→B2; B2←--B1
Training criterion:
14 of 15 consecutive trials correct

Part 3
Sequence Test (without feedback)
A1--→A2; A2←--A1
B1--→B2; B2←--B1
C1--→C2; C2←--C1
D1--→D2; D2←--D1
Test criterion:
19 of 20 consecutive trials correct
or 25 trials

Part 4
Random Sequence Test (without feedback)
A1--→D2; D2←--B1
C1--→B2; etc.
(all possible combinations)
Test criterion:
19 of 20 consecutive trials correct
or 25 trials

Table 2 (continued)

Part 5

Equivalence Test (without feedback)
Matching-to-sample procedure, with A/B/D stimuli serving sample and comparison role
Test criterion:
19 of 20 consecutive trials correct
or 25 trials

Part 6

Equivalence Test (without feedback)
Matching-to-sample procedure
with all stimuli serving sample/comparison role
Test criterion:
29 of 30 consecutive trials correct
or 45 trials

Phase II

Part 1

Conditional Equivalence Training (with feedback)
Second-order matching-to-sample procedure
with background color (red/green) serving
as second-order conditional stimulus
(If green and if A1, then B1/C1/D1
if A2, then B2/C2/D2
If red and if A1, then B1/C2/D2
if A2, then B2/C1/D1)
Training criterion:
39 of 40 consecutive trials correct

Part 2

Sequence Training (with feedback)
on randomly alternating background
Green: B1--→B2; Green: B2←--B1
Red : B2←--B1; Red: B1--→B2
Training criterion:
14 of 15 consecutive trials correct

Part 3

Sequence Test (without feedback)
on randomly alternating background
Green: A1--→A2; Red: A2←--A1
Green: B1--→B2; Red: B2←--B1
Green: C1--→C2; Red: C2--→C1
Green: D1--→D2; Red: D2--→D1
Test criterion:
19 of 20 consecutive trials correct
or 25 trials

Table 2 (continued)

Part 4

Sequence Test (without feedback)
on randomly alternating background
Green: A1---C2; Red: D2---B1
Green: D1---B2; etc.
(all possible combinations)
Test criterion:
19 of 20 consecutive trials correct
or 25 trials

Parts 5 and 6

Conditional Equivalence Tests (without feedback)
Identical to those of Phase I, Parts 5 and 6,
but with randomly alternating background

Phase III

Part 1

Conditional Equivalence Training (with feedback)
Identical to that of Phase II

Part 2

Second-Order Sequence Training (with feedback)
on randomly alternating background

Tone 1/green:	B1---B1;	Tone 2/green:	B2---B1
Tone 1/red:	B1---B2;	Tone 2/red:	B2---B1

Training criterion:
19 of 20 consecutive trials correct

Part 3

Second-Order Sequence Test (without feedback)
on randomly alternating background

Tone 1/green:	A1---B1;	Tone 2/green:	A2---A1
Tone 1/green:	B1---B2;	Tone 2/green:	B2---B1
Tone 1/green:	C1---C2;	Tone 2/green:	C2---C1
Tone 1/green:	D1---D2;	Tone 2/green:	D2---D1
Tone 1/red:	A1---A2;	Tone 2/red:	A2---A1
Tone 1/red:	B1---B2;	Tone 2/red:	B2---B1
Tone 1/red:	C2---C1;	Tone 2/red:	C1---C2
Tone 1/red:	D2---D1;	Tone 2/red:	D1---D2

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

Table 2 (continued)

Part 4

Second-Order Random Sequence Test (without feedback) on randomly alternating background

Tone 1/green: B1--→D2;   Tone 1/red: D2--→A2

Tone 2/red: B2--→C2;   etc.

(all possible combinations)

Test criterion:

39 of 40 consecutive trials correct or 45 trials

Parts 5 and 6

Conditional Equivalence Tests (without feedback)

Identical to those of Phase II, Parts 5 and 6

Table 3

Training and Test Sequences

Experiment 2

Phase I

Identical to Phase I, Experiment 1

Phase II

Part 1

Equivalence Training (with feedback)
Identical to Part 1, Phase I

Part 2

Second-Order Sequence Training (with feedback)
Tone 1: B1--→B2; B2←--B1
Tone 2: B2--→B1; B1←--B2
Training criterion:
14 of 15 consecutive trials correct

Part 3

Second-Order Sequence Test (without feedback)
Tone 1: A1--→A2; Tone 2: A2--→A1
Tone 1: B1--→B2; Tone 2: B2--→B1
Tone 1: C1--→C2; Tone 2: C2--→C1
Tone 1: D1--→D2; Tone 2: D2--→D1
Test criterion:
19 of 20 consecutive trials correct
or 25 trials

Part 4

Second-Order Random Sequence Test (without feedback)
Tone 1: A1--→C2; Tone 2: D2--→B1
Tone 2: D1←--B2; etc.
(all possible combinations)
Test criterion:
19 of 20 consecutive trials correct
or 25 trials

Parts 5 and 6

Identical to those of Phase I, Parts 5 an 6

Phase III

Identical to Phase III, Experiment 1

Table 4

General Overview of Results (Experiment 1 and 2)

Percentage of Subjects Showing Transfer of a Sequence Response with or without a Specific Equivalence Test

	Transfer of the Sequence Response					
	Experiment 1			Experiment 2		
Training:	No ET	ET 1	ET 2	No ET	ET 1	ET 2
Simple Equivalence and ---Sequence	50%		50%	50%		50%
---Condit. Sequence				50%	25%	25%
Conditional Equivalence and ---Sequence	75%		25%			
---Condit. Sequence	100%			75%		25%

ET = Equivalence Test
ET 1 = Equiv. Test without C's
ET 2 = Complete Equiv. Test

APPENDIX B

FIGURES

Figure 1

Flow Chart of Task Presentation

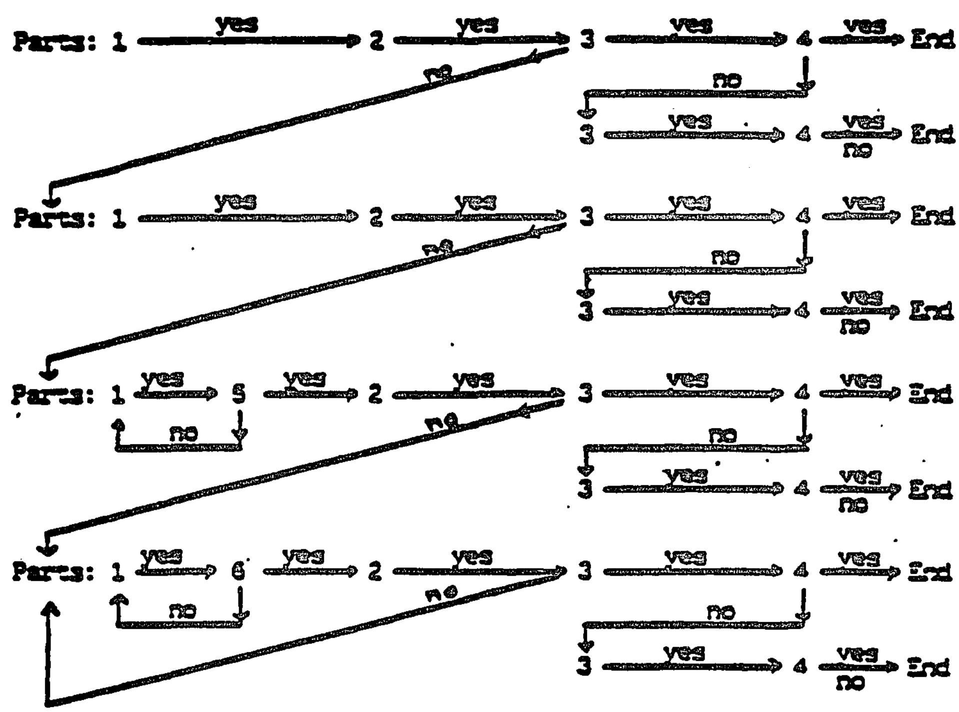


Figure 2

Diagram of the General Strategy for

Experiments 1 and 2

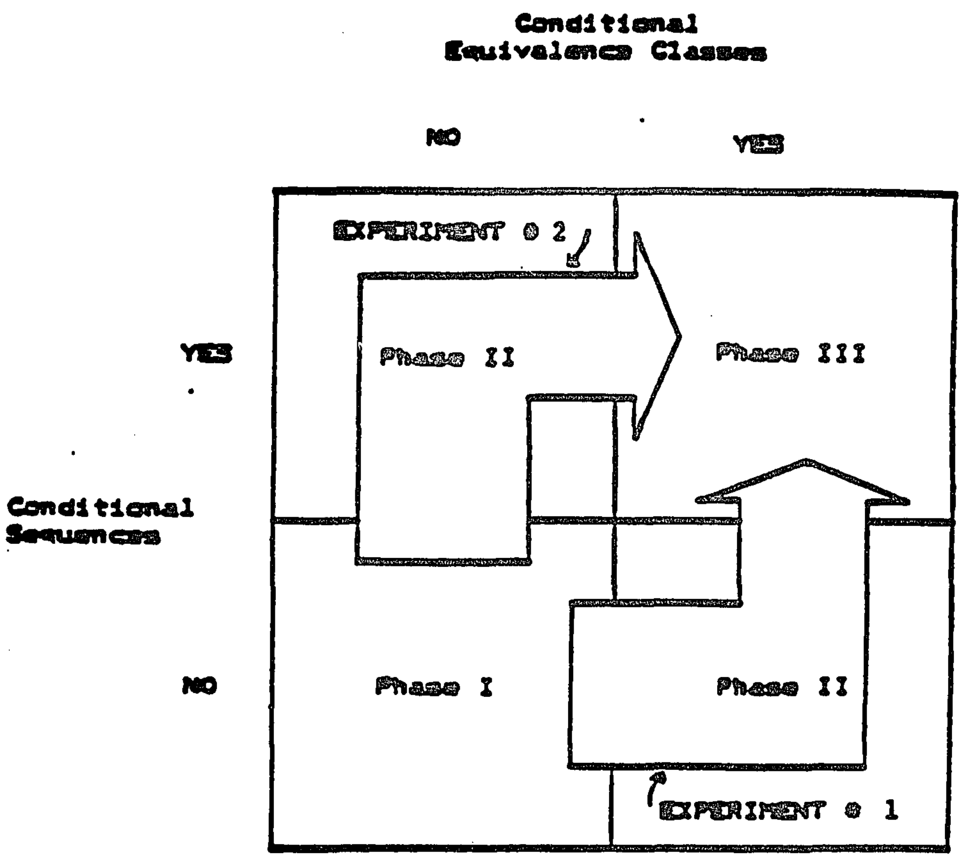


Figure 3

Symbols Presented to Subjects

as Stimulus Material

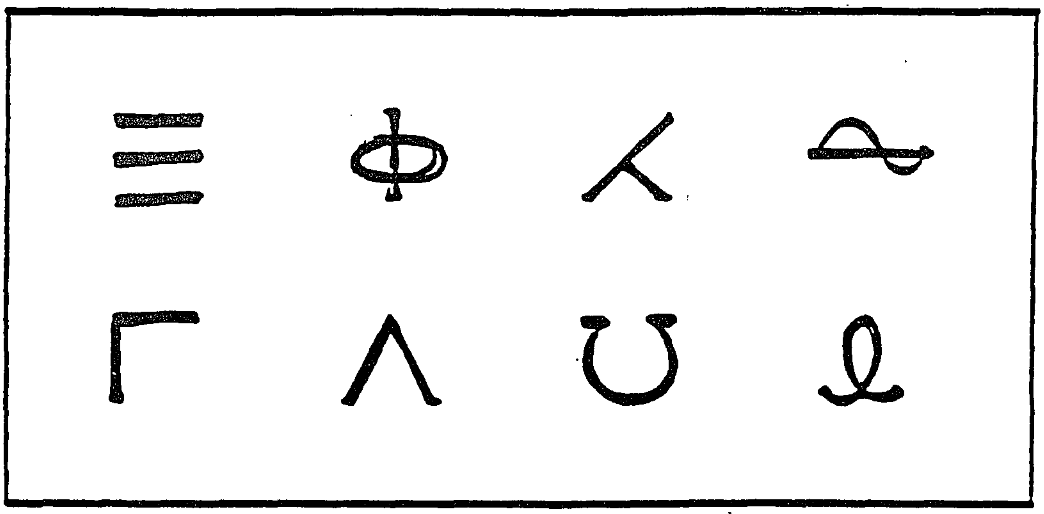
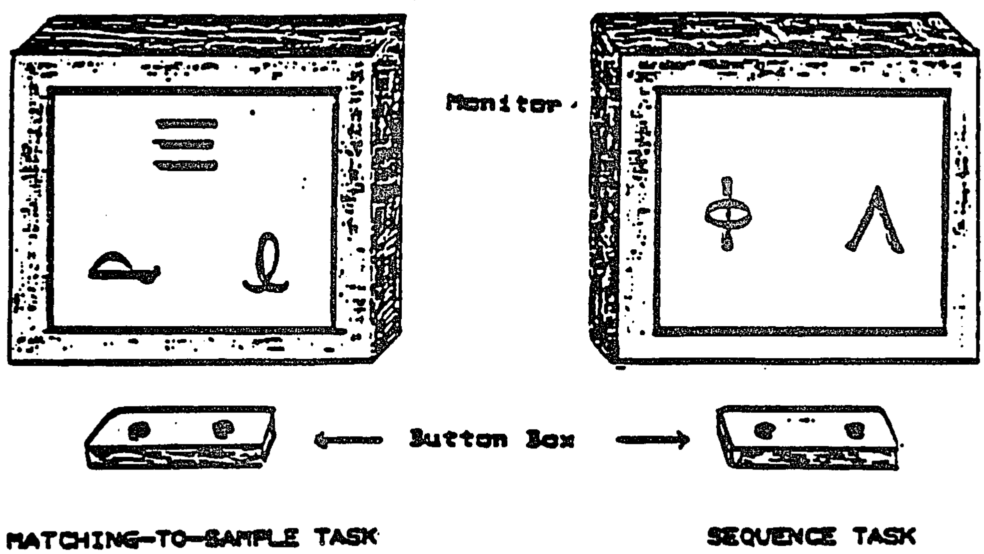


Figure 4

Stimulus Display on the TV Monitor for Matching-to-Sample and Sequence Trials



General Explanation of the Abbreviations Used in Figures 5 to 12

In White Bar Graphs:

MS = Matching-to-Sample Training
STg = Sequence Response Training

Below Polygons:

ST = Sequence Test
RST = Random Sequence Test
ET 1 = Partial Equivalence Test (without C's)
ET 2 = Complete Equivalence Test (all stimuli)

Below black Histograms:

A = A1-A2 Sequences (Symmetry)
B = B1-B2 Sequences (Trained)
C = C1-C2 Sequences (Transitivity)
D = D1-D2 Sequences (Transitivity)

a = Random Sequences with A stimulus (Symmetry)
b = Random Sequences with B stimulus (Trained)
t = Random Sequences with C/D stimuli (Transitivity)

L = Equivalence Test: Trained Relations
S = Equivalence Test: Symmetrical Relations
T = Equivalence Test: Transitive Relations

Figure 5

Subject # 1 (Experiment 1)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Tests

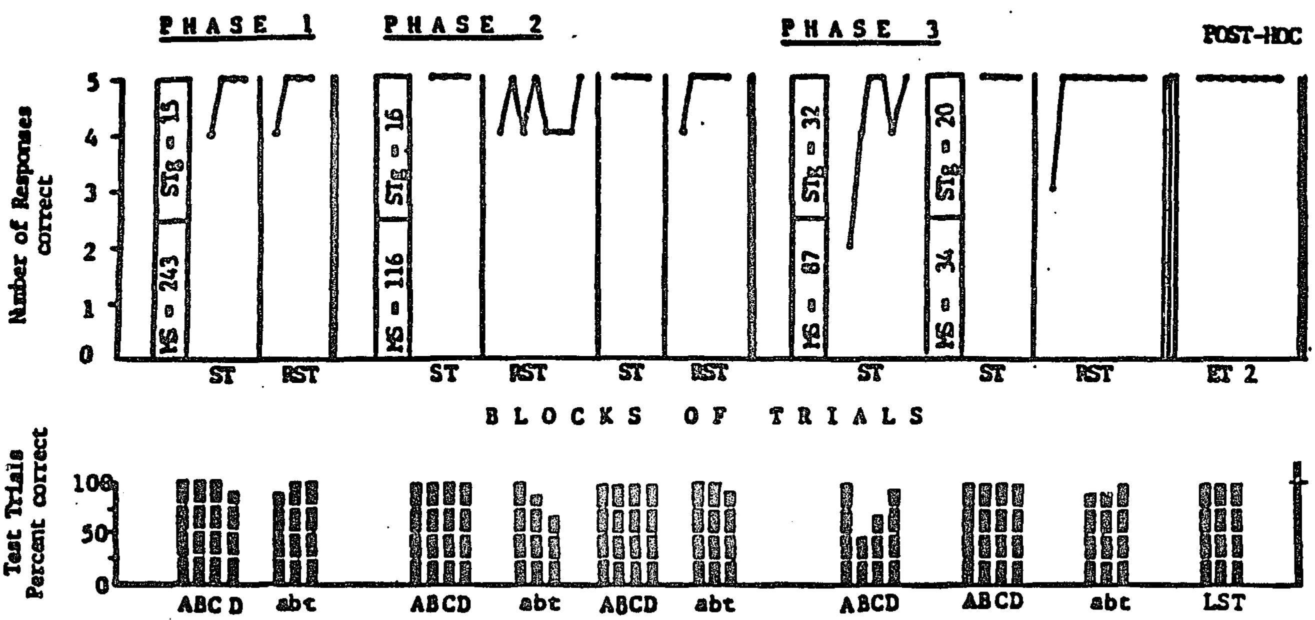


Figure 6

Subject # 2 (Experiment 1)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Tests

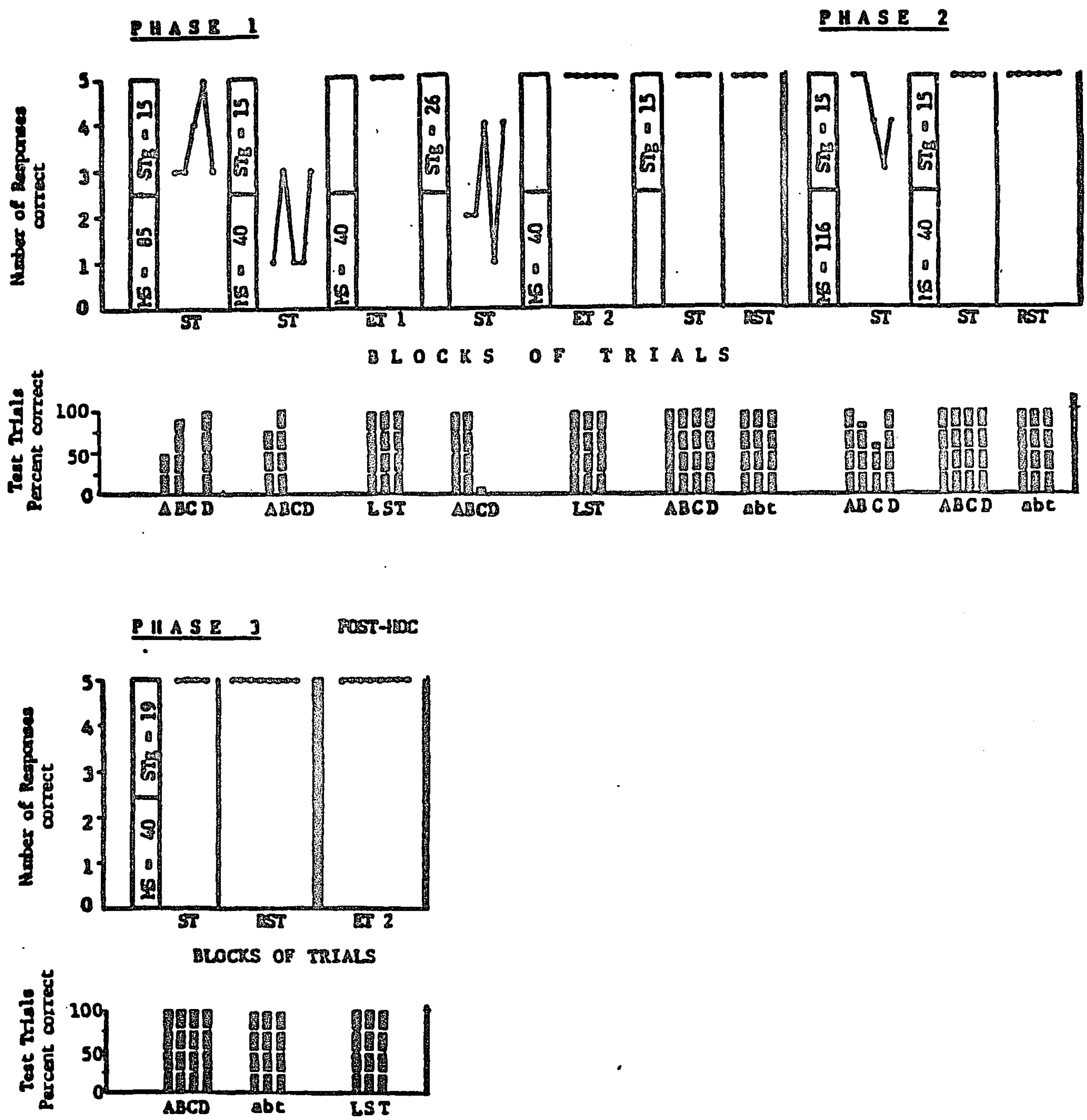


Figure 7

Subject # 3 (Experiment 1)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Tests

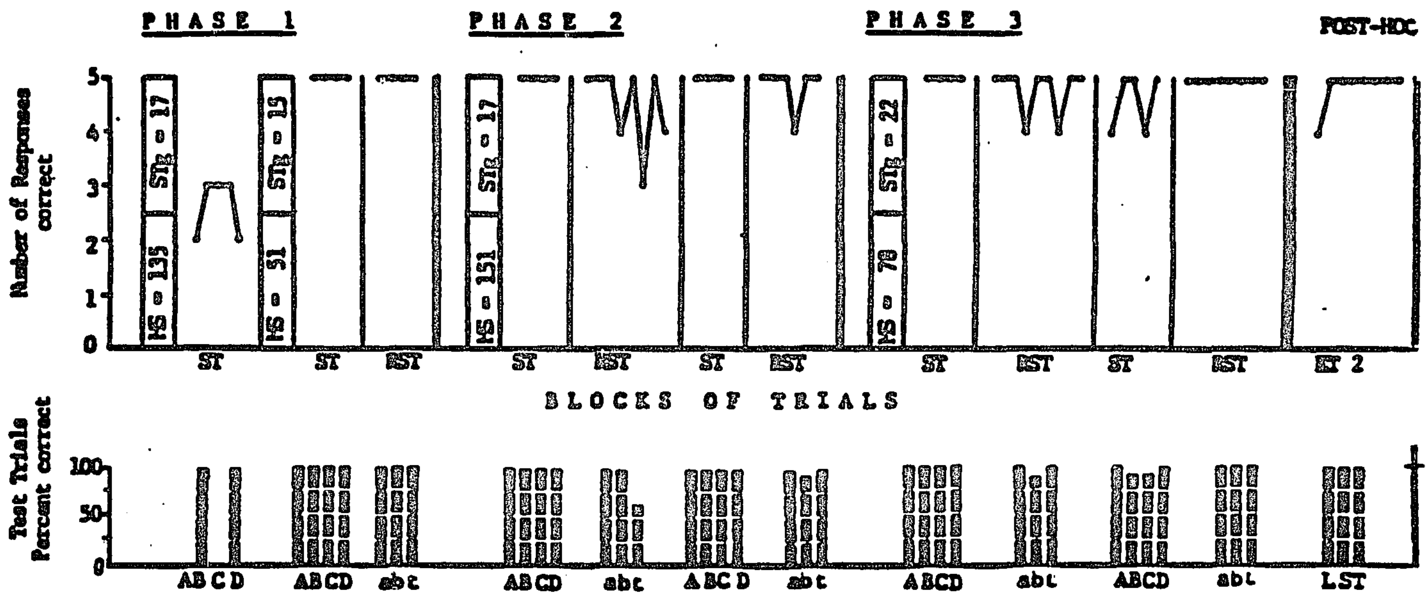


Figure 8

Subject # 4 (Experiment 1)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Tests

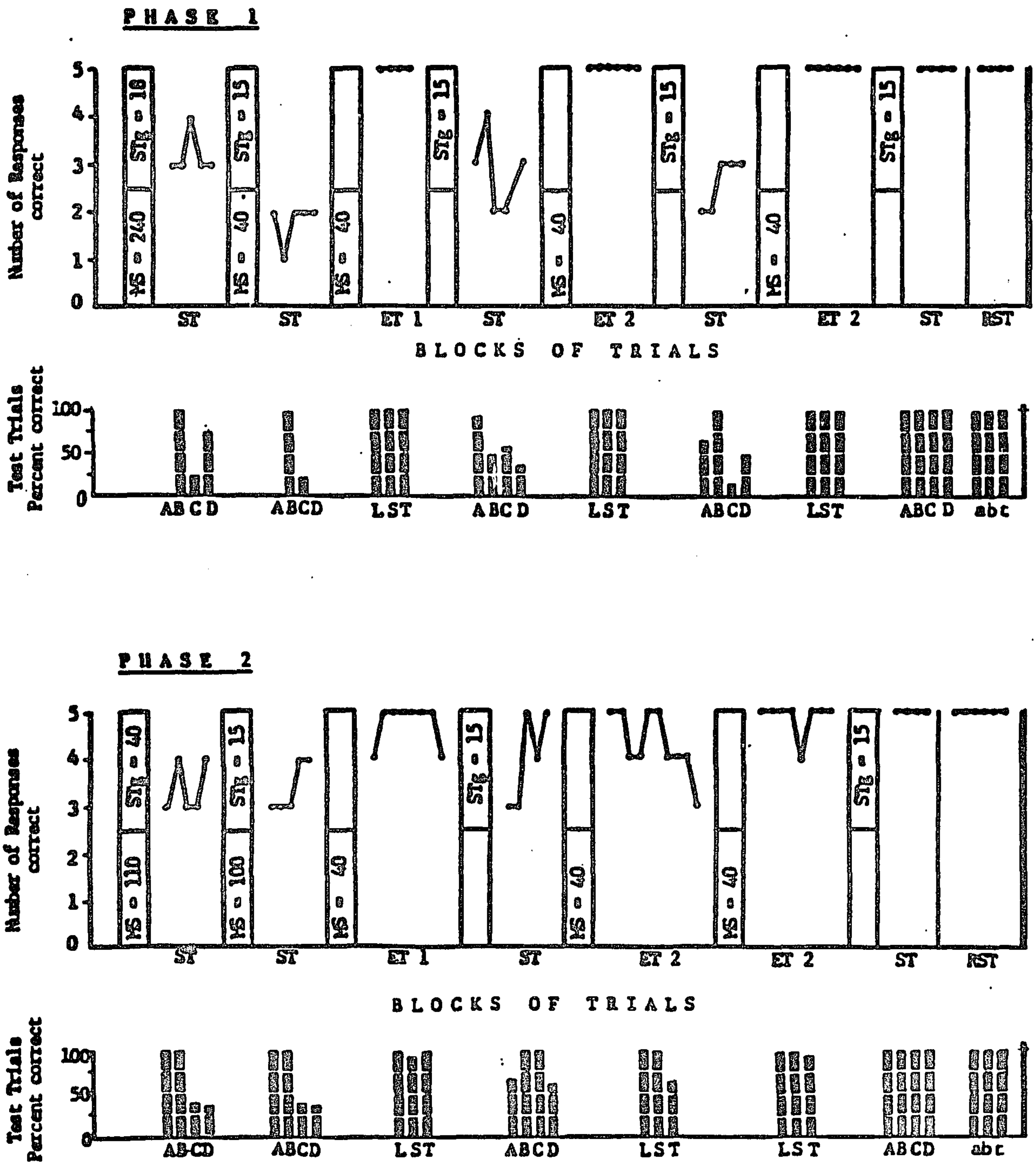


Figure 8 (continued)

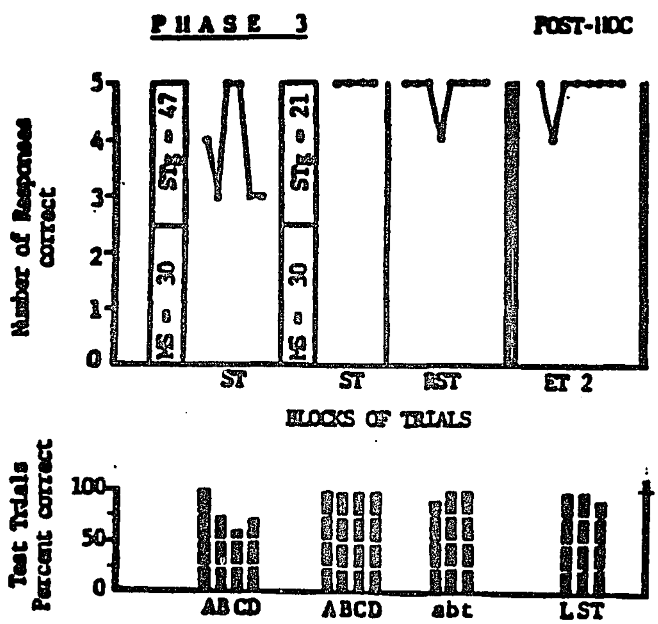


Figure 9

Subject # 5 (Experiment 2)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Tests

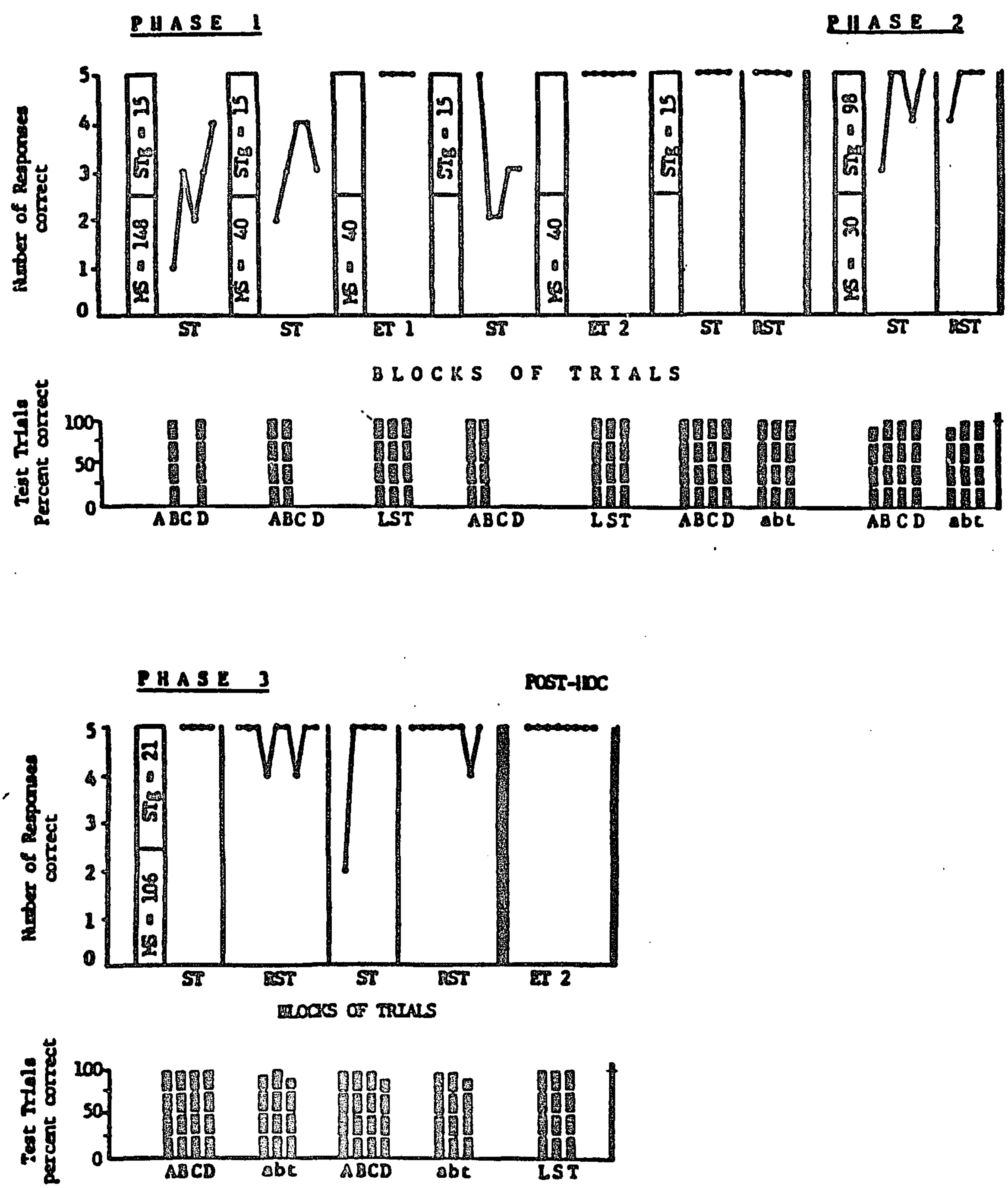


Figure 10

Subject # 6 (Experiment 2)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Tests

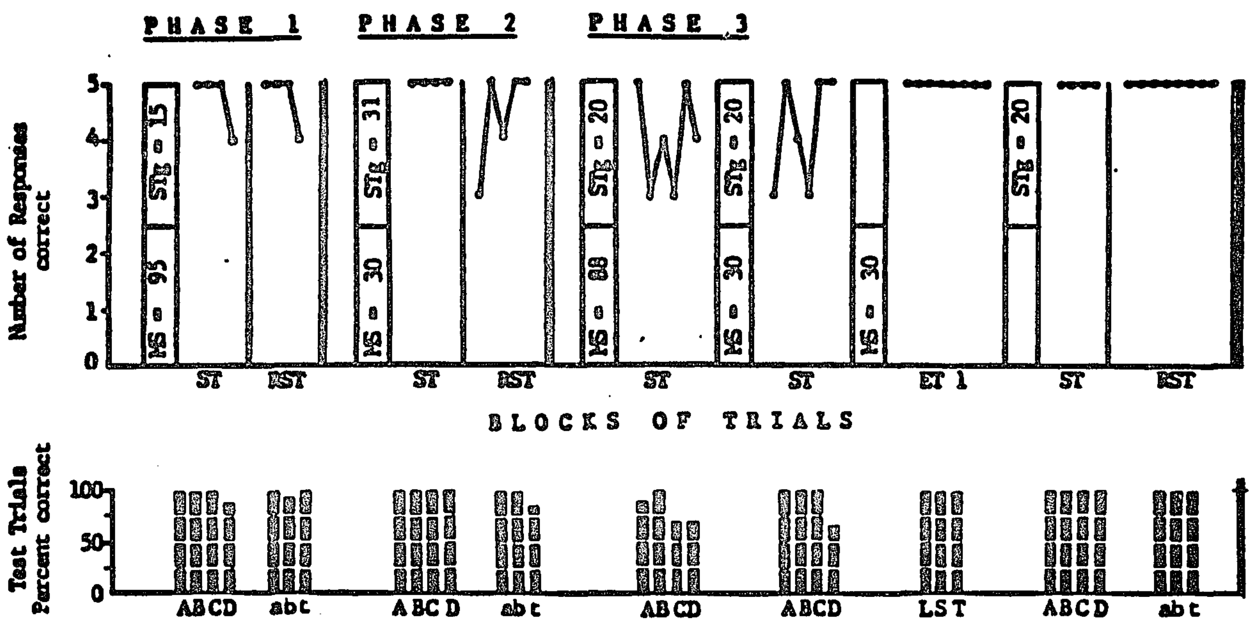


Figure 11

Subject # 7 (Experiment 2)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Tests

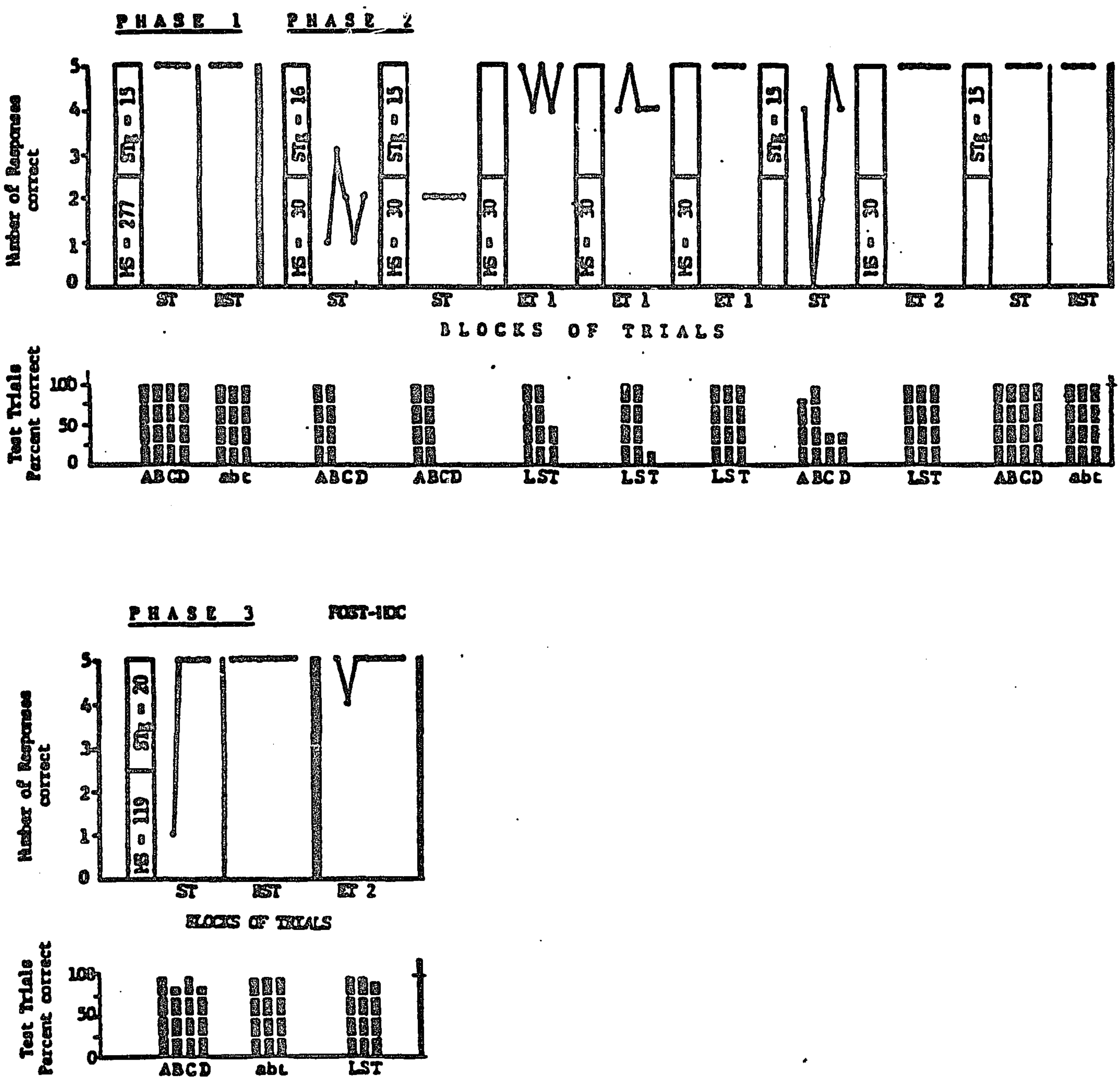


Figure 12

Subject # 8 (Experiment 2)
Performance on Training and Test Trials and Percent of Responses Correct to Trained, Symmetrical, and Transitive Relations on Sequence and Equivalence Test

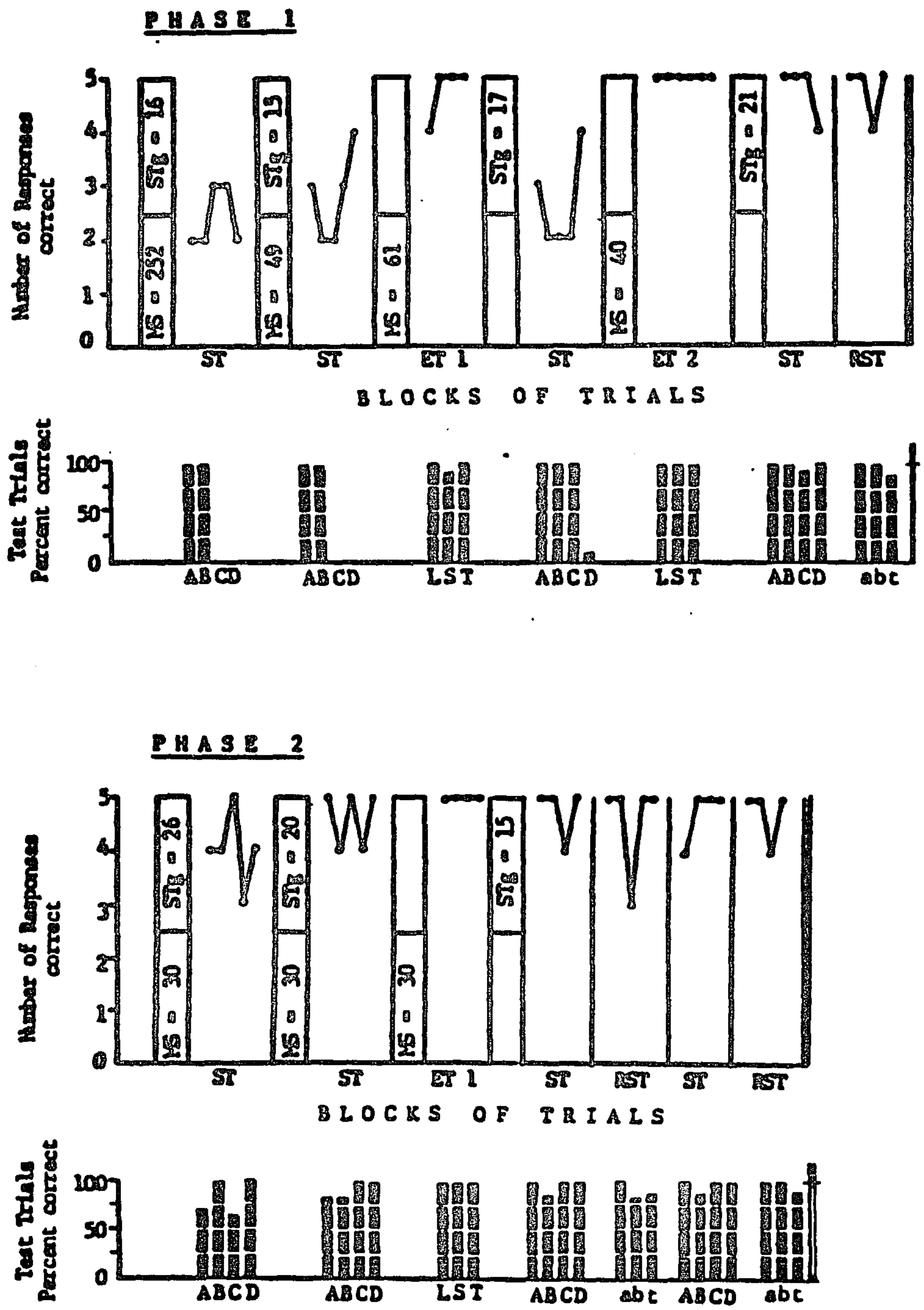


Figure 12 (continued)

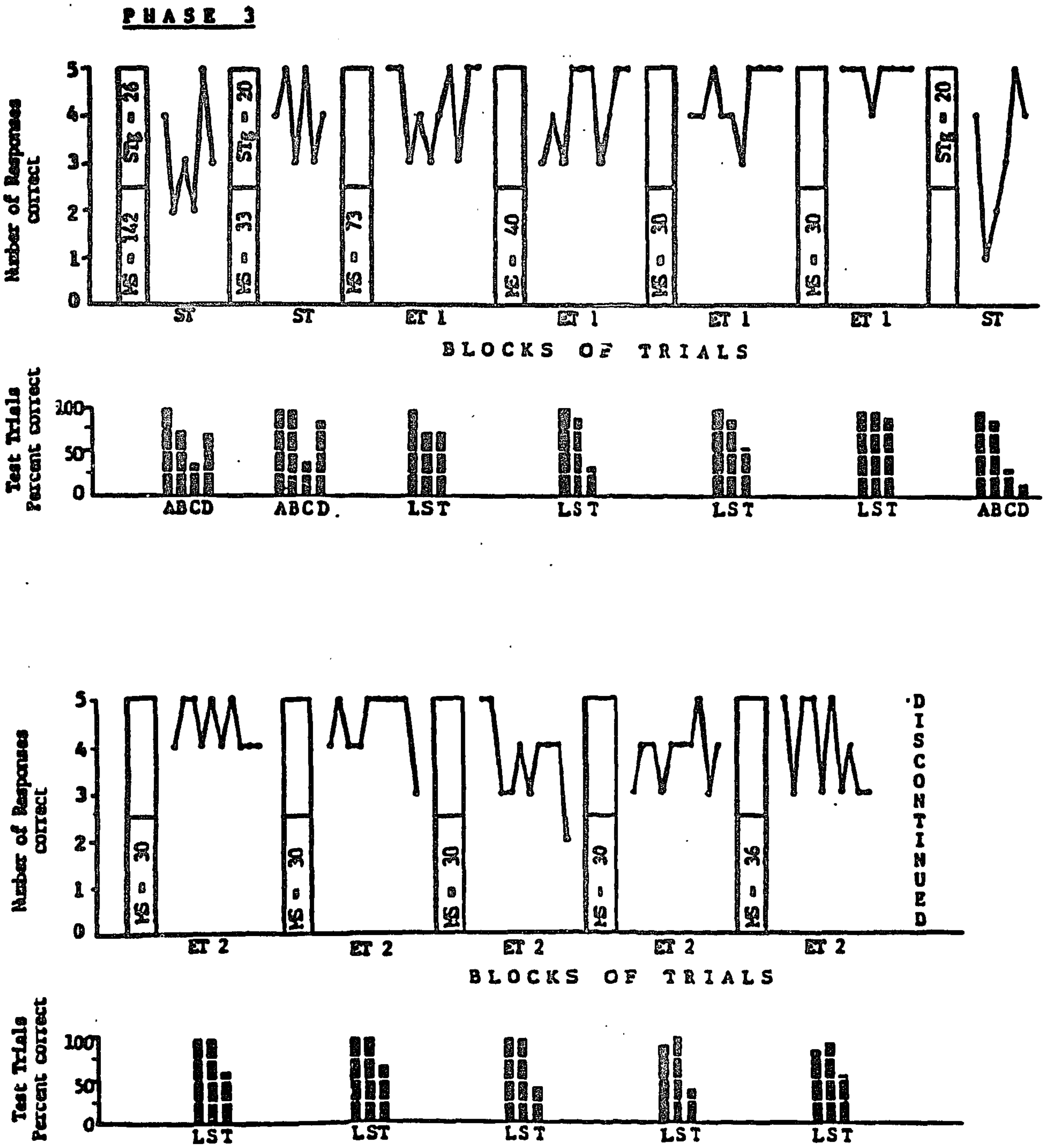
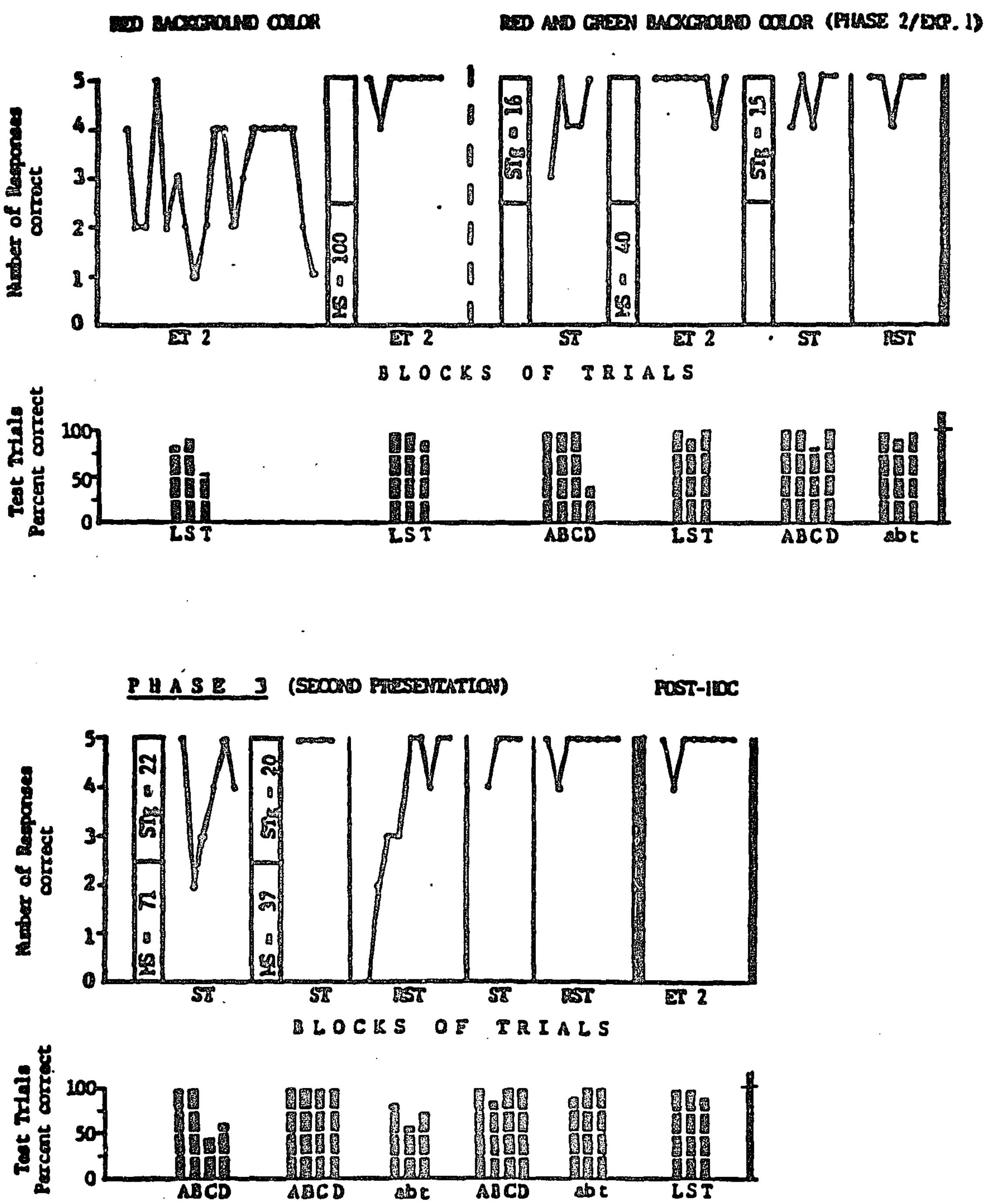


Figure 12 (continued)



APPENDIX C

INSTRUCTIONS

INSTRUCTIONS

This is an experiment in learning; it is not a psychological test of any kind. We are simply interested in certain aspects of learning common to all people.

When the experiment begins, the screen in front of you will show symbols. On some tasks, you will see three symbols: 1 at the top of the screen, and 2 at the bottom. 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 now press the buttons in sequence (left-right or right-left).

On some tasks, the computer will tell you whether your answers are correct or wrong, but on other tasks no feedback will be given. All the tasks are interrelated, and you can solve those without feedback by paying attention during parts in which feedback is provided.

At the beginning, you may find the experiment very easy, and it is tempting not to pay attention. However, the tasks will become progressively more difficult. Therefore it works best to pay attention right from the start. Also, responding impulsively may not work to your advantage.

If you have any questions, please ask them now. The experimenter is not allowed to answer any questions once the experiment has started.