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Simultaneous discrimination and matching-to-sample with numerosity stimuli

Kilchenmann, Silvia, Ph.D.

City University of New York, 1995

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Simultaneous Discrimination and Matching-to-Sample with Numerosity Stimuli

by

Silvia Kilchenmann

A dissertation submitted to the graduate faculty in Psychology in partial
fulfillment of the requirements for the degree of Doctor of Philosophy,
the City University of New York.

1995

This manuscript has been read and accepted for the graduate faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

Oct 27, 1994
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Abstract

Simultaneous Discrimination and Matching-to-Sample with Numerosity Stimuli

by

Silvia Kilchenmann

Advisor: Donald E. Mintz, Ph.D.

Studies of conceptual behavior in pigeons using conditional discrimination procedures have reported differences in rate and the extent to which identity and symbolic relations are learned. This finding is commonly attributed to differences in stimulus discriminability. In the present thesis, pigeons were trained in a series of two-key simultaneous and three-key matching-to-sample procedures. The discriminations were based on elements in the stimulus display. In identity matching, the elements were asterisks. In symbolic matching, solid color symbolic equivalents were used. All non-symbolic stimuli differed in number of elements only. In Experiments 1 and 3, identity-matching and identity-matching with symbolic-matching trials were conducted. In Experiment 2, the discriminability of the stimuli was assessed with simultaneous discriminations. On some trials, stimuli with a novel element type were used, effecting a change in number-related differences between the comparison stimuli. Experiment 3 re-examined the acquisition of a conditional response with the procedure used in Experiment 1, except that symbolic-matching trials were added in each session. The results of Experiment 1 showed that subjects did not learn to match identity although they discriminated between stimuli in a simultaneous discrimination test. In Experiment 2, all subjects discriminated stimuli that differed by as few as two elements. On trials with two element types, birds reinforced for responding to numerically smaller stimuli performed better when the correct response was to the novel element. Birds responding to numerically larger stimuli performed better when the correct response was to the familiar element. In Experiment 3, rate and degree of acquisition differed between symbolic- and identity-matching trials. All birds rapidly learned to match symbolically. Center-key-symbolic matching was accurately learned. Compared to symbolic-matching, the rate of learning to match identity was slower and the extent to which the relationship was learned inferior. These data suggest that unknown differences in processing invoked the observed behavioral differences between the two procedures. Thus, the failure to match identity was a not a function of stimulus discriminability. The differences in rate and extent of acquisition was not due to the number of associations learned.

Acknowledgements

I would like to thank my advisor, Professor Donald Mintz, for his patience. In addition, the remaining members of my dissertation committee, Doctors Sheila Chase, Robert Thompson, Eric Heineman and Peter Balsam all deserve credit.

To the following people I am particularly indebted: Professor Sheila Chase for her friendship and invaluable help, Ellen Breheny for keeping track of all the deadlines, Richard Ruiz for his help with the birds, William H. Swan for his support. Foremost, I am indebted to George O. Guldi, Esq., for lending me his computer for much longer than he thought he would. A special thank you to Elva Victoria and Bob Allard.

Finally, I would like to thank my husband, Doctor Harry E. Hughes, for being himself.

This dissertation is dedicated to all the pigeons who had no choice but to participate.

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General Introduction

Background. The ability to conceptualize, to engage in 'complex' cognitive behavior, is commonly attributed to humans and great apes, although findings reported in a number of studies involving nonprimate subjects--predominantly birds--suggest that depending on their definition, such behaviors may be the rule rather than the exception and may reflect a basic, innate mechanism necessary for experiental information to be processed. More generally, such findings question the extreme constraints on what is considered incontrovertible evidence demonstrating conceptual abilities in animals other than humans.

The reluctance to interpret non-human behaviors as evidencing conceptual thinking is a function of *a priori* assumptions that this ability is an expression of higher mental processes associated with consciousness. Together with perceptions referred to as "feelings," these processes are said to delimit man from other animals (e.g., Premack, 1978), in accordance with the concept of the existence of a hierarchical scale of competencies. Such assumptions are then contradicted when certain behaviors in non-human animals are postulated as evidencing complex cognitive abilities, i.e., when states or abilities assumed to define the highest level of brain development are ascribed to what are considered comparatively simple organisms.

The theory governing a particular conceptualization of the *relationship* among organisms determines the choice of the defining criteria for a behavior. The interpretation of a behavior is foremost determined by its definition, and a comparison of a behavior in different species presupposes an agreement on the definition of the behavior. Definitions of conceptualization which incorporate criteria which themselves represent higher-order processing are expressions of a philosophy which postulates both absolute differences (differences in kind) and relative differences (differences in degree) between human and non-human animals. Absolute differences are established by defining the criteria used as delimiting humans from non-humans, while relative differences are implied in the notion that there exists a uniformity of mechanisms across species including humans.

The interpretation of what constitutes conceptual behavior--its "essence,"--cannot be based on objective criteria. Because such behavior is inferred, its interpretation is with reference to a theoretical framework, a particular philosophy expressed as the arbitrarily chosen criteria used in the definition of that behavior. Hence the assessment of the "essential difference" in a particular behavior--either in degree or in kind--between two species is based on two inferences: the inference concerning the significance of the behavior, already contained in the definition of the behavior, and the inference made about the observed behavior based on the definition. Hence in a comparison of conceptual behavior in different species, the essential difference is largely a matter of semantics.

The particular assessment of differences between organisms which contains a directional judgment such as in "sub-" vs. "non-"primate or "infra-" vs. "non-" human, is fundamental to the philosophy expressed as the "phylogenetic scale," and to definitions of behavior in which both the referent and the direction of the interpretation are presumed. For example, statements such as "...one might expect animal numerical competence to be closer to that of very young humans than that of adult humans" (K.C. Fuson, in Davis and Perusse, 1988) appear thus to be more informative about the nature of the definition used to assess the behavior than about the nature of the behavior.

The notion that there exists a phylogenetic scale emerged from the unlikely union between the tenets inherent in 18th-century classifications of living organisms and the post-Darwinian classification known as the "phylogenetic tree," a concept which represents "a genealogy based on the data of paleontology and comparative morphology" (Hodos and Campbell, 1969). Pre-Darwinian classifications such as Petty's "Scale of Creatures" (in McGrane, 1989, pp. 81-82) were hierarchical, with man on top and a collection of organisms arranged along the scale, with their locations determined by some criterion of similarity with respect to man. As McGrane writes, in such scales "...[space is] already constituted, stratified, immobile, ordered at one end of which, as limit and parameter, stands 'man,' and at the other end, again as limit and parameter, stands the smallest and simplest animal that man can discern." Therefore, "the space on the scale...is not generated by the arranging of one after another of the...creatures but it is already there as common space making juxtaposition and evaluation of appropriateness possible." Hence, within the respective limiting parameters, such scales already contained all "not-yet-discovered" instances of organisms. In the context of modern animal cognition, these classifications are the historical roots of the search for uniformity, the universal relationships connecting living organisms, here not in terms of structural similarity, but of behavioral similarity.

The 18th-century "Scale of Creatures" was a one-dimensional, spatial arrangement of organisms. Organisms had no history. It was in the 19th century that a different dimension, time, "the space opened up by [Lyell's] 'geological time' [in which] Darwin found the room he needed to construct 'evolution'" (McGrane, 1989, p. 91), changed the criterion for the classification of species from "similarity" to "genetic relatedness," reflected in the classification system which came to be known as the "phylogenetic tree." In the wake of these developments, the "scale of creatures" became the "phylogenetic scale."

While it is true that pre-Darwinian classifications were "neither more nor less 'scientific' than the arrangement generated by the 19th century, ...merely guided by different values and governed by a different...system of classification," (McGrane, 1989, p.81), the merger of the two classifications into the "phylogenetic scale" implied a kinship which differed fundamentally from, and at no point coincided with, the kinship expressed in the phylogenetic tree. The distances separating organisms on the uniform, one-dimensional phylogenetic scale--distances which on earlier scales were without reference as to the origin of the differences between organisms--came to imply evolutionary differences.

Herrnstein (1982) proposed that all categorizations have two aspects in common, experience and gaps in experience. The "gaps in experience...are filled in by similarity, which accounts for the recognition of an instance of a class of objects as belonging to a particular class, even if it does not exactly match previously experienced instances." To use the construct of "gaps in experience" as an analogy, on the phylogenetic scale some similarity in behavior was generalized across the "gaps," i.e., across the non-represented members of the category "animals" and chronological distance. Hence, with reference to man, behavioral differences among species came to be interpreted as representing earlier stages in the evolution of that behavior.

With a change in category and criteria, this scale is identical to that found in 19th- to mid-20th-century anthropology (see, e.g., Smith-Bowen, 1964), where absolute differences between cultures had become relative differences, and different cultures were viewed as representing "stages...through which our own ancestors passed long ago" (Taylor, cited in McGrane, 1989, p.93.)

Sharing with anthropology a primary interest in the human species, psychology traditionally studied non-human animals in terms of models for human behavior, based on the premise that the mechanisms studied are similar, although greatly reduced in complexity in non-human animals; that there exists a "smooth continuity between living animal forms, rather than the discontinuities implicit in the theory of evolution as a result of the divergence of evolutionary lines and the extinction of many intermediate forms. This continuity, which Lovejoy called 'the principle of unilinear gradation,'...[was a principle subscribed to by the early behaviorists such as]...Harlow, who speculated that 'simple as well as complex learning problems might be arranged into an orderly classification in terms of difficulty, and [that] the capabilities of animals on these tasks would correspond roughly to their positions on the phylogenetic scale.'" (Hodos and Campbell, 1969). Similarly, D.A. Lieberman (1993, p. 31), in a textbook on learning asserts that "humans are unique...[but]...because humans and other species have shared millions of years of evolution in common...it would be surprising if they were not similar in important respects". Lieberman thus echoed Herrnstein's (1982) view that "whatever a pigeon does easily must be reckoned neurophysiologically simple compared to higher mammals, whatever a pigeon does easily must be reckoned elementary."

By definition, implicit in the belief that there exists such a uniformity is the assumption that differences in behavior between species are shared differences. To illustrate, relativity judgments such as "taller" or "shorter" are based on the difference between two objects. The essential difference between the two is not directly observable and is not contained in either object but rather, is shared by both. Interpreting observed differences in behaviors as exemplifying "gradations in complexity" presumes not only shared differences in basic physiological processes such as innate categorizations, but also that the integration of the activity of these processes--the observed behavior--

proceeds in a homologous fashion across species. The nature of the observed differences then becomes a difference in degree rather than in kind. Thorndike (quoted in Bitterman, 1965) best exemplified this view when stating: "If my analysis is true, the evolution of behavior is a rather simple matter. Formally the crab, fish, turtle, dog, cat, monkey and baby have very similar intellects and characters. All are systems of connections subject to change by the laws of exercise and effect."

The assumption that all learning mechanisms could be described by a set of universal laws was challenged notably by Breland and Breland (1961). Using traditional operant conditioning procedures to teach a range of species various tasks, Breland and Breland noticed that the initially readily conditioned behaviors deteriorated over time, "drifting into behaviors that are entirely different from those which were conditioned, ...behaviors [which are] clear-cut examples of instinctive behaviors having to do with the natural food getting behaviors of the particular species." Such species- specific differences, in this instance in associability of stimuli observed in conditioning tasks, came to be known as "biological constraints." The authors cautioned that "the behavior of any species cannot be adequately understood, predicted, or controlled without knowledge of its instinctive patterns, evolutionary history, and ecological niche."

Constraints on learning were subsequently reported in a number of investigations (reviewed, e.g., by Seligman, 1970; Rozin and Kalat, 1971; Domjan and Galef, 1983), contradicting the principle of "equivalence of association" (Seligman, 1970), the basic tenet of the general process theory of learning. In pigeons, such constraints were most evident in attempts of conditioning key pecking to reinforcers other than food (reviewed by Delius, 1983). The interest in constraint concepts, however, was not long-lived. Domjan and Galef (1983) suggest that the reason for the failure of such phenomena to effect fundamental changes in the study of animal learning was their failure to lead "to a successful theoretical framework for systematizing knowledge about constraint phenomena." If so, the abandonment of such studies appears rather unnecessary in light of some critics' charges that comparative psychology in general "never generated any theories or even broad points of view" (Beach, 1950). It seems likely, however, that with the recent interest in more complex forms of learning, interest in "constraints" on learning will resurface.

Animal Cognition. The interest in animal cognition, relatively dormant since Kohler's (1925) "insight" experiments with chimpanzees and Tolman's (1948) work on cognitive maps in rats, gradually gained new impetus from naturalistic studies reporting behaviors which suggested complex cognitive abilities. For example, observational learning as well as foraging-related tool use were reported for a variety of species (reviewed in Morse, 1980). In the present context, of particular interest were reports on the acquisition of cryptic prey recognition in jays and chaffinches (de Ruiter, 1952) and great tits (Kettlewell, 1955; Tinbergen 1960, Royama, 1970), learning abilities which were also demonstrated experimentally in blue jays (Pietrewicz and Kamil, 1977, 1979). Such foragers are said to form a "searching image" (Tinbergen, 1970) for the prey species after the first few encounters with it, seemingly exhibiting behaviors which in psychology are subsumed under the term "concept formation."

Such specific learning is well described by what Mayr (1974) called "open" behavior programs, that is, "genetic programs which allow for additional input during the lifespan of its owner." In addition to searching-image formation, such relatively restricted learning is evident in the process of imprinting reviewed by Hinde (1966). The defining feature of such programs is their relative specificity for the type of information which can be learned; that is, certain information is more readily assimilated than other information. For example, the flexibility of such a program governing feeding strategies should vary as a function of degree of specialization and amount of learning required, and should increase with decreased specialization.

Marler (1970) provided a conceptual framework for such restricted learning by explaining the mechanisms underlying song-acquisition in white-crowned sparrows in terms of "template-matching." This construct refers to the process by which particular experiental information is assimilated by matching the defining features against some previously stored, or innate standard in a neural substrate. These substrates are the physiological mechanisms for innate (primary) categorizations, for behavioral tendencies readily identified with a particular adaptive advantage conveyed. It is probably unlikely that the principle governing the basic neural organization of such processes differs radically from that permitting categorizations conventionally associated with conceptual abilities. However, the way that sensory information is integrated by such processes is likely to differ across species.

In a landmark study, Herrnstein and Loveland (1964) combined operant conditioning procedures with "naturalistic" stimuli, training pigeons to detect human beings in photographs. All birds rapidly learned the concept "people," establishing that conceptual behavior was not restricted to higher primates. The general finding was confirmed in a host of studies employing a variety of experimental procedures and stimuli, such as, e.g., photographs of people (Siegel and Honig, 1970), pigeons (Poole and Lander, 1971), man-made vs. non- man-made objects (Lubow, 1974), trees (Herrnstein, Loveland and Cable, 1976), oak-tree leaves (Cerella, 1979), water (Herrnstein, 1979), and fish (Herrnstein and de Villiers, 1980).

The findings suggested the ability to conceptualize across a variety of "naturalistic" stimuli to be rather general--at least in birds. However, the observed rapid acquisition of the concepts disagreed with expectations based on the general process theory of learning that initial chance performance is followed by a relatively gradual increase in proficiency. Herrnstein and Loveland (1964) cautioned that such performances might not represent true evidence of concept formation but rather indicated that the subjects had entered the experimental situation with the concept already formed. This left open questions concerning the "essence" or nature of the purported innate classification system permitting such performances or, if the behaviors were somehow learned prior to the task, how all birds acquired a similar level of discrimination of the various stimuli in the absence of reinforcement. The number and disparity of concepts birds have been able to learn seems to suggest not so much a pre- existence of particular concepts as it seems to suggest the presence of a neural organization permitting the abstraction of the relevant information contained in the stimuli presented. The nature of the abstracted information--the pigeons' concept of "our" concept--is not known.

When Is A Concept A Concept? In a relatively simple organism, the external world is represented as a collection of few, largely innate, concepts. External signals that provide information crucial to survival are integrated and, if some threshold is exceeded, elicit an appropriate response. The responses indicate the organism's knowledge about the world, its "innate quality space" (Herrnstein, 1982), the "representation of invariances" which define its "world space" (Staddon, 1983). According to Staddon, "a tick, equipped with a genetically programed set of preferences, changes its location both in the real world and in its world space when moving. Any environment the tick finds itself in is a point in such an internal space. The internal representation itself solves the problem of recognition: since the space is defined by just those physical dimensions that are important to the animal, the location of the representation in its world space constitutes 'recognition' of a particular situation." In Herrnstein's (1982) view, "the innate quality space is the crux of all ontogenetic theories of categorization, because it provides the matrix within which experience is stored and it provides the proximities to explain generalization."

Whether or not non-human animals "have a concept" or can "form a concept" appears to be largely a matter of semantics, that is, depends on the definition of the term "concept." For example, concerning the concept of number Davis and Perusse (1988) suggest that the term "counting" apply exclusively to the expression of "numerical discrimination in which formal enumeration (i.e, counting in the human sense) has been observed," and the term "numerical competence" be reserved for a possible animal analog, because although "...nonhuman animals are capable of various forms of numerical competence...there is no evidence to suggest that animals have exhibited a sense of number." Their conclusion leads the authors to question more generally the "natural utility" for such a concept in non-human animals (although the authors do not suggest its natural utility for humans).

"Counting in the human sense" is not universally practiced by humans: the anthropologist Richard Lee (1979, p.230) notes that "the art of counting is not well developed among the !Kung. The numbers from 1 to 10 are represented by the 10 fingers or by numbers derived from them (e.g., the number six is 'hand plus one'). Numbers over 10 are usually covered by the word 'many'...." Similarly, in their review on numerical competence, Thomas and Lorden (1993) cite a report describing cultures where quantities greater than four are expressed by the terms "many" or "countless," and O'Hanlon (1988) claims that the "entire mathematical notation [of the Yanomami culture] consists of one, two and more than two. Three ones meant more than two."

Davis and Perusse's (1988) rejection of the evidence for a number concept in non-humans is a function of their definition of the concept of number. In their definition, the concept itself is defined exclusively by the expression of one of two proposed sub-categories which in turn is associated with one of four "key-processes." While, according to the authors, the sum of these processes defines "numerical competence," it does not define the concept of number. The sub-category which is indicative of the concept is defined by "number manipulation," that is, generalization and discrimination behaviors specific to the what the authors view as the most advanced process. Behaviors subsumed under the category "numerical competence," are therefore not conceptual in nature. By this definition of conceptualization only humans (strictly, only individuals) can be shown to "have" a concept of number. That is, such a concept exists--and only potentially so--at the level of only one--the human--species.

Such a definition is "species-specific," so to speak. With reference to the concept of number, the criterion defining the concept is a process assumed to be universal in humans, and assumed to represent the most advanced of all possible alternate instances of such a process. In the case of formal enumeration, defining a concept by a process which depends on extensive, specialized instruction, i.e., on a specific history while excluding all related behaviors, is not unlike declaring asymptotic performances in a typical learning task as being governed by processes differing qualitatively from processes governing acquisition.

Judging from the seeming absence of formal enumeration in human societies lacking an apparent need for it, by this definition no non-human animal will prove to "have" a concept for number. Davis and Perusse, appreciating the implications of their definition suggest that human findings should be considered in the light of "...the 'more-capacity-than-meets- the-eye' hypothesis of Gelman and Gallistel," but do not think such leniency to be appropriate for other animals: "...we suggest that [the use of the hypothesis] with nonhuman subjects be tempered by rigorous controls for alternative, non-numerical mechanisms," although it would seem to be difficult to compare behaviors analyzed at different levels.

Applying the same rigorous controls to human subjects would most likely show explanations in terms of non-numerical mechanisms to be sufficient in explaining human behavior as well. While depending on the level of analysis virtually all behaviors are amenable to explanations in terms of the simple contingencies controlling them, it seems rather unlikely that complex cognitive behaviors are directly comparable across species.

An example of a traditional behavioristic analysis of behavior is Epstein, Lanza and Skinner's (1981) interpretation of the data they collected in an experiment which showed that pigeons could use mirrors to detect and peck at not directly visible spots painted on their chests. With this study the authors attempted to demonstrate that what appear to be complex behaviors can be explained in terms of simple stimulus relationships as opposed to invoking "higher mental processes" such as, in this case, a concept of "self." The study and its interpretation of the observed behaviors was in response to inferences Gallup (1970) drew from his observations of chimpanzees who, when tested with mirrors, touched a spot which (under anesthesia) had been painted on their forehead, behaviors Gallup considered indicative of a concept of "self." Epstein, Lanza and Skinner (1981), objecting to this "mentalistic" interpretation, asserted that "...[the chimps] should have had many opportunities [during pretest exposure] to discover the contingencies that govern mirror use" and that an explanation in terms of environmental events was sufficient to account for the behaviors of both chimps and pigeons.

While the pigeons were taught how to use mirrors, the chimpanzees were not, and the--perhaps elusive--concept of "familiarity with the contingencies of mirror-use" does not readily explain why all subjects touched the spot on their foreheads (rather than the reflections in the mirrors, for example), since familiarity with the contingencies governing mirror-use alone is independent of self-recognition. The independence of these two concepts is demonstrated by the complete absence of such self-directed behaviors in Gallup's repetition of the experiment with macaques as subjects, assuming that during pretest exposure to the mirrors, the macaques, like the chimpanzees, habituated to the novel stimuli--the mirrors themselves and the reflections they provided.

While familiarization with the features associated with the reflected stimulus (the chimpanzee's face) during pretesting can explain subsequent discrimination between that particular countenance and other countenances, this notion alone does not satisfactorily explain how a change in that stimulus (the addition of the spot on the forehead) in the absence of some type of comprehension of "self" would result in the observed self-directed behaviors. The "contingencies governing mirror-use," presumably discovered by chimpanzees during pretesting and learned rapidly by pigeons during training, were readily recognized during testing. This seems to indicate that--if nothing else--pigeons and chimpanzees, but not macaques, came to the experimental situation with the "mirror-concept" already formed. While mirror-use may not be a result of natural selection, the cognitive processes governing whether an animal is capable of recognizing such a contingency is; in this instance, an explanation of behavior purely in terms of environmental events does not fully account for the observed behaviors.

In an experimental situation, contrary to the requirement placed on non-human animals, people are not naive subjects. They have a long history of learning to classify and categorize, both formally through language acquisition and schooling, and informally through observation and imitation. While humans appear largely to share a similar perception of the physical world, there are nevertheless real differences in the extent of categorization and differentiation within particular categories, differences generally attributable to the relevance the category has for individuals adapted to a particular environment or way of life.

Eskimos, for example, are said to differentiate the category "snow" into a multitude of subcategories, while inhabitants of temperate zones recognize only few. If a typical concept-formation task of the type used with birds were designed by Eskimos, Eskimos would likely show performances indicative of a pre-task existence of the concept and, almost as likely, non-Eskimos would be judged to have not much of an ability to conceptualize.

The important aspect of categorizations such as that exhibited by Eskimos is that although differences in the texture of snow might be sufficient to allow a non-Eskimo to learn to identify the subcategories, a classification based solely on this dimension would prove to be deficient in some important dimensions, namely, the host of specific values of the attributes associated with each instance such as altitude, temperature, local environment, etc. A certain type of snow may be associated with certain expectancies about the conditions associated with it, which may "elicit" some behaviors (such as hunting) and "inhibit" others (such as fishing), meaning that certain responses are incompatible with one, while eminently compatible with a different, particular subcategory.

Similarly, conceptualization behaviors observed in non-humans likely result from the integration of various processes, and the integration specific to a particular species is the outcome of its evolutionary history. While in different species a number of the processes involved in the acquisition of a particular conceptualization may well be similar, others contributing to the integration of information will not be. Hence judgments of what constitute similar instances of a learned relationship will most likely be different for different species.

While basic learning principles can largely explain generalities underlying the acquisition and extinction of a response across different species, conceptualization behaviors are reflections of a species's experience of, and interaction with, its perceived world. There are likely substantial qualitative differences in the processes involved in the integration of particular experiences among different species and the relationship between some (to humans) seemingly related categories may be unintelligible (because non-existent) to a non-human animal. Even at the level of stimulus recognition it is, as Hinde (cited in Herrnstein, 1982) pointed out, "...important to remember that the 'characters' of the stimulus situation studied may be only artificial abstraction of the experimenter; the animal may abstract differently."

The difficulties inherent in comparing conceptual behaviors across species led Davis & Perusse (1988) to propose that cross-modal transfer exclusively be used to test for such behaviors. This suggestion, as an expression of the notions outlined above, presumes both an equivalence in primary categorization across species and an equivalence in the processes which govern cross-modal transfer. If such processes are different among comparison species, the observed behavior is discontinuous and thus unintelligible even if a superficial resemblance exists. The literature on behavioral constraints strongly suggests, that such uniformity does not exist for complex behaviors.

While the addition of the criterion of cross-modal transfer was suggested to standardize the definition for conceptual behavior, the effect is quite the reverse: the difficulties in determining species-specific differences in the ability to demonstrate a learned behavior via a different modality renders such a test not very useful across species.

The criteria for conceptualization in more general definitions are generalization and discrimination behavior: "generalization within classes and discrimination between classes...is the essence of concepts" (Keller-Schoenfeld, 1950), and "generalization...tells us about the dimensions of a creature's experience, hence about its categories" (Herrnstein, 1982). Similarly, Malott and Siddall (1972) define a behavior as conceptual when the same response is emitted to all members of a given stimulus class. Conceptualization then is the expression of both simple and complex categorization behaviors, such as a) insertion of new information into an existing concept (enlarging a class), b) formation of subcategories within a concept (discrimination between classes of stimuli) and c) formation of new concepts (associating superordinate relationships between concepts). All such behaviors presuppose some existent organizational framework (some innate substrate, i.e., concept) which has the potential to change as a result of experience. The degree of conceptualization depends on the flexibility, or "openness," of the substrates, and studies in concept formation can be said to assess the flexibility of such innate categorization schemes.

What Is Learned? Conditional discrimination learning in birds has been extensively studied by means of matching-to-sample procedures. A number of models were developed to account for the behaviors observed. As evident from the literature discussed below, the analyses of behavior furnished by such models frequently are "procedure specific." This is particularly apparent when considering the behavioral differences effected by different transfer testing procedures.

In "standard" matching-to-sample procedures, the subject is generally--either successively or simultaneously--presented with a stimulus sample and two choice stimuli of which one matches the sample. In an identity-matching procedure, a response to the matching choice key, and in oddity learning a response to the non-matching choice key is reinforced. The objective in such studies is to assess the subject's ability to conceptualize "sameness" (a concept frequently used interchangeably with "identity") or conversely, "difference," assessed by oddity from sample procedures. Such studies generally employ arbitrary rather than "naturalistic" stimuli such as hues (e.g., Cumming and Berryman, 1961, 1965; Farthing and Opuda, 1974; Urcuioli and Nevin, 1975), lines (e.g., Santi, 1982, Carter and Werner, 1978), and shapes (Delius, 1978, 1982, 1988), primarily because such stimuli are more readily operationally defined. The assessment of conceptualization is accomplished by replacing one or more of the familiar training stimuli with novel stimuli. A subject is said to have learned the concept when the previously learned response is transferred to the novel stimuli, i.e., it is said to exhibit "single-rule" or "concept" learning. According to Carter and Werner (1978) "...both matching and oddity performances may be viewed as instances of behavior governed by a single rule, provided that it can be shown empirically that the subject continues to match or to choose the odd stimulus in accordance with previous training, even though the stimuli used are being presented for the first time."

In addition to the single rule model of learning, the configuration model and the multiple rule model were advanced to account for behaviors observed in conditional discrimination learning procedures. The configuration model proposes "that all aspects of the stimulus situation, or configuration, that can be detected by the subject exert some control over the discriminative response" (Carter and Werner, 1978). For example, in a traditional matching-to-sample procedure, animals "learn a group of three-key discriminations" (Pisacreta, Redwood, and Witt, 1984). Of the three models, configuration learning received the least empirical support, questioned, for example, by findings which showed that in transfer tests the addition of a novel stimulus did not result in a discrimination decrement on trials with the familiar stimuli (e.g., Cumming and Berryman, 1961).

The multiple rule model of learning proposes that animals learn a set of "if...then" rules (Carter and Werner, 1978), i.e., a set of two component chains (Pisacreta, Redwood and Witt, 1984). Also referred to as "response chain learning" (Zentall and Hogan, 1974), this model received support particularly from early studies which used three key matching-to-sample procedures with few training stimuli and transfer tests where, generally, the familiar stimuli were presented together with the novel test stimuli (e.g., Cumming and Berryman, 1961, 1965). According to this model, since the associations learned are specific to the stimuli presented on individual trials, they cannot be transferred to novel stimuli. Hence failure of transfer of a learned conditional discrimination is taken as evidence that multiple rules but not the more general relationship among the stimuli are learned.

In their influential study, Cumming and Berryman (1961) trained pigeons on three different hues. The sample was either green, blue or red. One of the comparison stimuli displayed the matching color while the alternate comparison displayed either of the other two colors. After the conditional discrimination was learned, the blue stimulus was replaced with a novel, yellow hue. While this change did not affect the birds' performances in the presence of red and green samples where the incorrect response was to the novel stimulus, performances were at chance levels in the presence of the yellow sample where the correct response was to the novel stimulus.

Cumming and Berryman interpreted their findings to indicate that "training to match red, green, and blue stimuli had not resulted in the formation of a 'matching' concept applicable to novel stimuli; or, stated in another way, the birds had not learned that the 'odd' hue was S delta," i.e., should always be avoided. Instead, the birds appeared to have learned a set of specific "if...then" rules which were not applicable to the new situation. These investigators further observed that during initial training, in the presence of the novel sample the birds reverted to pronounced position preferences rather than color preferences, i.e., responses were as likely to the familiar comparison as to the novel comparison. This preference "begins to disappear at about the same time the matching performance starts to develop. At this time all subjects showed some tendency to exhibit color preferences."

This finding is interesting, since position preferences generally are found to precede stimulus preferences in the ontogeny of matching behavior (Carter and Werner, 1978). Referring to Cumming and Berryman's (1961) data, Carter and Werner suggest that in the transfer test, the observed continued accurate matching behavior to the familiar stimuli while performances on the novel hue dropped to chance levels indicates that "matching to sample is also best described by a set of sample-specific S-delta rules." According to Carter and Werner, in a matching-to-oddity procedure, the birds "might learn the rule [for example] after pecking red on the center key, avoid pecking red on the side keys. The sample is assumed to serve as a cue designating which of the comparison stimuli is S-delta." Hence, in a matching-to-sample procedure the non-matching comparison is avoided.

A similar conclusion was reached by Farthing and Opuda (1974), who trained birds on a three-key matching-to-sample task with three hues (red, green and blue) and three forms (cross, triangle, circle). One-half of the birds were first trained on hues and the remaining birds on forms. After the discrimination was learned, the tasks were switched between the two groups. Farthing and Opuda found that on initial training, forms were learned with greater difficulty than hues, and the group matching hues showed significant position- and color-preferences, while the group matching forms did not show a preference for either form. When pooling responses for the first six transfer sessions, both groups performed better than the group with no prior matching training. Although this observation suggests that their birds had learned a generalized rule to some extent, Farthing and Opuda concluded that based on performances on the first transfer session which differed not significantly from chance levels, "...the pigeons learn a set of specific stimulus-response chains, rather than a general matching concept or a set of discriminations based on specific stimulus configurations."

These conclusions regarding pigeons' abilities to conceptualize, based on a small number of studies representing only a small number of procedures were challenged, among others, by Zentall and Hogan (1974) who investigated transfer of a conditional hue discrimination by replacing all familiar training stimuli differing in brightness with novel color stimuli and found evidence of single rule learning, i.e., that the birds had conceptualized the more general relationship among the stimuli. Zentall and Hogan suggested that the absence of transfer of the learned stimulus relationship observed by Cumming and Berryman was the result of a novelty effect, evidenced by the fact that the performances were disrupted only when the sample was novel and the incorrect comparison was familiar, but not when the sample was familiar and the incorrect comparison was novel. When novelty (or familiarity) was controlled for, the birds were able to show that they had, to some extent, learned a general rule.

The extent to which the choice of testing procedure can influence behavior is well illustrated by Cumming and Berryman's (1965) unsuccessful attempt, some years prior to Zentall and Hogan's study, to control for novelty effects by pre-training pigeons on the hue subsequently used during testing. Similar to observations in their earlier experiment, performances dropped to chance levels when the birds were required to match the "novel" test stimuli. This observation is not particularly surprising. It is difficult to conceive that pre-training on the stimulus subsequently used in transfer testing could adequately control for the effect created when, after extensive intervening training in its absence, that stimulus suddenly reappears together with the now thoroughly familiar and (exclusively) expected stimuli. If the birds, subsequent to pre-training on the test stimulus, had in fact exhibited transfer to that stimulus, the objection could equally have been raised that such behavior was not actually transfer of the learned response but was simply the result of a memorization of that specific stimulus relationship during pre-training. With Cumming and Berryman's (1961) procedure, neither positive nor negative results constitute incontrovertible evidence for or against generalized rule learning.

Carter and Eckerman (1975) replicated and extended Cumming and Berryman's (1961) experiment by training pigeons on zero-delay hue matching, zero-delay symbolic hue matching, zero-delay symbolic hue oddity, simultaneous hue matching and simultaneous symbolic hue matching. Simultaneous matching procedures resulted in faster acquisition of the conditional discrimination, and of the two simultaneous procedures, identity hue matching resulted in faster learning than symbolic hue matching. In the zero-delay procedures, the performances on hue matching and symbolic hue matching were rather similar, while the performances on symbolic hue oddity were inferior to performances on the other two zero-delay procedures. In general, learning to match was more difficult on zero-delay procedures, and oddity from sample learning was more difficult than matching-to-sample learning.

Carter and Werner (1978), who do not subscribe to the view that pigeons learn a general rule when trained on conditional discrimination tasks, maintained that--at least in procedures using three hues--identity matching as well as symbolic matching was accomplished by learning three S-delta rules and oddity from sample learning was accomplished by learning six S-delta rules. The observed differences in acquisition rates on the two types of procedures (zero-delay and simultaneous matching) addressed by the suggestion that a different learning process might be invoked when the sample was present at the time a response was made than when the sample disappeared simultaneously with the appearance of the choice stimuli, and by the statement that: "with the zero-delay procedure, matching-to-sample contingencies may be just as arbitrary as the contingencies in symbolic matching, i.e., both tasks may involve the learning of three S-delta rules and nothing more." It is not clear, however, why the rather minor procedural differences between a zero-delay and a simultaneous presentation of the choice stimuli might invoke different learning processes while the seemingly greater differences between symbolic and identity procedures, or, for that matter, between training on one set of stimuli and testing on a different set of stimuli should be governed by the same learning process.

The notion that learning a general relationship is governed by a process which differs from that governing learning a simple discrimination, which is one component of generalized rule learning, is appealing. It is conceivable that associations between stimuli discriminable by means of primary (innate) categorizations, such as, for example, brightness and wavelengths, are not further processed, hence no general relationship is learned.

Considering the tenets of the multiple rule model it is not self-evident why the rate of acquisition on the simultaneous symbolic hue matching procedure should be inferior to that on the simultaneous hue matching procedure as Eckerman (1970) suggested. Presumably, the same number of rules are learned. On the simultaneous symbolic hue procedure in Carter and Eckerman's (1975) study, the rate of acquisition on the first three sessions was faster, and on the first four sessions the discrimination substantially better than the corresponding performances on the simultaneous identity matching procedure, suggesting that not all rules are equally rapidly learned, or that the learning mechanisms on the two procedures differ. According to Carter and Werner (1978), ..."approximately the same number of trials per rule to be learned are required to reach a steady-state level of performance, regardless of whether the procedure used is matching or oddity," i.e., "the rate of acquisition depends...on the number of S-delta rules to be learned. " Since in the two procedures the number of rules to be learned were equal, Carter and Werner's data would seem to contradict predictions based on the multiple rule model. Further, if different learning processes governed acquisition in the two procedures, or if different processes are invoked by different types of stimuli in the same procedure, it is unlikely that the behavioral expressions of these processes would be simply additive, as Carter and Werner suggest.

A number of investigations addressed the question of stimulus coding in conditional discrimination procedures. According to Carter and Werner (1978), "the sample stimulus appears to function as a cue that indicates which of two comparison stimuli is the correct choice...The sample stimulus exercises what might be thought of as an instructional function." The sample stimuli are assumed to be coded by means of a mediating response, "a response (often covert) made directly to the stimulus. The reporting response...is conditional on the occurrence of the coding response...." In support of the coding hypothesis, Carter and Werner cite a study by Cohen (1969), who trained birds on a two-key matching procedure with either two, four or six sample hues. The sample appeared on one of the keys and the birds were required to peck the second key until the hue displayed matched the sample. When new samples were added for the groups trained on less than six sample hues after the discrimination was learned, the birds initially treated the novel samples as if they were one of the familiar samples.

An explanation of this finding by virtue of the coding hypothesis rests on the premise that when a novel stimulus is presented, one of the already established coding responses is emitted to that stimulus. Based on Carter and Werner's (1978) view that the reporting response (response choice) is a function of the properties of the coding response (observing response), a novel test hue should therefore result in a hue preference (which could be different for different birds) but not, as, for example, Cumming and Berryman (1961) found using a three-key matching procedure, in a position preference. Carter and Werner (1978) state that "it is as if the pigeon does not (or cannot) attend to both the sample and the comparison stimuli, and under these conditions, the coding response serves as a cue when the pigeon responds to the side keys."

If the reporting response is based on the coding response and a subject emits the same mediating response to both red and the novel yellow samples, for example, then not only should all response choices in the presence of a yellow sample be to the red comparison, but the level of discrimination on red-red matches should decrease since each erroneous coding of the novel yellow sample results in an extinction trial for the "if the sample is red then peck the red comparison" rule. Carter and Werner (1978) do not suggest that these birds cannot tell the difference between the two hues.

Eckerman (1970) used a procedure where the sample stimulus (one of two different hues) was displayed on a 24.76 cm long display key. On this key, and cued by either of the two colors, three different groups of birds were required to peck at different locations to produce the comparison stimuli, which consisted of horizontal and vertical lines. For one group, the topography of the observing response was to the center region of the key independent of the sample hue, while for the other two groups the observing response location was cued by the color displayed on the sample key. For the two groups, the distance between the two response locations was either 7.62 cm or 15.24 cm. Eckerman found that the speed with which the discrimination was learned was inversely related to the distance between observing response locations. Again, since the same number of rules had to be learned in each condition, these findings suggest that attentional factors differ for different response topographies and should be included when analyzing behavior in terms of multiple rule learning. This is a formidable endeavor since the degree to which attentional factors alone affect the acquisition of different associations cannot be directly assessed.

Presumably, attentional factors differ not only with response topography but also with complexity of the stimuli. Since the relative complexity of particular "complex" stimuli as they are perceived by pigeons is not known and is difficult to determine behaviorally without engaging in circular reasoning, attentional factors cannot be controlled for in a transfer test.

Eckerman, Lanson, and Cumming (1968) reported that pigeons in their study had more difficulties learning a simultaneous conditional discrimination when no observing response was required than when one such response was needed to produce the choice stimuli, and that established identity matching was disrupted when the requirement for the observing response was dropped. Concerning the latter procedure, it is not surprising that the removal of the center key peck requirement resulted in a disruption of a well learned behavior after such responding was well established. The extinction of responding was primarily the extinction of responding to a location.

This procedural aspect of Eckerman, Lanson and Cumming's (1968) investigation, i.e., to eliminate sample stimulus responses entirely, thus is an important variation of the procedure used by Maki, Gilund, Hauge, and Siders (1977), where observing responses to only one of the sample stimuli were extinguished. In this procedure, responding to one particular sample stimulus but not responding to the center key location, was extinguished, thereby maintaining the birds' continued attention to the display key. Eckerman, Lanson and Cumming's procedure in effect conditioned inattention to the display key. This procedural difference between the two studies could well explain why Maki, Gillund, Hauge and Siders, in contrast to Eckerman, Lanson and Cumming, did not observe a total disruption of the learned behavior.

If the observing response is indeed necessary to code the sample as several theorists (e.g., Carter and Werner, 1978; Lawrence, 1963; Kamil and Sacks, 1972) hold, then the procedure used by Maki, Gillund, Hauge and Siders (1977) should have resulted in chance performances on trials with the sample to which observing responses had been extinguished. Assuming that birds ignore (or avoid) stimuli for which they received extinction training, and further assuming that the observing response is necessary to mediate between the sample and the choice key, the removal of the observing response requirement could easily result in the subjects' attending exclusively to the choice keys, with attempts at the discrimination essentially not dissimilar to those in a simultaneous discrimination task. In the presence of a conditional discrimination contingency, attempts to solve the problem as if it were a simultaneous discrimination would be expected to result in chance performances. The better than chance performances observed by Maki, Gillund, Hauge and Siders (1977) on trials where no observing response was required therefore suggest that the observing response is only partly responsible for the subsequent response choice, and that in a conditional discrimination task the primary function of such responses is that of forcing the subjects to attend to the sample.

Cumming and Berryman's (1961) findings that their birds initially resorted to a position preference when presented with novel stimuli indicate that pigeons do not have to learn the appearance of the different hues, since they did not mistake the novel hue for a familiar hue. It can be assumed that in the initial phase of training, the observing response is undifferentiated, i.e., does not resemble any of the coding responses which, according to the proponents of the coding hypothesis, develop in the course of discrimination training. Unless a single rule is learned, the response to the novel stimulus should be undifferentiated, i.e., the novel stimulus should not be coded as if it were one of the familiar stimuli.

A further consideration might be entertained concerning the function such coding might serve pigeons outside an experimental environment. It seems somewhat easier to argue the case for the usefulness of recognizing general relationships independent of specific stimuli than it is to conceive of instances where such coding might have a survival function.

Considering the data from different investigations of conditional discrimination learning, the most striking finding is the extent to which procedural variations effect differences in the acquisition and transfer of such a discrimination. For example, Zentall and Hogan (1978) trained different groups of pigeons on either an identity-matching or an oddity-from-sample procedure. They then either substituted novel stimuli while the procedure remained the same or changed the procedure such that birds trained to match identity were switched to the oddity from sample procedure and birds trained on the oddity-from-sample procedure were changed to the matching procedure. Zentall and Hogan found that the rate of learning on transfer was faster when the procedure remained the same than when it was changed, contradicting predictions based on the multiple rule model. Here, the observed savings in rate of acquisition during transfer was considered an indication that the more general relationship among the stimuli was learned.

It seems quite possible that a simple discrimination problem is learned by means of simple associations. If learning individual associations is a more basic strategy than single rule learning and the stimuli are particularly readily discriminated, individual associations rather than, in this case the less parsimonious, general rule might be learned. Unequivocal findings, rather than questioning abilities for general rule learning, substantiate pigeons' capability for such learning while suggesting that particular training procedures may impose constraints on the birds' learning of such rules, or, may not permit them to demonstrate their ability to learn such rules.

Wright, Cook, Rivera, Sands and Delius (1984), for example, demonstrated that when pigeons are presented with a procedure where learning a single rule is the more parsimonious learning strategy, they will in fact exhibit acquisition of the general relationship among the stimuli. In their study, two different groups of birds were trained on a simultaneous matching-to-sample procedure with either two or 152 different stimuli. For the group trained with two stimuli, each of the stimuli appeared as the sample and the correct comparison on one-half of the trials in each session, and as the incorrect comparison on the remaining trials. For the group trained with 152 stimuli, each stimulus appeared only once in each session. In this group, the composition of the stimulus pair for each trial and the order of presentation of the 76 trials varied randomly each day. The criterion for acquisition was 76 percent of trials correct, which the trial unique birds reached after 360 training sessions and the birds trained with two stimuli after 16 sessions.

A transfer session consisted of 25 warm-up trials, 41 trials with familiar stimuli and 10 trials with novel stimuli. On transfer trials, both stimuli were novel. The trial unique birds showed perfect transfer while the subjects trained on two stimuli performed at chance levels. As the authors point out, "the trial unique group was presented with each stimulus once each session for a total of 360 presentations over the 360 acquisition sessions," while the two-stimuli group was exposed to each stimulus a total of 1216 times over the 16 acquisition trials. Hence "the trial unique group required fewer presentations of individual stimuli to acquire the discrimination than did the 2-stimuli group." Wright et al. suggest that "the facilitation of acquisition on a per exposure basis indicates that something in addition to a series of 'if...then' rules were learned by the trial-unique group and is indirect evidence that a more generalized matching rule was being learned."

Conversely, the subjects trained on two stimuli and failed to show any transfer of the learned behavior received additional training and testing for 244 sessions. The procedural changes included training with two novel stimuli together with the familiar two stimuli, the new stimuli separated from the familiar stimuli, and gradual fading in of the old stimuli into the novel ones. While performances to the familiar stimuli remained at baseline levels, the birds did not transfer to the novel stimuli. According to Wright et al., these findings suggest that "pigeons trained with only a few stimuli rapidly become rigid in their focus on the absolute properties of the stimuli."

The disagreement among investigators whether particular findings are indicative of single rule learning or should be interpreted as evidencing the acquisition of individual associations, is partly the result of the differences in criteria adopted when testing for single rule learning. Zentall and his associates measure such learning by assessing savings scores across procedures, and Pisacreta, Redwood, and Witt (1984) hold that "either above chance performances with novel stimuli, or at least rapid acquisition when confronted with novel problems of conditional discriminations" evidences conceptual behavior. Other investigators (e.g., Cumming and Berryman, 1961, 1965; Carter and Werner, 1978; Davis and Perusse, 1988) use more stringent criteria, maintaining that if on the first session of transfer training the discrimination is not at pre-testing levels, the animal cannot be said to have learned the concept. In view of the exhaustive amount of training pigeons generally receive (usually with few stimuli) until their performances have well reached asymptotic levels, it would be surprising if novel stimuli did *not* disrupt what in the course of training comes to resemble more an automatic motor pattern of responding than a conditional discrimination. Because of the disruptive effect novel stimuli seem to exert on well-established behavior when presented simultaneously with familiar stimuli, savings scores would appear to be a less biased measure of concept learning than the measure provided by one-trial tests or first test session performances.

However, since the nature of the stimuli, i.e., their discriminability, greatly influences acquisition of a discrimination, observed savings might result simply from the greater ease with which particular test stimuli can be discriminated rather than indicate a transfer of the learned response. For example, if trained with horizontal and vertical lines (difficult) as stimuli and tested on hues (easy), the data could be interpreted to show that the birds had learned a general rule, while training and testing with these stimuli reversed would not show such "transfer."

Statement of Purpose. This thesis investigated pigeons' abilities to utilize number-related information when asked to respond to two classes of stimuli consisting of few and many stimulus elements displayed. Using a within-subject design, birds were trained in a series of two-key simultaneous-discrimination, and three-key matching-to-sample procedures. Responses were emitted to a touchscreen mounted in front of a monitor which displayed the stimuli.

In the initial (identity-matching) experiment, the rate and extent of general rule learning, i.e., of learning the respective relative concepts "few" and "many" was assessed. The difficulties the birds experienced learning this task as evidenced by the poor performances, suggested the investigation of the birds' abilities to differentiate between five, or for some birds three, stimulus pairs differing in amount of disparity of elements using simultaneous discrimination procedures.

Since the nature of the stimuli remained unchanged from the stimuli used in the matching-to-sample procedures, the simultaneous discrimination procedures further permitted a comparison between performances in conditional and simultaneous discriminations. The behavior was probed on one multiple disparity, simultaneous discrimination procedure. On each probe trial both stimuli were members of the same category, i.e., for different groups, members of the usually negative or usually positive stimulus category. With the probe trials, an attempt was made to determine whether response choices resulted from a relational judgment or whether individual stimulus associations were learned.

The conditional discrimination procedures in the final experiment incorporated both identity-matching and symbolic-matching trials. Since throughout the study all non-symbolic stimuli differed in number of elements displayed only, the extensive training with such stimuli in Experiment 2 was expected to have a facilitatory effect on identity-matching in Experiment 3. The simultaneous presence of symbolic trials in each session served 1), to assess whether with the numerical stimuli used, the resultant performances would show similar differences between rate and degree of acquisition of symbolic matching and identity matching as did those reported by Carter and Eckerman (1975) and 2), to assess the extent to which steady-state performances in either condition differed from those in simultaneous discrimination procedures.

On symbolic-matching trials two arbitrarily chosen hues represented the two respective numerical stimulus categories. The addition of these trials permitted to assess possible differences in the acquisition of an identity and a symbolic relationship, and in the condition where the center key was symbolic and the choice keys colored, whether the numerical stimuli could be judged absolutely, since in this condition the stimulus representing the alternate category was not present.

In both Experiments 2 and 3, some subjects were trained with stimuli which contained fewer elements than did the stimuli presented to the remaining birds and used in Experiment 1. This reduction in number of elements affected some of the number-related differences between the response-choices, such as brightness differences. This procedural change was introduced in an attempt to determine the extent to which number-related differences affected acquisition of both the simultaneous and the conditional discrimination.

The general relationship in the conditional discrimination procedures was "sameness" or "identity," while in the simultaneous discrimination procedure the pertinent aspect was the identification of the "correct" stimulus category, i.e., the category with the numerically smaller, or the numerically larger stimuli. The stimuli used were on a continuum and differed only in number of stimulus elements. While the location of the individual elements was random on each new trial, in some procedures the difference in number of elements between the two stimuli was 30 elements, i.e., substantial enough to provide several number-related cues when the birds discriminated between stimuli of each pair, and in the identity-matching condition, the pattern of stimulus elements was always identical on the two matching stimuli. While the difference in number of elements between stimuli or the number of stimulus pairs differed across procedures, except when the behavior was probed the two stimulus categories (positive and negative) always differed such that one category consisted of stimuli with fewer than 20 elements and the second category of stimuli with more than 20 elements.

Experimental Method and Procedures

Method

Subjects. Four female (P5, P25, P14 and P15) and two male (P4008 and P4398) adult white Carneaux pigeons were maintained at 80 percent of their free-feeding weight with unrestricted access to water. Weights were recorded daily and Bay-Mor PC-700 Pigeon Feed was supplied in the home cage on days when no experiments were scheduled or, if necessary, to supplement the food obtained during an experimental session. The same food mixture was used for both maintenance and reinforcement. The birds were housed individually in standard stainless-steel pigeon cages at an ambient temperature of 21° C (+-2°) and a light:dark cycle of 13:11 hrs. Two birds (P4008 and P15) had prior exposure to a 3-key color matching-to-sample procedure. None of the subjects had experience with compound stimuli or with responding on a touchscreen.

Apparatus. The test apparatus, consisted of a test cage and a 13-inch diameter IBM CGA monitor (model 5153) fitted with a 5 x 8-inch (w x h) Elographics E264 touchscreen. The test cage was a modified Coulbourn Modular Test Cage (model E10-10), inside dimensions 24 x 33 x 30 cm (w x h x d). The floor, cage back and top were aluminum, the sides clear acrylic. A hinged panel on one side provided access into the cage. The front wall consisted in part of four equidistant vertical tracks intended for insertion of modular elements. The outside tracks constituted the front corners of the cage and the Coulbourn feeder (module E14-10) was inserted between the remaining two tracks which were then cut flush with the upper edge of the feeder module at a height of 17 cm from the cage floor to provide unobstructed access to the screen. The lower edge of the feeder opening was 2 cm from the floor. Feeder operation was accompanied by the hopper noise and the illumination of the magazine light. Blank modular aluminum slats filled the remaining spaces between the tracks and an aluminum frame, with a window of 22 x 14 cm (w x h), held between the corner tracks, completed the front wall. This window provided screen access with the lower edge of the opening 19 cm above the cage floor.

The monitor was installed such that a hypothetical line bisecting the key stimuli horizontally was approximately 24 cm above the cage floor. The front of the touchscreen was covered with Mylar and taped to the back of a flat-black aluminum frame with an opening of 20 x 12.5 cm (w x h), which was then affixed to the monitor housing. The lower edge of the visible area of the touchscreen was 19 cm above the cage floor. The screen locations on which the stimuli appeared were in direct contact with the monitor surface.

Except for response shaping and during the early part of matching-to sample training, no houselight or other ambient light was used, to minimize the subjects' reflections on the screen. Due to an obstruction by electrical cables connecting the touchscreen and the feeder to their respective activating devices, the door to the room containing the test apparatus was ajar by approximately 2 cm throughout training and testing. The back of the test cage faced the door and visual inspection of the room with the door closed deemed the amount of light and sound entering through the opening negligible.

Data acquisition and scheduling of events was by means of a Fountain FTN-88 computer. The touchscreen was driven by an Elographics E264-142 controller and programmed with Elodev software. A monitor outside of the test environment was connected in parallel with the monitor in the test room, simultaneously displaying the stimuli as they appeared on the screen viewed by the birds. To observe the birds, a closed- circuit video camera was placed to the rear left of, and capturing the inside front wall of, the cage. All devices controlling the scheduling of events and the monitoring of the subjects were in the adjacent room.

Stimuli. Colored squares, hereafter referred to as "keys," were displayed on a black (color 0) monitor screen. Each key measured 24.5 x 29.0 mm (h x w). The maximum distance between the outer edges of the keys was 97 mm. The lower boundary of the keys was 22.8 cm from the cage floor. The inter-key distance in a 3-key display was 5 mm, and the distance between the inside edges of the two choice keys 39.0 mm.

The keys were displayed on a medium resolution screen (320 dots by 200 lines). Each key contained 40 programmable locations. Each location contained either a stimulus element (ASCII character) or a non-element (solid color). Thirty-two black screen line dividers were faintly visible between 33 colored horizontal lines. A key could accommodate 4 rows of 10 stimulus elements. Vertically, individual elements occupied 5 lines and were separated by 3 lines. Above the top programmable row of elements one line was always empty, and below the bottom programmable row two lines were always empty.

Each key displayed either a solid red color (color 4) or a solid blue color (color 1), or contained a predetermined number of black (color 0) stimulus elements against a green (color 2) background. For all experiments, the stimulus elements consisted of either ASCII code 42 ("*") or ASCII code 43 ("+"). An individual "*" fell within an area of 3.5 x 2.9 mm (h x w) and an individual "+" within an area of 3.5 x 2.0 mm (h x w). A row of 10 "*"s occupied the entire width of the key without any visible spaces either between elements horizontally or between the vertical boundaries of the key and the immediately adjacent elements. A row of "+"s was continuous with the left but not the right vertical boundary of a key. Adjacent "+"s, as well as the ultimate elements and the right vertical boundary of the key were separated by 0.5 mm.

Procedure

Schedules of Reinforcement. On a continuous schedule of reinforcement, all correct responses resulted in primary reinforcement (access to grain). On a random ratio schedule of reinforcement primary reinforcement was scheduled for 25% of trials, and correct responses which did not result in primary reinforcement were signaled with a 50 msec activation of the feeder which resulted in the illumination of the magazine light and the noise concomitant with feeder operation but no opportunity to obtain grain.

Shaping. Magazine-training and response shaping were accomplished using the closed-circuit monitor. To facilitate viewing of the birds, the chamber was illuminated by a 60- watt bulb in a metal housing, mounted on the wall to the right of the test cage at a distance of approximately 2.0 meters.

The birds were magazine-trained by hand in the presence of the green sample key containing, on different trials, either 5 or 35 randomly located black asterisks within the 40 possible locations. Shaping to peck the key commenced as soon as the birds ate from the feeder. During shaping, the feeder was activated either manually or by a peck at the illuminated key. A keypeck resulted in 4.0 s of access to grain and manually reinforced approximations to key pecking in an average of 4.0 s feeder operation.

After responding to the sample key was established the procedure was changed so that one response to the sample extinguished that key and produced the two choice keys which contained 5 and 35 asterisks. Prior to each trial the number and location of the stimulus elements within the key and the location (left or right) of the choice key which matched the sample were selected randomly by the computer. The birds were then hand-shaped to peck the choice keys. One peck to either location, matching or non-matching, terminated the trial and was reinforced with 4.0 s access to the feeder. The criterion for shaping was the completion of one session of 100 keypecks without intervening manual shaping. The individual number of sessions to reach this criterion was 25 for bird P14, 8 for bird P4008, 7 for bird P4398, 14 for bird P25, 4 for bird P5, and 4 for bird P15.

Experiment 1
Matching-to-Sample Procedures and Simultaneous Discrimination Test

Procedure: Zero-Delay Matching-to-Sample. For each bird, shaping was immediately followed by a zero-delay matching-to-sample procedure. The stimuli used were identical to those in the response shaping procedure: either 5 or 35 black asterisks were displayed against a green background. Prior to each trial and for each stimulus, the nature of the sample stimulus in the center key location, i.e., the character of the stimulus elements, the number and location of the stimulus elements within the key and the location (left or right) of the matching choice key were selected randomly by the computer. The pattern of the stimulus elements on the sample key was always identical to that on the matching, i.e., "correct" choice key. The positions of the stimulus elements on the incorrect key were random and independent. The monitor screen was black both prior to and subsequent to a session, as well as during intertrial intervals.

A trial began with the presentation of the sample stimulus on the sample key. One peck at the sample produced the choice keys one of which matched the sample. Simultaneously the sample key was extinguished. One peck to either choice key completed the trial. On each new trial, both stimuli had an equal probability to appear on the sample key, and, selected independent of the sample, on either side location.

The intertrial interval for incorrect responses timed from the occurrence of a choice key peck to the onset of the next trial, was 6.0s. The intertrial interval for correct responses was 0.5s. and was timed from feeder offset to the presentation of the sample signaling the next trial. The availability for reinforcement was adjusted for each bird over a period of days until their weight was generally maintained by the food obtained during a session. These durations ranged from 2.7 to 3.7s.

A continuous schedule of reinforcement was in effect. The first two sessions for birds P15 and P5 and the first session for bird P4008 consisted of 100 trials with no correction trials. On all subsequent sessions for these birds and beginning with the first session for the remaining three birds (P4398, P14 and P25), correction trials were instituted whereby an incorrect response occasioned the repetition of the exact stimuli for the trial on which the error occurred.

A session length at this juncture, including correction trials, was 200 trials. A session was aborted if a subject failed to respond for two hours. Bird P14 remained in this procedure for five, and P25 for 18 sessions, while each of the remaining birds P4008, P4398, P5 and P15 completed 20 sessions.

The discriminability of the two stimuli was then ascertained by testing all birds on a simultaneous discrimination procedure. This was accomplished by using the general procedure described for the matching-to-sample procedure, except that the presentation of the sample was omitted, and only pecks to the choice key displaying the numerically smaller stimulus (five elements) were reinforced.

A trial began with the simultaneous presentation of the two familiar stimuli, keys with 5 or 35 asterisks, in the usual choice key locations. A peck to one of the choice keys terminated the trial. The location of each stimulus (left or right choice key) and the location of the stimulus elements displayed within each key were selected randomly for each trial. Birds P25, P4008 and P4398 remained in this test for one session and birds P5, P14 and P15 for three sessions. The test was repeated for the latter three subjects with a change in the S+ assignment, whereby only responses to the numerically larger stimulus (35 elements) were reinforced. A random ratio schedule ($p=.25$) of reinforcement was implemented on the last session. Correct responses which did not result in primary reinforcement were signaled with a 50msec activation of the feeder which resulted in the illumination of the magazine light and the noise concomitant with feeder operation but no opportunity to obtain grain. Session length was 600 trials or 100 reinforcements, whichever came first.

After their one session in the simultaneous discrimination test, P4008, P4398 and P25 received further training on the zero-delay matching-to-sample procedure, followed by training on a simultaneous matching-to-sample procedure.

In general, the simultaneous-matching procedure was identical to the procedure described for zero-delay matching-to-sample, except that subsequent to the single sample key response the sample remained on the screen concurrent with the choice keys. All three stimuli remained on the screen until a choice on one of the side keys was made. A random ratio schedule of reinforcement (p=.25) was put into effect beginning with the second zero-delay matching-to-sample session. Session length was 800 trials or 100 reinforcements, whichever came first.

Table 1 summarizes the experimental procedures and amount of training for all subjects in Experiment 1. For each procedure the number of sessions, the respective number of scheduled trials and actually completed trials are shown.

Since advancement to the first matching-to-sample procedure depended on the individual subjects' successful completion of response shaping, exposure to the first zero-delay matching procedure differed among subjects. Subsequent changes in procedure were implemented for all birds simultaneously. The procedures diverged for two groups of birds beginning with the second procedure: subsequent to one session in the simultaneous discrimination test, three birds (P25, P4008 and P4398) received prolonged training

Table 1
Procedures and Individual Training
Experiment 1

Bird	Procedure	(S+)	Stimulus Pairs	#of Trials	Tot.	Sessions Length(#)
P25	OMTS		5/35	3409	18	200(18)
	SIM Test	(few)	5/35	125	1	200(1)
	OMTS Cont'd.		5/35	4045	7	200(1),800(6)
	SMTS		5/35	5594	12	600(10),500(2)
	SMTS Test		5/35	886	2	400(1),500(1)
	SMTS Test		5/10	1074	4	400(4)
	SIM	(few)	5/35	1538	4	500(4)
P4008	OMTS		5/35	3940	20	200(20)
	SIM Test	(few)	5/35	200	1	200(1)
	OMTS Cont'd.		5/35	4822	7	200(1),800(6)
	SMTS		5/35	7600	13	600(11),500(2)
	SMTS Test		5/35	900	2	400(1),500(1)
	SMTS Test		5/10	1427	4	400(4)
	SIM	(many)	5/35	1847	4	500(5)
P4398	OMTS		5/35	3974	20	200(20)
	SIM Test	(few)	5/35	200	1	200(1)
	OMTS Cont'd.		5/35	4781	7	200(1),800(6)
	SMTS		5/35	7600	13	600(11),500(2)
	SMTS Test		5/35	500	1	500(1)
	SMTS Test		5/10	1550	4	400(4)
	SIM	(many)	5/35	1938	4	500(4)
P5	OMTS		5/35	3833	20	200(20)
	SIM Test	(few)	5/35	420	3	200(3)
	SIM Test	(many)	5/35	1403	8	200(7),600(1)
P14	OMTS		5/35	995	5	200(5)
	SIM Test	(few)	5/35	431	3	200(3)
	SIM Test	(many)	5/35	783	5	200(5)
	SIM Test	(few)	5/35	697	3	200(2),600(1)
P15	OMTS		5/35	3577	20	200(20)
	SIM Test	(few)	5/35	488	3	200(3)
	SIM Test	(many)	5/35	1452	8	200(7),600(1)

OMTS=Zero-Delay Matching-to-Sample; SMTS=Simultaneous Matching-to-Sample
SIM=Simultaneous Discrimination

on matching-to-sample procedures while the remaining birds (P14, P5 and P15) were trained on simultaneous discrimination procedures only. The light in the test room was extinguished beginning with the last procedure in Experiment 1 and remained off for the rest of the study.

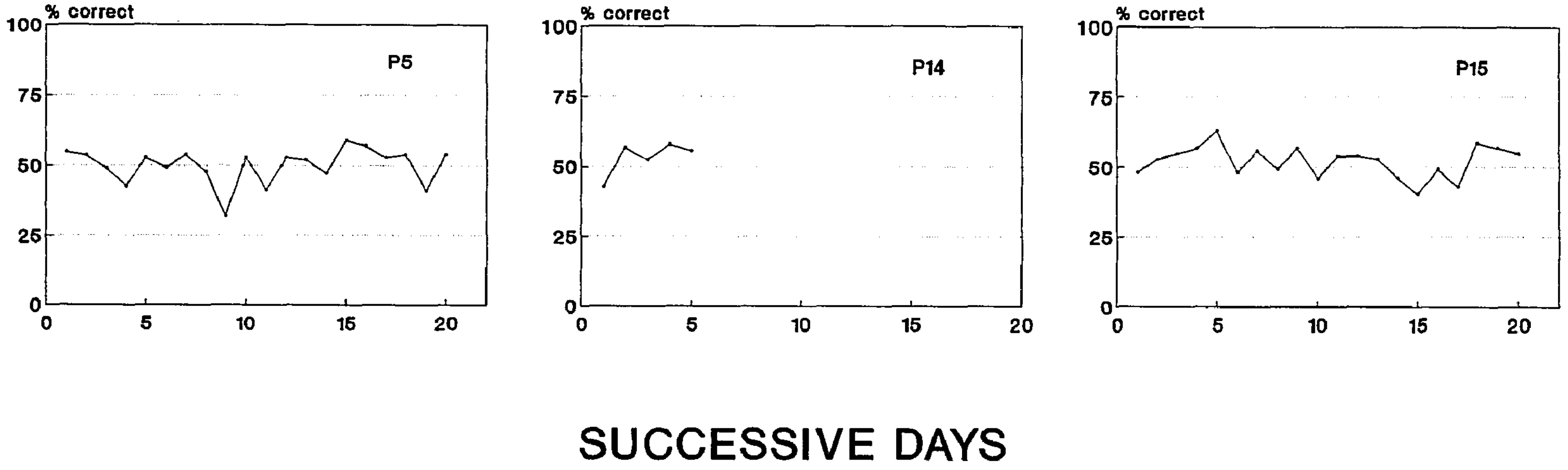
Results: Zero-Delay Matching-to-Sample. The performances are shown as mean percent trials correct in Figure 1.1 for each subject and all sessions. The percentages correct were determined from non-correction trials only. Thus, the denominator depended upon number of errors made.

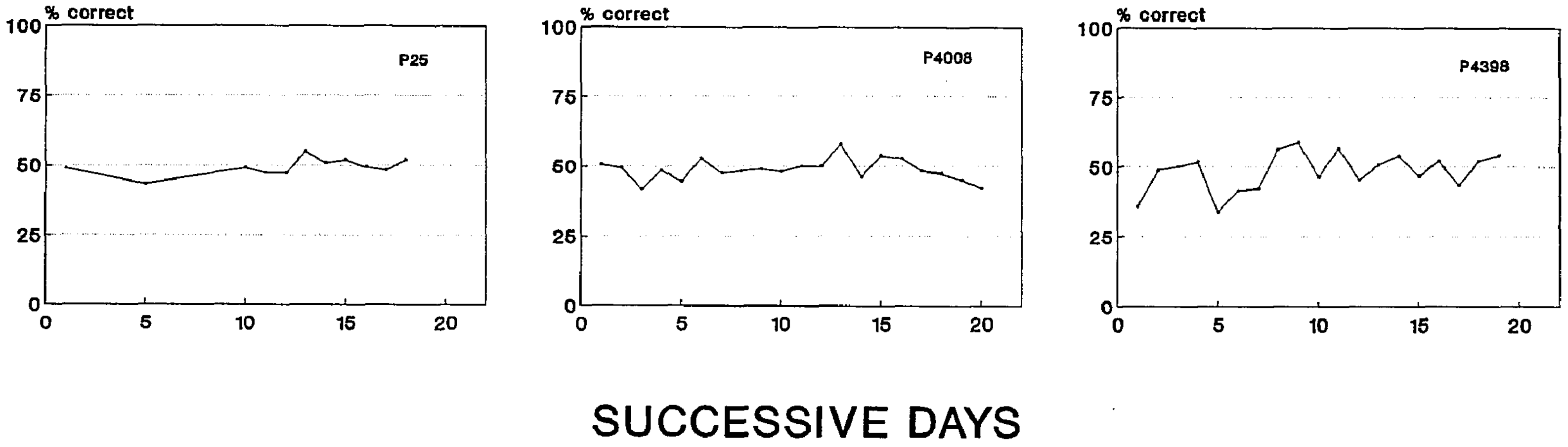
The individual means plotted for each session show that all performances remained at chance levels throughout this phase of training. Similarly, none of the curves suggest any systematic change. Although the performance by bird P14 suggests a gradual improvement in the discrimination with, on the successive five sessions, performances of 42.8, 56.9, 52.5, 58.0, and 55.7 percent correct, this bird received only a limited amount of training in the subsequent second zero-delay matching condition, and was not trained on the additional matching procedures in Experiment 1. Therefore, the extent to which this bird would have learned to perform correctly in the procedure is not known.

Since the data did not suggest a recognition of number-related differences between the two stimuli, the discriminability of the two stimuli was ascertained by testing all birds on a simultaneous discrimination procedure.

Procedure: Simultaneous Discrimination Test. The procedure was the same as that described for the zero-delay matching-to-sample, except that the presentation of the center key was omitted and it was arbitrarily determined that only pecks to the choice key displaying the stimulus containing five elements would be reinforced.

Figure 1.1. Zero-delay matching-to-sample training with a stimulus disparty of 30 elements. Individual mean percent trials correct for each session and all birds.


% correct
100
75
50
25
0
0
5
10
15
20
P5
P14
P15
SUCCESSIVE DAYS


% correct
100
75
50
25
0
0
5
10
15
20
P25
P4008
P4398
SUCCESSIVE DAYS

A trial began with the simultaneous presentation of the two stimuli displaying the familiar number of stimulus elements (5 and 35 asterisks) in the usual choice key locations. The location of each stimulus (left or right choice key) and the location of the elements in each key were selected randomly for to each trial. The intertrial interval for correct responses was .5s and was timed from the offset of the feeder presentation until the presentation of the two comparisons signaling the next trial. The intertrial interval for incorrect responses was 6s. Birds P14, P15 and P5 remained in this procedure for three, and birds P4008, P4398 and P25 for one session of 200 trials or 100 reinforcements, whichever came first.

To further ascertain the discriminability of the stimuli, a discrimination reversal was instituted for birds P14, P15 and P5 after the three initial sessions with the positive stimulus as five asterisks. Responding was now reinforced only after responses to the choice key with 35 elements. Birds P15 and P5 remained in this condition for 8 sessions. Bird P14, after 5 sessions, returned to the "few elements" correct condition for the final 3 sessions in preparation for the subsequent simultaneous discrimination experiment (Experiment 2).

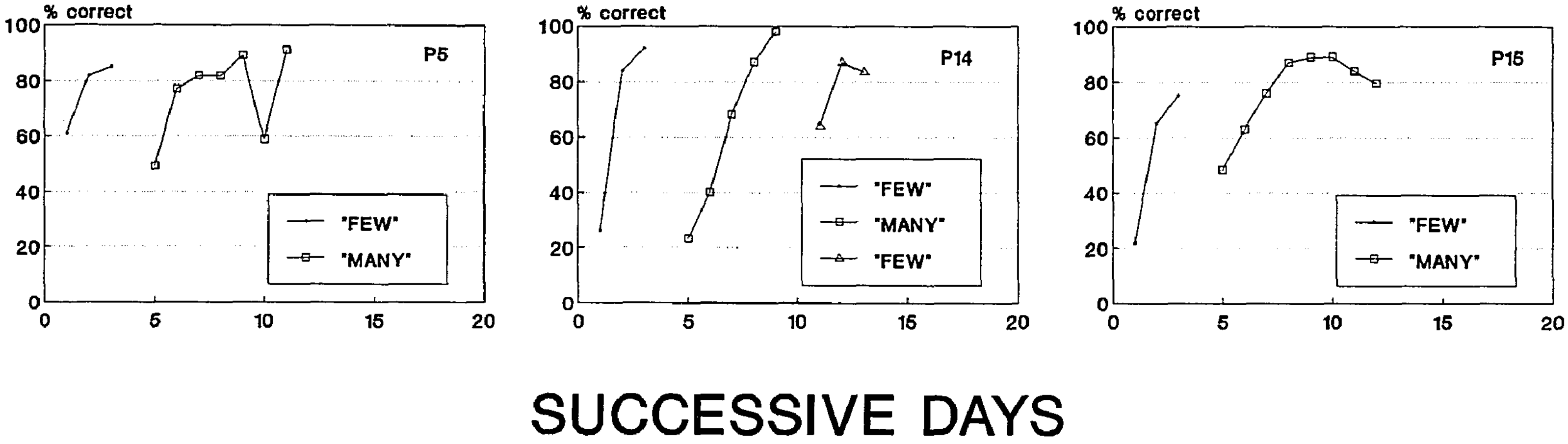
Coinciding with its implementation for the birds concurrently trained on a different procedure, a random ratio schedule of reinforcement (p=.25) was put into effect on the last session in the simultaneous discrimination test. Correct responses for which no primary reinforcement was scheduled were cued by a 50ms illumination of the feeder light and the sound produced by the concomitant feeder operation. The intertrial interval of .5s for correct responses for which no primary reinforcement was scheduled was timed from the occurrence of a choice key peck to the presentation of the choice keys signaling the next trial. Duration and timing of intertrial intervals for responses followed by the feeder presentation and following incorrect responses were as described above. The first seven sessions with the positive stimulus reassigned ended after 200 trials or 100 reinforcements, and the final session after 600 trials or 100 reinforcements. The number of sessions, the respective number of scheduled trials and actually completed trials are shown in Table 1.

Results: Simultaneous Discrimination Test. Figure 1.2 shows individual overall means as percent trials correct for each session and all test conditions for each bird completing more than one test session. In these graphs, the functions on the left depict performances prior to, and the functions on the right (center for bird P14) performances subsequent to the discrimination reversal. For bird P14, the righthand function depicts the performance on the final three sessions in the test, i.e., retraining on the "few elements" correct condition.

The values plotted in Figure 1.2 clearly indicate that the two stimuli were readily discriminable and that the rate of acquisition was independent of the nature of the positive stimulus (5 or 35 elements). This finding substantiated the previous inference that the two stimuli were equally available to sustain responding. On the first condition, i.e., with the positive stimulus as "few elements" correct, bird P5 responded correctly on 61, 82, and 85 percent of trials, respectively, on the successive three sessions on the test ("few elements" correct). With a change in the assigned positive stimulus, this bird responded correctly on 77 percent of trials by the second session, and on 91 percent of trials by the seventh session.

The cause for the bird's poor discrimination on session six with the positive stimulus reversed is not known, but was possibly the result of a procedural error in programming the specific S+ condition for the particular test session. The data for session eight for this bird are not available.

Figure 1.2. Simultaneous Discrimination Test with a stimulus disparity of 30 elements, birds P14, P15 and P5. Overall mean percent trials correct for each session and all conditions. The lefthand functions show responses with the S+ as "few-elements" correct and the functions on the right (center for P14) responses with the S+ as "many elements" correct. The righthand function for bird P14 shows retraining performances on the "few-elements" correct condition.


% correct
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60
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5
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15
20
P5
"FEW"
"MANY"
% correct
P14
"FEW"
"MANY"
"FEW"
% correct
P15
"FEW"
"MANY"
SUCCESSIVE DAYS

Both bird P14 and bird P15 followed a poor discrimination on the first test session with an impressive improvement in performance on the subsequent two sessions. On the second and third sessions, bird P15 responded correctly on 65 percent and 75 percent of trials, respectively, and bird P14 on 84 percent and 92 percent of trials, respectively.

All birds rapidly learned to switch to the new stimulus category with the positive stimulus reversed to "many elements" correct. Both birds P14 and P15 followed a poor performance on the first session with a rapid improvement in the discrimination on the subsequent sessions. Bird P14 correctly discriminated 98 percent of trials by the 5th session, and bird P15 79.4 percent of trials correctly by the eighth and final session. On the subsequent three retraining sessions on the "few-elements" correct condition, bird P14 responded correctly on 63.9, 87, and 83 percent of trials, respectively.

When retrained with the S+ as "few elements" correct, bird P14 discriminated considerably better (63.9 percent) on the first retraining session compared to the first two sessions in the test, suggesting that either the original discrimination had been retained or the bird conceptualized the two stimulus categories and responded appropriately to either category as required by the reinforcement contingency.

Because of the difficulties the birds evidently experienced in the matching procedure while demonstrably readily able to discriminate the stimuli, further training on the matching procedure seemed indicated. Therefore, after their one simultaneous discrimination session birds P4008, P4398 and P25 were returned to the zero-delay matching-to-sample procedure with a random ratio schedule of reinforcement (p=.25) in effect beginning with the second session. The first session ended after 200 trials or 100 reinforcements and all subsequent sessions after 800 trials or 100 reinforcements, whichever came first. Birds P4398 and P4008 remained in this procedure for seven, and P25 for six sessions. The total number of sessions and trials completed are shown in Table 1.

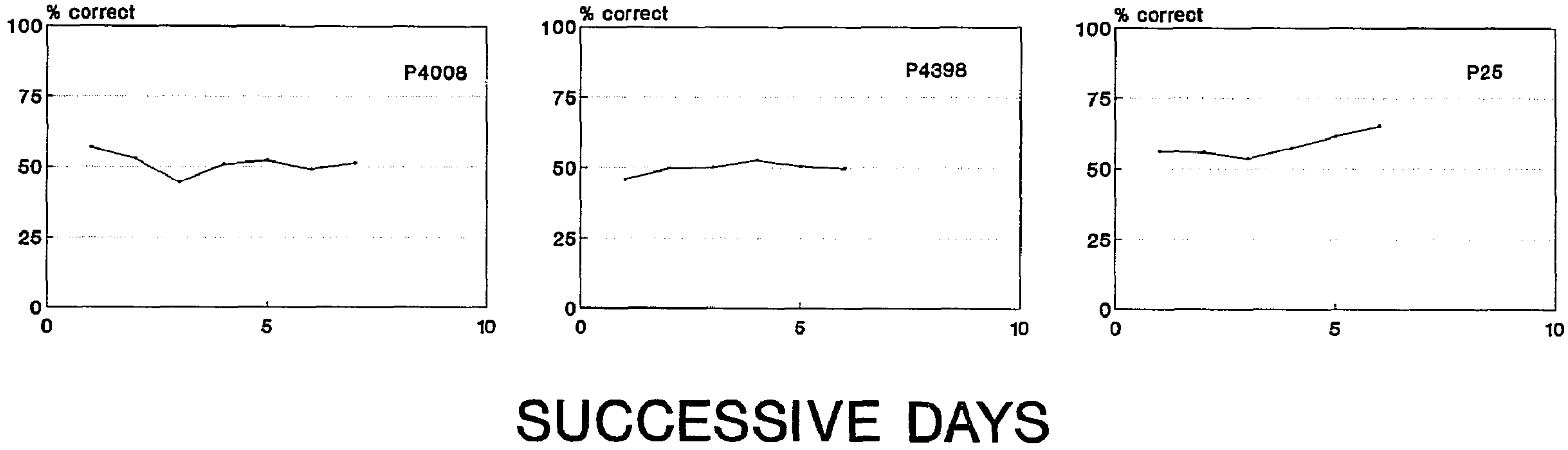
Results: 2nd Zero-Delay Matching-to-Sample. Figure 1.3 shows the individual performances on the second zero-delay matching-to-sample procedure as overall mean percent trials correct for all sessions. The data for the first session for bird P4398 are missing. The functions depicted for this bird include sessions 2-7 only.

As the functions show, after six sessions in the procedure only bird P25 showed some improvement in performance. This bird discriminated correctly on an average of 56.1 percent of trials on the first session, and on an average of 55.9, 53.5, 57.4, 61.7 and 65.1 percent of trials, respectively, on the remaining five sessions. The curves in Figure 1.3 further show that birds P4008 and P4398 did not benefit from the additional discrimination training.

Since the matching procedure in the present study required only a single response to produce the choice keys while simultaneously extinguishing the center key, inattention to the sample conceivably contributed to the observed performances. To clarify whether attentional factors contributed to the birds' difficulties with the zero-delay matching-to-sample condition, the procedure was changed to a simultaneous matching-to-sample condition.

Procedure: Simultaneous Matching-to-Sample. Birds P4008, P4398, and P25 were trained for 13 (P4398 and P4008), or 12 sessions (P25) in a simultaneous matching-to-sample condition. The procedure was identical to that in the zero-delay matching procedure, except that subsequent to the one center key response required to produce the choice keys, the sample remained on the screen concurrent with choice key

Figure 1.3. Second zero-delay matching-to-sample training with a stimulus disparity of 30 elements. Individual overall mean percent correct trials for each session, birds P4008, P4398 and P25.


% correct
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P4008
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P4398
% correct
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P25
SUCCESSIVE DAYS

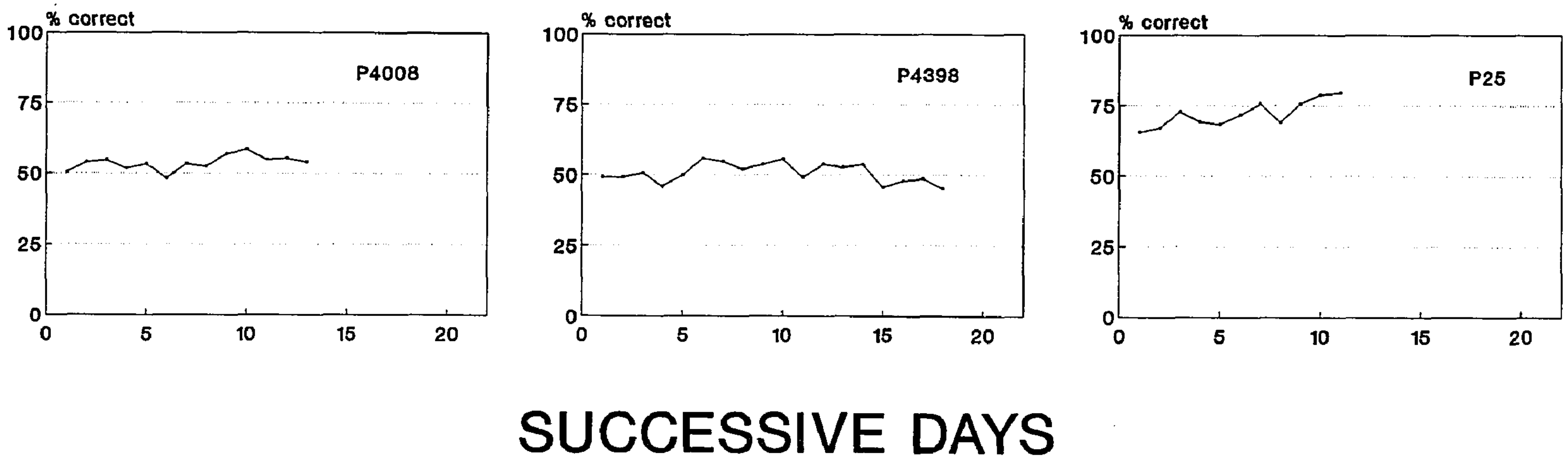
presentation until a choice response was made. Pecks to the center key in the presence of the choice keys had no consequences. All other parameters, including the stimulus elements and the stimulus disparity, remained unchanged. Session length was 600 trials or 100 reinforcements, whichever came first. Number of sessions and trials completed are shown in Table 1.

The individual performances on the simultaneous matching-to-sample condition are shown as mean percent trials correct for each session in Figure 1.4. The performances were consistent with the respective performances observed in the preceding (second) zero-delay matching procedure. Bird P25 continued to improve, while the performances by birds P4008 and P4398 remained at levels observed on the preceding training.

Conceivably, the negligible physical effort required to travel the short (5 mm) distance between the sample key and either choice key rendered the locations of the three keys indistinct, particularly since both the background against which the keys were displayed and the elements themselves were black. The close proximity of the keys could have fostered a response-choice based on some local stimulus features attended to on the sample and the immediately adjacent choice key. Although this explanation seems less probable for the birds' failure to match in the zero-delay matching-to-sample procedure where the sample was not on the screen concurrent with the choice keys, local features attended to during the one observing response and available in short-term memory could equally have governed responding to the choice keys.

To control for such possible incidental effects on behavior resulting from some aspects of the stimulus presentation, specifically the physical presentation of the keys and the particular disparity in number of stimulus elements, birds P25, P4008 and P4398 were briefly tested with a change in center key location and a reduction in number of

Figure 1.4. Simultaneous matching-to-sample training with a stimulus disparity of 30 elements. Overall mean percent trials correct for each session, birds P4008, P4398 and P25.


% correct
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0
5
10
15
20
P4008
% correct
100
75
50
25
0
0
5
10
15
20
P4398
% correct
100
75
50
25
0
0
5
10
15
20
P25
SUCCESSIVE DAYS

elements in the numerically larger stimulus.

To increase the distinction between the keys, the center key location was changed such that its lower boundary was 5 mm above the location previously occupied by its upper boundary. The choice key locations remained unchanged. On this display, the three birds received two sessions with the familiar disparity, followed by four sessions with stimuli containing 5 and 10 asterisks. The decrease in the number of elements in the numerically larger stimulus was instituted to briefly assess whether the extreme difference in appearance of the two stimuli somehow affected performance in the matching tasks, while clearly not affecting the discrimination in the simultaneous discrimination test.

Neither raising the physical location of the sample key nor the reduction in number of elements resulted in an improvement of the performances by birds P4008 and P4398, while concomitant to the reduction in element number the performance of bird P25 deteriorated to chance levels.

In preparation for Experiment 2, the three birds were then removed from the matching procedure and trained for four sessions on the simultaneous discrimination procedure with the familiar stimuli containing 5 and 35 asterisks. Bird P25 was reinforced for responding to the numerically smaller, and birds P4008 and P4398 for responding to the numerically larger stimulus. The data for the performances with the procedural changes in effect and for the retraining sessions are not shown.

Results of Experiment 1

Analysis of the behaviors observed on the different procedures in Experiment 1 did not suggest the cause of the difficulties the birds experienced when required to match identity, while showing successful performances in the simultaneous discrimination procedure. Since all birds failed to match in the first zero-delay matching-to-sample condition but easily discriminated between the two stimuli on the discrimination test, it seemed unlikely that the failure to learn the matching procedure was a function of a generalization between the two stimuli or a short-term memory failure, particularly since the performances in the simultaneous discrimination procedure demonstrated that these birds easily remembered the nature of the positive stimulus on successive trials. The observed behaviors suggested that during initial zero-delay matching-to-sample training the birds had attended to the appearance of, and discriminated between, the two stimuli.

Based on these observations, the simultaneous matching-to-sample procedure was implemented, thereby providing the birds with a situation where the sample could be compared concurrently to either of the choices without necessitating referencing some memorized abstraction or representation of the sample. If the failure to match in the zero-delay procedure had been a function of short-term memory failure, in the simultaneous matching procedure the concurrent availability of both the sample stimulus and the comparison stimuli should have facilitated acquisition of the discrimination. The simultaneous-matching procedure used did not require the birds to increase the amount of physical attention to the sample stimulus since--as in the zero-delay matching procedure--a single peck to the center key sufficed to produce the choice keys. However, unlike the zero-delay procedure, the simultaneous matching condition provided the birds with an opportunity to perform a direct comparison between the sample and the two comparison stimuli if they were uncertain of the correct response-choice. That is, in this condition all stimulus determinants of a correct choice were present at the time of responding.

Conditional discriminations of the type used in the present matching-to-sample conditions are in effect composed of two simultaneous discrimination procedures with the nature of the correct comparison cued prior to (zero-delay matching procedure), or simultaneously on each trial by the sample stimulus (simultaneous-matching procedure). Hence the poor performances were not readily explicable considering that the contingencies presented in the matching condition seemed (to a human observer) not more difficult to learn than the identification of the correct comparison on successive trials in the simultaneous discrimination procedure.

In order to investigate the extent of the birds ability to discriminate among stimuli differing in the disparity between number of elements displayed and to assess the relative importance of the various cues available on which to base a response, in Experiment 2 the birds were trained on a succession of simultaneous discrimination procedures with one or two element types and on a multiple disparities procedure with a reduction in numerosity of both comparison stimuli.

Experiment 2

Multiple Disparities

Simultaneous Discrimination Procedures
and Probes

General Procedure. All six birds were trained on a simultaneous discrimination procedure with five disparities of element number. Each stimulus pair differed in the disparity between number of elements displayed on the two keys, ranging from 2 to 32.

As in the preceding experiment, the maximum number of elements that could be displayed in a key was 40. For all subjects the positive stimulus ("few-" or "many-elements" correct) was in accordance to the respective reinforcement history in the last procedure in Experiment 1. Birds P25 and P14 were reinforced for responding to the numerically smaller stimulus and birds P4398, P4008, P5 and P15 for responding to the numerically larger stimulus.

A trial began with the presentation of the two comparison stimuli in the choice key locations and was completed with a peck to either choice key. The intertrial interval for incorrect responses timed from the occurrence of a choice key peck to the onset of the next trial, was 6.0s. The intertrial interval for correct responses was .5s and was timed from feeder offset to the presentation of the two choice key stimuli signaling the next trial. Correction trials were instituted whereby an incorrect response occasioned the repetition of the exact stimuli for the trial on which the error occurred.

One-half of the subjects (P14, P15, P5) then performed on the procedure with a reversal in the assigned S+. Bird P14 was thus reinforced for responding to the numerically larger stimuli and birds P15 and P5 to the numerically smaller stimuli.

Probe trials were introduced on a small number of trials for all birds on their respective final 15 sessions. In these probes stimulus pairs other than those used in the basic procedure were employed.

The birds were subsequently trained on two further procedures to assess the extent to which response-choices were number-related. In the first procedure, all birds were trained on the familiar five disparities (of 2, 4, 8, 16, and 32 elements) with the addition of a second type of element, ASCII character 43 ("+"). This procedural change maintained the integrity of the numerosity of the five stimulus pairs, while affecting correlated differences--e.g., brightness--between pairs of stimuli where one or both comparisons displayed the novel element type.

In the second procedure, two of the subjects (P25 and P4398) received training with three disparities (of 2, 4, and 8 elements) and two types of elements. The two stimulus elements were identical to those used in the five disparities procedure. The three-disparities procedure incorporated both a reduction in the numerical value of the stimuli (with pairs of 2:4, 4:8, and 2:8 elements) and a reduction in the number of stimulus pairs. Because the ratio of key background to elements was reduced in all stimuli, the brightness difference between stimuli was reduced in each pair, thereby providing conditions where attention to the stimulus elements was presumably essential for a correct discrimination.

Procedure: Five Disparities Simultaneous Discrimination and S+ Reversal Training. Except for the change to multiple disparities, the procedure was identical to that described for the simultaneous discrimination procedure in Experiment 1 where all trials entailed a discrimination between 5 and 35 elements, that is, a disparity of 30 elements.

The stimulus elements consisted of the familiar ASCII character 42 ("*"). The five stimulus pairs were composed of stimuli with, respectively, 19:21, 18:22, 16:24, 12:28 and 4:36 elements, i.e., stimulus disparities of 2, 4, 8, 16, and 32 elements, respectively. All five pairs appeared with equal probability on each new trial. A trial began with the simultaneous presentation of both choice keys displaying one of the five pairs of stimuli and ended with a response to either key. Birds P25, P4008 and P4398 were trained in this procedure for 31 sessions, birds P5 and P14 for 30 sessions and bird P15 for 29 sessions. Individual birds, in accordance with their respective reinforcement history in Experiment 1, were reinforced for responding to the numerically smaller stimulus ("few elements" correct birds P25 and P14) or to the numerically larger stimulus ("many elements" correct birds P4008, P5, P4398, and P15). For birds P25, P4008 and P4398, all sessions ended after 500 trials or 100 reinforcements, whichever came first. Bird P5 completed 20 sessions of 600 trials and 10 sessions of 500 trials per session. Bird P15 remained in the procedure for 19 sessions of 600 trials and 10 sessions of 500 trials per session, and P14 for 19 sessions of 600 trials and 11 sessions of 500 trials per session. The reduction in session length was necessitated by some individuals' extended session durations and permitted daily running of all birds in the single test apparatus. A session ended after the specified number of trials or 100 reinforcements, whichever came first.

To control for differences in performance as a function of the nature of the assigned positive stimulus ("few" or "many" elements"), birds P5, P14 and P15 followed initial training with an additional 30 sessions in the same procedure but with a reversal of the positive stimulus. Bird P14 was now reinforced for responding to the numerically larger, and birds P5 and P15 for responding to the numerically smaller stimulus. All other parameters remained unchanged. All sessions ended after 500 trials or 100 reinforcements, whichever came first.

Procedure: Probes. For all birds, probe trials were substituted for 56 baseline trials on each of the final 15 sessions in the experiment, i.e., after completion of 31 sessions (birds P25, P4008, and P4398), 60 sessions (birds P5 and P14), or 59 (P15) sessions. The baseline disparities and the respective S+ assignment contained those on the immediately preceding 30 sessions. Fourteen probe trials were conducted for each of four probe stimulus-pairs for a total of 56 possible probes per session.

The sequence in the trials was random. Correct responses on probe trials were followed by secondary reinforcement only, and errors on probe trials were not followed by correction trials. For birds reinforced for responding to the numerically smaller stimulus, the probes consisted of four pairs of stimuli with 12:16, 12:18, 24:28, and 24:36 elements, respectively, while of pairs with 24:28, 22:28, 12:16 and 4:16 elements, respectively, for birds reinforced for responding to the numerically larger stimulus. Therefore, with respect to baseline trials the procedure incorporated two each of probes composed of normally positive, and of normally negative stimuli for both groups of birds. A session ended after 500 trials or 100 reinforcements. The number of sessions and trials completed are shown in Table 2.

Table 2A shows the percentage of "few" elements relative to "many" elements in each stimulus pair, and the percentage of absolute element differences between comparison stimuli for both baseline and probe stimulus disparities. The table shows that for the "few elements" correct birds stimulus pair 16:24 (disp. 8) on baseline trials, and the two probe stimulus pairs 24:36 (disp. 12, both stimuli normally negative) and 12:18 (disp. 6, both stimuli normally positive), had an equal relative density difference of 66.6 percent. None of the probes for the "many elements" correct birds had corresponding density values on baseline disparities.

Table 2
Procedures and Individual Training, Experiment 2

Bird	Procedure	(S+)	Stimulus Pairs	Trials Completed	# of Sessions
P25	5D 1ET	(F)	4:36,12:28,16:24, 18:22,19:21	15210	31
	Probes	(F)	12:16,18;24:28,36	7500	15
	5D 2ET	(F)	4:36,12:28,16:24 18:22,19:21	20794	42
	3D 2ET	(F)	2:4,4:8,2:8	12854	26
P4398	5D 1ET	(M)	4:36,12:28,16:24 18:22,19:21	15420	31
	Probes	(M)	24,22:28;12,4:16	7500	15
	5D 2ET	(M)	4:36,12:28,16:24 18:22,19:21	20937	42
	3D 2ET	(M)	2:4,4:8,2:8	13000	26
P4008	5D 1ET	(M)	4:36,12:28,16:24, 18:22,19:21	15481	31
	Probes	(M)	24,22:28;12,4:16	7500	15
	5D 2ET	(M)	4:36,12:28,16:24 18:22,19:21	20822	42
P5	5D 1ET	(M)	4:36,12:28,16:24 18:22,19:21	16291	30
	S+ change	(F)	" "	14734	30
	Probes	(F)	12:16,18;24:28,36	7500	15
	5D 2ET	(F)	4:36,12:28,16:24 18:22,19:21	20576	42
P14	5D 1ET	(F)	4:36,12:28,16:24 18:22,19:21	16308	30
	S+ change	(M)	" "	14861	30
	Probes	(M)	24,22:28;12,4:16	7500	15
	5D 2ET	(M)	4:36,12:28,16:24 18:22,19:21	20508	42
P15	5D 1ET	(M)	4:36,12:28,16:24 18:22,19:21	14633	29
	S+ change	(F)	" "	15000	30
	Probes	(F)	12:16,18;24:28,36	7500	1

Session length = 500 trials, except on first procedure for P5,600(20), 500(10), P14 600(19), 500(11) and P15 600(19), 500(10). Legend: 5D=5 Disparities, 3D=3 Disparities; 1ET=1 Type of Element, 2ET=2 Types of Elements; F="few," M="many"

Table 2A
Simultaneous Discrimination Procedure, Five Disparities
Relative Density Values, All Stimulus Pairs

Stimulus Pairs	Dis-parity	% Density of "few"	% Absolute diff.
1. 5 Disparities, 1 Type of Element			
A. Baseline Disparities			
4:36	32	11.1	88.9
12:28	16	42.8	57.2
16:24	8	66.6	33.3
18:22	4	81.8	18.2
19:21	2	90.4	9.6
B. Probe Disparities			
a) "Few elements" correct birds			
24:36	12	66.6	33.3
24:28	4	85.7	14.3
12:18	6	66.6	33.3
12:16	4	75.0	25.0
b) "Many elements" correct birds			
4:16	12	25.0	75.0
12:16	4	75.0	25.0
22:28	6	78.6	21.4
24:28	4	85.7	14.3
2. 3 Disparities, 2 Types of Elements, Densities for Asterisks only			
2:8	6	25.0	75.0
4:8	4	50.0	50.0
2:4	2	50.0	50.0

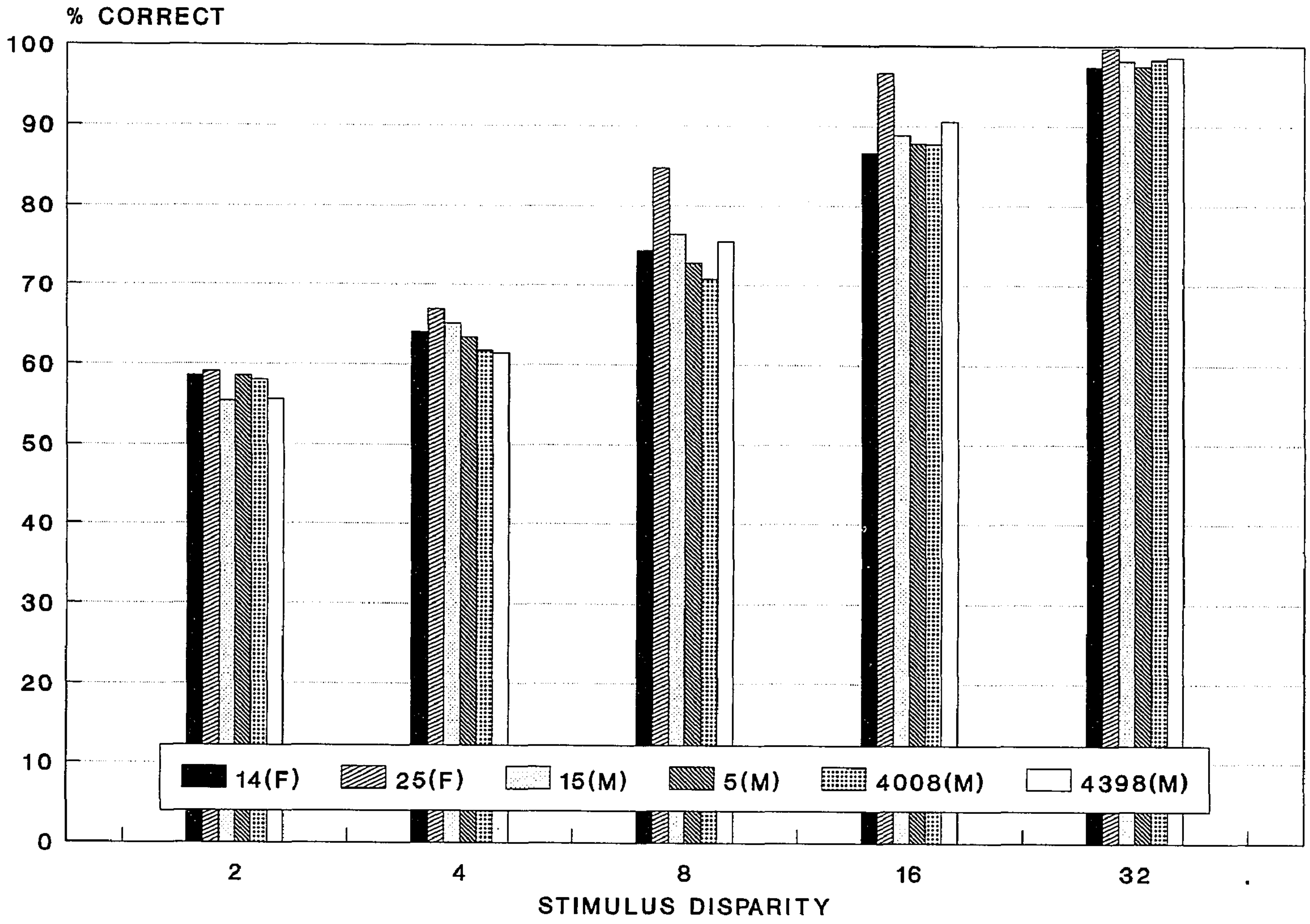
The two probe stimulus pairs 24:28 and 12:16, both with a disparity of 4 elements, were used for both groups. Both stimuli in pair 24:28 were normally positive and both stimuli in pair 12:16 normally negative for the "many elements" correct birds, while the reverse held true for the "few elements" correct birds.

Results: Training with Multiple Disparities and with the S+ Reversed. The data for the final 20 sessions were pooled for each bird, and mean percent trials correct calculated using non-correction trials only.

Figure 2.1 illustrates mean percent trials correct for each bird and all disparities on initial training. As the graph shows, increases in percent correct responses were related to increases in the disparity of the number of elements. A comparison of the individual performances reveals negligible differences among subjects, suggesting that the identity of S+ "few" or "many" did not differentially influence performances. The exception was "few elements" correct bird P25, who discriminated substantially better than all other birds on disparities 8 and 16.

The overall means calculated for all subjects for the respective five stimulus disparities (2, 4, 8, 16 and 32 elements) were 57.3, 63.8, 75.8, 89.8 and 98.3 percent of trials correct. The relative homogeneity of the function across birds can be seen by the fact that among birds there is no overlap in percent correct for adjacent disparities. Between disparities 2:4, 4:8, 8:16, and 16:32, the averaged performances increased by 6.5, 12.0, 14.0, and 8.5 percent. While the largest gain occurred between disparities 8 and 16, the observed reduction in the discrimination increment between disparities 16:32 is due to a ceiling effect imposed by the superior performances on the two largest disparities.

Figure 2.1. Simultaneous discrimination training with stimulus disparities of 2, 4, 8, 16, and 32 elements. The data are shown for each subject as mean percent trials correct averaged for the final 20 sessions. On each disparity, the performances for birds reinforced for responses to the numerically smaller stimuli ("few elements" correct birds P14 and P25) are depicted by the two bars on the left. The remaining bars illustrate performances for birds reinforced for responses to the numerically larger stimuli ("many elements" correct birds P15, P5, P4008, P4398).


% CORRECT
100
90
80
70
60
50
40
30
20
10
0
2
4
8
16
32
STIMULUS DISPARITY
14(F)
25(F)
15(M)
5(M)
4008(M)
4398(M)

While the "few elements" correct group performed overall somewhat better than the "many elements" correct group on all disparities, this group difference was attributable primarily to superior performances by "few elements" bird P25. Table 2B shows the range in performances on the five disparities for all subjects, and and separately with bird P25 excluded. An inspection of the percentages shows that with bird P25 excluded, group differences were negligible.

Individual mean percent correct responses and overall means for all subjects averaged for the final 20 sessions on the procedure with the S+ reversed are illustrated in Figure 2.2 for subjects P14, P5 and P15 together with the birds' respective performances on initial training. An inspection of the performances shows a close similarity in the subjects' behaviors on the two respective conditions.

The exception was bird P15. With the S+ reversed, this bird showed a severe decrement in performance, compared both to her performance on initial training, as well as in comparison to the performances by the other two subjects. P15 showed physical as well as behavioral deficits at this time and was removed from the study subsequent to the probe sessions. The data for this bird are shown in Figure 2.2 but were not included in the calculation of group means.

Table 2C shows the data as percent trials correct for all conditions, including performances on baseline trials on probe sessions. The table also shows changes in percent correct responses between conditions, i.e., between initial training and training with the S+ reversed, between training with the S+ reversed and probe-session baseline trials for birds trained with the S+ reversed, and between initial training and probe-session baseline trials for the non-reversed birds.

Table 2B
Simultaneous Discrimination Procedure, Five Disparities
Group Mean Percent Correct, Final 20 Sessions
Range In Performances With And Without P25

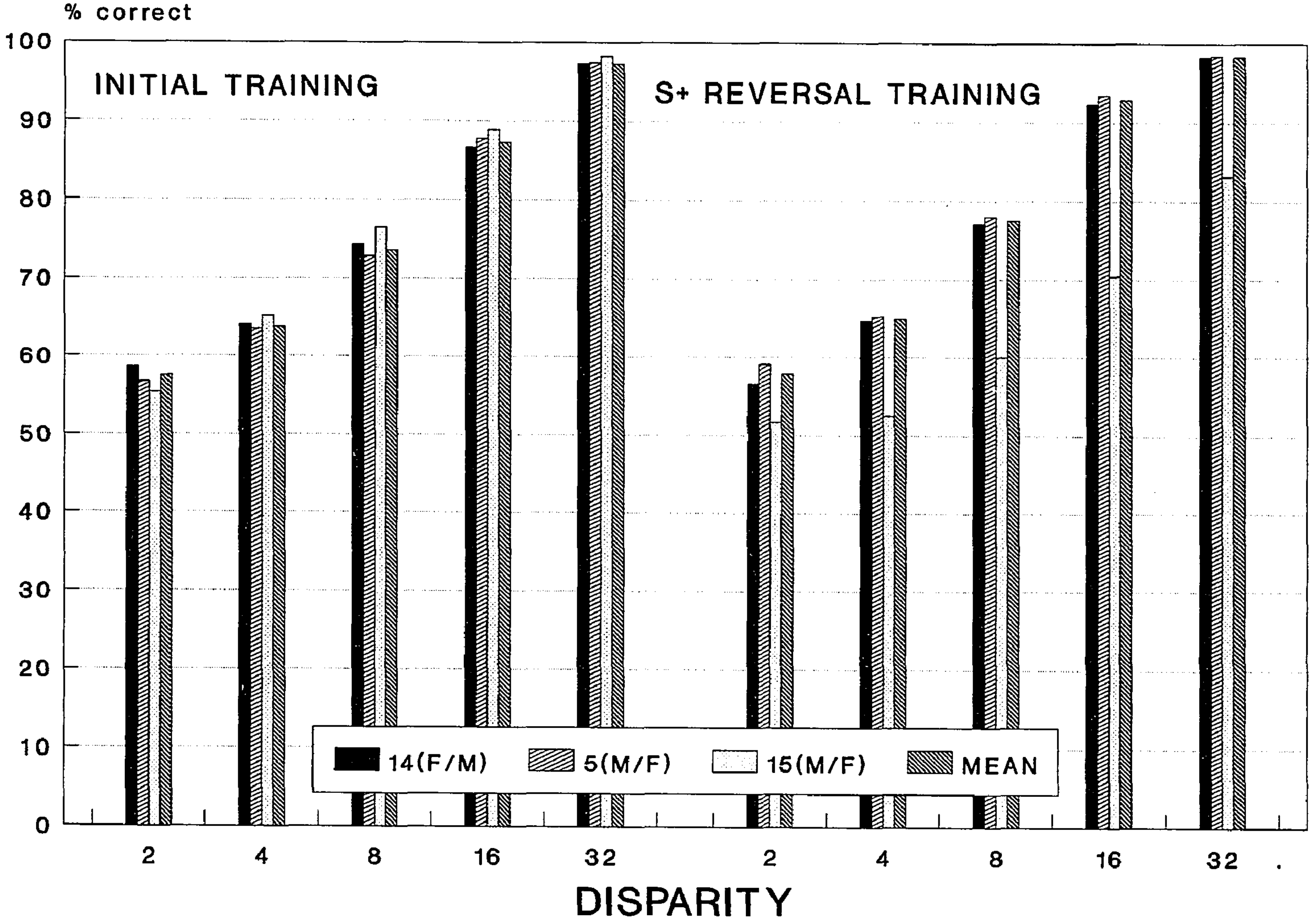
Disparity	Range All Birds	Range Without Bird P25
32	97.4-99.7 + 2.3	97.4-98.6 +1.2
16	86.7-96.6 + 9.9	86.7-90.6 +3.9
8	70.7-84.8 +14.1	70.7-76.5 +5.8
4	61.4-67.0 + 5.6	61.4-65.2 +3.8
2	55.4-59.2 + 3.8	55.4-58.6 +3.2

Table 2C
Simultaneous Discrimination Procedure, Five Disparities
Change in Percent Correct Responses Between Conditions
Individual Mean Percent Trials Correct
Final 20 Sessions Pooled

Bird	Procedure	Disparities and Percent Change									
		32	%	16	%	8	%	4	%	2	%
P4398	IT	98.6		90.6		75.5		61.4		55.6	
(M)	B	97.6	-1.0	89.7	-0.9	75.6	+0.1	68.1	+6.7	55.4	-0.2
P4008	IT	98.3		87.7		70.7		61.7		58.1	
(M)	B	99.0	+0.7	90.6	+2.9	73.8	+3.1	61.5	-0.2	57.3	-0.8
P25	IT	99.7		96.6		84.8		67.0		59.2	
(F)	B	99.8	+0.1	95.6	-1.0	84.8	0.0	69.7	+2.7	62.4	+3.1
P14	IT	97.4		86.7		74.3		64.1		58.6	
(F/M)	S+	98.4	+1.0	92.3	+5.6	77.1	+2.8	64.7	+0.6	56.6	-2.0
	B	98.1	-0.3	93.5	+1.2	78.7	+1.6	65.0	+0.3	54.0	-2.6
P5	IT	97.5		87.8		72.8		63.5		56.8	
(M/F)	S+	98.5	+1.0	93.5	+5.7	78.0	+5.2	65.3	+1.8	59.1	+2.3
	B	98.6	+0.1	95.4	+1.9	81.8	+3.8	70.2	+4.9	59.7	+0.6
P15	IT	98.2		88.9		76.5		65.2		55.4	
(M/F)	S+	83.2	-15.0	70.5	-18.4	60.0	-16.5	52.6	-12.6	51.7	-3.7
	B	82.9	-0.3	71.9	+1.4	61.1	+1.1	55.6	+3.0	52.2	+0.5

IT = Initial Training
S+ = S+ reassigned condition
B = Probes: Baseline Trials

Figure 2.2. Simultaneous discrimination training and training with the S+ reversed, with stimulus disparities of 2, 4, 8, 16, and 32 elements. Each bar represents mean percent correct responses for the final 20 sessions in the respective procedure. For each stimulus disparity, the four bars represent, from left to right, performances for P14 ("few-" changed to "many elements" correct), P5 ("many-" changed to "few elements" correct), P15 ("many-" changed to "few elements" correct), and group mean percent correct responses. Group means do not include the data for bird P15.

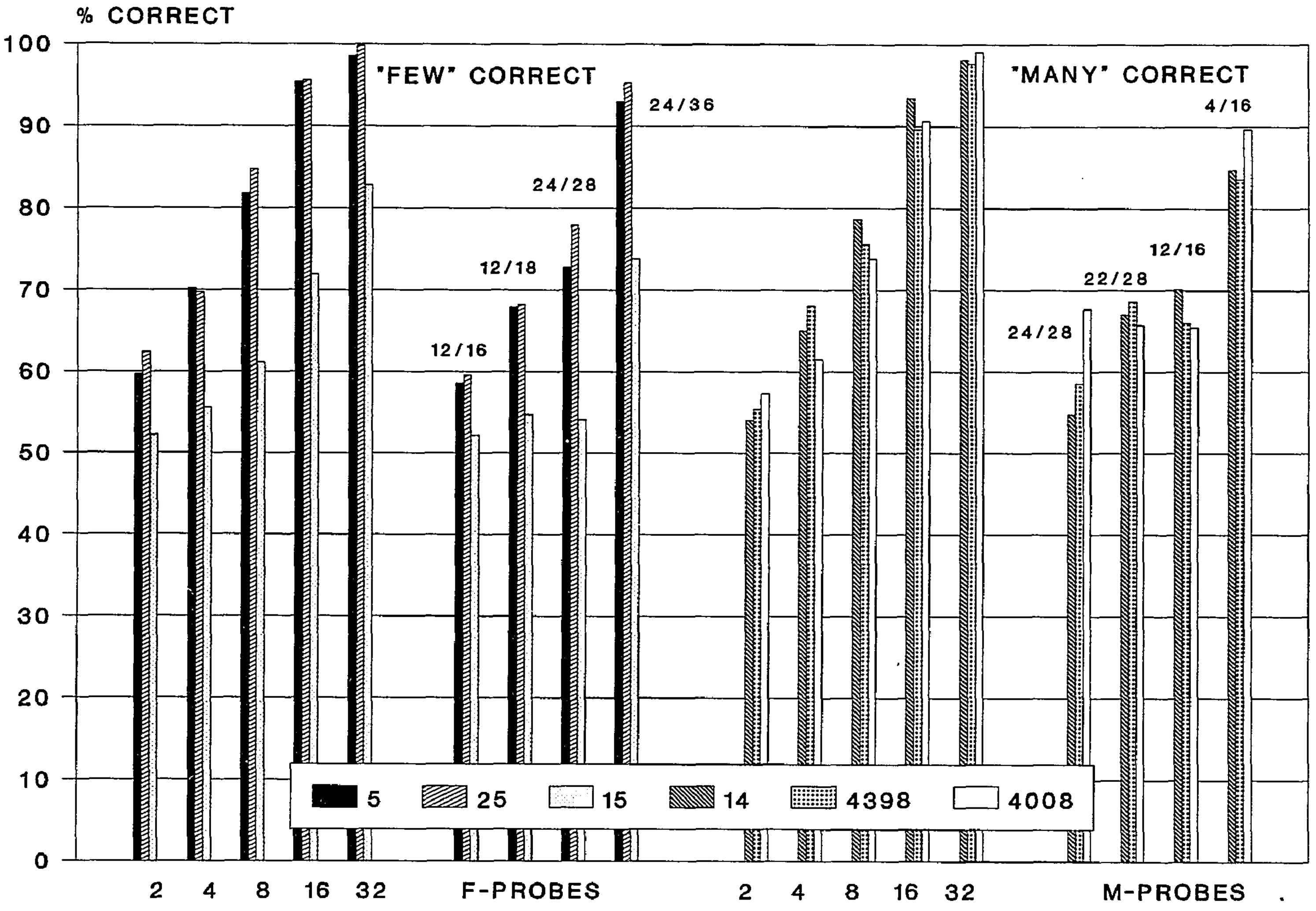

% correct
100
90
80
70
60
50
40
30
20
10
0
INITIAL TRAINING
S+ REVERSAL TRAINING
14(F/M)
5(M/F)
15(M/F)
MEAN
2
4
8
16
32
2
4
8
16
32
DISPARITY

A comparison of the performances on initial training and training with the S+ reversed reveals negligible differences in mean percent trials correct for disparities 2, 4 and 32. The only notable differences in performance occurred on disparities 8 and 16 for Birds P14 ("few-" reassigned to "many correct") and P5 ("many-" reassigned to "few correct"). In comparison to initial training, the performance by bird P14 improved by 2.8 percent on disparity 8 and by 5.6 on disparity 16 on the reversed S+ condition. Similarly, the performance by bird P5 improved by 5.2 percent on disparity 8 and by 5.7 percent on disparity 16.

Results: Probe Sessions. Overall, similar to behaviors in the preceding training, on probe-session baseline trials as well as on each type of probes (S- only and S+ only) between-disparity increases in discrimination were related to increases in stimulus disparity for both groups of birds. Both groups performed substantially better on S- only probes than on S+ only probes. Thus in comparison to baseline performances on comparable disparities, the birds discriminated substantially better on S- only probes and moderately worse on S+ probes.

Figure 2.3 shows probe-session performances for each subject and all disparities both for baseline trials and probe trials as percent trials correct averaged across all 15 probe sessions. Non-correction trials only were used to calculate the percentages correct for performances on baseline trials. There were no correction trials for errors on probes. Group mean percent correct responses for each probe are further illustrated in Figure 2.4 for both groups of birds and the data for behaviors to each choice key are shown for all probe disparities in Table 2D as mean percent correct. For disparity 4, which was used on both regular and probe trials, mean percent correct responses are shown both for regular trials and probe trials.

Figure 2.3. Simultaneous discrimination training with probe sessions. The data are shown as mean percent correct responses averaged for all 15 probe sessions. The left half of the graph depicts performances for the "few elements" correct group and the right half of the graph performances for the "many elements" correct group. For each group, performances on baseline trials with stimulus disparities of 2, 4, 8, 16, and 32 elements are shown by the five bars on the left, and performances on probe trials by the four bars on the right. For both groups, the stimulus-pairs on S+ probes differed by 4 and 6 elements, and by 4 and 12 elements on S- probes. The numerical value of the elements in the probe stimulus-pairs for the "few" group was 12:16 (S+ only),12:18 (S+ only), 24:28 (S- only), and 24:36 (S- only), and for the "many" group 22:24 (S+ only), 24:28 (S+ only), 4:12 (S- only), and 12:16 (S- only).


% CORRECT
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30
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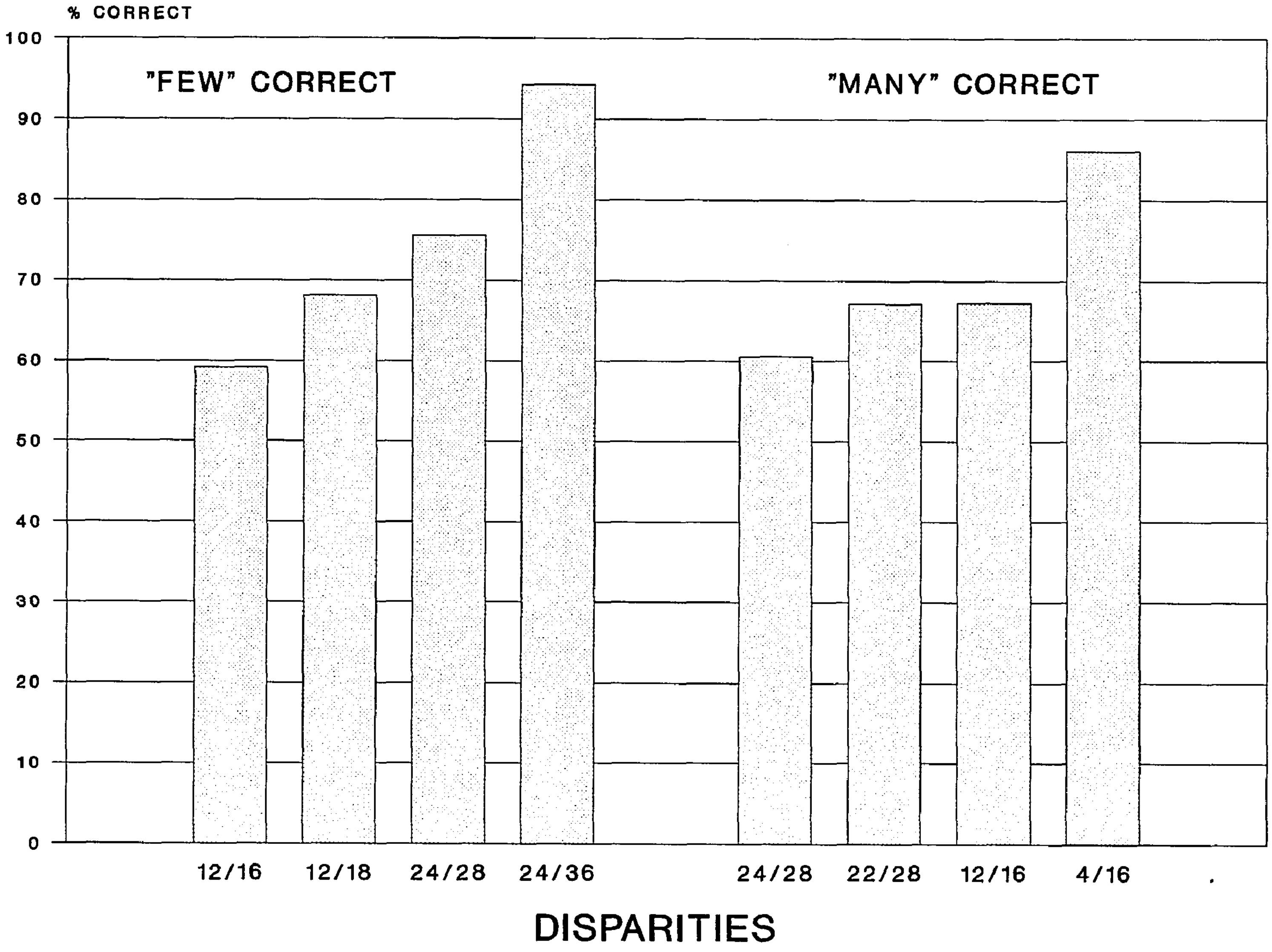
10
0
"FEW" CORRECT
"MANY" CORRECT
12/16
12/18
24/28
24/36
24/28
22/28
12/16
4/16
5
25
15
14
4398
4008
2
4
8
16
32
F-PROBES
2
4
8
16
32
M-PROBES

Figure 2.4. Group mean percent trials correct for probe trials. The performances, averaged for each group across the 15 probe sessions, are shown for the "few elements" correct birds by the four bars on the left, and for the "many elements" correct birds by the four bars on the right. For each group the first two bars on the left show performances for S+ only probes, and the next two bars performances for S- only probes. For both groups, the two S+ only stimulus-pairs differ by 4 and 6 elements, and the two S- only stimulus-pairs by 4 and 12 elements, respectively. For the "few elements" correct birds, the four respective probes consisted of stimuli with 12:16(S+ only),12:18(S+ only), 24:28(S- only), and 24:36(S- only) elements, and for the "many elements" correct birds of stimuli with 24:28(S+ only), 22:28(S+ only), 12:16(S- only), and 4:16(S- only) elements.


% CORRECT
100
90
80
70
60
50
40
30
20
10
0
"FEW" CORRECT
"MANY" CORRECT
12/16
12/18
24/28
24/36
24/28
22/28
12/16
4/16
DISPARITIES

The stimulus disparities of 6 and 12 elements were used on probe trials but not on the baseline condition. For discussion purposes, the performances on these disparities are compared to performances on the numerically closest baseline disparities.

A comparison of the baseline- and probe-trial performances reveals that with respect to baseline, for S+ only probe disparity 4 the performance by the "few elements" correct birds was 10.8 percent lower, and the performance by the "many elements" correct birds 4.2 percent lower. The "few elements" correct birds averaged 69.9 percent of trials correct on baseline disparity 4, 59.1 percent correct on S+ only probe disparity 4, and 68.1 on S+ only probe disparity 6. The "many elements" correct birds averaged 64.8 percent of trials correct on baseline disparity 4, 60.6 percent correct on S+ only probe disparity 4, and 67.1 percent correct on S+ only probe disparity 6.

On probe disparity 6, which was not used on the baseline condition, the performances by the "few elements" correct birds were worse, while the performances by the "many elements" correct birds were slightly better than the respective performances on baseline stimulus disparity 4.

Compared to performances on both baseline and S+ only probe trials, both groups discriminated better on comparable S- only probe disparities. On probe disparity 4, the "few elements" correct group responded correctly on 75.5 percent, and the "many elements" correct group on 67.2 percent of trials. Hence compared to baseline disparity 4, the performance by the "few elements" correct birds was better by 5.6 percent, and the performance by the "many elements" correct birds better by 2.3 percent.

While probe disparity 12 was not used on baseline trials, the data show that the performance by the "few elements" correct group on disparity 12 (94.3 percent correct) differed only negligibly (-1.2 percent) from the group's performance on baseline disparity 16 (95.5 percent correct), clearly a superior performance in the presence of S- stimuli. A similar comparison for the "many elements" correct group shows a less substantial increase in percent correct responses on S- only probe disparity 12, although the overall performance (86.1 percent correct) similarly suggests a facilitation of the discrimination in comparison to the nearest baseline stimulus disparities 16 (91.3 percent correct) and 8 (76.0 percent correct). That is, on probe disparity 12, the "many elements" correct birds performed overall 10.1 percent better than on baseline disparity 8, but fell by 5.2 percent short of the averaged performance observed on baseline disparity 16.

A between-group comparison for each of the two types of probes shows that on S- only probes, the group trained on "few elements" performed substantially better than the group trained on "many elements," both on disparity 4 (+8.3 percent) and disparity 12 (+8.2 percent). On S+ only probes, the group differences were negligible. The "many elements" correct birds performed slightly better than the "few elements" correct group on S+ only disparity 4 (+1.5 percent), while the "few elements" correct birds performed slightly better (+1.0 percent) on S+ only disparity 6. Thus, while the increase in percent correct responses between the two disparities on each type of probe was remarkably similar for the two groups, the level of discrimination was markedly dissimilar.

Group mean percent correct choice key responses are presented for baseline trials and each probe in Table 2D. The data show that all subjects preferentially responded to the left choice key on both types of probes. In both groups, this preference was more pronounced on S+ only probes than on S- only probes, and was substantially more pronounced on both types of probes compared to similar preferences on comparable

Table 2D
Simultaneous Discrimination Procedure, Five Disparities
Choice Key Preferences on Probe Sessions
Group Mean Percent Correct

Stimulus Pairs	Left	Right	% Difference	Overall % Correct
A: "Few Elements" Correct Birds				
12:16 (S+)	83.9	33.8	50.1	59.1
12:18 (S+)	89.1	47.0	42.1	68.1
24:28 (S-)	81.2	69.4	11.8	75.5
24:36 (S-)	95.9	92.6	3.3	94.3
B: "Many Elements" Correct Birds				
24:28 (S+)	83.0	38.7	44.3	60.6
22:28 (S+)	89.9	40.2	49.7	67.1
12:16 (S-)	74.5	59.2	15.3	67.2
4:16 (S-)	88.5	83.8	4.7	86.1
C: Baseline "Few Elements" Correct Birds				
19:21	75.9	46.2	29.7	61.6
18:22	85.3	54.2	31.1	69.9
16:24	91.9	74.5	17.4	83.3
12:28	98.6	92.2	6.4	95.5
4:36	100	98.5	1.5	99.2
D: Baseline "Many Elements" Correct Birds				
19:21	73.0	38.9	34.1	55.6
18:22	79.7	49.3	30.4	64.8
16:24	88.2	63.9	24.3	76.0
12:28	96.5	86.1	10.4	91.3
4:36	99.3	97.2	2.1	98.2

Group means for "few elements" correct birds do not include bird P15 baseline disparities.

Differences in responding to the two types of probes were further apparent from the response latencies recorded for the probe trials. The data presented in Table 2E show that the median latencies for S- only probes were consistently longer than the latencies for S+ only probes, and that among S- only probes, latencies on disparity 12 were generally longer than the latencies on disparity 6.

To confirm that the addition of probe trials did not affect behaviors on baseline trials, each subject's baseline performance on probe sessions was compared with the respective performance on the immediately preceding condition, i.e., either initial training or reversed S+ training, depending on the subject.

The data, summarized in Table 2F for all subjects except bird P15 show that overall, performances continued to improve moderately across conditions. The most substantial increase in percent correct responses was observed on the condition with the S+ reversed for the subjects trained on both multiple disparities procedures. Except for bird P14 (F/M) on stimulus disparity 2, both birds' performances improved on all disparities, and the differences in performance between the two conditions (i.e., initial training and S+ reversal training) were somewhat more pronounced for bird P5.

Since only three subjects were trained with the S+ reversed, the observed differences were likely due to chance. However, the finding that a change in the S+ assignment resulted in a more substantial improvement in performance than the additional training provided by probe-session baseline trials for the non-reversed subjects (as well as the S+ reversed subjects) suggests that as on S- probe trials, when trained with novel stimuli, response choices were based on different stimulus determinants. It is possible

Table 2E
Simultaneous Discrimination Training, Five Disparities
Median Latencies In Seconds
Probe Trials, All Birds

	Disparities			
Bird	S+Probes		S- Probes	
	4	6	4	12
14	4.4	5.0	6.0	7.0
25	.6	.6	1.2	.8
15	1.2	1.0	2.6	2.4
4398	1.4	1.2	1.8	2.4
5	.6	.6	.8	1.0
4008	.6	.6	.8	1.0

Table 2F
Simultaneous Discrimination Procedure, Five Disparities
Percent Change In Performance Between Conditions

		Disparities, Percent Change				
Bird	Procedure	32	16	8	4	2
P4398	5D 1ET					
	Baseline	-1.0	-0.9	+0.1	+6.7	-0.2
P4008	5D 1ET					
	Baseline	+0.7	+2.9	+3.1	-0.2	-0.8
P25	5D 1ET					
	Baseline	+0.1	-1.0	0.0	+2.7	+3.1
P14	5D 1ET					
	Reversal	+1.0	+5.6	+2.8	+0.6	-2.0
	Baseline	-0.3	+1.2	+1.6	+0.3	-2.6
P5	5D 1ET					
	Reversal	+1.0	+5.7	+5.2	+1.8	+2.3
	Baseline	+0.1	+1.9	+3.8	+4.9	+0.6

that on the S+ reversed condition the birds performed--at least initially--a simultaneous comparison of the unfamiliar stimuli and based their response choices on some relative difference contributed to by both stimuli.

A comparison of the probe-session baseline performances with performances on the immediately preceding multiple disparities conditions shows that birds trained on both conditions exhibited overall a more general further improvement on baseline trials than the subjects trained on one condition only. Among birds trained on the two multiple-disparities conditions, the most notable improvements occurred on disparities 4 (+4.9 percent) and 8 (+3.8 percent) for bird P5. For the group trained on one multiple-disparity condition only, the most notable improvements occurred on disparity 2 for bird P25 (+3.1 percent), on disparity 4 for birds P4398 (+6.7 percent) and P25 (+2.7 percent), and on disparities 8 and 16 for bird P4008 (+3.1, and +2.9 percent, respectively).

On baseline trials, the "few elements" correct group (P5 and P25) discriminated better than the "many elements" correct group (P14 and P4008) on all disparities. On the respective five stimulus disparities (2, 4, 8, 16 and 32 elements), the two groups differed by 1.0, 4.1, 7.3, 5.1 and 6.0 percent, respectively. These differences were likely the result of the composition of the two groups: while both were matched with respect to amount of training on the multiple disparities condition, i.e., in both groups one bird had been trained on both multiple-disparities conditions and one bird on one condition only, of the birds trained on one condition only, P25 was assigned to the "few elements" correct group. This bird's baseline performance on probes was superior to those of the remaining subjects on all disparities, hence the superior baseline performances by the "few elements" correct group was primarily the result of the performances by bird P25.

At this point a procedural change was introduced in the familiar five-disparities procedure by the addition of a second type of stimulus element, ASCII character 43 ("+"). While maintaining the integrity of the numerosity of the five stimulus pairs, this procedural change affected other differences in appearance of the stimulus pairs where one or both comparisons displayed the novel element type. This procedure attempted to assess the extent to which the response-choices were number-related, that is, whether the birds had formed some abstraction of the number of stimulus elements within each of the keys on the five disparities.

Procedure: 5 Disparities, 2 Types of Elements. The five birds were trained for 42 sessions on the five standard stimulus disparities with two different types of stimulus elements. The procedure was identical to that in the five disparities condition using asterisks only, except that on 75 percent of trials a novel element type, ASCII character 43 ("+") was introduced on one or both comparison stimuli. Each element type "+" covered approximately two-thirds of the area covered by the element type "*." As in the one element type procedure, the stimulus elements were colored black (color 0) and the non-elements (key background) colored green (color 2).

On each new trial, each of the five disparities was equally likely to appear with one of four possible combinations of element types, i.e., "*/+", "+/*", "*/*", and "+/+". On each session, 50 percent of trials were composed of uniform element type combinations (25 percent "+/+" and 25 percent "*/*") and 50 percent of trials of mixed element type combinations (25 percent "*/+" and 25 percent "+/*").

A trial began with the presentation of the two comparison stimuli in the choice key locations and was completed with a peck to either choice key. The intertrial interval for incorrect responses timed from the occurrence of a choice key peck to the onset of the next trial, was 6.0s. The intertrial interval for correct responses was .5s and was timed from feeder offset to the presentation of the two choice key stimuli signaling the next trial. Correction trials were instituted whereby an incorrect response occasioned the repetition of the exact stimuli for the trial on which the error occurred.

For each bird the assigned positive stimulus was consistent with that in the preceding simultaneous discrimination training. Birds P5 and P25 were reinforced for responding to the numerically smaller stimulus ("few elements" correct), and birds P14, P4398 and P4008 for responding to the numerically larger stimulus ("many elements" correct). The total number of sessions and trials completed are shown in Table 2.

Results. Since each of the 20 conditions accumulated only a small number of trials per session and the birds had prior experience with the five disparities, the data for each subject were pooled across all sessions and overall percent of trials correct were calculated using non-correction trials only.

The data for bird P4398 are not included in the discussion. This bird exhibited an overwhelming preference for the left choice key on all disparities, indicated by the high percentage of trials correct on the left-, compared to the right choice key, shown together with the performances for the remaining subjects in in Table 2G. With an extreme side preference, correct responses on that key are rarely missed, and a failure to switch when the correct response is required on the alternate key is counted as an error on the alternate key. Hence perfect "discrimination" scores on a preferred location are possible.

The graphs in Figure 2.5-2.8 show individual mean percent correct trials for all disparities and combinations. Graphs 2.5 and 2.6 show individual performances on uniform combinations of element type "+/+" and element type "*/*," respectively, and graphs 2.7 and 2.8 performances on mixed element type combinations ("+/*"), when the correct response was either to element type "+" or element type "*." To facilitate comparison of the behaviors on mixed combinations, the performances are shown in terms of "stimulus preference." As discussed below, the "few elements" correct birds tended to track stimulus element "+," and the "many elements" correct birds tended to track stimulus element "*." Graph 2.7 shows individual performances for the "preferred" stimulus element and graph 2.8 individual performances for the "non-preferred" stimulus element. In all graphs, the performances for the "few elements" birds P5 and P25 are depicted by the two bars on the left. The next two bars illustrate performances for the "many elements" correct birds P14 and P4008. For comparison and independent of S+ assignment, the averaged performances on the one-element type ("*") procedure immediately preceding the probe sessions are shown for each disparity by the bar at the extreme right.

As in the preceding multiple disparities procedure, the level of discrimination increased with an increase in disparity for both groups of birds. However, compared to the one-element procedure, the performances among subjects on the two-element procedure were substantially more variable on all disparities and combinations, although on uniform combinations group differences were negligible.

Figure 2.5. Simultaneous discrimination training with five disparities and two types of elements. The graph shows individual mean percent correct responses averaged across all sessions for uniform combination of element type "+/+." Overall mean percent correct performances on the preceding five-disparities one-element type procedure are added for each disparity for comparison. The "few elements" correct group consisted of birds P5 and P25, and the "many elements" correct group of birds P14 and P4008.

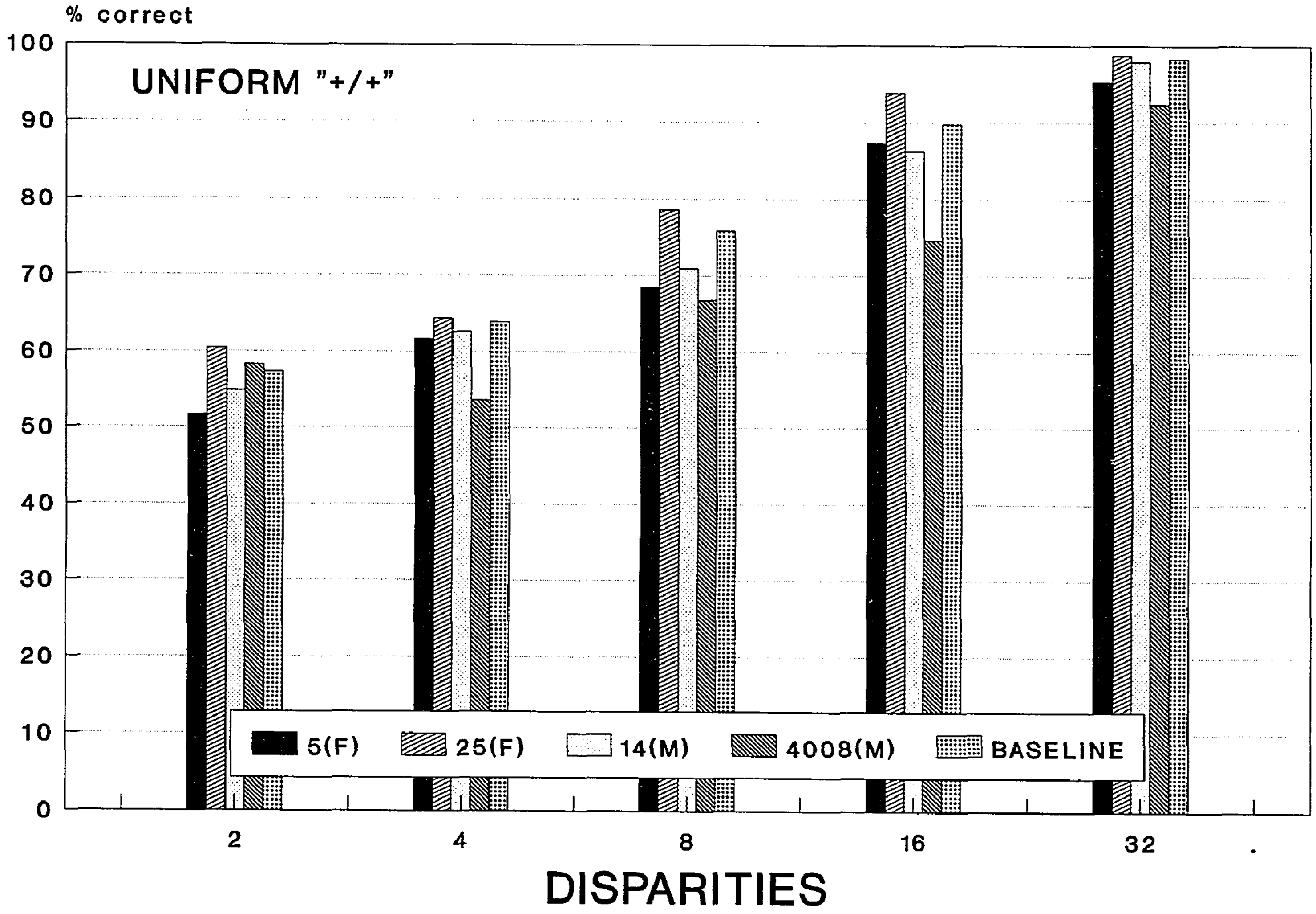

% correct
100
90
80
70
60
50
40
30
20
10
0
UNIFORM "+/+"
5(F)
25(F)
14(M)
4008(M)
BASELINE
2
4
8
16
32
DISPARITIES

Figure 2.6. Simultaneous discrimination training with five disparities and two types of elements. The graph shows individual mean percent correct responses averaged across all sessions for uniform combination of element type "*/*." Overall mean percent correct performances on the preceding five-disparities one-element type procedure are added for comparison for each disparity. The "few elements" correct group consisted of birds P5 and P25, and the "many elements" correct group of birds P14 and P4008.

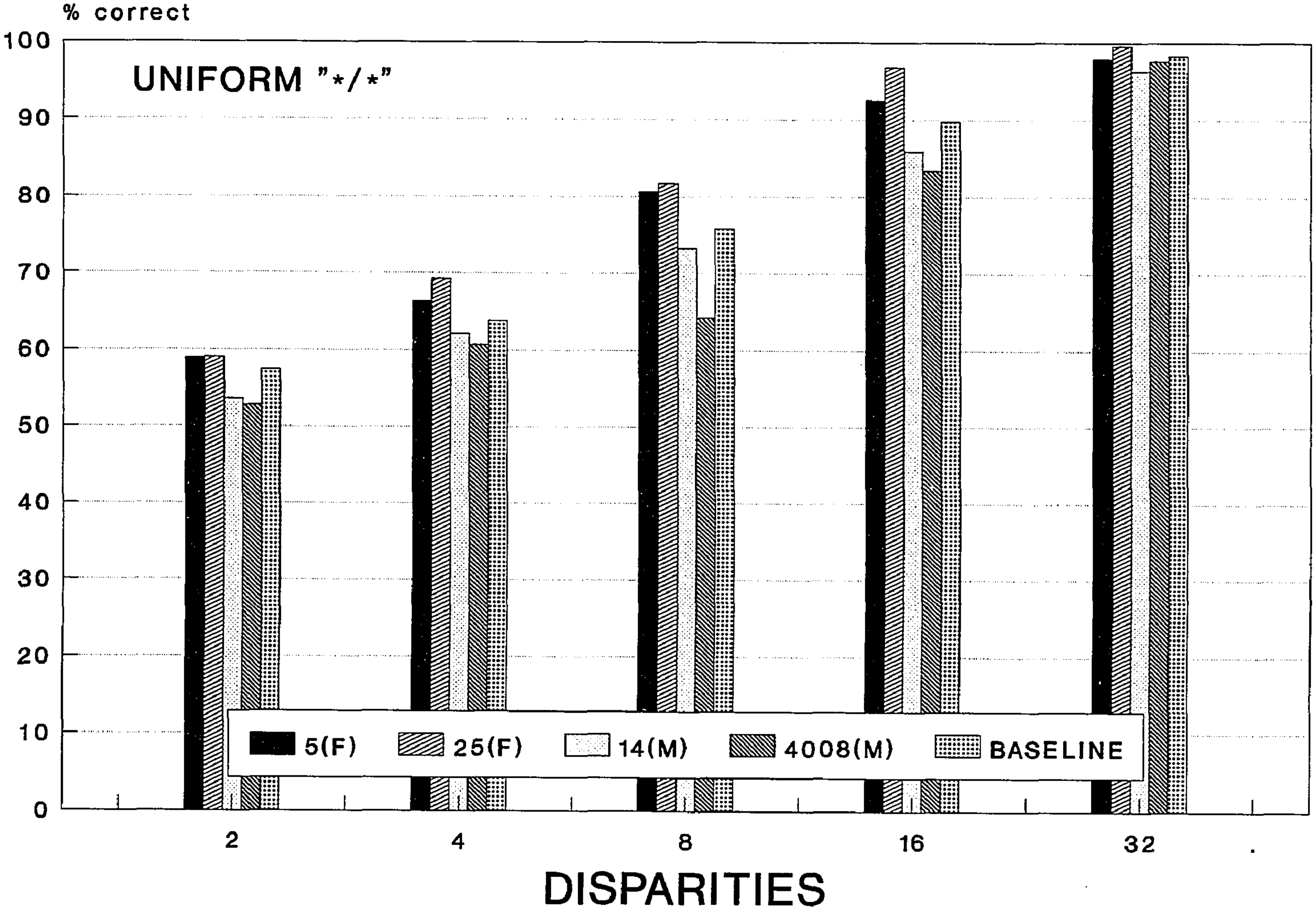

% correct
UNIFORM "*/*"
100
90
80
70
60
50
40
30
20
10
0
5(F)
25(F)
14(M)
4008(M)
BASELINE
2
4
8
16
32
DISPARITIES

Figure 2.7. Simultaneous discrimination training with five disparities and two types of elements, mixed combination. The graph shows individual mean percent trials correct averaged across all sessions to the "preferred" stimulus element. The "many elements" correct birds behaviorally tracked element type "*" and the "few elements" correct birds element type "+." For all disparities group mean percent correct performances on the preceding five-disparities one-element type procedure are added for comparison. The "few elements" correct group consisted of birds P5 and P25, and the "many elements" correct group of birds P14 and P4008.

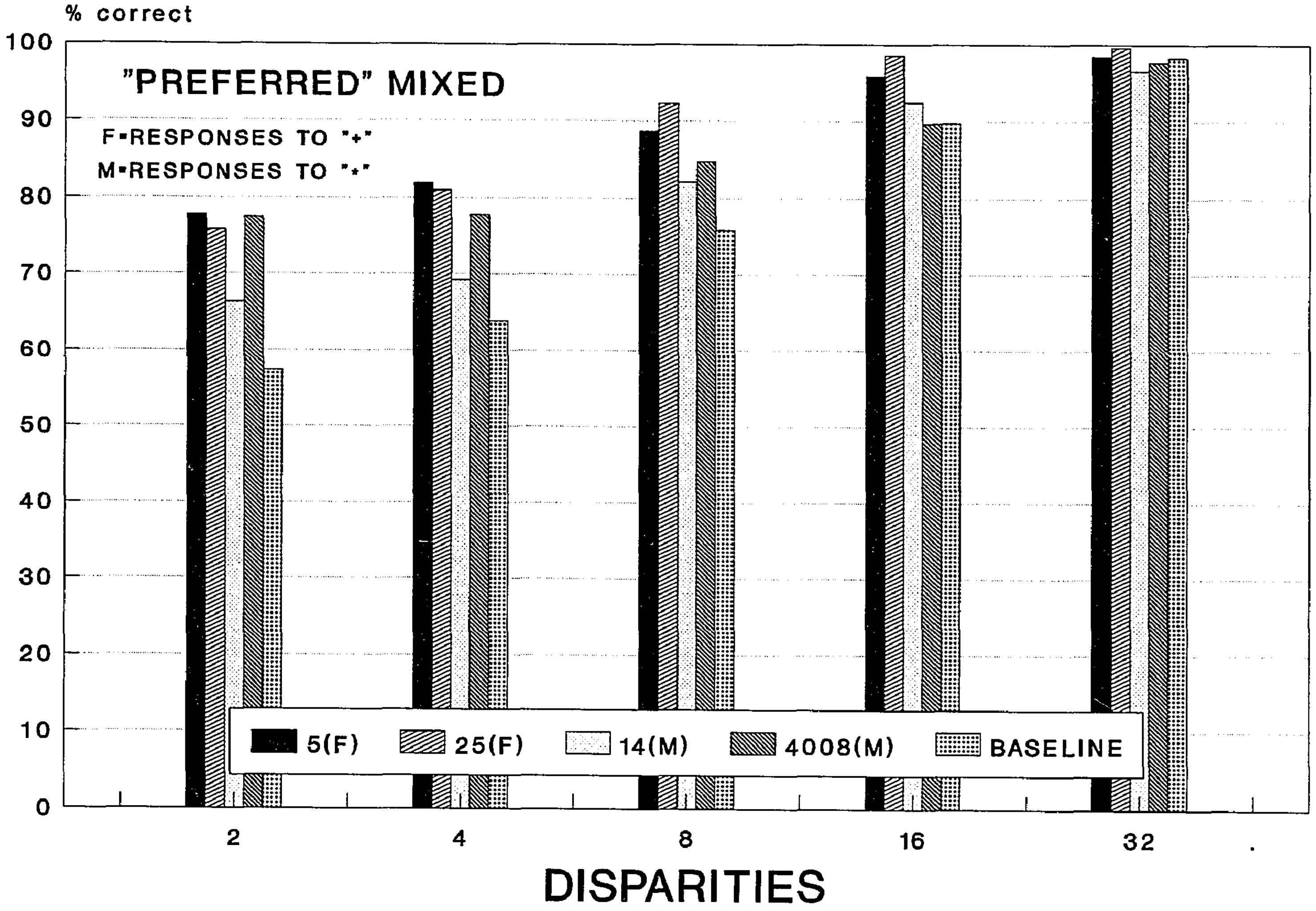
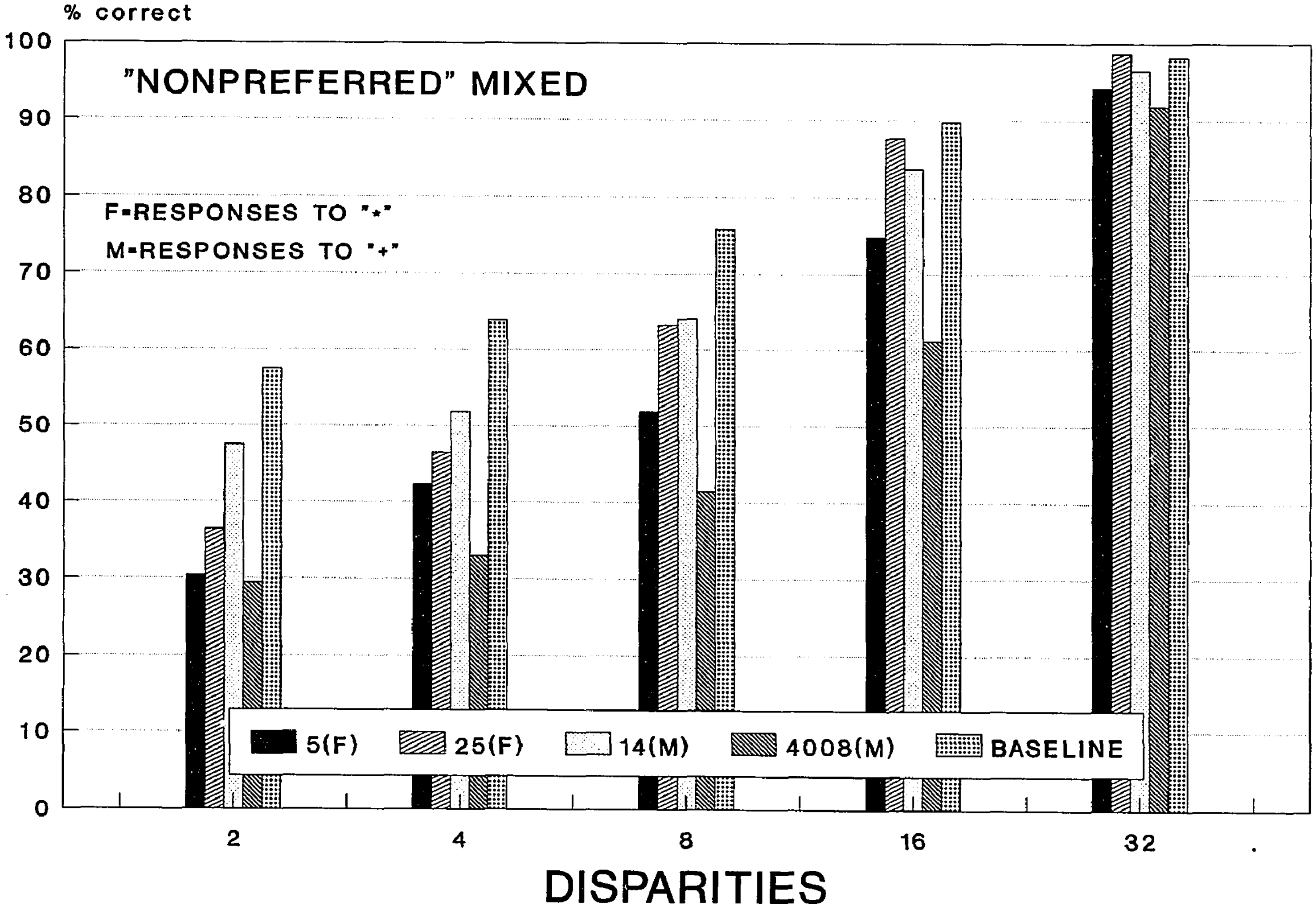

% correct
"PREFERRED" MIXED
F=RESPONSES TO "+"
M=RESPONSES TO "*"
100
90
80
70
60
50
40
30
20
10
0
5(F)
25(F)
14(M)
4008(M)
BASELINE
2
4
8
16
32
DISPARITIES

Figure 2.8. Simultaneous discrimination training with five disparities and two types of elements, mixed combination. The graph shows individual mean percent trials correct averaged across all sessions to the "non-preferred" stimulus element. For the "many elements" correct birds, the non-preferred stimulus element was of type "+" and for the "few elements" correct birds of element type "*." For all disparities, group mean percent correct performances on the preceding five-disparities one-element type procedure are added for comparison. The "few elements" correct group consisted of birds P5 and P25, and the "many elements"correct group of birds P14 and P4008.


% correct
"NONPREFERRED" MIXED
F=RESPONSES TO "*"
M=RESPONSES TO "+"
100
90
80
70
60
50
40
30
20
10
0
5(F)
25(F)
14(M)
4008(M)
BASELINE
2
4
8
16
32
DISPARITIES

Mixed Combinations. Individual performances on the mixed combination of element type "+/*," i.e., percent correct responses when the S+ coincided with element type "*" and conversely, when the S+ coincided with element type "+", are shown for all disparities in Figure 2.9 for the "few elements" correct birds and in Figure 2.10 for the "many elements" correct birds. In both graphs, the panel on the left shows percentages correct when the correct response coincided with stimulus element "*" and the panel on the right percentages correct when the correct response coincided with stimulus element "+."

A comparison of the performances by the two groups shows that except for negligible differences on disparity 32, when the correct response coincided with element type "+" the "few elements" correct group performed substantially better than the "many elements" correct group on all disparities, and performed substantially worse than the "many elements" correct group when the correct response coincided with element type "*".

The group differences in performance to the two element types are consistent with behavioral tracking of a preferred element by the two groups. The "few elements" correct birds preferentially responded to stimuli with the element type "+" and the "many elements" correct group to element type "*," evidenced by the behavioral differences observed between the two groups on the mixed combination.

The term "preferred element type" is used for descriptive purposes and does not imply that the birds literally preferred either of the two stimulus elements. The discrimination was equally likely based on the amount of stimulus element "material" which can reflect the number of elements as the amount of the key surface subsumed by an element, as on some abstraction of differences contributed to by both comparison

Figure 2.9. Simultaneous discrimination training with five disparities, mixed combination. The graph illustrates group mean percent trials correct for "few elements" correct birds, for stimulus disparities of 2, 4, 8, 16 and 32 elements. The lefthand panel illustrates performances to stimulus element "*" and the righthand panel performances to stimulus element "+."

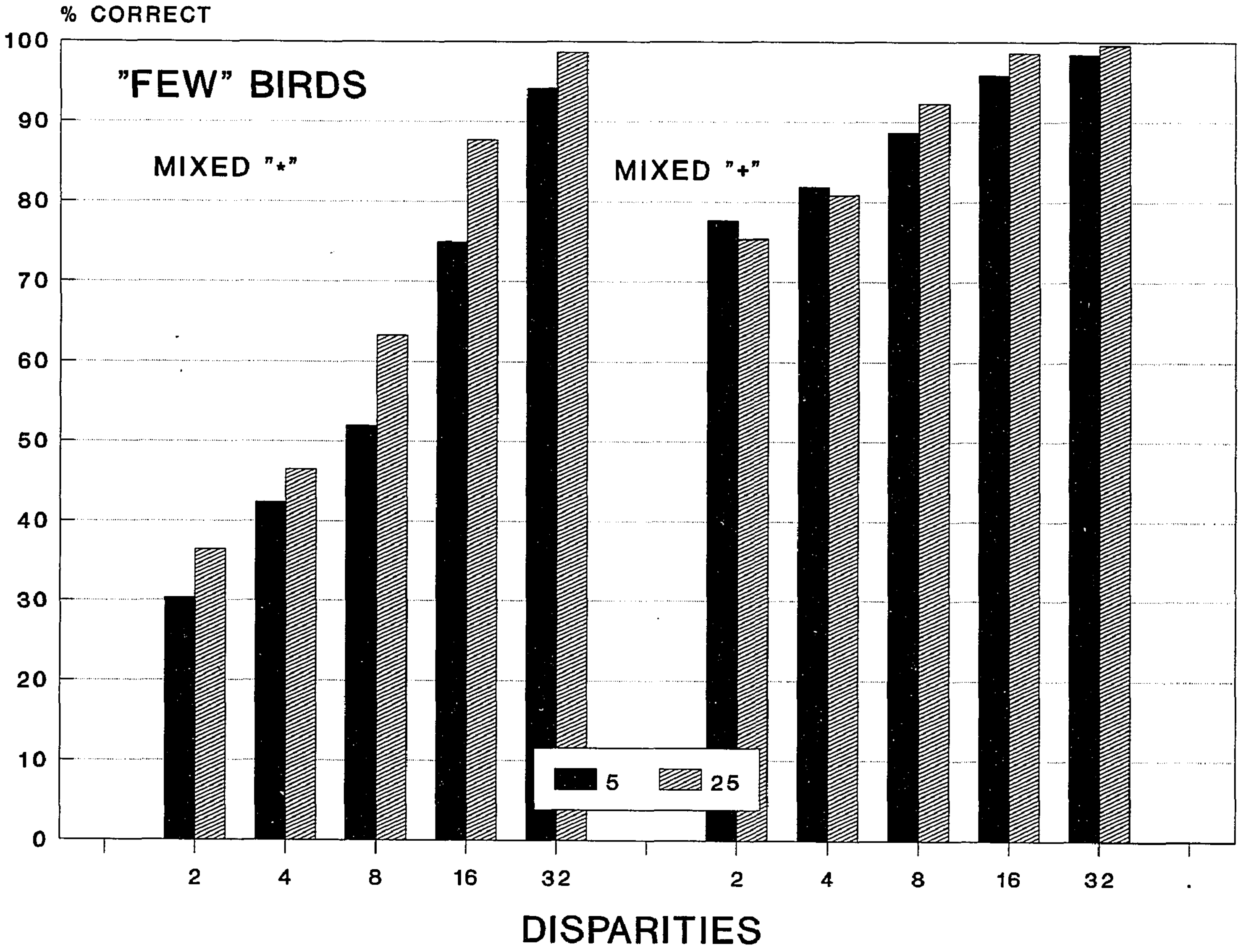
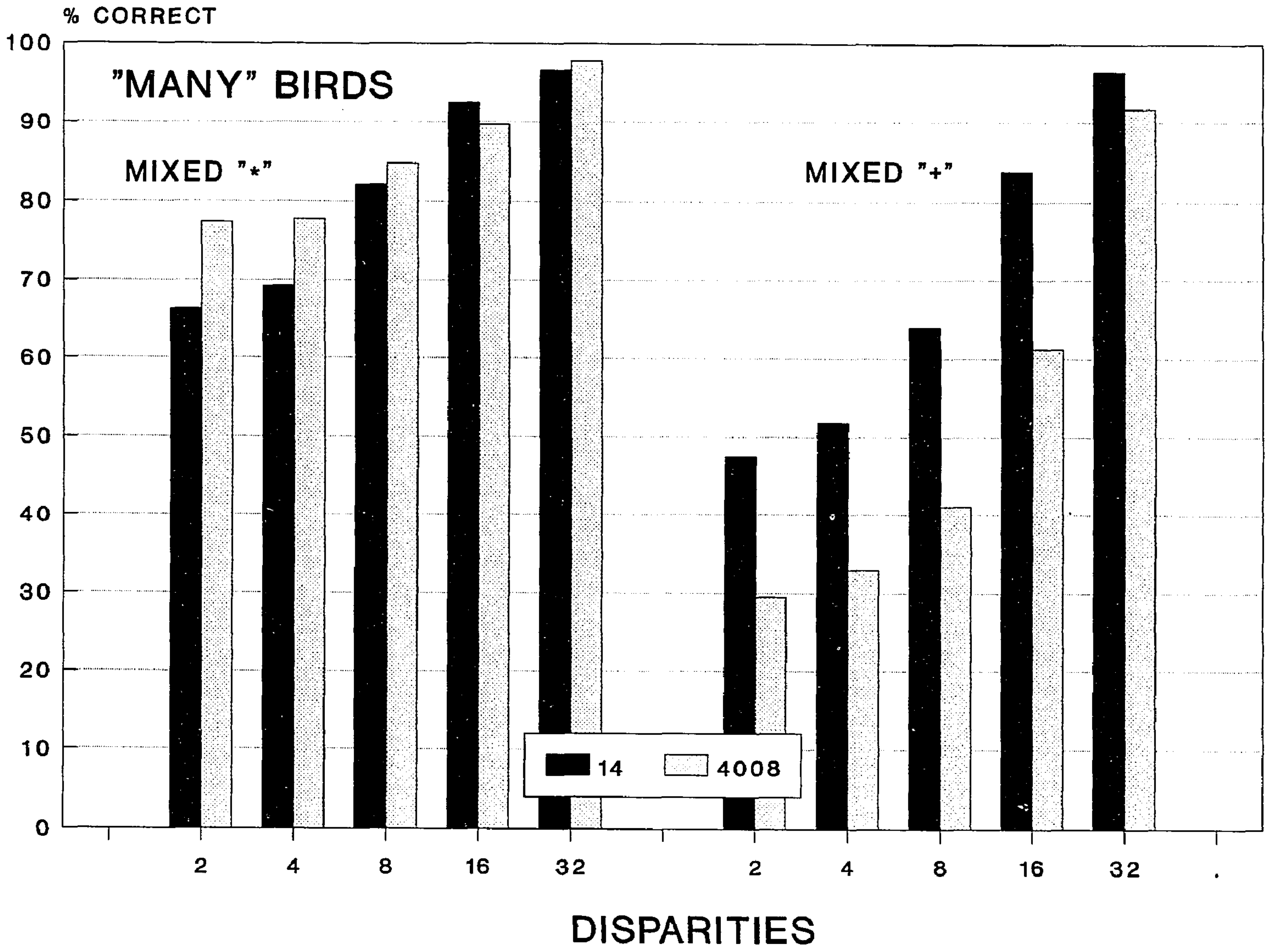

% CORRECT
"FEW" BIRDS
MIXED "*"
MIXED "+"
100
90
80
70
60
50
40
30
20
10
0
2
4
8
16
32
2
4
8
16
32
DISPARITIES
5
25

Figure 2.10. Simultaneous discrimination training with five disparities, mixed combination. The graph illustrates group mean percent trials correct for "many elements" correct birds for stimulus disparities of 2, 4, 8, 16 and 32 elements. The lefthand panel illustrates performances to stimulus element "*" and the righthand panel performances to stimulus element "+."


% CORRECT
100
90
80
70
60
50
40
30
20
10
0
"MANY" BIRDS
MIXED "*"
MIXED "+"
14
4008
2
4
8
16
32
2
4
8
16
32
DISPARITIES

The incidence of stimulus-type preference was considered analogous to the calculation described above for choice key preferences by substituting element type for choice key.

Individual choice key preferences on the two mixed combinations are illustrated for each bird in Table 2G as mean percent trials correct. An inspection of the data reveals that all subjects preferentially responded to the left choice key on all disparities and both combinations, with the most pronounced differences in preference occurring on disparities 2, 4, and 8, independent of the stimulus element. Overall, the "many elements" correct birds exhibited a greater degree of a left choice key preference than the "few elements" correct group. This group difference was more pronounced for responses to the preferred element.

Uniform Combinations. As for the mixed combination, the data for the uniform combinations were pooled for each subject across all sessions and mean percent trials correct calculated using non-correction trials only. Individual performances are shown in Figure 2.11 for the "many elements" correct group, and in Figure 2.12 for the "few elements" correct group for both combinations ("*/*" and "+/+") and all disparities. In both graphs, the left panel shows mean percent trials correct for combination "+/+," and the right panel mean percent trials correct for combination "*/*."

As in the preceding condition with one element type and in the present condition on the mixed combination, an increase in correct responding was related to increases in disparity between comparison stimuli. Overall, the "few elements" correct birds performed better than the "many elements" correct birds. Compared to group mean performances on the preceding probe session baseline condition, both groups performed worse on the uniform combination of element type "*/*" on all disparities.

Table 2G
Simultaneous Discrimination Procedure, Five Disparities
Two Element Types
Choice Key Performances, Mixed Combinations
Mean Percent Trials Correct, All Birds

Dis-parity	Mixed Combination "+" Correct"			Mixed Combination "*" Correct		
	L	R	Diff.	L	R	Diff.
	1. "Few Elements" correct Bird P25					
2	86.1	65.0	21.1	48.8	24.5	24.3
4	90.8	70.9	19.9	60.9	33.1	26.9
8	96.9	87.7	9.2	78.4	47.1	31.3
16	100	97.4	2.6	95.6	80.3	15.3
32	99.7	99.5	0.2	99.5	98.0	1.5
	2. "Few Elements" correct Bird P5					
2	88.8	67.0	21.8	45.2	17.4	27.8
4	93.1	70.1	23.0	56.4	27.1	29.3
8	94.3	83.5	10.8	68.3	37.3	31.0
16	98.2	93.5	4.7	86.6	63.2	23.4
32	99.7	96.9	2.8	98.0	90.4	7.6
	3. "Many Elements" correct Bird P4008					
2	43.8	16.6	27.2	92.3	61.9	30.4
4	49.7	17.3	32.4	91.8	64.5	27.3
8	57.3	24.1	33.2	93.1	76.2	16.9
16	73.9	47.5	26.4	97.6	83.4	14.2
32	95.9	87.6	8.3	99.1	96.3	2.8
	4. "Many Elements" correct Bird P14					
2	75.6	19.2	56.4	89.6	43.3	46.3
4	76.8	27.1	49.7	92.0	46.7	45.3
8	87.8	36.4	51.4	95.6	68.9	26.7
16	94.8	71.6	23.2	97.7	87.2	10.5
32	98.8	94.1	4.7	99.2	93.9	5.3
	5. "Many Elements" correct Bird P4398					
2	96.7	31.1	65.6	78.7	3.8	74.9
4	94.5	31.9	62.6	84.6	4.3	80.3
8	96.6	47.0	49.6	85.9	7.9	78.0
16	97.6	52.5	45.1	92.0	17.6	74.4
32	100	84.9	15.1	97.8	63.1	34.7

Figure 2.11. Simultaneous discrimination training with five disparities, uniform combinations. The graph illustrates group mean percent trials correct for "many elements" correct birds, for stimulus disparities of 2, 4, 8, 16, and 32 elements. The lefthand panel illustrates performances for uniform combination of element type "*/*" and the righthand panel performances for uniform combination of element type "+/+."

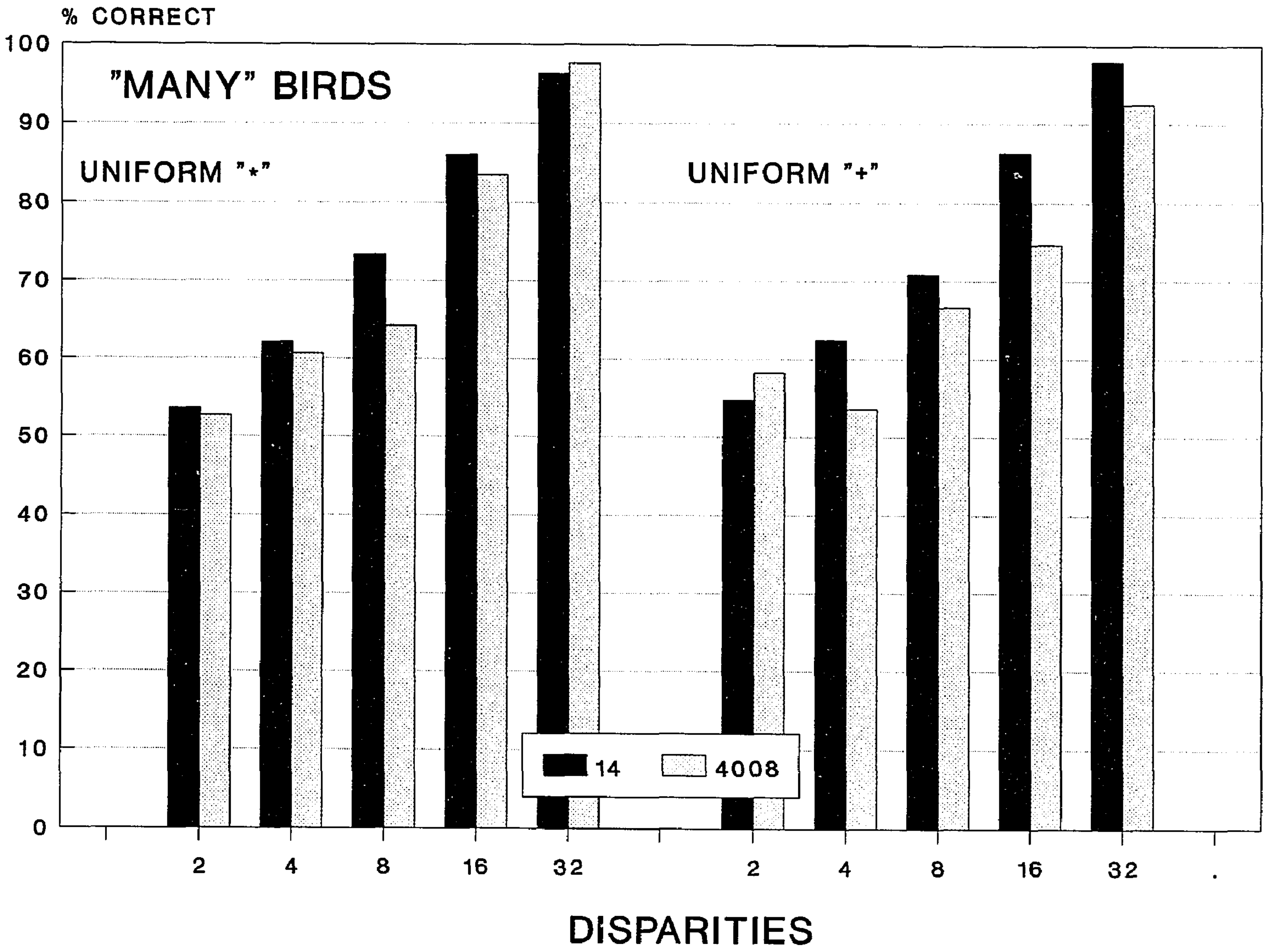
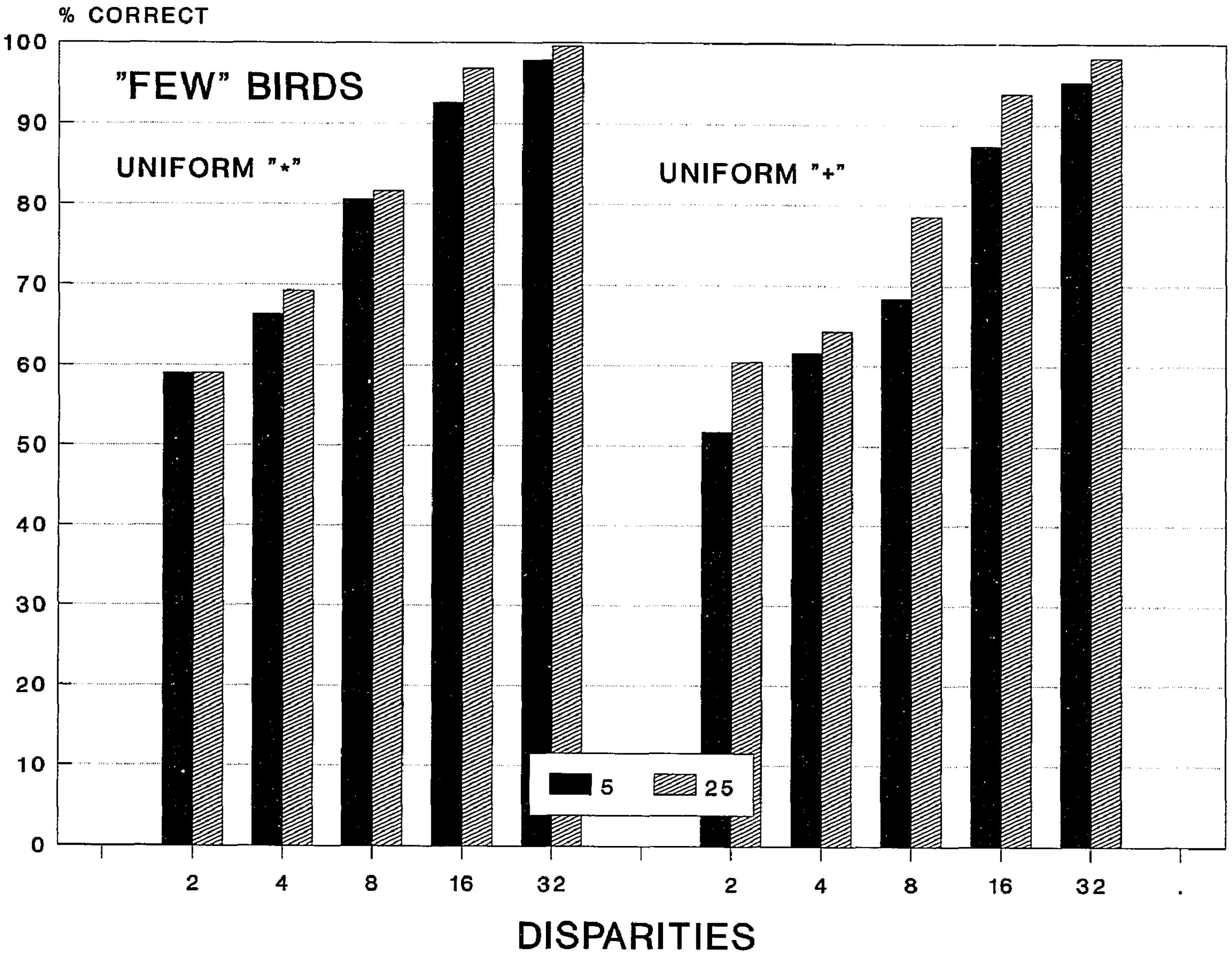

% CORRECT
100
90
80
70
60
50
40
30
20
10
0
"MANY" BIRDS
UNIFORM "*"
UNIFORM "+"
14
4008
2
4
8
16
32
2
4
8
16
32
DISPARITIES

Figure 2.12. Simultaneous discrimination training with five disparities, uniform combinations. The graph illustrates mean percent trials correct for "few elements" correct birds, for stimulus disparities of 2, 4, 8, 16 and 32 elements. The lefthand panel illustrates performances for uniform combination of element type "*/*" and the righthand panel performances for uniform combination of element type "+/+."


% CORRECT
100
90
80
70
60
50
40
30
20
10
0
"FEW" BIRDS
UNIFORM "*"
UNIFORM "+"
5
25
2
4
8
16
32
2
4
8
16
32
DISPARITIES

The individual performances are presented in Table 2H both for uniform conditions and for the preceding baseline trials on probe sessions. The data show that overall, the "few elements" correct birds performed better on the uniform combination of element type "*/*" than on the combination of type "+/+," and the "many elements" correct birds performed overall better on the combination of type "+/+" than on the combination of type "*/*." The exceptions were "few elements" correct bird P25 with a preference for combination "+/+" on disparity 2, "many elements" correct bird P14 with a preference for combination "*/*" on disparity 8 and "many elements" correct Bird P4008 with a preference for combination "*/*" on disparities 4 and 32. The table further shows that for the present procedure, performances on the familiar stimulus combination ("*/*") were inferior to performances on comparable disparities on the baseline condition. This decrement in performance was more pronounced in the "many elements" correct subjects, particularly on disparities 8 and 16.

Choice key preferences on the two uniform combinations are illustrated in Table 2I for each bird as mean percent trials correct. As the data show, all subjects responded to the left choice key on the majority of trials on all disparities. The most pronounced differences in this preference occurred on disparities 2, 4, and 8, independent of combination.

As on the mixed combinations, the "many elements" correct birds exhibited a greater left choice key preference than the "few elements" correct group. Both groups showed a greater degree of choice key preference on combinations with the preferred stimulus element, i.e., on combination "*/*" for the "many elements" correct birds and on combination "+/+" for the "few elements" correct birds.

Table 2H
Simultaneous Discrimination Procedure, Five Disparities
Two Element Types
Mean Percent Trials Correct
Uniform Combinations and Probe Sessions Baseline
All Birds

Combination	Disparities				
	2	4	8	16	32
1. "Few Elements" correct Bird P25					
Uniform "+/+"	60.4	64.3	78.6	93.8	98.2
Uniform "*/*"	59.0	69.3	81.7	96.8	99.6
Baseline "*/*"	62.4	69.7	84.8	95.6	99.8
2. "Few Elements" correct Bird P5					
Uniform"+/+"	51.6	61.6	68.4	87.3	95.2
Uniform "*/*"	58.9	66.3	80.6	92.5	97.9
Baseline "*/*"	59.7	70.2	81.8	95.4	98.6
3. "Many Elements" correct Bird P4008					
Uniform "+/+"	58.3	53.6	66.7	74.7	92.4
Uniform "*/*"	52.7	60.6	64.2	83.4	97.6
Baseline "*/*"	57.3	61.5	73.8	90.6	99.0
4. "Many Elements" correct Bird P14					
Uniform "+/+"	54.8	62.5	70.9	86.3	97.9
Uniform "*/*"	53.6	62.1	73.3	86.0	96.3
Baseline"*/*"	54.0	65.0	78.7	93.5	98.1

Table 21
Simultaneous Discrimination Procedure, Five Disparities
Two Element Types
Choice Key Responses, Uniform Combinations
Mean Percent Trials Correct, All Birds

Dis-parity	Uniform Combination ("+/+")			Uniform Combination ("*/*")		
	L	R	Diff.	L	R	Diff.
		1. "Few Elements" correct Bird P25				
2	75.8	45.9	29.9	67.4	50.9	16.5
4	78.1	50.9	27.2	80.5	56.8	23.7
8	91.5	65.3	26.2	91.7	72.3	19.4
16	98.1	89.4	8.7	98.9	94.7	4.2
32	99.7	97.8	1.9	99.7	99.4	0.3
		2. "Few Elements" correct Bird P5				
2	68.2	37.1	31.1	73.1	44.5	28.6
4	80.4	45.0	35.4	77.3	53.5	23.8
8	87.1	50.4	36.7	88.8	72.6	16.2
16	94.4	79.1	15.3	96.6	88.9	7.7
32	96.7	93.6	3.1	98.8	97.3	1.5
		3. "Many Elements" correct Bird P4008				
2	70.1	45.5	24.6	77.6	29.8	47.8
4	65.8	41.6	24.2	79.9	41.1	38.8
8	76.1	56.2	19.9	86.2	45.0	43.2
16	83.7	65.9	17.8	96.7	69.9	26.8
32	94.8	89.9	4.9	98.9	96.1	2.8
		4. "Many Elements" correct Bird P14				
2	79.4	29.4	50.0	82.4	21.2	61.2
4	84.1	41.5	42.6	86.4	37.9	48.5
8	92.4	48.5	43.9	91.8	54.2	37.6
16	95.5	77.5	18.0	97.6	74.1	23.5
32	99.1	96.7	2.4	99.7	92.8	6.9
		5. "Many Elements" correct Bird P4398				
2	86.8	12.7	74.1	93.9	6.9	87.0
4	89.4	23.1	66.3	97.8	8.9	88.9
8	94.8	26.3	68.5	95.7	13.4	82.3
16	94.2	45.4	48.8	96.8	30.5	66.3
32	99.3	71.7	27.6	98.5	74.6	23.9

Overall, the behaviors on the procedure with multiple elements seem to suggest that relative brightness, resulting from the proportion of the key surface made up of elements and background within a key or from the difference between these proportions between stimulus pairs, were a major determinant of the response choices.

To assess behavior when brightness as a cue was minimized, in the final procedure of Experiment 2 an increase in brightness within each stimulus was effected by a large reduction in the number of stimulus elements displayed Although the exact values could not be calculated, the brightness differences for S+ and S- were negligible. This condition presumably provided a condition in which attention to the numerical value of the stimulus elements ("dark matter") was imperative for a successful discrimination.

Procedure: 3 Disparities, 2 Element Types. Birds P5 and P4398 were trained for 26 sessions on a simultaneous discrimination procedure with three disparities of number and two types of elements. The procedure and the two types of elements ("+" and "*") were essentially the same as those in the immediately preceding procedure using five disparities with both types of features.

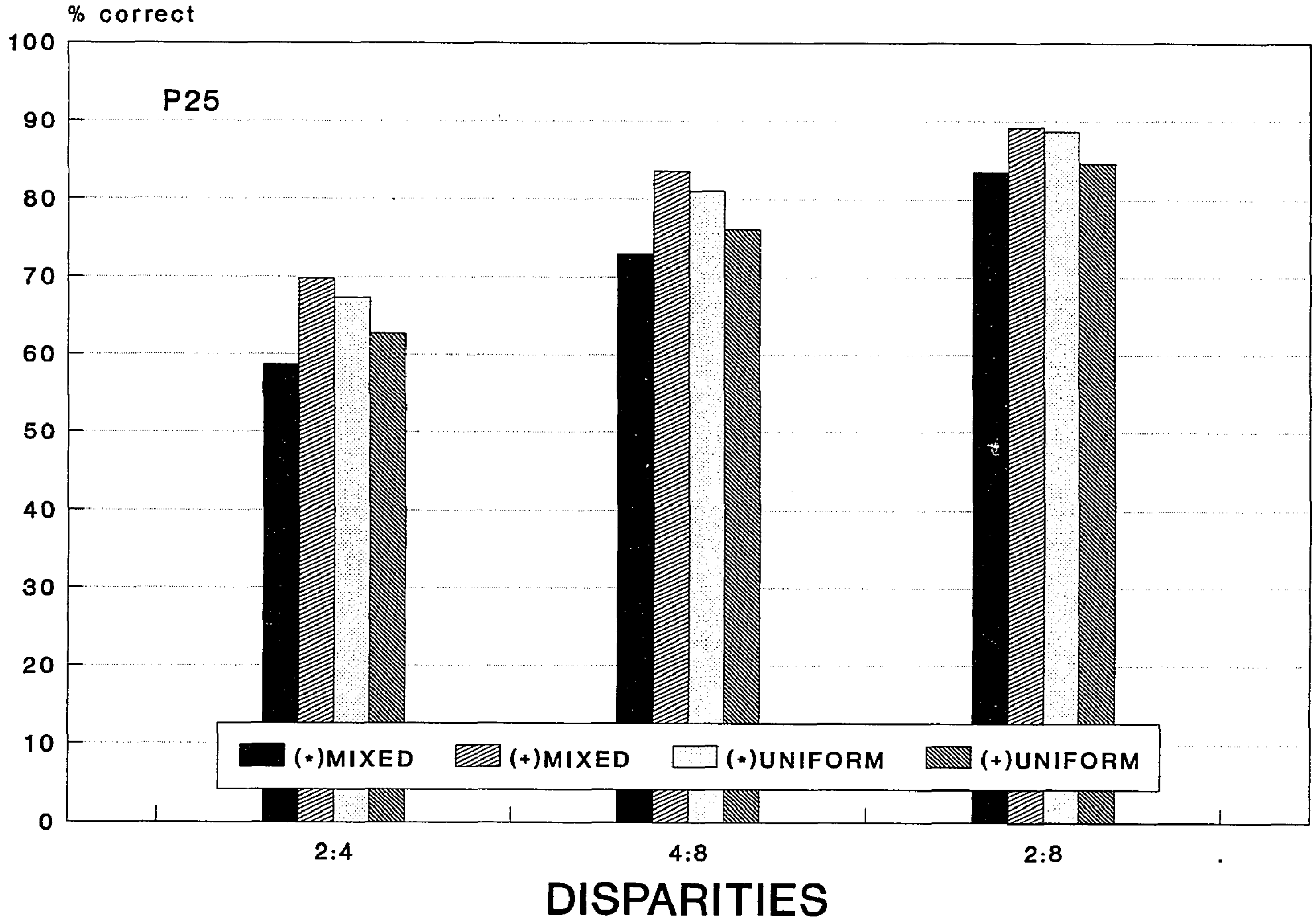
To reduce the relative brightness difference between the two stimuli, three stimulus pairs with, respectively, 2:4, 4:8 and 2:8 elements (disparities of 2, 4 and 6 elements) were used. The stimulus containing 4 elements was familiar, while the stimuli with 2 and 8 elements were novel. Stimuli with 2 and 8 elements were always positive or negative, depending on the S+ assignment, while the stimulus containing 4 elements was either positive or negative as determined by the comparison stimulus. The remaining procedures were identical to those for the five-disparities procedure. The S+ assignment remained unchanged for both birds. Bird P25 was reinforced for responding to the numerically smaller, and bird P4398 to the numerically larger stimulus. A session ended after 500 trials or 100 reinforcements, whichever came first. The number of sessions and total trials completed are presented in Table 2.

Results. The data were pooled across all sessions, and mean percent trials correct computed for non-correction trials only. Bird P4398 continued an overwhelming leftside preference. The data for this bird are excluded from the discussion.

The performances for the remaining subject P25 are shown for all combinations in Figure 2.13 as mean percent trials correct. Analogous to findings in the five-disparities condition, an increase in level of discrimination was related to an increase in stimulus disparity. As in the preceding procedure, the performance on mixed combinations was better on all three disparities when the correct response coincided with element type "+" than when the correct response coincided with element type "*." When the correct response coincided with stimulus element "+" rather than element "*," percent correct responses increased by 11.2, 10.6, and 5.7 percent on disparities 2, 4 and 6, respectively. However, these differences were markedly reduced in comparison to differences in stimulus "preferences" on the five-disparities procedure (39.3 percent and 34.4 percent for disparities 2 and 4, respectively).

On the uniform combination with element type "*/*" and stimulus disparities 2, 4, and 6, bird P25 responded correctly on 67.2, 81.0, and 88.7 percent of trials, respectively, and on the uniform combination with element type "+/+" on 62.6, 76.1, and 84.6 percent of trials. That is, the performance on the two element types differed by 4.6, 4.9, and 4.1 percent on the respective stimulus disparities of 2, 4, and 6 elements.

Figure 2.13. Simultaneous discrimination training with three disparities and two types of elements, "few-elements" correct bird P25. For each of the three stimulus-disparities 2, 4, and 6, the bars illustrating mean percent correct responses represent, from left to right, performances on the mixed combination with the S+ as "*," and the second bar for performances with the S+ as "+." The third bar illustrates mean percent correct for the uniform combination of element type "*/*," and the fourth bar performances for the uniform combination of element type "*/*." The numerical value of the elements in the three stimulus-pairs was 2:4, 4:8, and 2:8. Stimuli with two elements were always positive and stimuli with 8 elements always negative. Stimuli with 4 elements were either positive or negative, depending on the comparison stimulus.


% correct
100
90
80
70
60
50
40
30
20
10
0
P25
(*)MIXED
(+)MIXED
(*)UNIFORM
(+)UNIFORM
2:4
4:8
2:8
DISPARITIES

For comparison, Table 2K shows mean percent performances for both the five-disparities, and the three-disparities condition. The table shows that compared to the respective performances on the uniform combinations in the preceding five-disparities condition, in the present condition the bird's performance on element type "*/*" was better by 8.2 percent on disparity 2, and by 11.7 percent on disparity 4, and on element type "+/+" the performance was better by 2.2 percent on disparity 2, and by 11.8 percent on disparity 4.

In comparison to performances on the mixed combination in the preceding five-disparities procedure, correct responding to the generally non-preferred stimulus element "*" was better by 22.2 percent on disparity 2, and by 26.5 percent on disparity 4. However, when the required response was to the generally preferred stimulus element "+," the discrimination on disparity 2 in the present condition was poorer (-5.9 percent), and on disparity 4 only moderately better (+2.7 percent). Stimulus disparity 6 was not used in the five disparities procedure.

Table 2K
Performance on Three- and Five-Disparities Simultaneous Discrimination Procedures with Two Element Types
Mean Percent Trials Correct
Bird P25

Combination	Disparities 2	 4	 8	 16	 32
	1. 5 Disparities, 2 Element Types				
mixed "*"	36.4	46.5	63.2	87.7	98.7
mixed "+"	75.7	80.9	92.3	98.6	99.6
uniform "*/*"	59.0	69.3	81.7	96.8	99.6
uniform "+/+"	60.4	64.3	78.6	93.8	98.2
	2. 3 Disparities, 2 Element Types				
mixed "*"	58.6	73.0	83.5 (disp. 6)		
mixed "+"	69.8	83.6	89.2 (disp. 6)		
uniform "*/*"	67.2	81.0	88.7 (disp. 6)		
uniform "+/+"	62.6	76.1	84.6 (disp. 6)		

Results of Experiment 2

The multiple disparities procedures were designed in part to assess the basis for the response choices, and to assess the extent to which the pigeons could discriminate between stimulus pairs differing in disparity of stimulus elements. Since group differences were generally negligible, an equal discriminability of the two categories of stimuli ("few" and "many" elements) can be assumed, although, as discussed below, the data seem to suggest that response choices for the "few elements" correct birds were determined by number-related brightness differences and response choices for the "many elements" correct birds were determined by density of elements, i.e., the amount of "dark matter."

The observed behaviors on probe trials, on the uniform combination with novel elements in the five-disparities, two element-types procedure, as well as the behavior observed for bird P25 in the three-disparities procedure suggest that the birds could avail themselves of different response strategies. The data is not inconsistent with the view that prolonged training on the one-element-type multiple disparities procedure resulted in recognition of individual positive stimuli, and that the recognition of the stimuli determined the response choice. When a response choice based on stimulus recognition was not possible, such as on S- only probes, the observed superior performances were entirely consistent with response choices based on a relational judgment.

The group differences in performances on S- only probes suggests that training on the numerically smaller, but not the numerically larger, stimuli facilitated the discrimination of the unfamiliar stimuli. Considering the difference in appearance between stimuli of the two respective stimulus categories, the two groups therefore likely differed with respect to response determinants used on other conditions as well.

As described in the method section, stimulus elements in adjacent rows in a key did not abut, but were separated by three lines of background color. Conversely, elements which occupied adjacent locations within a row were continuous. For the "many elements" correct birds, the resultant effect was one where a number of elements frequently formed solid "bars" of asterisks which might have aided discrimination by creating "super-dark" areas, hence increasing the apparent density of elements. Such massing of elements was less likely in the stimulus display for the "few elements" correct birds.

For the "many elements" correct birds, the S- only probes consisted of stimuli where the frequency of such massing of stimulus elements occurring was greatly reduced, i.e., the individual elements were more frequently separated by one or more non-element(s) (background). Hence the differences between the two S- stimuli (all with fewer than 20 elements) might have been less distinct for these birds. Along similar lines, the inverse argument could be made to explain the superior performances on S- probes by the "few elements" correct birds. The elements in the numerically smaller training stimuli were more evenly distributed within a key, rendering the (bright) background more prominent, likely fostering response determinants based on relative amount of brightness within a key. If relative brightness was the response determinant for the "few elements" correct birds, this strategy might have been more readily applicable to a discrimination between stimuli from the usually non-reinforced, in this case the numerically larger, stimulus category. "Non-elements" were more numerous hence brighter, essentially featureless, and lacked a possible "shape" since all areas not covered by the stimulus elements (asterisks) were continuous with the "non-elements." A judgment based on relative brightness within a key (i.e., based on non-elements) should therefore be less likely affected by the appearance of the stimulus elements than a judgment based on the relative "mass" or density of elements.

To reiterate, the data are not inconsistent with the view that while training on the different S+ assignments resulted in similar behaviors, the response choices of the two groups were determined by attention to different aspects of the stimulus display. The "many elements" correct birds' behavior on probe trials suggests attention to the "dark" aspect (density, stimulus elements), while the behavior of the "few elements" correct birds suggests attention to the non-elements (brightness).

While it is possible that each group learned to recognize stimuli belonging to the respective relevant stimulus category, the probe data suggest that these birds can use a response strategy based on a relational judgment when the stimulus display does not contain a member of the recognized stimulus category. As stated earlier, the data show a general overall left choice key preference regardless of the procedure. On S+ only probes, this tendency greatly increased the likelihood of a response to the left choice key. While on S- only probes the difference in correct responding between the two choice keys reflects the extent of the preference, on S+ probes this preference is exaggerated by the extent to which the S+ is recognized. Hence, assuming that the pronounced left side preferences on S+ only probes indicate that on each new trial the birds recognized the first stimulus attended to as a member of the positive category and responded to it without performing a comparison of the two choice stimuli, then the reduction in left choice key preferences observed on S- only probes suggest that in the presence of two normally negative stimuli the birds compared the two stimulus choices prior to responding.

The inference that the birds differentially attended to the stimuli on the two types of probes is substantiated by the response latencies recorded for the probe trials. The median latencies for S- only probes were consistently longer than the latencies for S+ only probes, and among S- only probes the latencies on disparity 12 were generally longer than the latencies on disparity 6. On S+ only probes, the observed very short latencies together with pronounced left choice key preferences, suggest that the stimulus on the left choice key was more frequently attended to first, was immediately recognized as having a positive value and was responded to. In this instance, no further comparison was performed with the stimulus in the alternate choice key location suggesting that on S+ only probes individual recognition of the stimuli rather than a relational judgment governed the response choices.

Conversely, on S- only probes, the longer response latencies and the superior performances suggest that the first comparison stimulus attended to failed to match any internal abstraction defining the different S+ stimuli and was rejected. Since on S- only probes the alternate comparison similarly did not match any abstraction, if the birds had not learned the more general concepts "few" and "many" (numerically smaller or numerically larger stimuli) independent of the number of elements displayed, the responses should have been randomly distributed between the two choice keys. The observed performances on the S- only probes thus suggest that both comparisons were considered prior to a response choice, hence the birds could avail themselves of a relational judgment when choosing a response.

A response choice based on a relative judgment of the two comparison stimuli is further suggested by the behaviors observed in some conditions with two element types. Specifically, the absence of novelty-engendered behaviors by the "few elements" correct birds, evidenced by the group's mirror-image performances on novel stimulus element type "+/+" of the "many elements" correct group's performances on the familiar stimulus element type "*/*" strongly suggests that for the "few elements" correct group the primary aspect of the stimulus situation attended to were relative brightness differences between stimuli.

If the birds had attempted to identify the correct comparison by means of abstractions of the positive stimuli formed during preceding training, as the behaviors on S+ probes suggested, the performances by the "few elements" correct birds on the novel uniform combination should have been substantially inferior to those actually observed, since for this group, the reduction in amount of dark matter effected by substituting element type "+" for element type "*" likely resulted in S- stimuli which equally well matched some generalized abstraction. For the "many elements" correct birds, the stimuli on the novel uniform combination less likely coincided with any internal representation. Although the stimuli (both of element type "+") differed in relative amount of "dark matter," the reduction in the total mass provided by the stimulus elements was probably sufficient to render these stimuli truly novel.

Similarly, the argument could be made that on mixed combinations, when the positive stimulus coincided with the "preferred" element type, a correct response was a result of the closer match that stimulus provided for some internal representation formed in preceding training. However, if the birds had responded to individual stimuli based on such recognition, then the respective percentages correct responding on the two mixed combinations should not have shown such dramatic differences. Particularly where the correct response coincided with the familiar stimulus element, that is, to stimuli which had an internal representation, the degree of correct responding would have reflected the conflict when presented with two stimuli of which one matched an internal representation while the comparison (in this case the S-) was brighter in appearance.

The performances on the two element types conditions suggest that neither group attended to the actual number (amount) of stimulus elements, that the birds did not have to learn the discrimination of the novel stimuli, but were able to respond to alternate number-related stimulus differences. The performances further suggest that the discrimination was more difficult for the "many elements" correct birds when the correct response was to the non-preferred element, assuming that the degree of choice key preference reflects the degree of confidence in the response choice. As stated earlier, it is possible that training to respond to the numerically smaller, but not the numerically larger, stimuli exerted a facilitatory effect on discrimination behavior both in the presence of non-familiar stimuli--as in the two-element types procedure--and in the presence of normally non-reinforced stimuli, as on S- only probe trials.

Overall, the behaviors on the multiple-disparities conditions seem to suggest that relative brightness, resulting from the proportion of the key surface made up of elements and background within a key or from the difference between these proportions between stimulus pairs, were a major determinant of the response choices. The performances on the one element type procedure as well as on S+ only probe trials suggest that response choices were largely governed by the recognition of the positive stimuli, while the performances on S- only probes suggest that response choices were governed by a relational judgment. In either situation, the response choices for the "many elements" correct group appeared to have been determined by the density of stimulus elements (dark matter), while the response choices for the "few elements" correct birds appeared to have been determined by brightness differences either within a key or between comparison stimuli.

In contrast, the data for bird P25 for the three-disparities, two element-types procedure seems to suggest that this birds may have attended to the actual number of stimulus elements. Compared to her performances in the preceding five-disparities procedure, in the present procedure the discrimination of the non-preferred stimuli (element type "*") on the mixed combination was substantially better for all disparities. This increase appears to be primarily the result of a reduction in the behavioral tracking of stimulus element "+," evidenced by the reduction in the differential responding to the two elements.

Further, the bird's performance was not affected by the conditional nature of the stimulus with a numerosity of 4 stimulus elements. In the three-disparities procedure, the stimulus with 4 elements was either positive or negative with respect to the alternate comparison. The three stimulus pairs were composed of stimuli 2:4, 4:8, and 2:8. While it could be argued that the bird learned that a stimulus with two elements was always positive while a stimulus with 8 elements was always negative it seems more likely, that the response choice was based on a relational judgment: if the superior performance on stimulus disparity 6 (2:8) was the result of a recognition that the stimulus with 8 elements was always positive, then the performances on disparity 4 (4:8) should have reflected that recognition, i.e., should have been better than the actually observed performance.

Together with the behaviors observed on the simultaneous discrimination test in Experiment 1, the performances in the present experiment suggest that these birds attended to different cues, and used different response strategies as necessitated by the experimental situation. This apparent availability of several strategies is particularly interesting considering the failure the birds exhibited in learning to match in the matching-to-sample procedure in Experiment 1. The sum of the data for the various procedures utterly fail to provide an explanation for the birds inability to match identity despite extensive training, and despite the demonstrated apparent flexibility in discrimination strategies.

In view of the performances observed on the various procedures, particularly the ease with which the birds were able to discriminate when the comparisons differed by only few stimulus elements, it seemed likely that the extensive training on the simultaneous discrimination procedures with predominantly the same stimulus element as was used in the matching procedures in Experiment 1 might facilitate matching behavior.

The birds were therefore returned to a simultaneous matching-to-sample procedure. To investigate different aspects of conditional discrimination behavior, in different conditions either symbolic-matching trials cued by a numerical sample, or cued by an arbitrary symbolic equivalent, were added to the identity trials on the same session.

Experiment 3

Matching-to-Sample Training with Symbolic-Matching Trials

Procedure. All birds were trained on a matching-to-sample procedure with approximately equal numbers of identity-matching and symbolic-matching trials in each session. On one-half of the scheduled trials the birds were required to match identity, and on the remaining trials the symbolic equivalent. In different procedures, either the sample contained the symbolic equivalent and the choice keys the numerical stimuli, or the sample contained the numerical stimulus and the choice keys the symbolic equivalents.

A trial began with the presentation of the sample on the center key. On identity trials, the sample stimulus was either the numerically smaller or larger stimulus with asterisks as elements, and the correct response was to the comparison which matched the sample. On the remaining trials, the sample contained an arbitrary symbolic equivalent, either red (color 4) or blue (color 1). In the presence of a red sample, responses to the numerically smaller, and in the presence of a blue sample, responses to the numerically larger comparison were reinforced. The numerical stimulus pair for the birds with prior training with numerically reduced stimuli (P25 and P4398) consisted of stimuli with 2 and 8 elements (disp. 6). For birds P5 and P4008 the 5/35 elements (disp. 30) of the earlier matching-to-sample procedure were reinstated.

One peck to the sample produced the two choice keys which, for birds P4008 and bird P5 always contained 5 and 35 asterisks, and for birds P25 and P4008, 2 and 8 asterisks, respectively. On each new trial, either numerical or color stimuli had an equal probability of appearing as the sample. Similarly, the side of the two choice key stimuli were randomized. The sample remained on the screen until one peck to one of the choice keys terminated the trial. Reinforcement was on a random ratio schedule (p=.25). Correct responses for which no primary reinforcement was scheduled were cued by a 50 ms illumination of the feeder light and the sound produced by the concomitant feeder operation. The intertrial interval of .5 s was timed from the occurrence of a choice key peck to the next presentation of the sample. An incorrect response resulted in 6.0 s time-out followed by a correction trial. The birds remained in this procedure for 25 sessions of 500 trials or 100 reinforcements, whichever came first. Except for the introduction of symbolic-matching trials, the conditions were essentially the same as the earlier experiments which failed to produce matching behavior.

Subsequent to initial training, all birds continued the procedure with a reversal of the sample and choice stimuli for symbolic matching. There were four equally probable choice key stimuli, two numerical and two symbolic colors. The sample stimulus on the center key was always numerical. This procedure served to control for the effectiveness of the numerical sample as a discriminative stimulus, particularly in light of the poor performances in the simultaneous matching procedure and the observed superior performances on the simultaneous discrimination test in Experiment 1.

On symbolic trials in the second phase, the center key contained the numerical stimuli and the choice keys the symbolic equivalents, red coding for the numerically smaller, and blue the numerically larger stimulus. A trial began with the presentation of one of the two stimuli, containing for different birds either 5 or 35, or 2 or 8 asterisks. One peck to the sample on these symbolic trials produced the two colored choice keys. In the presence of the numerically smaller sample, stimulus responses to the red comparison and in the presence of the numerically larger sample, responses to the blue comparison were correct. The remaining procedures were identical to those described in the general procedure above. The birds remained in this procedure for 25 sessions of 500 trials or 100 reinforcements, whichever came first.

To ascertain that the overall poor performance by bird P25 was not attributable to factors unrelated to the stimulus situation, such as an incipient health problem, subsequent to training on the condition with a disparity of 6 elements this bird was tested for 12 sessions on the procedure with stimuli of 5 and 35 elements (disp. 30). The number of sessions and trials completed for each bird and all procedures in Experiment 3 are shown in Table 3.

General Results. Bird P14 refused to respond despite daily introduction into the experimental chamber. After approximately 10 attempts, this bird was retired.

In general, the three remaining birds exhibited similar overall behaviors on each of the respective conditions, i.e., identity-matching, center-key-symbolic matching, and choice-key-symbolic matching. Performances on the identity-matching condition were always inferior to those on both center-key-symbolic and choice-key-symbolic matching, and center-key-symbolic matching performances were always superior to performances on the choice-key-symbolic procedure.

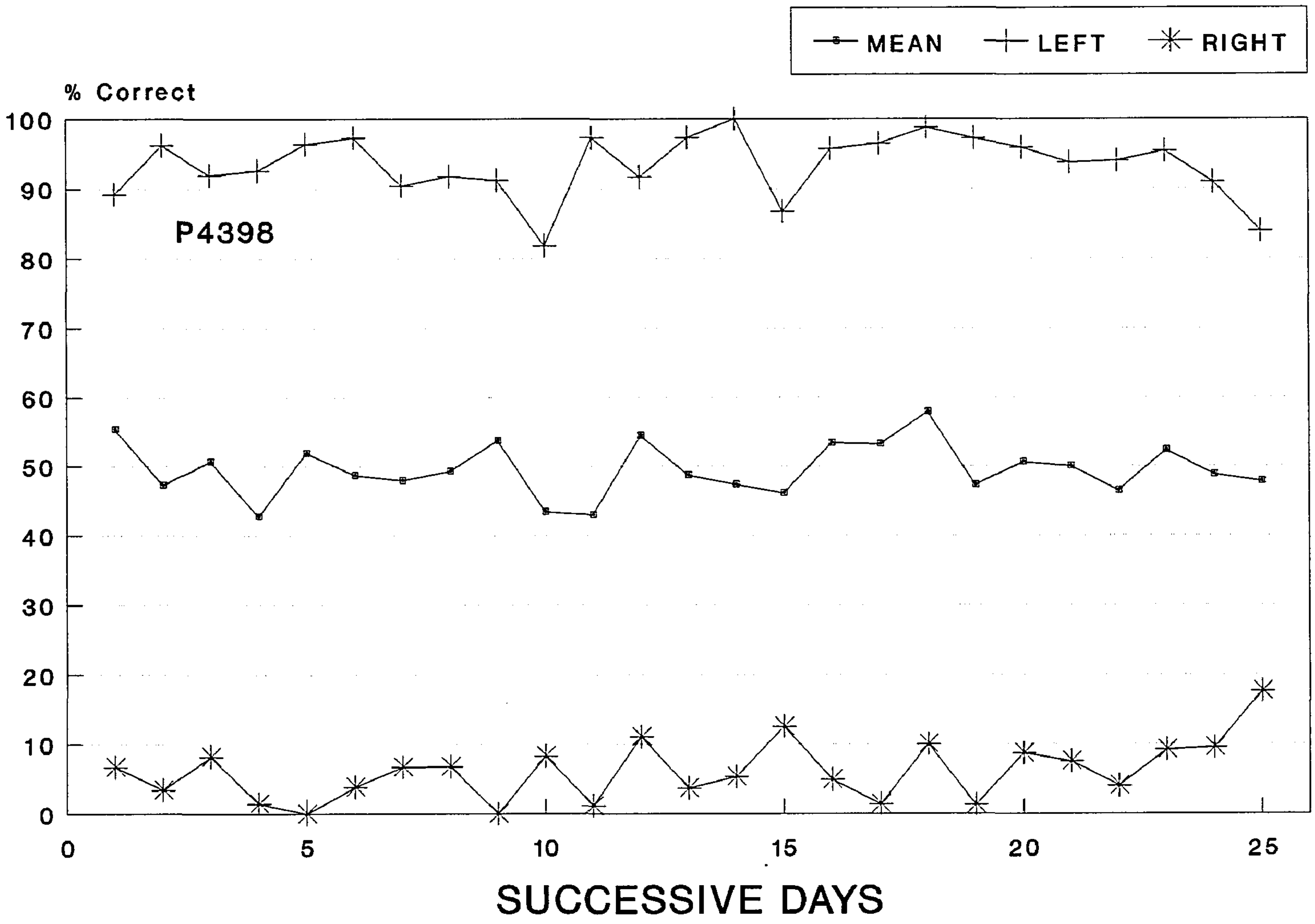
The data for bird P4398 are not included in the discussion. This bird continued an extreme leftside preference. Figure 3.1 shows that this bird "discriminated" correctly on over 90 percent of trials on 21 of the 25 sessions on the left choice key, while on less than 3.1 percent of trials on 21 of the 25 sessions on the right choice key.

Table 3
Procedures and Individual Training
Experiment 3

Bird	Procedure	Stimulus Pairs	Trials Completed	Sessions
P25	SN MTS/SYMTS	2/8	12338	25
	SN Reversal	2/8	12500	25
	LN MTS/SYMTS Test	5/35	5768	12
P4398	SN MTS/SYMTS	2/8	12239	25
	SN Reversal	2/8	12500	25
P4008	LN MTS/SYMTS	5/35	12368	25
	LN Reversal	5/35	12307	25
P5	LN MTS/SYMTS	5/35	12162	26
	LN Reversal	5/35	12715	26
	SN MTS/SYMTS Test	2/8	7913	16

SN=Numerically Small Stimuli
LN=Numerically Large Stimuli
MTS=Matching-to-Sample
SYMTS=Symbolic Matching-to-Sample

Figure 3.1. The curves illustrate overall mean percent trials correct and mean percent correct responses to the left and right choice keys for bird P4398 for the identity-matching condition in the first phase of the procedure and a stimulus disparity of 6 elements.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P4398
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SUCCESSIVE DAYS

Figures 3.2-3.4 show performances for all three birds for both phases of training. In essentially every instance there is a very large disparity between symbolic matching and identity matching. Birds P4008 and P5 show symbolic-matching accuracy rising rapidly on the Red/5, Blue/35 contingency. Although performance level was lower for bird P25, this subject similarly displays a disparity between symbolic and identity conditions with the small numbers (2 vs. 8) used for this subject.

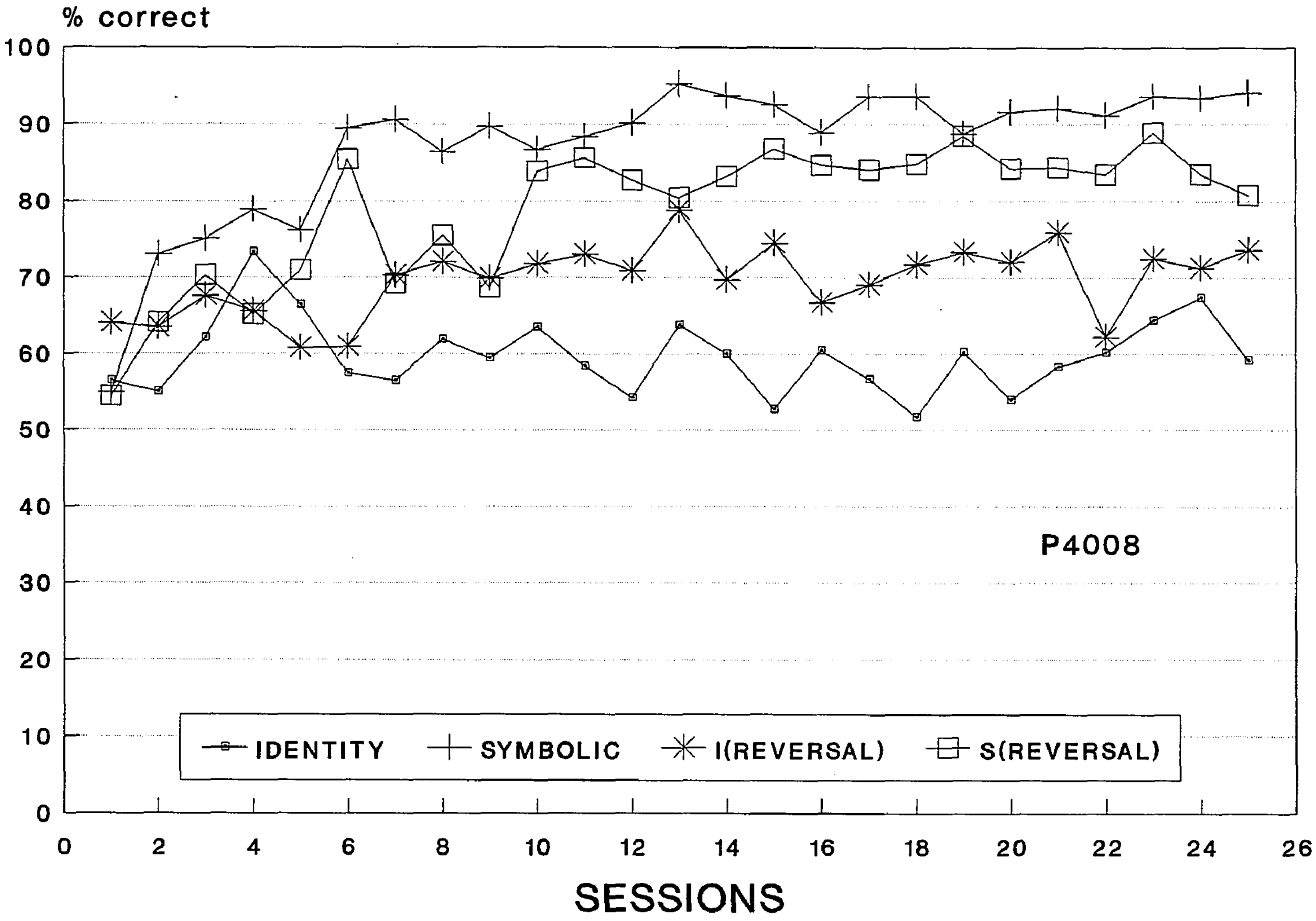
Identity matching does not appear to rise above chance accuracy for bird P4008 and bird P25. Progressive increase in accuracy is shown for bird P5's identity matching but it substantially below symbolic-matching accuracy.

In the subsequent phase, the three subjects underwent a reversal of the sample-choice relationship in that the sample was now always numerical and the choices symbolic. The red/few, blue/many relationship persisted. Identity-matching performance on day 1 in the second phase is essentially continuous with the last days in of the first phase.

Results: Stimulus Disparity 30. Phase 1, Identity-Matching with Center Key-Symbolic Matching Trials. Performances on the first phase only, i.e., identity-matching and center key symbolic training, are shown for bird P4008 in Figure 3.5, and for bird P5 in Figure 3.6 for all sessions as mean percent trials correct.

The function depicting identity-matching performance for bird P4008 in Figure 3.5 shows a gradual increase in discrimination over the first four sessions (mean initial 5 sessions = 63.4 percent correct) followed by a decrease in percent correct responding to the level observed on the first session in the procedure (mean, final 5 sessions = 61.8 percent correct). Although in comparison to the mean performance for the final 5

Figure 3.2. The graph shows performances for bird P4008 for both phases of the simultaneous matching-to-sample procedure, stimulus disparity 30, as mean percent trials correct for each session. The curves labeled "Identity" and "Symbolic" illustrate performances for the first phase in the condition with identity-matching, and center-key-symbolic trials. The curves labeled "R-Identity" and "R-Symbolic" illustrate performances for the second phase of training with identity-matching, and choice-key-symbolic matching trials.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SESSIONS
P4008
IDENTITY
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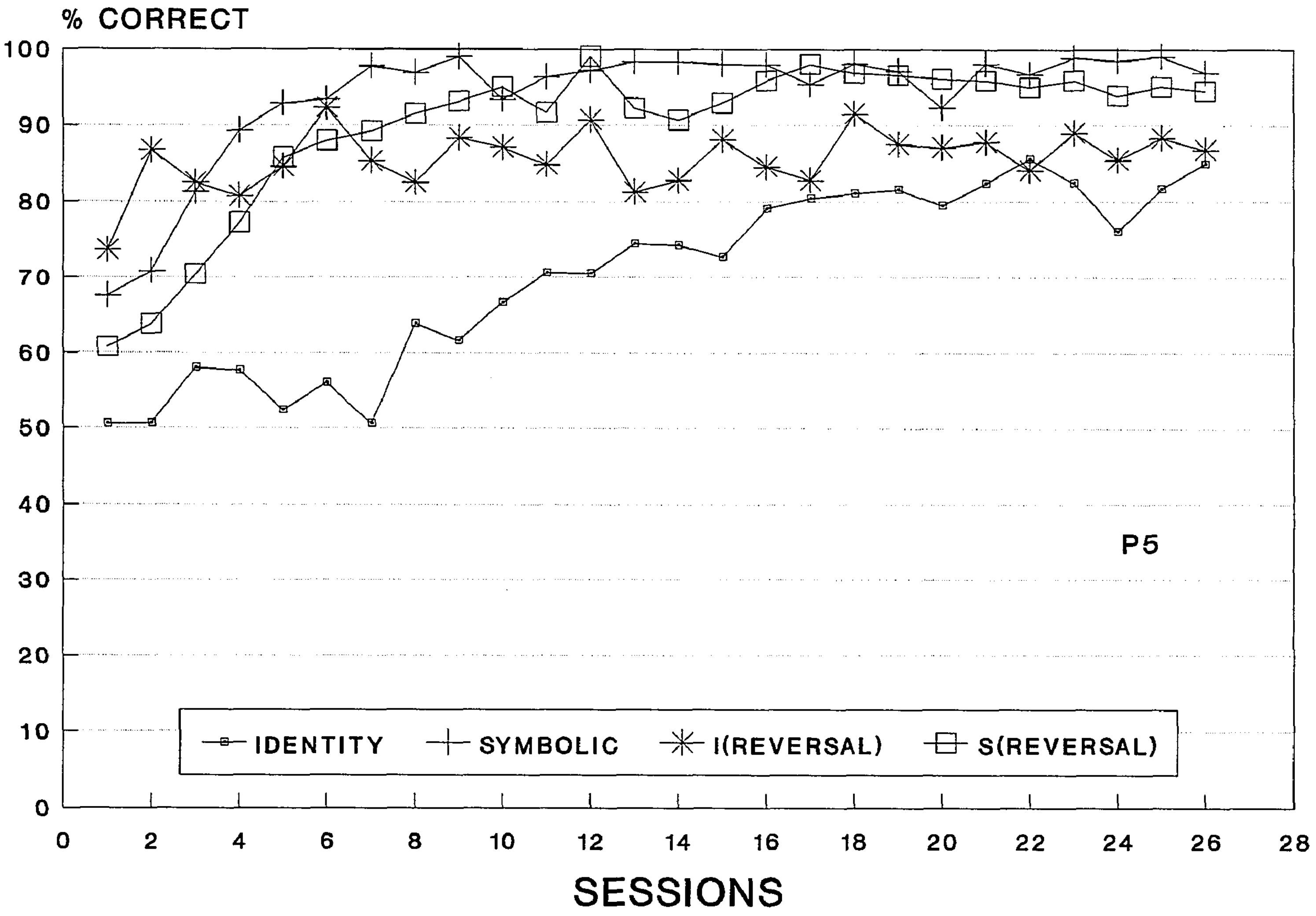
I(REVERSAL)
S(REVERSAL)

Figure 3.3. The graph shows performances for bird P5 for both phases of the simultaneous matching-to-sample procedure, stimulus disparity 30, as mean percent trials correct for each session. The curves labeled "Identity" and "Symbolic" illustrate performances for the first phase in the condition with identity-matching, and center-key-symbolic matching trials. The curves labeled "R-Identity" and "R-Symbolic" illustrate performances for the second phase of training with identity-matching, and choice-key-symbolic matching trials.



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P5
IDENTITY
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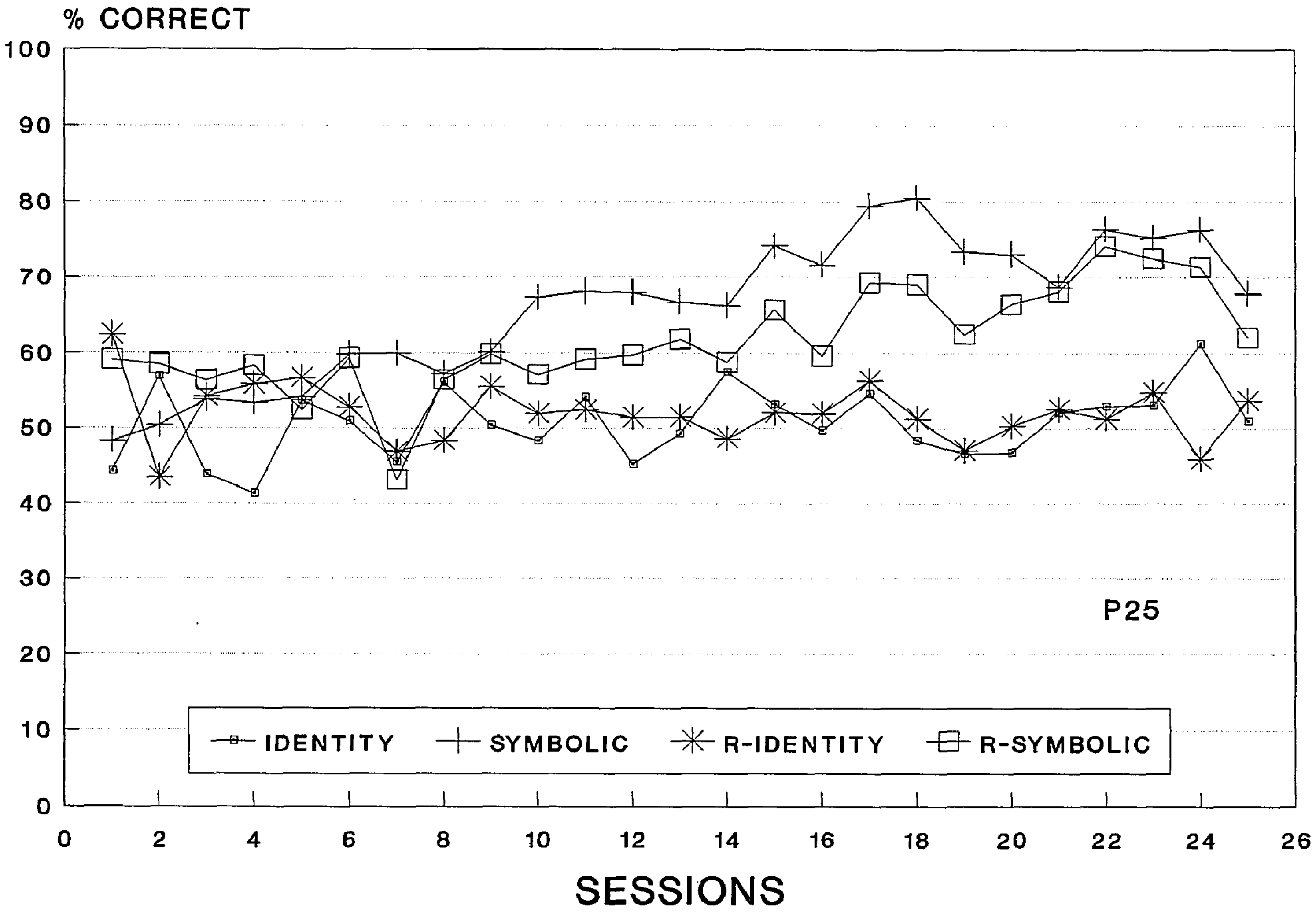
I(REVERSAL)
S(REVERSAL)

Figure 3.4. The graph shows performances for bird P25 for both phases of the simultaneous matching-to-sample procedure with a stimulus disparity of 6 elements. The data are shown as mean percent trials correct for each session. The curves labeled "Identity" and "Symbolic" illustrate performances for the first phase in the condition with identity-matching, and center-key-symbolic trials. The curves labeled "R-Identity" and "R-Symbolic" illustrate performances for the second phase of training with identity-matching, and choice-key-symbolic matching trials.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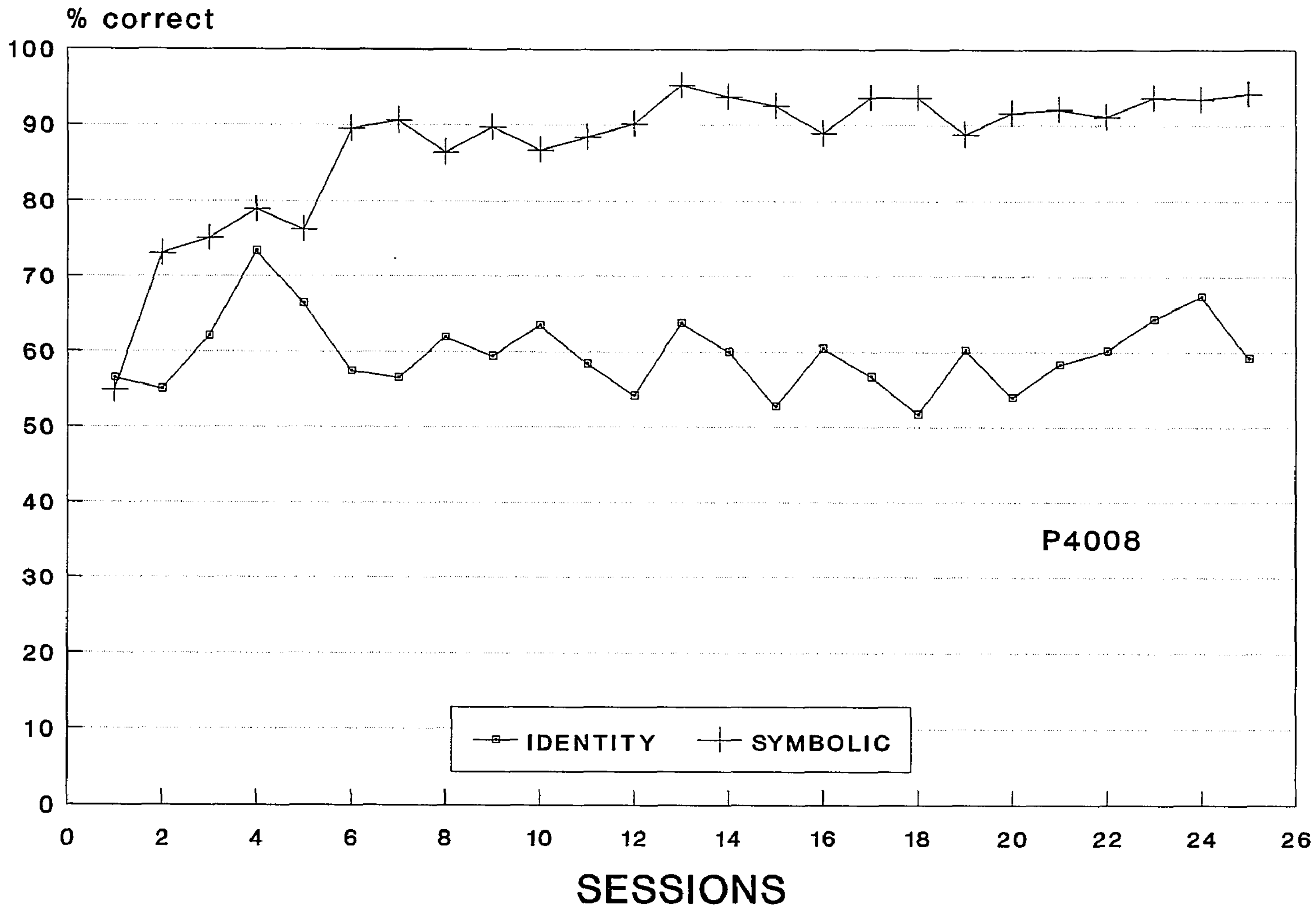
sessions of identity-matching in Experiment 1 (56.1 percent correct) the bird's performance on the final 5 sessions in the present procedure improved by an average of 5.7 percent, the overall behavior is not suggestive of the conditional discrimination.

In comparison, Figure 3.6 shows that the initially poor performance for Bird P5 (mean, initial 5 sessions = 54.3 percent correct) improved substantially on the seventh session and continued to improve to a high level of competence (mean, final 5 sessions = 82.1 percent correct). In the zero-delay matching-to-sample procedure in Experiment 1, this bird had shown no evidence of conditional discrimination behavior. Bird P5 had not been a subject in the simultaneous matching-to-sample procedure in Experiment 1.

Both subjects discriminated substantially better on the symbolic condition than on the identity-matching condition. Of the two birds, P5 discriminated better than bird P4008 on all sessions and all conditions, with the exception of the first seven sessions on identity matching.

Both birds showed a rapid rise in matching performance on the symbolic condition, reaching relatively stable levels of performance in 6 sessions. Bird P5 performed correctly on 70.7 percent, and bird P4008 on 72.9 percent of trials by the second session, while the identity-matching performances on the corresponding sessions (50.6 and 55.0 percent, respectively) remained near chance levels. For bird P5, the averaged performance on the final 5 sessions on the symbolic procedure (98.0 percent) was indistinguishable from that observed on disparity 32 (98.5 percent) in the multiple disparities discrimination procedure with one element type. Similarly, bird P4008 responded correctly on an average of 92.9 percent of trials on the final 5 sessions in the symbolic procedure, and of 98.3 percent of trials correct on the multiple disparities procedure.

Figure 3.5. Performances for bird P4008 for the first phase of the simultaneous matching-to-sample procedure with a stimulus disparity of 30 elements, are shown as mean percent trials correct for each session for both identity-matching and center-key-symbolic matching conditions.



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SESSIONS
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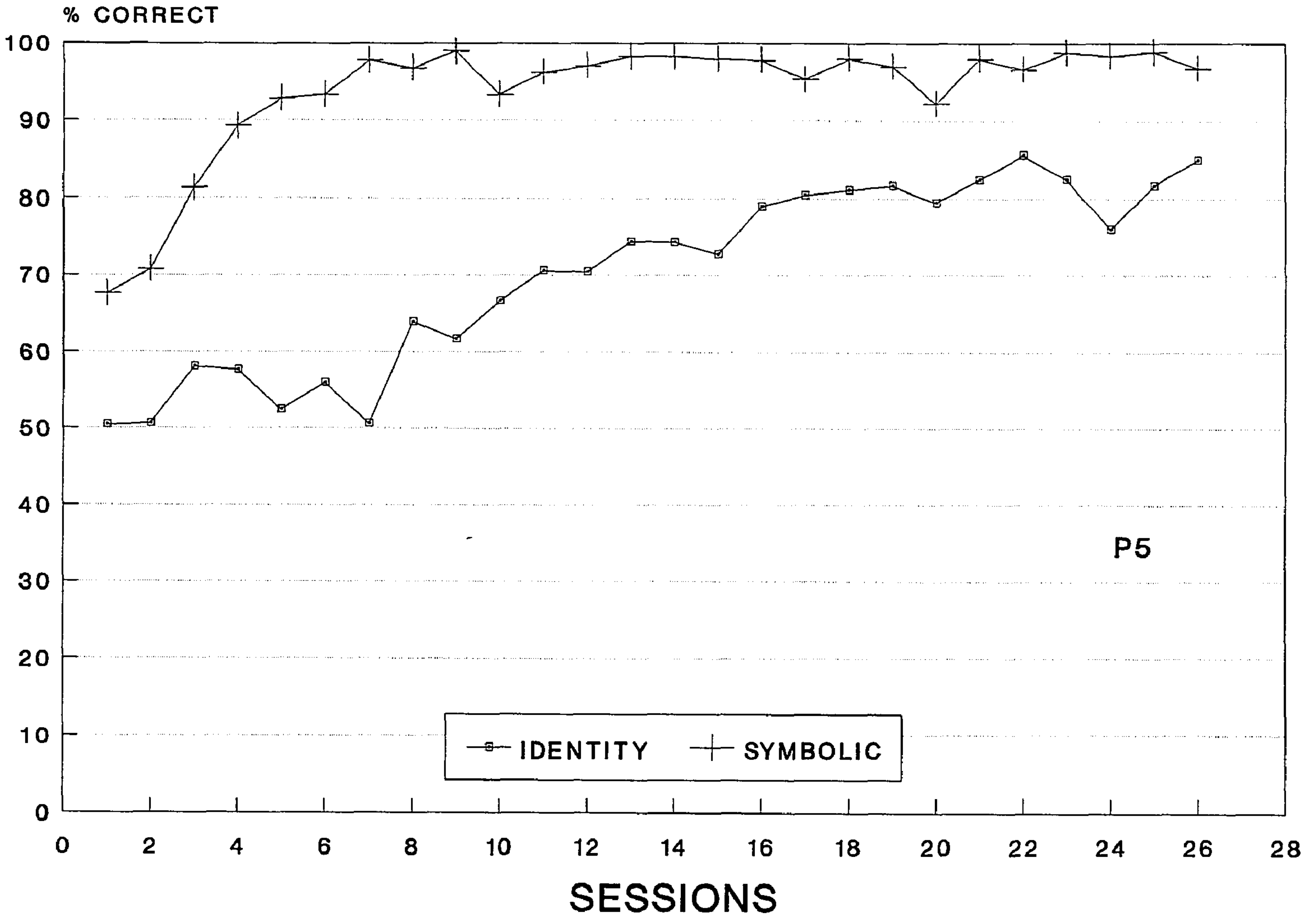
Figure 3.6. Performances for bird P5 for the first phase of the simultaneous matching-to-sample procedure with a stimulus disparity of 30 elements, are shown as mean percent trials correct for each session for both identity-matching and center-key-symbolic matching conditions.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SESSIONS
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Results: Stimulus Disparity 30. Phase 2, Identity-Matching with Choice-Key-Symbolic Trials. Figures 3.7 and 3.8 illustrate the respective mean percent correct performances for birds P4008 and P5 in the second phase, i.e., with identity-matching and choice-key-symbolic matching trials.

A comparison of the functions for each bird shows that the change in the symbolic condition did not affect identity-matching behavior. On the first five sessions of identity matching in reversal training, bird P5 performed correctly on an average of 81.9 percent, i.e., remained at the level observed on the averaged final 5 sessions of initial training (82.1 percent correct). This bird's identity-matching performance in the second phase eventually improved to an average of 86.5 percent correct on the final 5 sessions.

Bird P4008 performed correctly on an average of 64.2 percent of identity-matching trials on the initial 5 sessions in the second phase, compared to an average of 61.8 percent correct on the final 5 sessions in the first phase. While in the second phase this bird's performance remained above the levels observed in the first phase on all but the initial 5 sessions, the discrimination improved only moderately to an average of 71.1 percent of trials correct on the final 5 sessions. Compared to bird P5, bird P4008 performed worse on all sessions.

A comparison of the functions illustrating symbolic-matching performances reveals that the choice-key-symbolic condition was somewhat more difficult than the center-key-symbolic condition for both subjects, although after 15 sessions in the second phase bird P5 performed at a level which differed negligibly from that in the first phase. On the initial 5 sessions in the two respective conditions this bird performed correctly on an average of 81.3 percent of trials on the center-key-symbolic, and on 71.8 percent of

Figure 3.7. Performances for bird P4008 for the second phase of the simultaneous matching-to-sample procedure with a stimulus disparity of 30 elements, are shown as mean percent trials correct for each session for both identity-matching and choice-key-symbolic matching conditions.

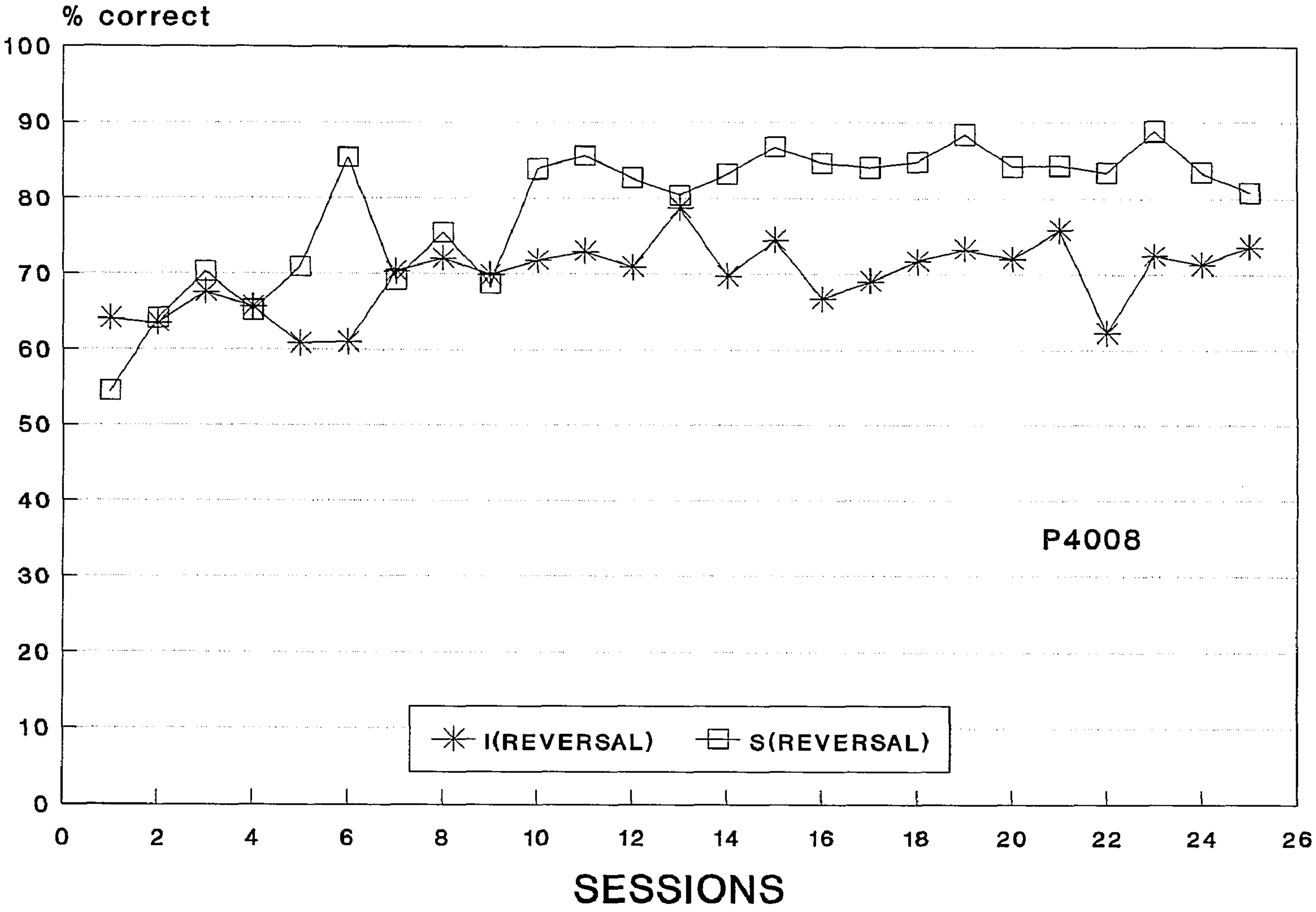
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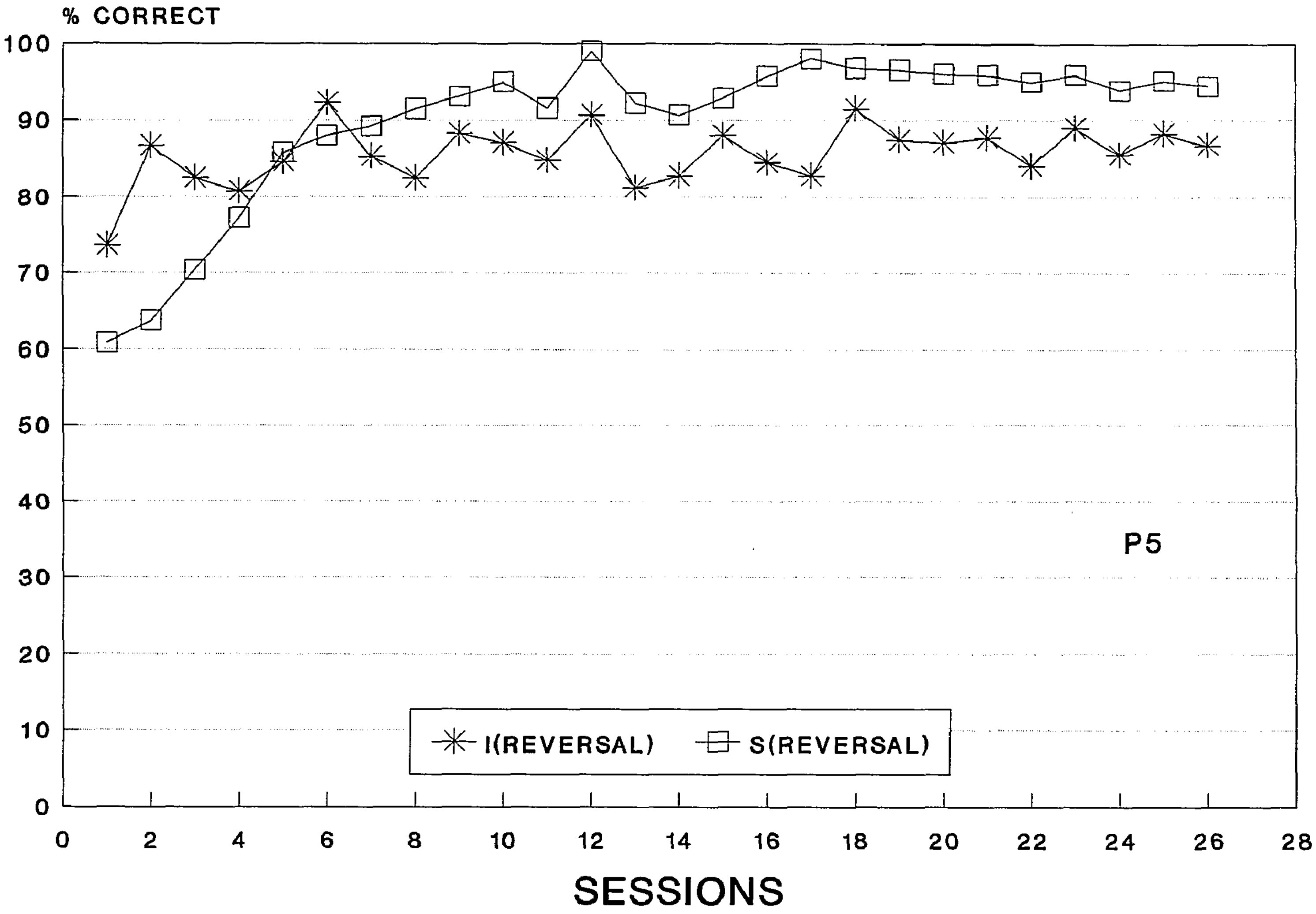
Figure 3.8. Performances for bird P5 for the second phase of the simultaneous matching-to-sample procedure with a stimulus disparity of 30 elements, are shown as mean percent trials correct for each session for both identity-matching and choice-key-symbolic matching conditions.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SESSIONS
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trials on the choice-key-symbolic condition. On the final 5 sessions in the two respective conditions, this bird reached a level of performance of 98.0 percent correct on center-key-symbolic, and of 94.0 percent on choice-key-symbolic trials. Bird P4008 performed worse on all sessions of choice-key-symbolic, compared to center-key-symbolic, training, except of session 19. On the first 9 sessions, the overall performance on the choice-key-symbolic condition differs only negligibly from that on the identity component.

The generally inferior performances on the choice-key-symbolic procedure suggest an incomplete memorization of the two stimulus categories ("few" and "many"). While both symbolic conditions required memorization of two relationships, response choices based on a symbolic sample were potentially easier since both element sizes were available for comparison. Assuming that the two relationships were memorized, the correct comparison could be identified by a recognition of the appropriate stimulus in comparison to the alternate choice. On the choice-key-symbolic condition, the determination of the element size was more difficult. Here, the correct identification of the sample depended on prior memorization of the two stimulus categories in absolute terms since the alternate stimulus category was not shown. Thus, misidentification of the sample stimulus was more likely in the presence of a non-symbolic S+. The difference between the symbolic equivalents was absolute (red or blue), hence an error in the presence of a symbolic sample was an error in the association itself, while errors in the presence of a non-symbolic sample were composed of errors of association and errors of misjudgment of the stimulus category.

Results: Stimulus Disparity 6. Both Phases. The data for bird P25 are shown as mean percent trials correct in Figures 3.9 and 3.10. Figure 3.9 illustrates performances for the first phase of training, i.e., identity-matching and center-key-symbolic matching, and Figure 3.10 performances for the second phase, i.e., identity-matching and choice-key-symbolic matching.

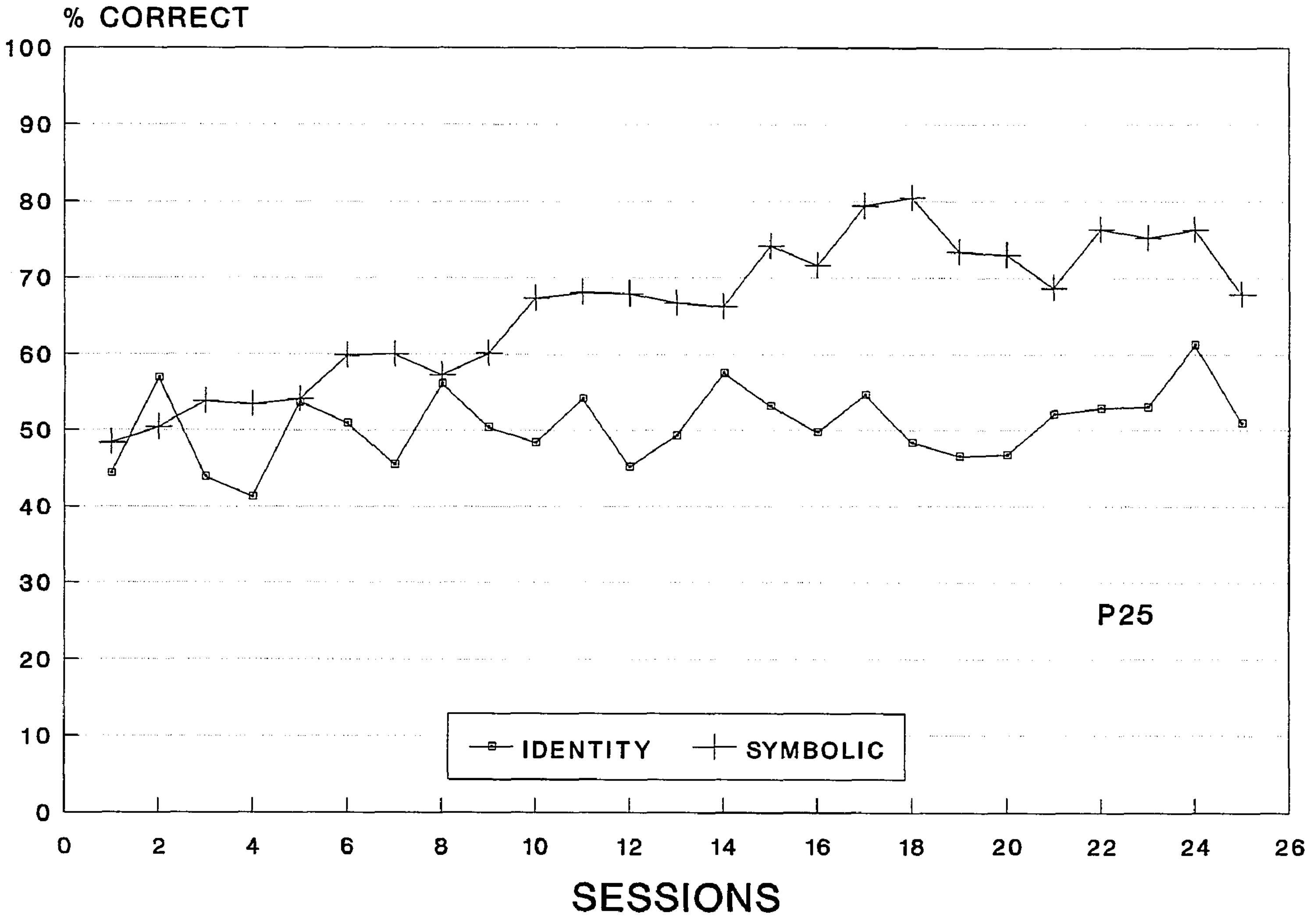
Although this bird performed correctly on an average of 88.7 percent of trials in the three-disparities procedure with element type "*" and disparity 6, this ability to discriminate stimuli of the same element type and stimulus disparity was not evident from the performance on the matching procedure. A comparison of the functions illustrating performance on the identity-matching component show that overall, performances remained at chance levels throughout the procedure.

Unlike the performances observed for the two birds trained on stimulus disparity 30, on the symbolic-matching component of the procedure the performance by bird P25 improved only very gradually on both center key symbolic and choice key symbolic conditions. Asymptotic performance remained at levels substantially below levels observed for the subjects trained with stimulus disparity 30. A comparison of the performances on the two symbolic components reveals that similar to subjects trained on disparity 30, bird P25 performed worse on the choice-key-symbolic component in comparison to the center-key-symbolic matching component.

To test whether the poor discrimination observed for bird P25 was indeed attributable to the training stimuli, the bird was then trained for 12 sessions on the identical training procedure used for birds P5 and P4008, i.e., with a stimulus disparity of 30 elements.

The data presented in Figure 3.11 clearly show that the difficulties the bird experienced were related to the numerical values of the stimuli. Compared to the performance on

Figure 3.9. Performances for bird P25 for the first phase of the simultaneous matching-to-sample procedure with a stimulus disparity of 6 elements, are shown as mean percent trials correct for each session for both identity-matching and center-key-symbolic matching conditions.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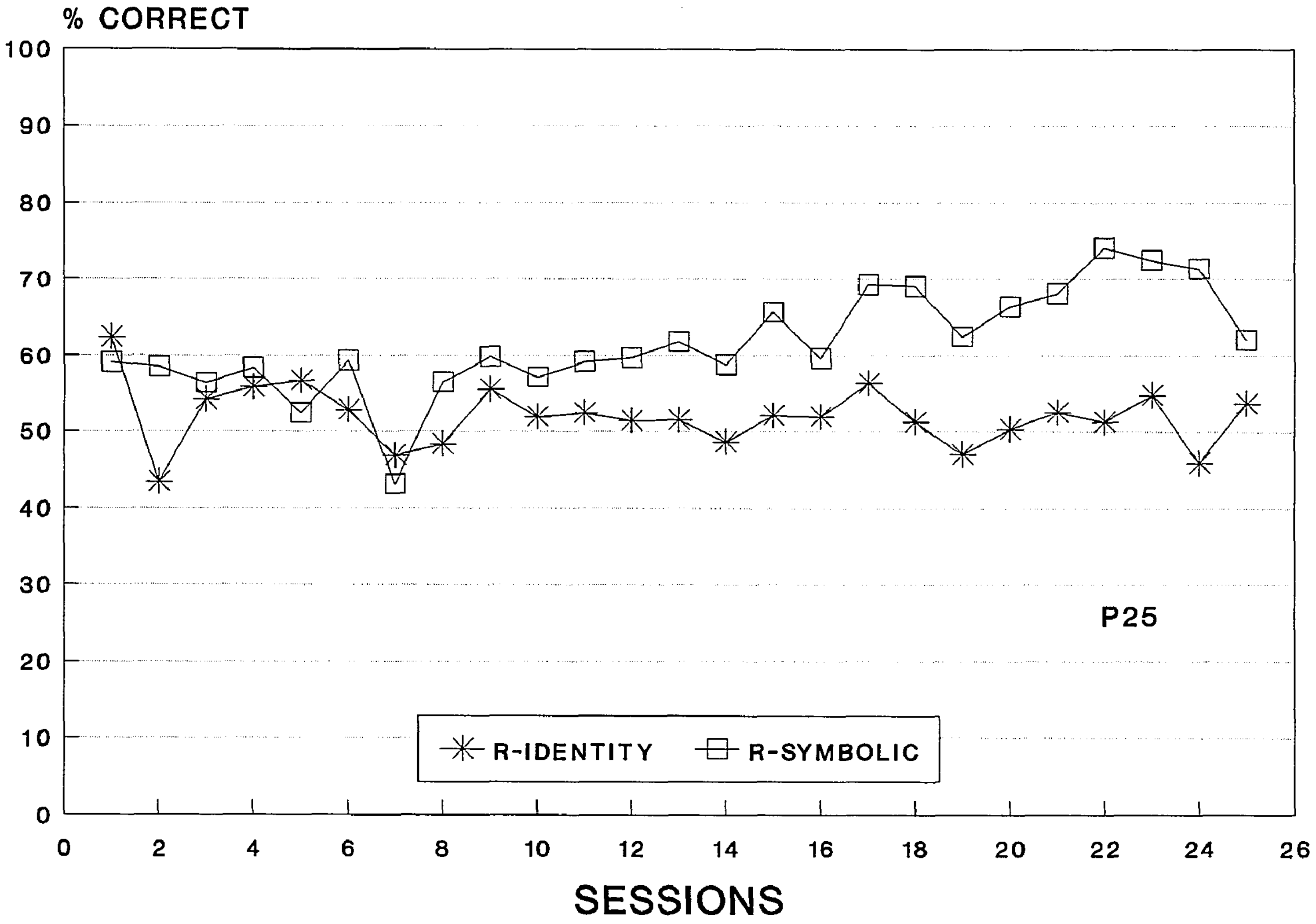
SESSIONS
P25
IDENTITY
SYMBOLIC

Figure 3.10. Performances for bird P25 for the second phase of the simultaneous matching-to-sample procedure with a stimulus disparity of 6 elements, are shown as mean percent trials correct for each session for both identity-matching and choice-key-symbolic matching conditions.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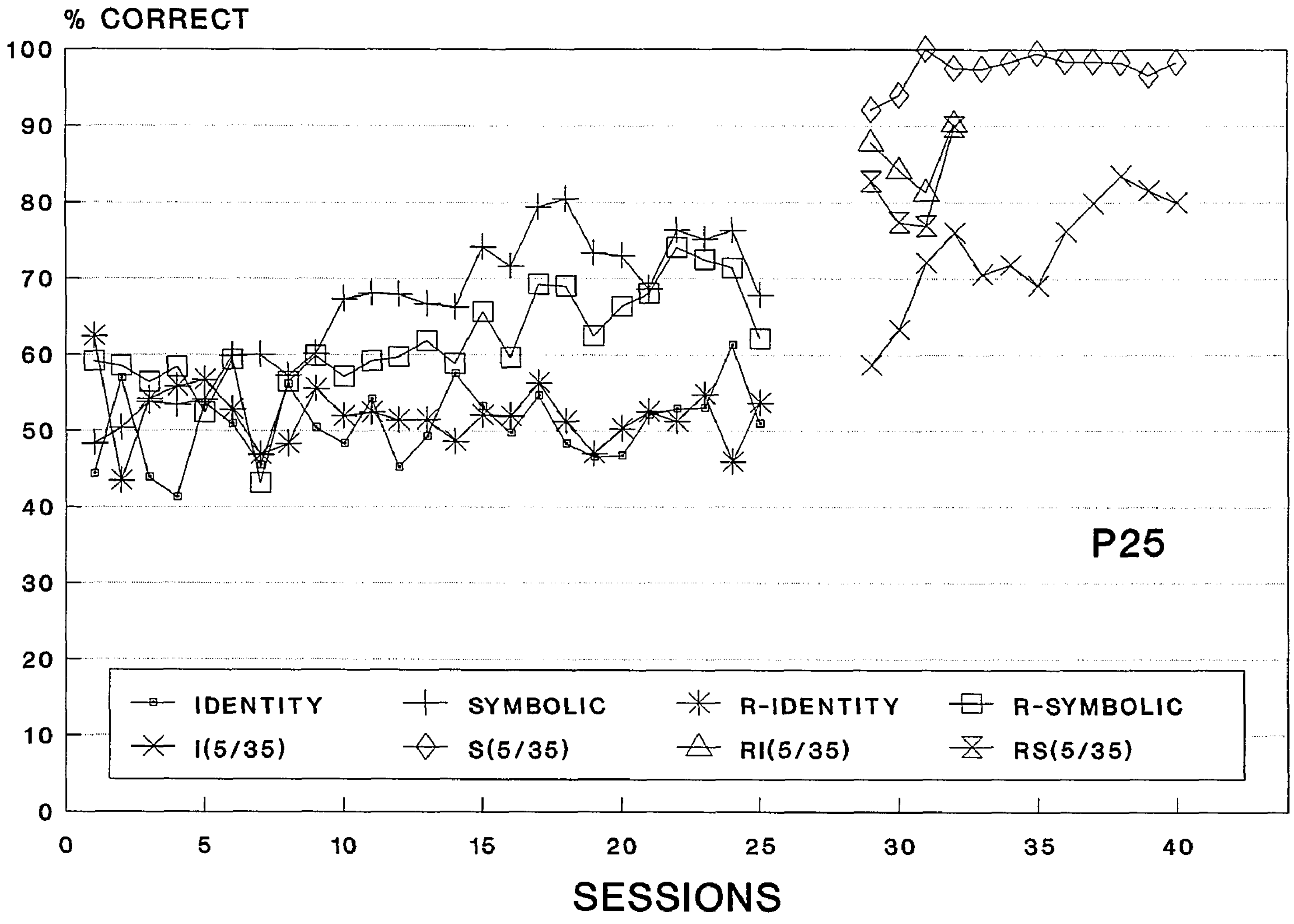
P25
R-IDENTITY
R-SYMBOLIC

each but the first session of identity matching in the second phase and stimulus disparity 6, the level of discrimination with disparity 30 was better already on the first session and increased to a level exceeding that observed for the center key symbolic condition with stimulus disparity 6. With the center key as the symbolic stimulus, the bird's performance with stimulus disparity 30 was 93 percent of trials correct on the first session and 100 percent of trials correct on the third session.

The matching behavior on the smaller stimulus disparity would appear to contradict the explanation of behavior offered when discussing this bird's performance on the three-disparities procedure. The suggestion was made that the data is consistent with response choices based on the actual numerosity of the comparison stimuli. The poor performance on the matching procedure with the identical stimulus disparity does not show any evidence of such discrimination. However, the superior performances on the larger stimulus disparity seems to suggest that the bird "knew" the contingencies of the procedure but was unable to express this knowledge behaviorally. As in Experiment 1, where superior performances on a simultaneous discrimination test followed chance level performances on a zero-delay matching condition, in the present procedure, superior performances on a conditional discrimination procedure with stimuli differing substantially in number of elements displayed, followed chance level performances on a procedure where the stimulus disparity was not pronounced.

Figure 3.11. The data for bird P25 are shown as mean percent correct trials for each session and both phases of simultaneous matching-to-sample and symbolic-matching training with stimulus disparity 6 by the four curves on the left. The two curves on the right illustrate means for symbolic-matching and center-key-symbolic matching performances for each session for the test procedure with a stimulus disparity of 30 elements.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Results of Experiment 3

Overall, the data for Experiment 3 confirmed that the poor performances observed for the matching procedure in Experiment 1 neither resulted from difficulties in stimulus discriminability, nor from the nature of the procedure (i.e., simultaneous discrimination vs. conditional discrimination), as shown by the differences in performances on identity-matching, and symbolic-matching trials in Experiment 3. While the sum of the data in the present study did not illuminate the cause for the behavioral differences on the various training conditions, they seem to suggest differences in cognitive processing of a simultaneous discrimination problem and a conditional conditional discrimination problem.

Overall, the birds' behaviors on each different condition were remarkably similar, independent of the assigned S+ ("few" or "many") and, on the multiple disparities procedures, independent of stimulus element and number of disparities. On conditional discrimination procedures, identity-matching was always inferior to symbolic-matching, both for the bird trained with stimulus disparity 6 and birds trained with stimulus disparity 30. Further, center-key-symbolic matching was always easier than choice-key-symbolic matching.

The difficulties the subjects exhibited in learning the identity relationship should not be interpreted to indicate that these birds cannot learn such a relationship. Instead, a comparison of the behaviors on identity-matching and symbolic-matching trials suggests that in different procedures, some types of stimuli are treated as qualitatively different.

General Results and Discussion

An unexpected finding in the present study was the pronounced difference in levels by which the birds discriminated on the three main procedures used in the present study. The procedures, identity matching-to-sample, simultaneous discrimination, and symbolic-matching, were all based on discriminations of stimuli differing only in numerosity of elements displayed.

When required to match identity in Experiment 1, the subjects failed to learn what appeared to be the obvious (to human eyes) general relationship among the stimuli. In the presence of a sample displaying five asterisks the correct response was to the choice key containing the numerically smaller stimulus (5 asterisks), and in the presence of a sample displaying 35 asterisks the correct response was to the choice key with the numerically larger stimulus (35 asterisks). Not only were the numbers an identity, the location of the elements in the key were identical as well.

While bird P25 eventually exhibited a moderate level of acquisition of the conditional discrimination, such learning developed only after extensive training. However, considering that at the close of Experiment 1 all other subjects remained at chance levels of performance, the behavior exhibited by bird P25 was important in demonstrating that such learning was in fact possible with the stimuli used in the present study.

When the simultaneous identity-matching condition (stimulus disparity 30) was reintroduced in the final experiment (Experiment 3), all subjects, with the exception of bird P5, continued to match poorly. In the final experiment Bird P25 was trained on a procedure with a reduced disparity (2/8 stimulus elements, disparity 6). On this condition, the bird's identity-matching performance remained at chance levels throughout training. However, when this bird was tested on the procedure with stimulus disparity of 30 elements, this bird's performances rapidly improved to a high level of competence.

The generally poor identity-matching performances in Experiment 1 markedly contrasted with performances on the discrimination test implemented to assess discriminability of the stimuli, and particularly to performances on the simultaneous discrimination procedures with multiple disparities in Experiment 2. In these conditions the birds showed that they were capable of discriminating between stimuli differing by as few as two elements. The positive value of one category of stimuli (e.g., "fewer") was quickly associated with reinforcement and the appropriate response was maintained.

The speed with which these discriminations were learned is not inconsistent with the hypothesis that the ability to perceive the differences between the two stimulus categories was the result of an innate categorization and not contingent on reward. All birds were readily able to avail themselves of any of several cues to respond correctly to the respective reinforced category of stimuli, i.e., stimuli with either fewer or more than 20 stimulus elements, depending on the S+ assignment. Interestingly, this ability to discriminate among stimuli was not sufficient to permit learning the two simple associations necessary to match identity, although it was clearly sufficient to permit learning the two associations necessary to solve the symbolic relationships.

Identity matching was consistently inferior to symbolic matching for all subjects in all conditions examined, although the same relationship, i.e., "the correct comparison is cued by the sample," governed the stimuli in both procedures and the stimuli in the identity-matching conditions were essentially identical to those used in the matching procedures in Experiment 1.

In identity-matching procedures with symbolic-matching trials (Experiment 3), identity-matching performances were always substantially inferior to the performances on either symbolic component, and symbolic-matching performances always inferior when the choice stimuli (choice-key-symbolic), rather than the sample stimulus (center-key-symbolic), contained the colored symbolic equivalents. On the center-key-symbolic condition in particular, responses rapidly came under control of the two stimulus categories, generating learning curves not dissimilar to those describing performances on the simultaneous discrimination procedures.

These findings basically agree with those reported by Carter and Werner (1978) for similar procedures. In their study, the identity-matching and symbolic-matching conditions were presented in separate experiments rather than on the same session, as in the present study. On some conditions in their experiment, birds were trained to match stimuli with horizontal and vertical lines and in a different condition, to match red and green hues. The symbolic condition required "matching" horizontal and vertical lines to either red and green. As in the present study, the symbolic aspect of the procedure was counterbalanced such that in different experiments the colored stimuli appeared either as the sample or as the choice stimuli. Carter and Werner found that simultaneous hue matching was learned faster than any of the remaining conditional discriminations while the birds had great difficulties learning to match lines. Similar to findings in the present study, in the line-matching conditions their birds acquired the discrimination faster when the sample stimulus was the symbolic equivalent than when the choice keys were colors. Carter and Werner found this difference both for zero-delay and simultaneous presentation of the choice stimuli.

Carter and Werner (1978) interpret the differences in acquisition between symbolic-matching and identity-matching procedures to indicate differences in discriminability "between the sample stimuli and between the comparison stimuli, with the former playing the more important role" and "identity between a sample and one of the comparison stimuli appears to play no role for pigeons...matching-to-sample is just as symbolic as is the symbolic-matching problem." Adherents of the multiple rule learning hypothesis, Carter an Werner suggest that "in both paradigms pigeons learn a set of specific 'if...then' rules, with the sample stimulus serving an 'instructional' function to indicate which of the comparison stimuli is the correct one." While such an interpretation is suggested by the observed absence of positive transfer, it does not readily account for the poor identity-matching performances with lines as stimuli.

Both in Carter and Werner's (1978) investigation and in the present study, the performances on the center-key-symbolic condition indicated that the two types of complex stimuli (lines, number of elements) were relatively easily discriminable. Assuming that when the choice key contains the symbolic equivalent the discriminability of complex stimuli affects rate of acquisition, it would seem that *any* identity-relation should be learned more rapidly than a choice-key-symbolic relation since the identity-matching relation provides and additional cue in the form of a matching comparison.

In the present study, the behaviors on the symbolic-matching conditions (stimulus disparity 30) established that the failure to match identity did not result from a "confusion" arising from the requirement to respond, on different trials, to either of the two stimulus categories. The stimuli were clearly readily discriminable. More importantly, the performances on the choice-key-symbolic condition showed that the birds could judge the pertinent category accurately in the absence of a numerical comparison. This finding is particularly notable since the stimulus differences were relative rather than absolute. Unless individual stimuli or overall categories ("less-than-" or "more-than-twenty") were recognized, a stimulus could not be judged to be either "few" or "many," but could obtain its value only in comparison with the alternate stimulus choice. From the performances in the center-key-symbolic condition it would thus appear that the extensive training on the simultaneous discrimination procedures resulted in some internal representation permitting the birds to form absolute judgments of each numerical sample.

When discussing their findings Carter and Werner (1978) suggest that the difference in rate of acquisition on the simultaneous hue matching procedures (identity and symbolic) might indicate different underlying learning processes. It seems likely that cognitive processing of "simple" (in human terms, for example, one-dimensional) and "complex" stimuli differs. Simple stimuli can be discriminated on the basis of some primary dimension (such as brightness), i.e., the discrimination may be governed by primary (innate) categorization processes. For example, the difference between red and blue stimuli is immediately apparent and does not have to be learned. What *is* learned is the differential association of the individual exemplars with reinforcement. With complex arbitrary stimuli, the animal first has to learn to differentiate the stimuli before an association with reinforcement can be learned.

The performances on the discrimination test in Experiment 1 of the present study suggest that the appearance of the numerical stimuli did not have to be learned, and the performances on the center key symbolic condition, that the appearance of the colors did not have to be learned. Instead, the behaviors suggest that both discriminations were the result of innate categorizations. What was learned on the initial sessions in these procedures were associations between two particular stimuli with reinforcement or conversely, the association of a particular category with reinforcement.

With these considerations, the difficulties the birds exhibited when required to match identity suggested a procedural constraint. The one aspect of the stimulus presentation which was only briefly investigated as possibly contributing to the failure to match was the physical proximity of the keys. Conceivably, since on simultaneous matching procedures the center key remained illuminated for the duration of a trial, the birds did not perceive the three keys as occupying separate and distinct locations and thus responded at random across a perceived "illuminated area."

This hypothesis was rejected as a result of a rather unexpected observation: subsequent to the present study, the three-key matching procedure with a stimulus disparity of 30 elements was adapted to serve as an autoshaping program. Naive birds were first presented with the two side keys location displaying stimuli with five and 35 elements, respectively, in the usual locations. One peck to either key resulted in access to grain. Pecking was quickly established. After completing 100 trials of side key shaping in one session, the center key was introduced in the absence of the side keys. One peck to the sample was programmed to result in the presentation of the side keys. With the introduction of the center key, some of the subjects ceased to respond and behaved as if the illuminated key did not exist, while other birds refused to peck the center key but persistently pecked at the dark areas normally occupied by the side keys.

A further indication that the stimuli were readily distinguishable was that casual observation of the birds' activities on the monitor during identity-matching training did not reveal repeated responding to the center key when lit, as might be expected if the subjects were confused about the response location. Although subsequent to a center key response the birds frequently directed pecking movements toward a choice key without actually touching the screen then switched to the alternate choice key, they were not observed to redirect their pecking to the sample display subsequent to pecks directed at one of the choice locations. It should be noted, however, that responses to the center key subsequent to the one peck required to produce the choice keys were not recorded and had no contingent effect.

These observations suggest that while learning to peck the choice keys in this particular autoshaping procedure, the birds did not in fact learn to peck "a lit key." They seemed to learn to peck a particular location associated with reinforcement, and a lit key served as a cue that pecking the location would lead to reinforcement. When the display "moved" to the center, the birds' responding did not follow the display, but remained faithful to the locations previously associated with reward. All four birds trained with this program tenaciously persisted in this behavior and required lengthy handshaping to peck the center key.

The behaviors observed in this autoshaping procedure can further be interpreted to suggest that when pigeons match, they do not match "identity" or "sameness," but rather, "similarity," since the stimulus displayed on the sample-key location cannot be identical to the stimulus displayed on the choice-key location. "Sameness" or "identity" only applies if a stimulus reappears in a location it previously occupied. Thus it cannot be said that a failure to match is the result of an avoidance to "peck the stimulus just pecked" if the matching stimulus appears in a different location.

It is possible that when responding to a stimulus, two associations are learned: an association of the stimulus with one or several possible locations and the association of that stimulus with reinforcement. Hence for the naive birds during autoshaping, the stimuli suddenly appearing on the center key were "expected" on the choice-key locations, particularly since these locations were associated both with the two stimulus categories and primary reinforcement. In this case, the familiar location was a more powerful stimulus than the stimulus display, evidenced by the cessation of responding when the display appeared in a new location, and the repeated pecks at the familiar, but not illuminated, choice key locations.

Possibly, associations of this type affect performances on transfer tests where one of the familiar stimuli is replaced by a novel stimulus. In a typical 3-key procedure, the choice keys are associated both with reinforcement *and* the familiar stimuli, while the center key is associated only with the familiar stimuli. The choice keys are therefore more similar to each other than they are to the center key. A novel stimulus on the center key only (such as in the center-key-symbolic condition) or novel stimuli on both choice keys only (such as in the choice-key-symbolic condition), therefore is less disruptive than when the novel stimulus appears both on the center key and one choice key, while the second choice key contains one of the familiar stimuli. In comparison to, and in an important departure from, transfer tests frequently used in three-key matching-to-sample procedures, namely the replacement of one of the familiar stimuli with a novel stimulus (e.g., Cumming and Berryman, 1961), in the present procedures the procedural changes were always symmetrical. That is, in both conditions the choice keys either contained numerical stimuli only or symbolic color equivalents only.

In the center-key-symbolic condition, the choice keys displayed the familiar stimulus categories in the familiar locations. In essence, this procedure was rather similar to the simultaneous discrimination procedure, except for the requirement to respond, on different trials, to stimuli from both numerical categories as cued by the sample. While the peck required to produce the familiar choices was to a novel stimulus, the value of this stimulus was rapidly determined by the association with, and the consequence of responding to, either of the familiar categories.

Conversely, in the choice-key-symbolic condition the center key contained the familiar numerical stimuli and the choice keys the symbolic color equivalents. Since the choice-key-symbolic condition for all subjects followed the center- key-symbolic condition, the colored choices were not neutral, although they were not associated with choice key locations. It can be assumed that during preceding training with the colored stimuli as samples, the birds formed relatively strong associations between either color and its arbitrary numerical equivalent. Arguably, a numerical sample was not strongly associated with either choice key and reinforcement as a result of the failure to learn the associations based on the sample on the identity trials in the same session. Hence on choice key-symbolic-matching neither the sample nor the choice keys were strongly associated with primary reinforcement.

The above considerations are supported by findings reported by Sidman (1992) for a rhesus monkey subject presented with a 5-key matching-to-sample procedure. The sample was always in the center while the locations of the comparisons on the outer keys varied on each trial. The presentation of the comparison stimuli "on six different pairs of keys, key position was expected to become an irrelevant aspect of the stimuli." However, "this expectation proved unfounded...pairs of key positions appeared to have become units unto themselves." The author writes that "...it is possible that failures of nonhumans to show generalized identity matching have been caused by a basically irrelevant feature of the standard conditional discrimination procedure. Because sample stimuli are typically presented on only one key in the display, and comparison stimuli on two other keys, subjects may come to identify stimuli not only by their physical characteristics but also by their locations."

While performances on the center-key-symbolic condition were clearly superior to performances on identity-matching, they were inferior to center-key-symbolic matching. However, the data show that the shape of the learning curves generated by the two symbolic conditions was similar, the observed rapid improvement very dissimilar from the much more gradual and extended acquisition for identity-matching. That is, the rate of acquisition of symbolic relations was similar while the level of discrimination was not. The differences in the shape of acquisition curves generated by the identity- and symbolic-matching conditions, respectively, would seem to support the notion that symbolic matching and identity matching might be mediated by different learning processes.

While it seemed possible that on symbolic relations the poorer performances on the choice-key-symbolic condition resulted simply from the relativistic nature of the numerical sample stimuli, similar findings have been reported, for example, by Santi (1978), and Mintz (unpublished). In these two studies pigeons were trained on procedures with both identity-matching and choice-key-symbolic matching trials, with horizontal and vertical lines as stimuli. The data in both studies show inferior performances on identity trials compared to performances on center key symbolic trials.

The difference between horizontal and vertical lines is absolute, at least to humans moving in a vertical plane. Birds move primarily in a horizontal plane and it is likely that for these organisms differences in line orientation are relative in nature. For present purposes the assumption is, that a vertical line can be assigned the value "vertical" without reference to a comparison line. Here, information about the second category of stimuli ("horizontal") need not be present to identify it as "vertical." In contrast, the categories "few" and "many" used in the present study had no independent existence, each presumably defined by comparison with the other category. However, the performances on the choice key symbolic condition where the numerical comparison was not available suggest that either the considerable training on various disparities resulted in the ability to recognize one category in the absence of the second, or else that the associations learned during training on the center key symbolic condition were transferred to the choice stimuli when the choice stimuli were symbolic. Because all subjects went through the same sequence of training conditions it is not known whether the performances on choice key symbolic training were in fact facilitated by training on the preceding, i.e., center-key-symbolic, condition.

The inferior performances on the choice-key-symbolic condition could conceivably have been the result of an incomplete memorization of the differences between the two stimulus categories. While both symbolic conditions required memorization of two stimulus relationships, response choices based on a symbolic sample were potentially easier since both numerical stimuli were displayed and therefore available for comparison. Assuming that the two relationships were memorized, the correct choice could be identified by comparison with the alternate stimulus. On the choice key symbolic condition, determining the numerosity of the sample was more difficult. The correct identification of the sample depended on prior memorization of the two stimulus categories in absolute terms since the alternate numerical stimulus category was not represented. Therefore, misidentification of the sample stimulus was more likely in the presence of a non- symbolic S+. The symbolic equivalents differed in absolute terms, hence an error in the presence of a symbolic sample was an error in the association itself, while an error in the presence of a non-symbolic sample was composed of an error of misjudgment of the numerical value of the sample and an error in the association.

While the birds did not have to learn the appearance of the stimuli, they did have to learn the associations between particular stimuli and reinforcement. The relevant dimensions by which the birds classified the stimuli was investigated by means of probe trials in the multiple disparities procedure in Experiment 2. Among several strategies, responding could be based on:

a) a relational judgment, i.e., a direct, trial-by-trial comparison of the number-related differences between the two comparisons. With a strategy based on a relational judgment neither positive nor negative stimuli are categorized, but a particular stimulus gains excitatory or inhibitory value in the presence of, and in relation to, a comparison stimulus,

b) a differentiation of the positive stimuli into one overall category predictive of reinforcement (number of elements greater or less than 20, depending on the assigned S+) while the negative stimuli are not categorized, or a differentiation of both types of stimuli (number of elements greater *and* less than 20) into two overall categories, each category associated with a particular event. Such categorizations result from the abstraction of some aspect shared by all stimuli of a particular type, such as "number of elements less than 20." These stimuli are thus represented by one generalized abstraction. Here, individual S+ stimuli differ negligibly in excitatory value. Since on each new trial the display is scanned for the stimulus matching the abstraction, negative stimuli are either overall aversive or not categorized,

c) individual associations of each positive stimulus with reward. Separately recognized S+ stimuli are individually represented, and differ in excitatory value. Each S+ abstraction is based on some defining element such as the brightness- or density value of the invariant proportion of non-elements to elements. S- stimuli remain neutral, i.e., are not categorized.

On probe session, the particular stimulus categorization(s) used as a response-strategy should result in specific changes in performances on probe trials compared to baseline trials.

If the categorization is based on a relational judgment, the performances on probe trials should parallel those on corresponding baseline disparities since all individual stimuli are neutral and gain value only by comparison with the alternate stimulus. Compared to categorizations discussed below, relational judgments result in fewer errors since the stimuli are not internally represented and false rejections based on a perceived mismatch between a choice stimulus and the internal representation do not occur.

If the positive stimuli only, or else both types of stimuli, are categorized overall, both comparisons are judged against the abstraction representing the positive category. On regular trials, the incorrect comparison provides an inferior match and is rejected. The subsequent response- choice depends on how well the alternate comparison matches the generalized representation. If only S+ stimuli are categorized, responses are as likely to either comparison, since the absence of an aversion to the negative stimulus prevents a response-bias in favor of the correct response.

On probe trials, a discrimination based on an overall categorization of both positive and negative stimuli should result in a severe reduction in the level of discrimination on both types of probes, the consequence of a response bias engendered by the first stimulus attended to where the particular response (approach or avoidance) is determined by the category represented by that stimulus.

Overall categorized stimuli differ negligibly in appetitive value. Since all positive stimuli are subsumed under the same overall categorization, the increment in discrimination between the two S+ probes should be negligible. The discrimination increment between performances on the two S- probes should be affected similarly if these stimuli are subsumed under an overall inhibitory category, since the behavioral outcome of responding in the presence of two negative stimuli or two positive stimuli is the same. If S- stimuli are neutral, responding should be under control of the primary conceptualization, i.e., a relational judgment, and performances on the two probes, as well as the rate of increase in discrimination between the performances on the two S- probes, should resemble corresponding baseline performances.

If the five positive stimuli are individually represented, a response on regular trials is determined by the degree to which the positive comparison matches one of the representations. On S+ probes both stimuli are compared to their respective abstractions and the response is to the comparison providing a better match. The discreteness by which an abstraction describes a particular stimulus is a function of the extent by which the invariant properties defining that stimulus differ from the invariant properties of the two stimuli nearest in number of elements.

The performances on probe trials suggest that two different strategies governed responding: in the presence of two negative comparison stimuli, the responses appear to have been based exclusively on a relational judgment, and in the presence of two positive stimuli to some extent on a relational judgment. This inference is suggested by the superior performances on S- only probes, both in comparison with performances on S+ only probes and performances on corresponding baseline disparities, by the rates of increase in discrimination between the respective probe-disparities, and the differences in median response latency observed for the two probe types. The latencies on S+ only probes were consistently shorter than the latencies on S- only probes, suggesting that on S+ probes the first stimulus attended to was recognized as positive and no further comparison was performed.

Positive stimuli which are categorized overall are represented by one general abstraction. Because this category is undifferentiated, the individual stimuli do not differ in appetitive value. In the presence of two positive stimuli, the first stimulus attended to is perceived to match the general abstraction and is responded to. Hence on some percentage of trials the incorrect of the two stimuli will be judged a better match, thereby decreasing the level of discrimination. Conversely, if both stimuli are separately represented, both are compared to their respective abstractions. While under an overall classification the first stimulus attended to automatically results in a rejection of the alternate comparison, individually represented stimuli are separately associated with reinforcement. The relative strength of an association is determined by the degree by which the particular stimulus is defined by its abstraction. In the presence of stimuli producing equal response strength, performance should be completely disrupted and deviations should be proportionate to the differences in relative match between the two stimuli and their abstractions. The observed moderate disruption of the discrimination on S+ probes is therefore contrary to behaviors predicted from an overall categorization.

This inference is further supported by the differences in side preferences on the two types of probes. The greater prevalence in location preference on S+ probes agrees with expected behaviors (outlined above) in the presence of two individually recognized stimuli, with the deviation from chance level of performance on each of the two S+ probe sets resulting from the relative differences in appetitive value of the two comparisons. Conversely, since S- stimuli are neutral, responding is based on a relational judgment and side preferences are overall not different from those observed on comparable baseline disparities.

A template-matching process provides also an alternate explanation to the hypothesis that an increase in disparity itself accounts for the observed between-disparity increases in discrimination on S+ probes as well as the superior levels of performance on S- probes. For both groups, the respective correct comparison ("few" birds = 12 elements, "many" birds = 28 elements) was the same on both S+ probes, and each differed by 4 elements from its respective, normally numerically closest S+ ("few" birds = 18 elements, "many" birds = 24 elements). On the smaller disparity (12:16 "few" birds, 24:28 "many" birds, disp. 4) the incorrect comparison for both groups differed by two elements ("few" birds = 18 elements, "many" birds = 22 elements), and on the larger disparity (12:18 "few" birds, 22:28, disp. 6) by one element from the respective, numerically closest S+ ("few" birds = 19 elements, "many" birds = 21). With respect to the correct comparison, the abstraction of the incorrect stimulus on the larger disparity was less distinct, biasing responding toward the alternate comparison.

Hence compared to the larger disparity, the incorrect comparison on the smaller disparity ("few" birds = 16 elements, "many" birds = 24 elements) is more discretely represented. While on both disparities the likelihood of a positive identification of the correct comparison is identical, the probability of a positive match of the incorrect comparison on the smaller disparity is increased, reducing the response-bias in favor of the correct comparison, i.e., decreasing the level of the discrimination. This interpretation then accounts for the differences in disruption, compared to baseline performances, of the discrimination on the two S+ probe sets. Although no direct corresponding baseline disparity exists for the larger of the two S+ disparities (disp. 6), compared to an inferred baseline performance, the discrimination on the larger, compared to the smaller of the S+ disparities, was less severely disrupted.

Both groups show a superior discrimination on S- probes compared to baseline levels, consistent with behavior based on a relational judgment. This suggests that individual recognition of the S+ stimuli governed responding on regular trials as well. On regular trials, a comparison of individual S+ against the respective internal abstractions likely results in false rejections of some positive stimuli, particularly those differing by few elements from the stimuli closest in number of elements, decreasing the level of discrimination. As indicated by behaviors on S- probes, discrimination based purely on a relational judgment would not similarly affect behavior. The reduced level of discrimination on baseline trials compared to the level of discrimination on S- probes on comparable disparities therefore suggests that responding on baseline trials was not based only on the relative differences between the comparisons.

Pigeons readily memorize large numbers of individual stimuli (see, e.g., Vaughan, Jr. W., and Greene, S. L., 1984) and it is certainly conceivable that in the present experiment the birds memorized the general appearance of each of the five positive stimuli based on the invariant proportion of elements relative to the area of the entire key. Responding to comparisons differing by only two elements was reliably better than 50 percent, a discrimination which, absent the use of a relational judgment, could be accomplished by either memorizing the general appearance of the five sets of comparison stimuli together with the respective correct response, or by memorizing the general appearance of the five positive stimuli. The probe data is in support of the latter but not the former strategy.

The judgment of the pertinent category was not based entirely on absolute invariances such as brightness, for example, and not so much on a comparison with the alternate category as evidenced by the absence of an aversion to the non-reinforced stimulus category, but rather, the S+ stimuli derived their positive value as a result of a comparison of the sample with the response-choice most resembling the sample. Presumably the sample triggers a memory search for a template resembling it. Based on the behaviors observed on choice-key-symbolic matching and simultaneous discrimination procedures with multiple disparities, such templates are not perfect. Considering the nearly indistinguishable steady-state performances among subjects on the five disparities in the multiple disparity procedure it appears that the extent to which such templates overlap is rather similar among subjects.

Overall, the findings reported in this study show that pigeons can avail themselves of different problem-solving strategies and the sum of the findings are not inconsistent with the inference that the learning processes invoked by identity relations differed from those invoked by symbolic- and simultaneous-discrimination relations. As suggested earlier, simultaneous discriminations as well as symbolic matching might have been based on innate, or primary, categorizations, similar to the type of discrimination suggested by Herrnstein (1964) as a possible explanation of behaviors observed in a concept-formation procedure with naturalistic stimuli. Here, the pigeons' rapid acquisition of the concept "people" indicated that they had "entered the experiment with the concept already formed." That is, the abstraction of some unknown aspect of the stimuli or the stimulus situation was performed in the absence of specific training.

By definition, primary (innate) classifications (e.g., "few-many," "bright-dark") require little complex cognitive processing. In the present study, the recognition of the differences between the stimuli in all uniform combinations of the simultaneous discrimination procedures as well as the identity-matching tasks was purely a function of the sensitivity of the visual system to the stimulus disparities, such as differences in brightness created by the various proportions of stimulus elements (asterisks) and non-elements ("background"). Presumably, the primary conceptualization of the numerical stimuli proceeded in the same fashion regardless of the procedure.

For simple stimuli, the process of abstracting the relevant features is not necessary. Hence differences in rate of acquisition between simultaneous discrimination and matching procedures may well be due to differences in cognitive processing. Since the stimuli in the conditional- and the simultaneous-discrimination procedures in the present study were the same the data suggest that some unknown differences in processing invoked the observed behavioral differences between the two procedures.

References

Beach, F.A. (1950). The snark was a boojum. *American Psychologist*, 5, 115-124.

Bitterman, M.E. (1965). Phyletic differences in learning. *American Psychologist*, 20, 396-410.

Breland, K., and Breland, M. (1960). The misbehavior of organisms. *American Psychologist*, 16, 681-684.

Carter, D.E., and Eckerman, D.A. (1975). Symbolic matching by pigeons: Rate of learning complex discriminations predicted from simple discriminations. *Science*, 187, 662-664.

Carter, D.E., and Werner, T.J. (1978). Complex learning and information processing by pigeons: a critical analysis. *Journal of the Experimental Analysis of Behavior*, 29 (3), 565-601.

Cerella, J. (1979). Visual classes and natural categories in the pigeon. *Journal of Experimental Psychology: Human Perception and Performance*, 5 (1), 68-77.

Cohen, L.R. (1969). Generalization during acquisition, extinction, and transfer of matching with an adjustable comparison. *Journal of the Experimental Analysis of Behavior*, 12, 463-474.

Cumming, W.W., and Berryman, R. (1961). Some data on matching behavior in the pigeon. *Journal of the Experimental Analysis of Behavior*, 4, 281-284.

Cumming, W.W., and Berryman, R. (1965). The complex discriminated operant: Studies of matching-to-sample and related problems. In: *Stimulus Generalization* (D.I. Mostofsky, ed.), Stanford, CA: Stanford University Press.

Davis, H., and Perusse, R. (1988). Numerical competence in animals: Definitional issues, current evidence and a new research agenda. *Behavioral and Brain Sciences*, 11, 561-615.

Delius, J.D. (1983). Learning. In: *Physiology and Behavior of the Pigeon* (M. Abs, ed.), New York: Academic Press.

Delius, J.D., and Habers, G. (1978). Symmetry: can pigeons conceptualize it? *Behavioral Biology*, 22, 336-342.

deRuiter, L. (1952). Some experiments on the camouflage of stick caterpillars. *Behaviour*, 4, 222-232.

Domjan, M., and Galef, Jr., B.G. (1983). Biological constraints on instrumental and classical conditioning: Retrospect and prospect. *Animal Learning and Behavior,* 1 1 (2), 151-161.

Eckerman, D.A. (1970). Generalization and response mediation of a conditional discrimination. *Journal of the Experimental Analysis of Behavior,* 1 3, 301-316.

Eckerman, D.A., Lanson, R.N., and Cumming, W.W. (1968). Acquisition and maintenance of matching without a required observing response. *Journal of the Experimental Analysis of Behavior,* 1 1, 435-441.

Epstein, R., Lanza, R.P., and Skinner, B.F. (1981). "Self-awareness" in the pigeon. *Science,* 2 1 2, 695-696.

Ewer, R.F. (1971). Review. *Animal Behaviour,* 1 9, 802-807.

Farthing, G.W., and Opuda, M.J. (1974). Transfer of matching-to-sample in pigeons. *Journal of the Experimental Analysis of Behavior,* 2 1 (2),199-213.

Gallup, G.G. (1970). Chimpanzees: self-recognition. *Science,* 1 5 7, 86-87.

Herrnstein, R.J. (1979). Acquisition, generalization and discrimination reversal of a natural concept. *Journal of Experimental Psychology: Animal Behavior Processes,* 5 (2),116-129.

Herrnstein, R.J. (1982). Stimuli and the texture of experience. *Neuroscience and Biobehavioral Reviews,* 6 , 105-117.

Herrnstein, R.J., and De Villiers, P.J. (1980). Fish as a natural category for people and pigeons. In: *The Psychology of Learning and Motivation,* (Vol.14) (G.H. Bower, ed.), New York: Academic Press.

Herrnstein, R.J., and Loveland, D.H. (1964). Complex visual concept in the pigeon. *Science,* 1 4 6, 549-551.

Herrnstein, R.J., Loveland, D.H., and Cable, C. (1976). Natural concepts in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes,* 2 (4), 285-311.

Hodos, W., and Campbell, C.B.G. (1969). Scala Naturae: Why there is no theory in comparative psychology. *Psychological Review,* 7 6 (4), 337-350.

Hollard, V.D., and Delius, J.D. (1982). Rotational invariance in visual pattern recognition by pigeons and humans. *Science,* 2 1 8, 804-806.

Kamil, A.C., and Sacks, R.A. (1972). Three-configuration matching-to-sample in the pigeon. *Journal of the Experimental Analysis of Behavior,* 1 7, 483-488.

Keller, F.S., and Schoenfeld, W.N. (1950). *Principles of Psychology.* New York: Appleton-Century-Crofts.

Kettlewell, H.B.D. (1955). Selection experiments on industrial melanism in the Lepidoptera. *Heredity,* 9, 323- 342.

Kohler, W. (1925). *The Mentality of Apes.* New York: Harcourt, Brace.

Lawrence, D.H. (1963). The nature of a stimulus: some relationships between learning and perception. In: *Psychology: A Study of Science,* Vol. 5, (S. Koch, ed.), New York: McGraw-Hill.

Lea, S.E., and Harrison, S.N. (1978). Discrimination of polymorphous stimulus sets by pigeons. *Quarterly Journal of Experimental Psychology,* 30, 521-537.

Lee, R.B. (1979). *The Kung San: Men, Women and Work in a Foraging Society,* Cambridge: Cambridge University Press.

Lieberman, D.A. (1993). *Learning: Behavior and Cognition* (2nd Ed.), California: Brooks/Cole.

Lohmann, A., Delius, J.D., Hollard, V.D., and Friesel, M.F. (1988). Discrimination of shape reflections and shape orientations by Columba livia. *Journal of Comparative Psychology,* 102 (1), 3-13.

Lubow, R.E. (1974) High-order concept formation in the pigeon. *Journal of the Experimental Analysis of Behavior,* 21 (3), 475-483.

Maki, W.S. Jr., Gillund, G., Hague, G., and Siders, W.A. (1977). Matching to sample after extinction of observing responses. *Journal of Experimental Psychology: Animal Behavior Processes,* 3, 285-296.

Malott, R.W., and Siddall, J.W. (1972). Acquisition of the people concept in pigeons. *Psychological Reports,* 31, 3-13.

Marler, P. (1970). Bird song and speech development: Could there be parallels? *American Scientist,* 58, 669-673.

Mayr, E. (1974). Behavior programs and evolutionary strategies. *American Scientist,* 62, 650-659.

McGrane, B. (1989). *Beyond Anthropology: Society and the Other,* New York: Columbia University Press.

Morse, D.H. (1980). *Behavioral Mechanisms in Ecology,* Cambridge, MA: Harvard University Press.

O'Hanlon, R. (1988). *In Trouble Again.*, New York: Atlantic Monthly Press.

Pietrewicz, A.T., and Kamil, A.C. (1979). Search image formation in the Blue Jay (Cyanocitta cristata). *Science*, 204, 1332-1333.

Pietrewicz, A.T., and Kamil, A.C. (1977). Visual detection of cryptic prey by Blue Jays (Cyanocitta cristata). *Science*, 195, 580-582.

Piscareta, R., Redwood, E., and Witt, K. (1984). Transfer of matching-to-figure samples in the pigeon. *Journal of the Experimental Analysis of Behavior*, 42 (2), 223-237.

Poole, J., and Lander, D.G. (1971). The pigeon's concept of a pigeon. *Psychonomic Science*, 25 (3), 157-158.

Premack, D. (1978). On the abstractness of human concepts: why it would be difficult to talk to a pigeon. In: *Cognitive Processes in Animal Behavior* (S.H. Hulse, H. Fowler, and W.K. Honig, eds.), Hillsdale, N. J.: Erlbaum.

Real, P.G., Iannazzi, R., Kamil, A.C., and Heinrich, B. (1984). Discrimination and generalization of leaf damage by Blue Jays (Cyanocitta cristata). *Animal Learning and Behavior*, 12 (2), 202-208.

Royama, T. (1970). Factors governing the hunting behavior and selection of food by the great tit (Parus major L.). *Journal of Animal Ecology*, 39, 619-668.

Rozin, P., and Kalat, J. (1971). Specific hungers and poison avoidance as adaptive specializations of learning. *Psychological Review*, 78 (6), 459-486.

Santi, A. (1982). Hue matching and hue oddity in pigeons: Is explicit training not to peck incorrect hue combinations a sufficient condition for transfer? *The Psychological Record*, 32, 61-73.

Seligman, M.E.P. (1970). On the generality of the laws of learning. *Psychological Review*, 77 (5), 406-418.

Sidman, M. (1992). Adventitious control by the location of comparison stimuli in conditional discriminations. *Journal of the Experimental Analysis of Behavior*, 58, 173-182.

Siegel, R.K., and Honig, W.K. (1970). Pigeon concept formation; successive and simultaneous acquisition. *Journal of the Experimental Analysis of Behavior*, 13 (3), 385-390.

Smith-Bowen, E. (1964). *Return to Laughter: An Anthropological Novel.* New York: Anchor Books, Doubleday.

Staddon, J.E.R. (1983). *Adaptive Behavior and learning.* Cambridge: Cambridge University Press.

Tinbergen, L. (1960). The natural control of insects in pinewoods. I. Factors influencing the intensity of predation by songbirds. *Archives Neerlandaises de Zoologie*, 13, 265-336.

Thomas, R.K., and Lorden, R.B. (1993). Numerical competence in animals: A conservative view. In: *The Development of Numerical Ability: Animal and Human Models* (S. Boysen and J. Capaldi, eds.), Hillsdale, N.J.: Erlbaum.

Tolman, E.C. (1948). Cognitive maps in rats and men. *Psychological Review*, 55, 189-208.

Urcuioli, P.J., and Nevin, J.A. (1975). Transfer of hue matching in pigeons. *Journal of the Experimental Analysis of Behavior*, 24, 149-155.

Vaughan, Jr., W., and Greene, S. L. (1984). Pigeon visual memory capacity. *Journal of Experimental Psychology, Animal Behavior Processes*, 10 (2), 256-271.

Wasserman, E.A., Kiedinger, R.E., and Bhatt, R.S. (1988). Conceptual behavior in pigeons: categories, subcategories and pseudocategories. *Journal of Experimental Psychology, Animal Behavior Processes*, 14 (3) 235-246.

Wright, A.A., Cook, R.G., and Rivera, J.J. (1984) Concept learning by pigeons: Matching to sample with trial-unique video picture stimuli. *Animal Learning and Behavior*, 56, 143-148.

Zentall, T.R., and Hogan, D.E. (1974). Abstract concept learning in the pigeon. *Journal of Experimental Psychology*, 102, 393-398.

Zentall, T.R., and Hogan, D.E. (1975). Concept learning in the pigeon: Transfer to new matching and nonmatching stimuli. *American Journal of Psychology*, 88 (2), 233-244.