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**DISSERTATION**

**ADVENTITIOUS DIFFERENTIAL REINFORCEMENT  
OF EMERGENT SAMPLE-SPECIFIC BEHAVIOR AND COMMON CODING  
IN PIGEONS' MATCHING-TO-SAMPLE**

Submitted by

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In partial fulfillment of the requirements for

the degree of Doctor of Philosophy

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Summer 2000

UMI Number: 9986248

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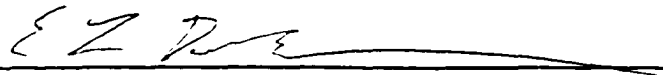
May 10, 2000

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY DANIEL L. WORTHEN ENTITLED "ADVENTITIOUS DIFFERENTIAL REINFORCEMENT OF EMERGENT SAMPLE-SPECIFIC BEHAVIOR AND COMMON CODING IN PIGEONS' MATCHING-TO-SAMPLE" BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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## **ABSTRACT OF DISSERTATION**

### **ADVENTITIOUS DIFFERENTIAL REINFORCEMENT OF EMERGENT SAMPLE-SPECIFIC BEHAVIOR AND COMMON CODING IN PIGEONS' MATCHING-TO-SAMPLE**

Matching-to-sample performance is enhanced if responses to the sample stimuli are required, and further enhanced if different responses are required to the different samples. Even when not required, differentiated sample responding may emerge spontaneously, either overtly or as an hypothesized covert "coding" response. Manabe, Kawashima, and Staddon (1995) trained budgerigars on a matching-to-sample task with two samples mapped onto each comparison stimulus (many-to-one training), where sample-specific vocal responses were required for one set of samples. Sample-specific responding emerged for the other set of samples and was congruent with respect to the comparison mappings. They concluded that the emergent behavior reflected emergent relations and called the behavior "naming", but it is possible that unintended adventitious differential reinforcement produced the effect. Experiment 1 was designed to replicate these findings in pigeons and determine whether naming or adventitious differential

reinforcement provides the best explanation. In Phase 1, 17 pigeons were trained to respond to different stimulus locations in the presence of red and green stimuli. In Phase 2 these stimuli became samples in a matching-to-sample task, with required sample-specific responding as in Phase 1. In Phase 3, a matching task with form samples was added so that 11 pigeons received many-to-one (MTO) training while 6 received one-to-one (OTO) training. Differential sample responding was not required for the new task, but it emerged for 7 MTO birds and 1 OTO bird. Adventitious differential reinforcement of the emergent behavior was clearly indicated for 5 of these MTO birds. The adventitious differential reinforcement hypothesis was generally supported, but little support was found for the naming hypothesis, which strongly predicted emergent sample-specific responding for OTO birds. In Experiment 2, the color samples were mapped onto new comparisons. Then the form samples were tested in a single session for transfer to the new comparisons. Those pigeons that had differentiated their responses to the form samples tended to show greater positive transfer, supporting the contention that the sample-specific behavior apparent in Experiment 1 is equivalent to the coding response that mediates positive transfer following many-to-one training.

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## **Dedication**

**To Mom, with love.**

**Of all that I am, more than anything else I am your son.**

**To Dad, with love.**

**You are the greatest man I will ever know, and the best  
role model a son could have.**

## Table Of Contents

<u>Chapter</u>		<u>Page</u>
I	INTRODUCTION .....	1
	The role of sample responses .....	3
	Spontaneous sample-specific behavior .....	7
II	EXPERIMENT 1: ADVENTITIOUS DIFFERENTIAL REINFORCEMENT OF "EMERGENT" SAMPLE-SPECIFIC BEHAVIOR .....	13
	Method .....	24
	Results .....	30
	Discussion .....	61
III	EXPERIMENT 2: EMERGENT SAMPLE-SPECIFIC BEHAVIOR AND THE COMMON CODING EFFECT .....	70
	Method .....	71
	Results and Discussion .....	73
IV	GENERAL DISCUSSION .....	78
	REFERENCES .....	83

## **Introduction**

The term “matching-to-sample” is often used in a generic sense to refer to a variety of conditional discrimination procedures which employ a similar arrangement of stimuli and contingencies (Cumming & Berryman, 1965). The typical procedure for pigeons takes place in an operant conditioning chamber with three plastic response discs (keys) that can be transilluminated with various colors and shapes. On a given trial, a stimulus (the sample), selected from a pool of two or more sample stimuli, is presented on the center key, followed by the presentation of two stimuli (the comparisons), one on each of the side keys. The outcome associated with pecking a given comparison stimulus is not invariant, but depends upon which sample stimulus has been presented on that trial. This is what defines matching-to-sample as a conditional discrimination procedure: the contingency associated with each of the comparisons depends on which sample has been presented. Choosing the comparison that has been defined as correct is reinforced; choosing the incorrect comparison is not reinforced.

This may be illustrated by considering a simple and commonplace example. At the beginning of each trial, the center key is illuminated with either green or red light (these samples are presented in random or mixed

order over the course of a session). The pigeon may be required to peck the sample stimulus a certain number of times, then the two side keys are illuminated, one red and the other green (the position of the colors and the correct choice are counterbalanced and vary in a random fashion over trials). A single peck to the comparison stimulus that is the same color as the sample produces brief access to food; selection of the nonmatching comparison results in brief darkening of the chamber (blackout). After an intertrial interval of several seconds, the next trial begins. This arrangement is referred to more specifically as *identity* matching-to-sample to distinguish it from other arrangements in which the sample–correct comparison relation is not specified by physical similarity. For example, when selection of the nonmatching comparison is reinforced, this is called oddity-from-sample. Alternatively, the samples and comparisons may not share any features in common, and the mapping of each sample onto its correct comparison is purely arbitrary. This is often called symbolic matching-to-sample, and the samples and comparisons are usually selected from orthogonal stimulus dimensions (e.g., hues as samples and shapes as comparisons).

One of the parameters that can be manipulated in matching-to-sample is the temporal relationship between the sample and the comparisons. When there is at least some overlap in their presentations, such that all three stimuli are present when the comparison choice is made (although sample onset ordinarily precedes comparison onset), this is called simultaneous matching-to-sample. Delayed matching-to-sample refers to various

procedures in which the sample and comparison presentations do not overlap. A common variation is zero-delay matching-to-sample, in which the sample offset and comparison onset occur simultaneously. Alternatively, a delay longer than zero, called a retention interval, may be interposed between the offset of the sample and the onset of the comparisons.

Although the response to the comparison stimulus produces the outcome, responding to the sample stimulus is usually also required. For example, a pigeon may be required to peck the sample a certain number of times (fixed ratio schedule) before the comparisons are illuminated. These “observing” responses are usually considered to serve the function of providing the subject ample opportunity to observe the sample stimulus, but they may do more.

### **The role of sample responses**

Sample responding clearly facilitates acquisition of matching-to-sample relative to conditions in which it is not required or actively precluded (Eckerman, Lanson, & Cumming, 1968; Maki, Gillund, Hague, & Siders, 1977) and a larger response requirement facilitates performance compared to a lesser requirement (Cohen, Looney, Brady, & Aucella, 1976; Lyderson, Perkins, & Chairez, 1977; Sacks, Kamil, & Mack, 1972). For example, Lyderson et al. trained pigeons on a zero-delay green/red oddity task with only one response required to the sample. Then the number of sample responses was changed through the series 1, 4, 8, 16, 32, 8, 4, and 1. Increases in sample responses systematically improved choice accuracy, and subsequent decreases

reduced accuracy. One interpretation of these findings is that observing responses are important because they produce greater exposure to the sample, allowing the necessary encoding to take place (Maki et al., 1977).

Another possibility is that sample responding itself develops discriminative properties. If different samples control different patterns or topographies of responding, these sample-specific behaviors could contribute to accurate matching, either by forming an additional discriminative dimension upon which to base the conditional discrimination, or by enhancing the discriminability of the samples. Several studies have examined these possibilities by explicitly requiring differentiated sample responding. Eckerman (1970), using an elongated sample key, found facilitated symbolic matching performance when sample peck locations along the key were differentiated in accordance with the sample color. Other studies (Lyderon & Perkins, 1974; Cohen et al., 1976; Paul, 1983; Urcuioli & Honig, 1980; Urcuioli, 1985) have correlated different response schedules with the samples, resulting in enhanced performance. Urcuioli trained pigeons to respond 16 times (FR 16 schedule) with green and horizontal line stimuli, and to space responses by a minimum of 3 s (DRL 3-s schedule) with red and vertical line stimuli. These stimuli then became samples, which were mapped onto green and red comparisons in a fashion, with respect to the schedules, that was either congruent (i.e., green/FR 16 and horizontal/FR 16 mapped onto the green comparison, and red/DRL 3-s and vertical/DRL 3-s mapped onto the red comparison) or incongruent (i.e., green/FR 16 and

vertical/DRL 3-s mapped onto the green comparison, and red/DRL 3-s and horizontal/FR 16 mapped onto the red comparison). Birds in the congruent-schedule group acquired the matching task much more readily. Following this, the sample response requirement was changed so that a single response produced the comparisons. Birds that had previously been in the congruent-schedule group experienced more difficulty in relearning the matching task. Later, the birds were retrained on the matching task with the original sample-specific schedules. Then the schedule requirements were reversed for one pair of samples (red and green for some birds; vertical and horizontal for the others). The effect of the reversal was to switch congruent-schedule birds to the incongruent-schedule condition and vice-versa. The group switched from congruent to incongruent was considerably disrupted, but the group switched from incongruent to congruent was disrupted much less. These manipulations converge upon the same conclusion: the sample-specific response patterns controlled choice for the original congruent group (but not for the incongruent group). Because both groups learned to discriminate the sample stimuli before beginning matching-to-sample training, and in view of the evident diminution of control by the samples themselves with correlated sample schedules (cf. Urcuioli, 1984), it is unlikely that the performance differences were due to enhanced sample discriminability. The results are consistent with the hypothesis that differential sample behaviors enhance conditional discrimination performance by generating an additional

discriminative cue, which may even overshadow control by the samples themselves.

The discriminative role of sample-specific behavior is further supported by studies in which spontaneous transfer to new matching relations was mediated by sample-specific responding (Cohen, Brady, & Lowry, 1981; Hogan, Zentall, and Pace, 1983; Urcuioli & Honig, 1980). Urcuioli and Honig found that a reversal from identity matching to oddity (or vice versa) was greatly facilitated if sample-specific response requirements were also reversed (Experiments 1 & 2). They also demonstrated positive transfer to a novel symbolic task (Experiment 3). In Experiment 3, pigeons were trained on identity matching with line orientations (vertical vs. horizontal) and sample-specific schedules (DRL 3-s and FR 10). Then they were reinforced according to the same schedules correlated with red and green stimuli. Red and green then became samples, mapped onto the line orientation comparisons in either a congruent or incongruent fashion with respect to the previously trained sample schedules. Congruent-schedule birds immediately performed at better than chance levels and acquired the symbolic matching task rapidly; the opposite result was obtained for incongruent-schedule birds. Using a similar strategy, Cohen et al. found that pigeons trained on symbolic hue–line and line–hue matching-to-sample with sample-specific schedules (FR 16 vs. DRL 3-s) transferred performance to identity matching with first-session accuracies ranging from 60% to 95%. Sample-specific responding appears to provide a salient cue for subsequent choice.

### **Spontaneous sample-specific behavior**

Even when differential sample behavior is not required, it may develop spontaneously and accrue to the subject the consequent discriminative benefit. In perhaps the earliest systematic investigation of delayed matching-to-sample with pigeons, Blough (1959) observed that while responding to the sample was not required, some pigeons performed idiosyncratic behaviors during the retention interval that were correlated with the sample. Performance of these behaviors seemed to facilitate choice accuracy. It has been suggested that the facilitation of matching performance as a function of increased number of sample responses (e.g., Lyderson et al., 1977) is due to greater opportunity to spontaneously differentiate sample responding (Cohen et al., 1976).

More generally, it has been theorized that conditional discrimination performance, trained without explicit differential sample response requirements, is nevertheless mediated by subtle or covert sample-specific behavior, and that successful transfer to new matching relations (e.g., Urcuioli, Zentall, Jackson-Smith, & Steirn, 1989) is mediated by these implicit responses or "codes" (Carter & Werner, 1978; Saunders, Williams, & Spradlin, 1996; Urcuioli, 1996). When two pairs of samples are mapped onto a single pair of comparisons (many-to-one matching-to-sample), followed by mapping of one of the sample pairs onto a new pair of comparisons, the other pair of samples will spontaneously control the same conditional discrimination. Urcuioli et al. (Experiment 2) mapped red and vertical line samples onto a

vertical line comparison, and green and horizontal line samples onto a horizontal line comparison. In the next training phase, the red and green samples were mapped onto circle and dot comparisons, respectively. In a final test phase, it was found that the vertical and horizontal line samples spontaneously controlled the choice of circle and dot comparisons, respectively. In a discussion of these findings, Saunders et al. speculated that subtle differences in sample responding might be adventitiously reinforced via subsequent correct comparison choice, thereby forming a response chain. Thus, in the many-to-one paradigm, when samples S1 and S3 are mapped onto comparison C1 (and S2 and S4 are mapped onto C2), S1 and S3 may elicit an untrained response, R1, so that the chains  $S1 \rightarrow R1 \rightarrow C1$  and  $S3 \rightarrow R1 \rightarrow C1$  are formed (and likewise for S2 and S4, mediated by a different response, R2). S1 continues to elicit R1 in the next phase when S1 is mapped onto a new comparison, C3, so the chain  $S1 \rightarrow R1 \rightarrow C3$  is learned. In the test phase, the previously learned relations  $S3 \rightarrow R1$  and  $R1 \rightarrow C3$  simply combine to form the “derived” behavior. Although this account is attractive in its ability to explain the results with standard conditioning principles, it does not clarify why two samples, by virtue of mapping onto the same comparison, should produce the same covert response. Perhaps the same adventitious differential reinforcement process occurs during baseline many-to-one training, such that subtle or covert responses to one sample acquire discriminative properties, then when the same response serendipitously occurs in the presence of the commonly mapped sample, it improves the probability of a correct choice and

is thereby differentially reinforced. Invoking a more cognitive analysis, Urcuioli (1996; see also Urcuioli, Zentall, & DeMarse, 1995; Zentall, Sherburne, & Steirn, 1993) hypothesized that the mapping of different samples onto a common comparison produces a "common code" which mediates transfer. The common code forms as a result of two samples giving rise to the same anticipatory response (cf. Honig & Dodd, 1986; Hull, 1939), which could be considered a prospective representation of the comparison stimulus upon which both samples are mapped (cf. Wasserman, 1986).

The concept of prospective coding was also invoked by Manabe, Kawashima, and Staddon (1995) in discussing the results of their unique and compelling study. They trained three budgerigars (parakeets) to produce two distinctive vocalizations (high vs. low frequency), then brought the two calls under stimulus control by red versus green light (Experiment 1). This was referred to as "color naming". In Experiment 2, two of the birds continued to be reinforced for color naming, and the third bird was trained on red/green identity matching-to-sample with the correct vocalization required as the sample observing response (comparison choice was indicated by a peck). Then all of the birds were trained on an additional symbolic matching-to-sample task in which forms (cross and circle) were mapped onto the red and green comparisons. Vocalizations were required as sample observing responses, but any vocalization was allowed for the form samples. The birds used the shaped vocalizations as observing responses for the form samples, and furthermore, two of the birds spontaneously differentiated their sample responding to

correspond with the color of the correct comparison. This spontaneous differentiation emerged quickly and was consistent only for the bird that had received the identity color matching training. The other two birds were subsequently trained (Experiment 3) on color-to-form symbolic matching with the sample-specific response requirement. Once they had learned this, identity matching with the forms was added. Both birds spontaneously emitted the vocal response to each form sample corresponding to the color mapped onto that form in the color-to-form task. Manabe et al. interpreted the findings of Experiments 2 and 3 as evidence of emergent relations. In Experiment 2 the trained relations were, for example, red → low vocalization and circle → red. From this training, the relation circle → low vocalization emerged. In Experiment 3, the trained relations were, for example, red → low and red → circle (and perhaps low → circle), and the emergent relation was circle → low. According to Manabe et al., the results of Experiment 2 in particular support a prospective coding interpretation, because the birds emitted the “name” of the correct color comparison stimulus as a response to the form sample, which suggests that they were anticipating the impending choice. Experiment 3 is equivocal with regard to the type of coding (prospective vs. retrospective), because the emergent sample-specific responses occurred in the identity form task, in the absence of colors as either samples or comparisons. The authors speculate that the emergent responses to the form samples occurred because an association forms in the color-to-form task between the sample observing response and the correct comparison

(e.g., low → circle). Because the association is expressed in the identity form matching task as circle → low, the association must be bidirectional, or symmetrical (Sidman & Tailby, 1982), a finding that is virtually unprecedented with animals (Hayes, 1989; McIlvane & Dube, 1996; Saunders, Williams, & Spradlin, 1996) despite extensive efforts (e.g., LeBlanc, 1995; Richards, 1988; Rodewald, 1974; Sidman et al., 1982).

The interpretations offered by Manabe et al. (1995) have not gone unchallenged. Saunders and Williams (1998) argue that the possibility of adventitious reinforcement of the very relations that were purported to be emergent cannot be excluded. With regard to the budgerigar in Experiment 2 that was trained on the identity color matching task, the trained relations might be better characterized as, for example, red → low → red. Upon transfer to the form-to-color task, the bird emitted one of the two shaped vocalizations as an observing response to the sample. When the sample was a circle, and the vocalization was, by chance at first, low, then the bird may have been more likely to correctly choose the red comparison, due to the previously learned relation between the low vocalization and red. Thus, the entire chain of behavior, including the low vocalization in the presence of the circle, was differentially reinforced. Likewise, a high response in the presence of the circle may have biased the bird to choose incorrectly, and therefore high responses to the circle were extinguished. The same analysis can be applied to Experiment 3. After learning the chain red → low → circle, low vocalizations in the presence of the circle when it was presented as a

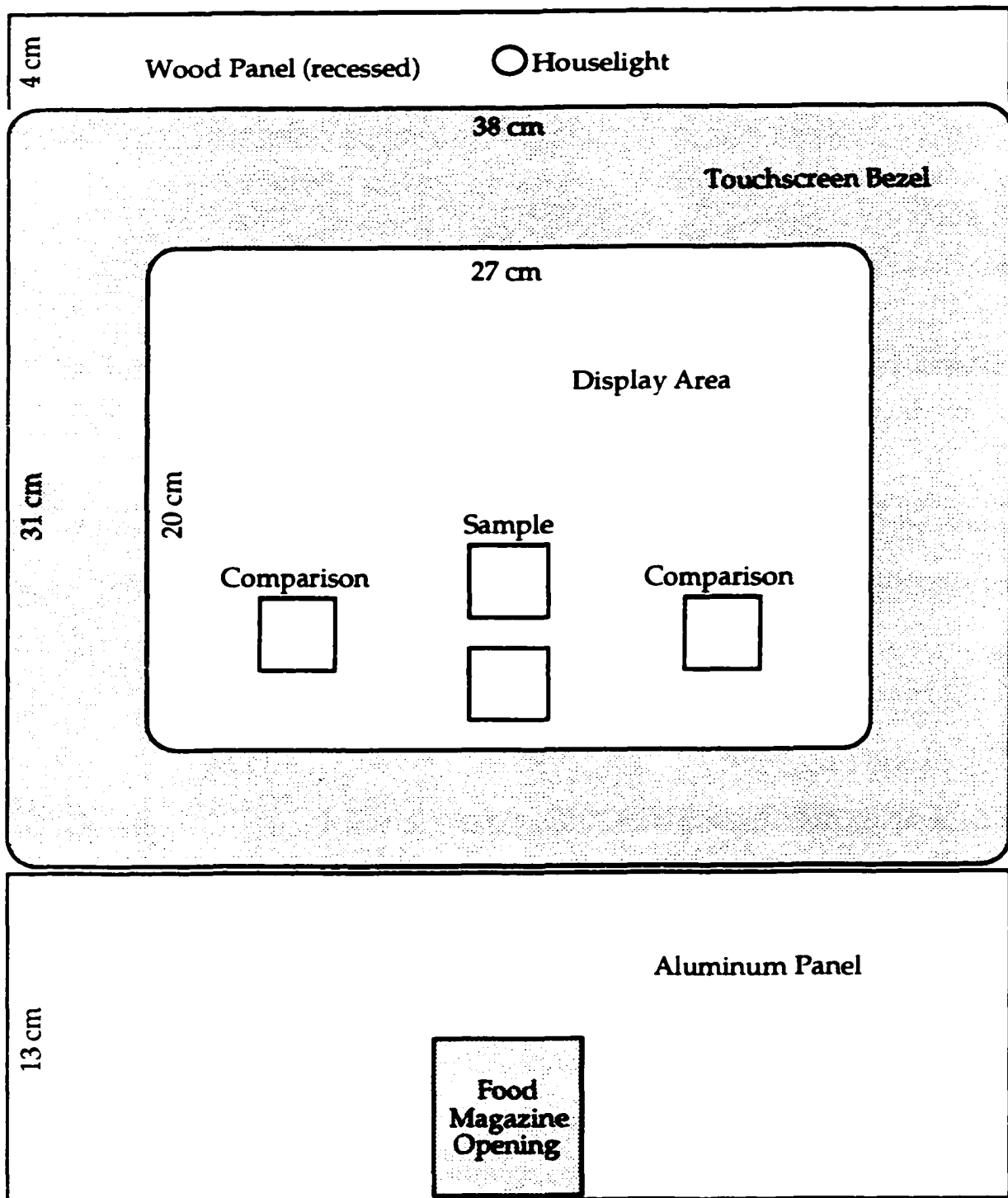
sample were more likely to lead to a correct choice, and were therefore differentially reinforced. High vocalizations to the circle were more likely to lead to an incorrect choice, and were therefore extinguished. This account is not only plausible, but it has parsimony on its side, as it does not require prospective stimulus representations or bidirectional associations.

In Manabe et al.'s (1995) experiments, sample-specific responding emerged whenever the training involved many-to-one mappings of samples onto comparisons. However, their experiments included only three subjects, so it would be desirable to assess the reliability of their findings using a larger number of subjects. It would also be desirable to determine whether sample-specific responding emerges during training that involves the same stimulus relations but lacks many-to-one mappings, which should reduce the likelihood of adventitious differential reinforcement of sample-specific behavior. In all cases, the presence of adventitious differential reinforcement could easily be assessed by determining whether comparison choice is a function of the uncoerced sample response. Finally, it would be advantageous to adapt the procedure to a more commonly used species, such as pigeons. Experiment 1 was designed with these objectives in mind.

## **Experiment 1: Adventitious Differential Reinforcement of "Emergent" Sample-Specific Behavior**

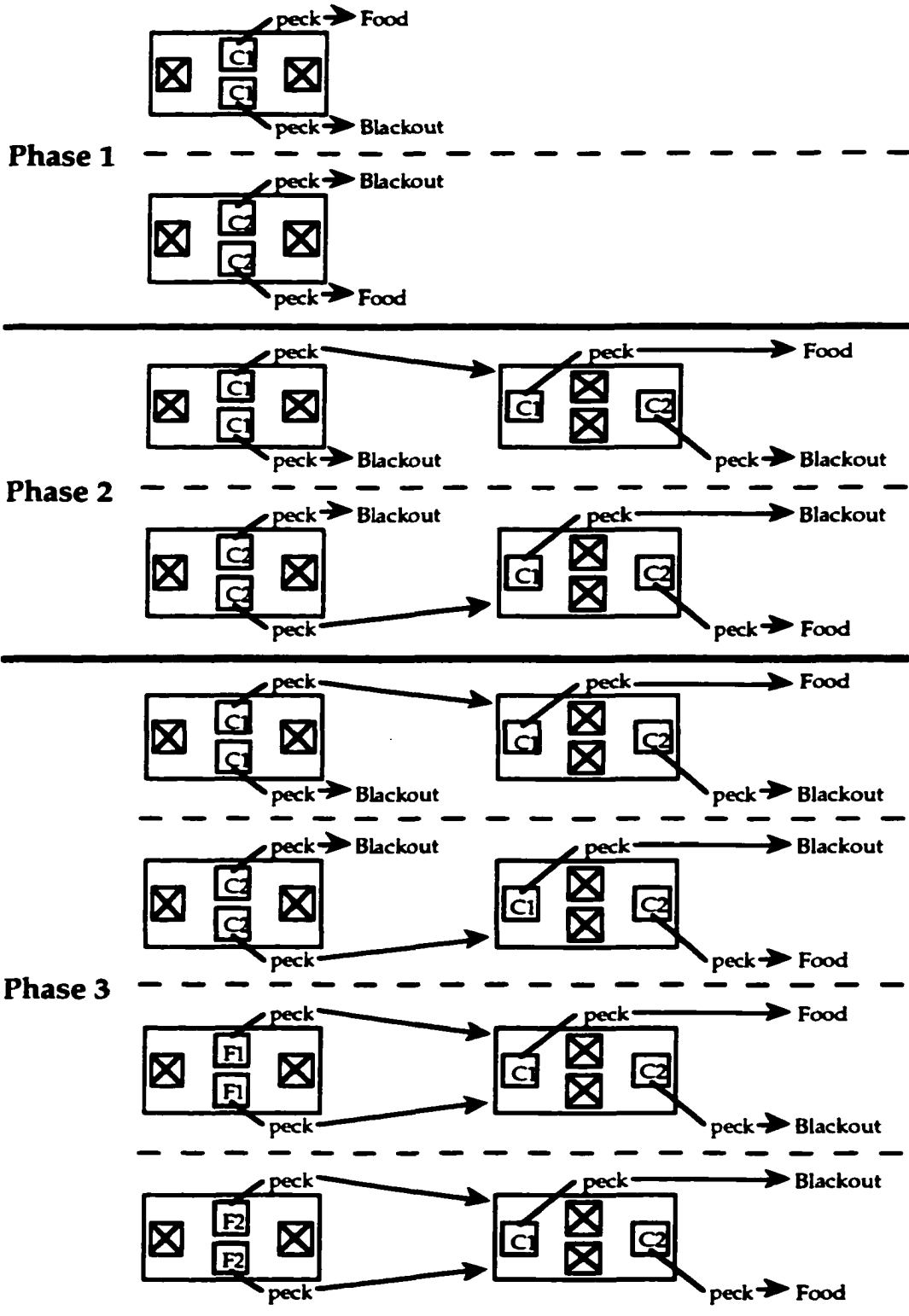
The goal of Experiment 1 was to replicate, extend, and explicate the findings of Manabe et al. (1995), using an analogous task with pigeons. Instead of a vocal sample observing response, three groups of pigeons were trained to peck at two different stimulus positions (cf. Eckerman, 1970) on a computer display that was equipped with an infrared touchscreen for detecting the location of pecks. Figure 1 shows the square positions in which stimuli were displayed. Every trial began by displaying a stimulus in both of the center locations. The response could therefore take one of two forms: a "top" response or a "bottom" response, analogous to the high and low vocalizations of the budgerigars in Manabe et al.'s experiments. Two groups, Group MTO-color comparisons and Group MTO-form comparisons, received many-to-one training comparable to Manabe et al.'s Experiments 2 and 3, respectively. The third group, Group OTO-symmetry, received one-to-one training in which colors were mapped onto forms and vice versa, so the relations were all trained in a symmetrical fashion.

Figures 2, 3, and 4 provide an overview of the training conditions for Groups MTO-color comparisons, MTO-form comparisons, and OTO-



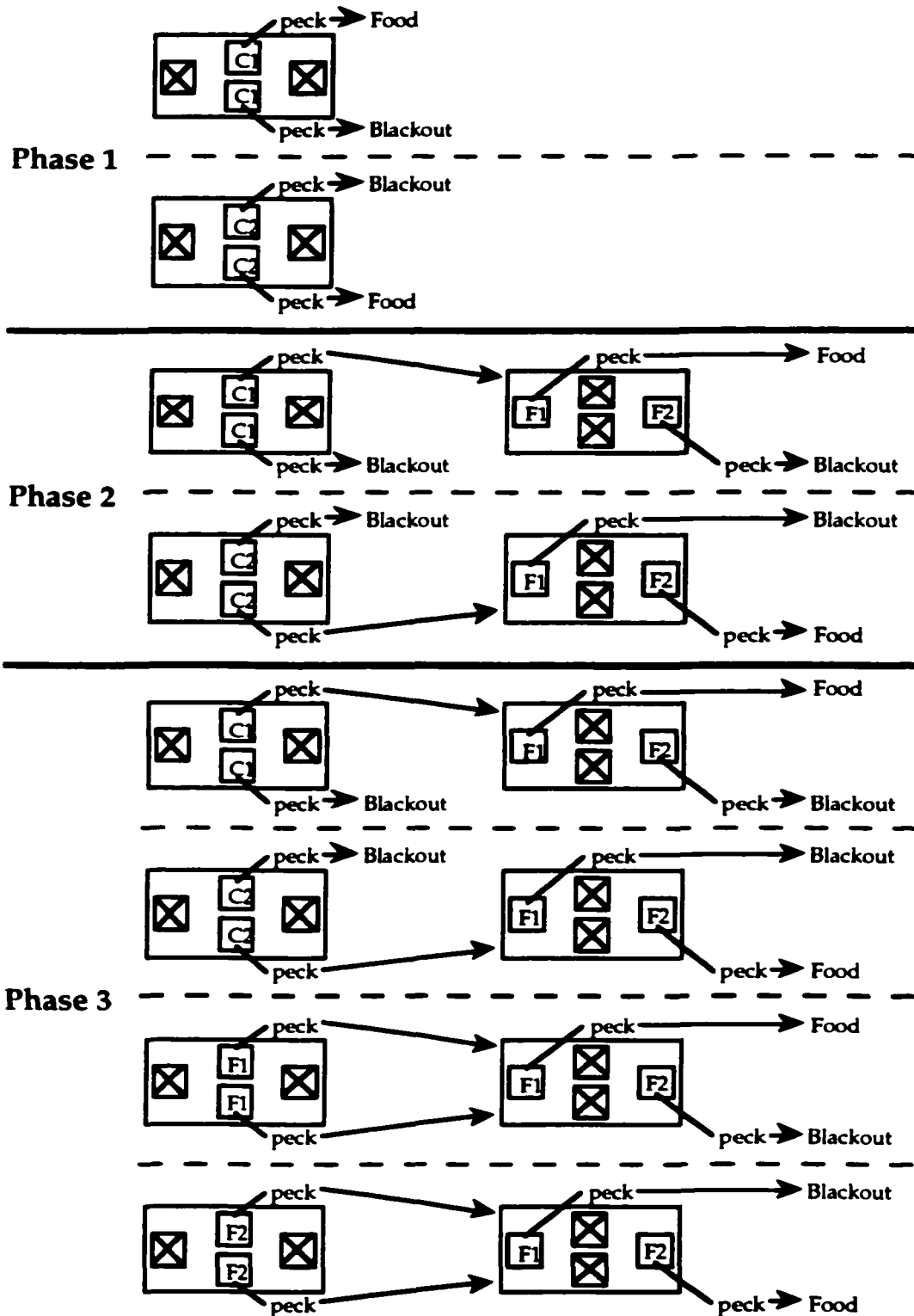
**Figure 1.** Scale (1 cm = 2.45 cm) diagram of "intelligence panel". The display area was black except for the stimulus fields, which were also black (no border visible) except when stimuli were displayed.

**Group MTO-color comparisons**



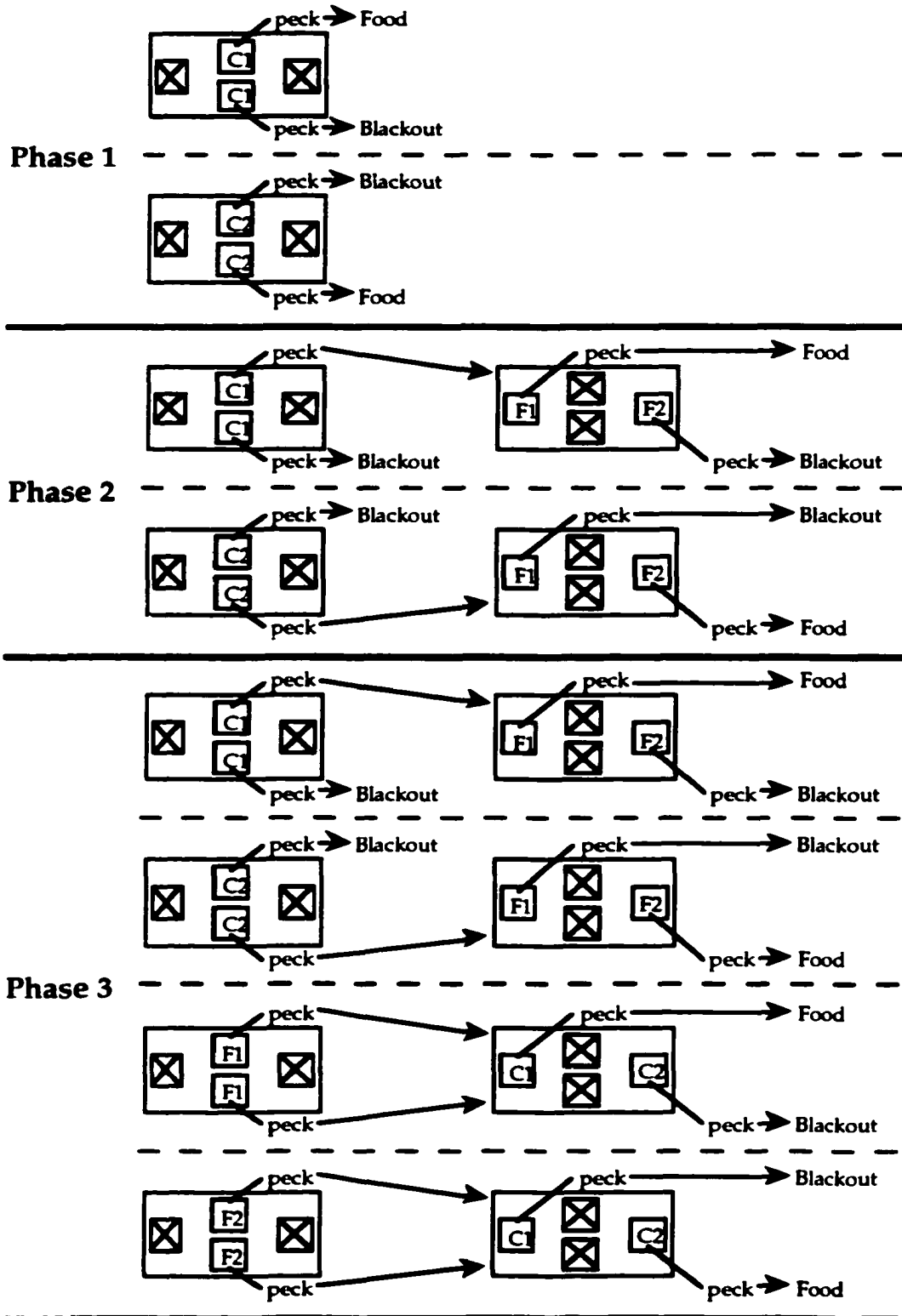
**Figure 2.** Trial types for Group MTO-color comparison birds during the three phases of Experiment 1, ignoring counterbalancing of comparison stimuli locations.

**Group MTO-form comparisons**



**Figure 3.** Trial types for Group MTO-form comparisons birds during the three phases of Experiment 1, ignoring counterbalancing of comparison stimuli locations.

**Group OTO-symmetry**



**Figure 4.** Trial types for Group OTO-symmetry birds during the three phases of Experiment 1, ignoring counterbalancing of comparison stimuli locations.

symmetry, respectively. In these figures, different trial types within a phase are separated by a dashed line, and phases are separated by a solid line. Not all counterbalancing is shown; for example, all comparison stimuli actually appeared equally often in the left and right positions. C1 and C2 denote color stimuli, which were green and red (not necessarily respectively due to counterbalancing). F1 and F2 denote form stimuli, which were a cross and a circle (not necessarily respectively). In Phase 1, all of the pigeons were trained to differentiate their responding according to the color presented on the top and bottom center stimulus fields; both center fields always displayed the same color on a given trial. When C1 was presented on both fields, top responses were reinforced, and when the C2 was presented on both fields, bottom responses were reinforced. In Phase 2, C1 and C2 became samples in a zero-delay matching-to-sample task. The pigeons were still required to peck the correct sample location (top or bottom), but this was followed by a choice between two stimuli presented on the side positions. Group MTO-color comparison birds learned color-to-color identity matching in Phase 2, followed by many-to-one training in Phase 3 that included the color-to-color task from Phase 2 as well as a form-to-color symbolic matching task. The form samples also appeared in duplicate on the center positions, but pecks to either location allowed the trial to advance to the comparison stage. Group MTO-form comparisons was trained in a similar fashion, except that the comparisons for all matching tasks were the forms. Group OTO-symmetry was trained on the color-to-form task in Phase 2, with the sample-specific

response requirement, exactly like Group MTO-form comparisons. However, for Group OTO-symmetry, the additional task in Phase 3 was a form-to-color symbolic matching task (the same as Group MTO-color comparisons). This training therefore lacked the many-to-one mappings provided to the MTO groups. Instead, these subjects received in Phase 3 two one-to-one mappings, with colors and forms reciprocally mapped onto each other.

The primary concern in this experiment was whether sample-specific responding would develop when the forms were employed as samples in Phase 3. In the arguments that follow, it will be convenient to denote a particular type of trial by indicating the sample stimulus, the positional response to the sample, and one of the comparison stimuli (either the correct comparison or the comparison that was chosen, which will be clear in context), as in the example  $C1 \rightarrow \text{top} \rightarrow F1$ . Table 1, which may usefully be consulted during the arguments that follow, employs this notation to summarize the reinforced relations that each group received. It is worth reiterating that although the pigeons were required to peck one of the sample positions, pecks to either position produced the comparisons when the samples were forms. Thus it was possible for the task to be learned without differentiated responding to the form samples.

The two hypotheses discussed above, the "naming" hypothesis and the "adventitious differential reinforcement" hypothesis, make the same prediction for both MTO groups, but for different reasons. Both hypotheses predict that MTO-color comparisons pigeons will make top responses in the

Table 1

Sample-response-comparisonMappings for Experiment 1, Phase 3

Group	Mappings
MTO- color comparisons	C1 → top → C1
	C2 → bottom → C2
	F1 → ? → C1
	F2 → ? → C2
MTO- form comparisons	C1 → top → F1
	C2 → bottom → F2
	F1 → ? → F1
	F2 → ? → F2
OTO- symmetry	C1 → top → F1
	C2 → bottom → F2
	F1 → ? → C1
	F2 → ? → C2

presence of F1 and bottom responses in the presence of F2. According to the naming hypothesis, this should occur because top responding refers to C1 and bottom responding refers to C2, which are the correct choices following F1 and F2, respectively. In other words, as a pigeon learns the task, a prospective representation of the correct comparison develops, which is manifested as the positional response that was conditioned to that stimulus in Phase 1. The adventitious differential reinforcement hypothesis predicts emergence of sample-specific responding via a different mechanism. In Phase 2 the pigeons learn the chains  $C1 \rightarrow \text{top} \rightarrow C1$  and  $C2 \rightarrow \text{bottom} \rightarrow C2$ . Then in Phase 3, when the F1 is presented as a sample, the pigeon must select one or the other of the sample positions. If the top position is selected, then this is likely to be followed by the choice of comparison C1, because  $\text{top} \rightarrow C1$  has already been conditioned. Since this is the correct choice, the entire chain  $F1 \rightarrow \text{top} \rightarrow C1$  is reinforced. If, on the other hand, the bottom sample position is selected, then this should lead to the choice of comparison C2, which is not reinforced, thereby extinguishing the  $F1 \rightarrow \text{bottom} \rightarrow C2$  chain. Likewise for trials in which F2 is the sample: correct choices should occur frequently following bottom responses, and seldom following top responses, so that bottom responding is differentially reinforced.

The naming hypothesis invokes a somewhat different explanation in predicting emergent sample-specific responding for Group MTO-form comparisons. The relations  $C1 \rightarrow \text{top}$  and  $C1 \rightarrow F1$  were trained in Phases 1 and 2. If the association between C1 and F1 is bidirectional (symmetrical), then

F1 could elicit a representation of C1. So when F1 is presented as a sample, it elicits a representation of C1, which is manifested as a top response.

(Alternatively, because top  $\rightarrow$  F1 was also learned in Phase 2, F1  $\rightarrow$  top might emerge as a backward manifestation of this association, which would also require bidirectionality.) The adventitious differential reinforcement hypothesis predicts emergent sample-specific responding in Group MTO-form comparisons by applying the same logic as it did to Group MTO-color comparisons. When F1 is presented as a sample, top responses are likely to be followed by the correct choice of F1, because top  $\rightarrow$  F1 has already been learned, and bottom responses are likely to be followed by the incorrect choice of F2, because bottom  $\rightarrow$  F2 has already been learned. Thus, top responding in the presence of F1 is differentially reinforced. Likewise, bottom responding in the presence of F2 is differentially reinforced, because it is more likely to lead to a correct comparison choice.

While the two hypotheses predict the same results for the MTO groups, they invoke different mechanisms. One of the difficulties in evaluating the naming hypothesis is that internal representations of stimuli are not directly observable. Differential reinforcement, however, can be observed and measured quite easily. To the extent that comparison choices are predicated on the location of the response to the form samples at the outset of Phase 3, differential reinforcement is indicated. If it can be shown that differential reinforcement occurs prior to the emergence of sample-specific responding, then this would support the adventitious differential reinforcement

hypothesis. And to the extent that the adventitious differential reinforcement hypothesis is supported, the naming hypothesis may come to seem superfluous at least, if not altogether incorrect.

Group OTO-symmetry provides a more direct test of the hypotheses, which make different predictions for this group. The naming hypothesis strongly predicts emergence of sample-specific responding in this condition, since the arguments given for the MTO groups can both be applied. A top response to F1 could emerge either as a prospective reference to C1, or it could be elicited by F1 as a manifestation of a bidirectional association between C1 and F1 (or between top responding and F1). The adventitious differential reinforcement hypothesis predicts that sample responding will not be differentiated. This is a direct consequence of the absence of many-to-one mappings. Although the top/bottom samples responses can control the choice between form comparisons in Phase 2 training, there is no precedent for which color comparison to choose following a top or bottom response in Phase 3. If a top response is made to F1, then there is no reason to expect that it will usually be followed by the correct choice of C1 (or the incorrect choice of C2). Therefore, top responses should not be differentially reinforced in the presence of F1, and likewise bottom responses should not be differentially reinforced in the presence of F2. As with the MTO groups, the presence of differential reinforcement can be measured directly. To the extent that it is absent, and to the extent that sample-specific responding to the form samples

fails to emerge in the absence of differential reinforcement, the adventitious differential reinforcement hypothesis will be supported.

## **Method**

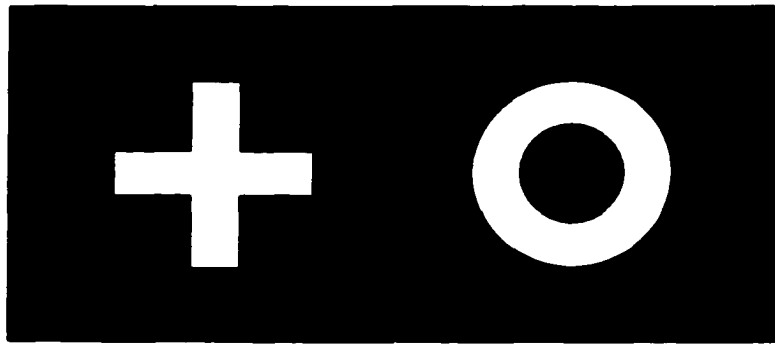
### **Subjects**

Eighteen female White Carneaux pigeons, about six years old at the time of the experiment, were maintained at 80% of their *ad libitum* weights throughout the experiment. After acquiring them as retired breeders from the Palmetto Pigeon Plant (Sumter, South Carolina), these pigeons had been trained to eat from the food magazine and shaped to peck the center key (illuminated red) in a standard commercial operant conditioning chamber (BRS/LVE SEC-002 small environmental cubicle with PIP-013 pigeon intelligence panel) as part of an undergraduate laboratory course in animal learning. Water and health grit were continuously available in their home cages.

### **Apparatus**

The pigeons were trained one at a time in a single operant conditioning chamber. The chamber consisted of a large wood box, with a smaller compartment inside to contain the pigeon. The inner compartment measured 38 cm x 38 cm horizontally and 48 cm vertically. It had a plexiglass door, and the wall to the right of the door was formed by the screen of a 13" NEC JC-1531VMA-3 computer monitor, which sat directly above a BRS/LVE GFM-001 grain feeder filled with a wheat and milo mix that could be accessed by the pigeon at floor level, and directly below a houselight which provided

general illumination. (The houselight was recessed behind the top edge of the monitor to reduce screen glare.) Stimuli were displayed on the monitor, against a black background, and responses were recorded by a Carroll Touch (Round Rock, Texas) infrared scanning touchscreen mounted on the screen. Stimuli could be displayed in four 3 cm x 3 cm locations, as diagrammed in Figure 1. Sample stimuli were presented on the two center fields, which were centered on the vertical midline of the screen and 22 cm above the chamber grate floor at the midpoint of the two fields, with a 1 cm gap between the fields. (During preliminary training, there was a single center stimulus field at a position intermediate to the two center fields shown in Figure 1.) The comparison stimuli were displayed on the left and right fields, which were centered 8 cm to either side of the midline of the screen and 22 cm above the chamber grate floor, leaving a 5 cm horizontal gap between the sample fields and each comparison field. Color stimuli (green and red) completely filled the stimulus frames; forms (cross and circle; see Figure 5) were white and were sized so that their outer extremities just contacted the edges of the stimulus frames. The outer box of the chamber served to contain the pigeon compartment, monitor, grain feeder, and interfacing equipment, as well as keep out extraneous light and sound. Ventilation was provided by two fans, one which drew air into the chamber (on the side closest to the pigeon compartment) and another which drew air out (over the top of the monitor, so that heat from the monitor was vented). The fans also provided some masking of extraneous sounds. The door of the outer box had a window made



**Figure 5. Form stimuli (cross and circle) used in Experiment 1.**

of one-way glass, covered by an opaque fabric drape. With the room lights in the laboratory off, the fabric drape could be lifted, and the one-way glass allowed the pigeon to be observed surreptitiously during experimental sessions. Stimulus events were controlled and data collected by programs run on a Power Macintosh microcomputer, positioned on a desk adjacent to the chamber.

### **Procedure**

**General.** Each session began with illumination of the houselight, which remained on at all times except during blackouts following incorrect responses and after the session ended. Reinforcement and blackout cycles were 3.5 s.

**Preliminary training.** All of the pigeons received at least one session of magazine training, in which the food hopper was raised periodically until the food was eaten consistently without delay. Most of the birds learned this quite readily, having been previously trained in a different apparatus, but one bird required five sessions of training. After magazine training, the birds were trained to peck at stimuli (red and green squares, a white cross, and a white circle, displayed on a black background) by method of autoshaping. Each stimulus appeared an equal number of times in each of three locations—left, center, and right. Once pecks were directed reliably at each stimulus, the intertrial interval was reduced gradually to 10 s, and then food delivery was made contingent upon pecking (operant shaping). Each bird received at least two sessions of autoshaping (some required more than two sessions),

followed by at least two sessions of operant shaping. Before beginning the experiment proper, the pigeons were randomly divided into three groups of six pigeons each. The experiment proper was conducted in three successive phases.

**Phase 1.** The goal in Phase 1 was to establish differential responding to red and green. Training in this phase was identical for the three groups. Both of the center stimulus fields were illuminated with either red or green. The birds were trained to peck the top square for one color and the bottom square for the other, counterbalanced so that three birds from each group learned red → top and green → bottom, and the other three learned red → bottom and green → top. The first peck to either stimulus location caused the other field to be turned off and made unavailable for further responses. A second peck to the selected field resulted in reinforcement if the correct field was selected, or a 3.5-s blackout (brief darkening of the chamber) if the incorrect field was selected. Pecks that failed to contact either portion of the stimulus had no scheduled consequence. Trials resulting in blackout were repeated until the correct response was made (correction procedure). Trials were separated by a 15-s intertrial interval. Training was continued for each bird until at least 95% of the responses were correct over a period of four successive sessions of 48 trials each (not including correction trials) or until 25 sessions were completed, whichever occurred first. One bird in Group MTO-form comparisons failed to learn the discrimination (it never chose the top

stimulus and therefore never completed a session) and was dropped from the experiment.

**Phase 2.** Immediately following achievement of the Phase 1 criterion, each pigeon began training on a zero-delay matching-to-sample task with the bipartite color stimuli as samples and top/bottom differential responding required as the sample observing response, in the same manner as in Phase 1. Comparison stimuli were displayed in the left and right positions (one on each side, counterbalanced). Group MTO-color comparisons birds were trained on identity color matching. The other two groups received symbolic training with colors as samples and forms as comparisons. For half of the birds in each of the latter two groups, the red sample was mapped onto the cross and green onto circle; the other half received the opposite mapping. Sample observing response errors resulted in blackout, omission of the comparisons, and repetition of the trial. Correct comparison choices were reinforced; incorrect choices resulted in blackout but not repetition of the trial (noncorrection procedure). Trials were separated by 15-s intertrial intervals. Sessions of 48 trials each were conducted for each bird until correct comparison choices were made at least 90% of the time over a period of four successive sessions.

**Phase 3.** Each pigeon began this phase immediately upon achieving the criterion for Phase 2. In this phase, a new matching-to-sample task (also zero-delay) with the forms as samples was mixed in with the Phase 2 task. Table 1 shows the mapping of samples and observing response locations onto correct

comparisons for the three conditions. For ease of exposition and to avoid the complexity that ensues from the counterbalancing of sample-response-comparison relations within each condition, the color associated with top responding is referred to as C1 and the color associated with bottom responding as C2. Likewise, F1 and F2 refer to the cross and circle, so that F1 indicates cross for half of the subjects in each group and circle for the other half. The form samples were presented in duplicate in the center stimulus fields (i.e., a cross in each position or a circle in each position), but differential responding was not required. As with the color samples, the first response darkened the unselected field, but the second response produced the comparisons regardless of which portion of the sample was selected. (Differential sample responding was still required on the task carried over from Phase 2.) Correct comparison choices were reinforced, and incorrect choices resulted in blackout, followed by the next 15-s intertrial interval. Sessions in this phase included 64 total trials; 32 of each task arranged in a mixed order. Training continued for each bird until comparison choice accuracy was 90% or better during 10 sessions (not necessarily consecutive) or until 200 sessions were completed, whichever occurred first.

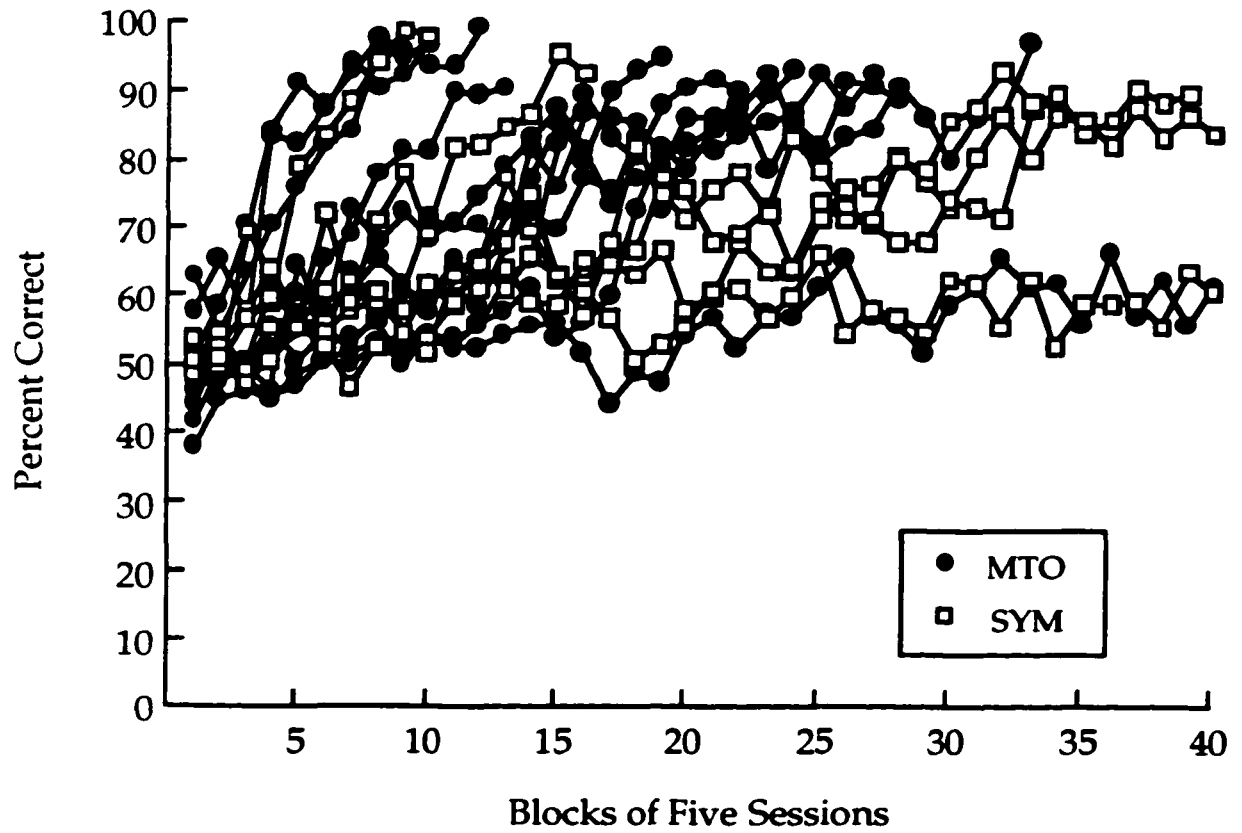
### **Results**

Of the 17 birds that completed Phase 1, all learned the Phase 2 matching task within 47 sessions, with some requiring as few as 12 sessions to reach criterion. The remaining analysis is concerned only with the matching task that was introduced in Phase 3. The arrangement of stimulus relations in

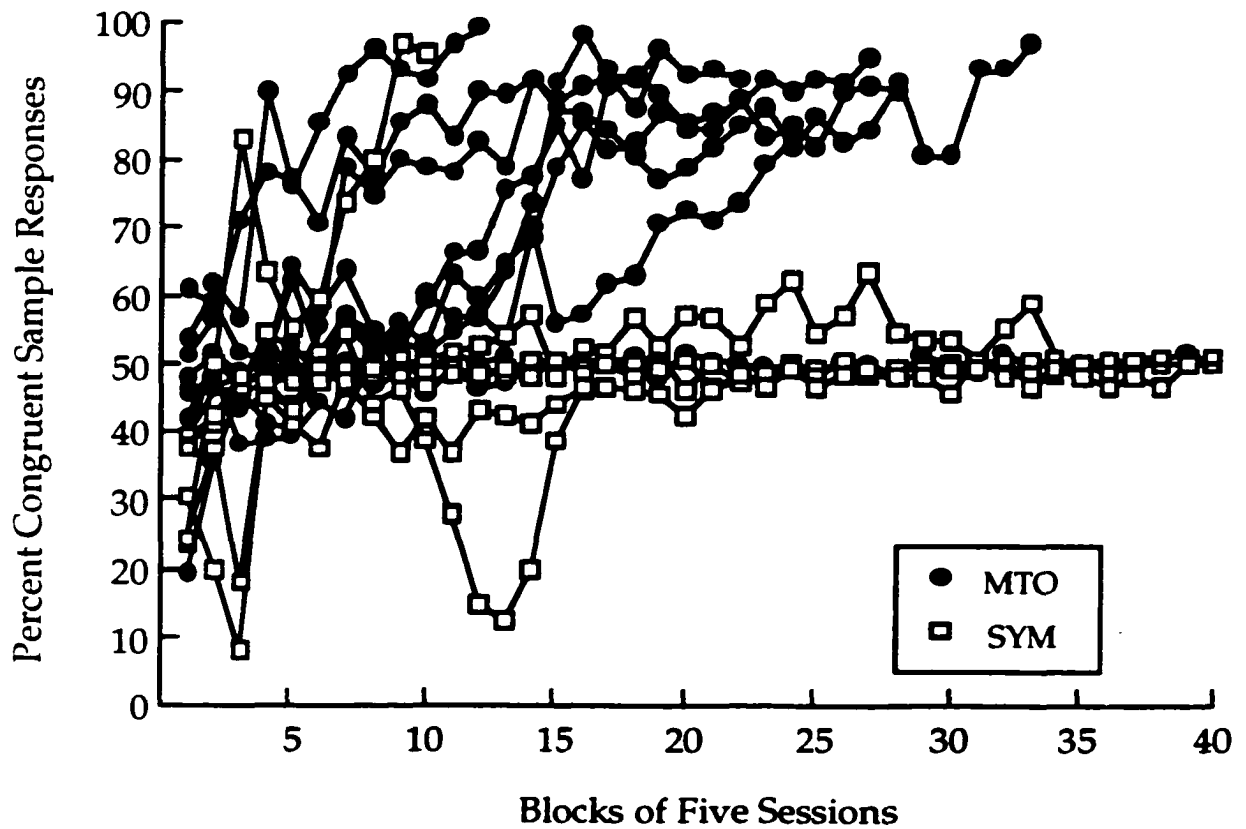
Phase 3 was logically identical for Groups MTO-color comparisons and MTO-form comparisons; both received many-to-one training (which consisted of two samples mapped onto each color comparison for Group MTO-color comparisons and two samples mapped onto each form comparison for Group MTO-form comparisons). For this reason, and because the pattern of results was very similar for these groups, subjects in Groups MTO-color comparisons and MTO-form comparisons will be referred to collectively as MTO subjects for much of the analysis. As expected, the pattern of results was quite different for birds in Group OTO-symmetry, so called because of the one-to-one symmetrical mapping of colors onto forms and vice-versa.

Figure 6 shows each bird's comparison choice accuracy over blocks of five sessions. Although there is some indication that acquisition was slower for some OTO birds, the overall lack of any consistent difference between the conditions is more striking. For both MTO and OTO birds, there was substantial variation in the rate of acquisition, with sessions to criterion ranging from 54 to 168 days for MTO birds and from 51 to 200 days for OTO birds. One bird in Group MTO-form comparisons (B7321) and one bird in Group OTO-symmetry (B7332) failed to learn the task within 200 days.

Figure 7 shows the extent of sample-response differentiation, expressed as the percent of sample responses that were congruent with previous training, over blocks of five sessions. For example, if a bird in Group MTO-color comparisons had been trained in Phase 2 to peck the top red field then choose the red comparison, and if crosses were mapped onto the red



**Figure 1.** Comparison choice accuracy for each pigeon over blocks of five sessions of Phase 3 training with cross and circles forms as sample stimuli.

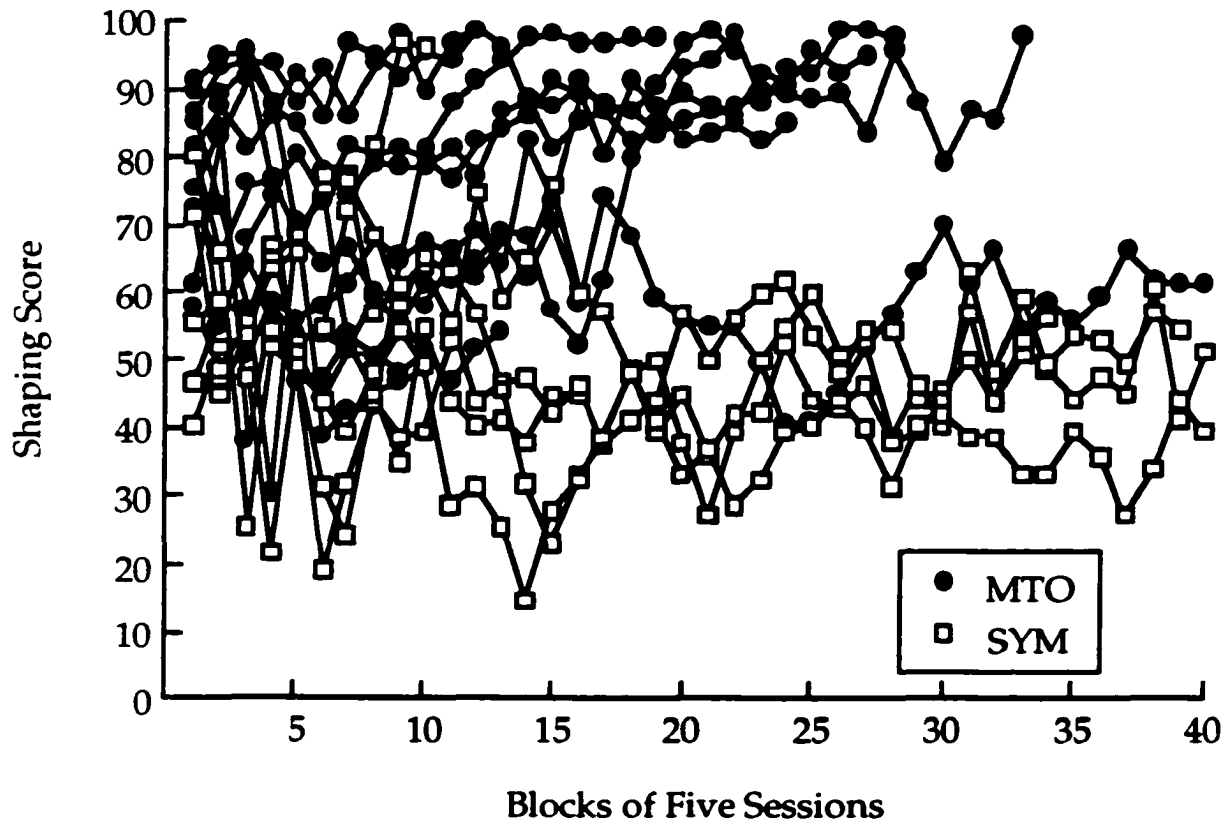


**Figure 2.** Percent of sample responses that were congruent with sample-comparison mapping for each pigeon over blocks of five sessions of Phase 3 training with cross and circles forms as sample stimuli.

comparison in Phase 3, then pecking the top cross would constitute a congruent sample response. A strategy of always pecking one sample position, regardless of whether the stimulus was a pair of crosses or a pair of circles, would produce a sample differentiation score of 50%. Complete differentiation of sample responding would produce a score of 100% if congruent, or 0% if incongruent. Seven MTO birds developed very high levels of congruent sample-specific responding; the four others, including the one that did not learn the task, did not develop sample-specific responding. One OTO bird (B7352) displayed very high levels of congruent sample-specific responding; the other five tended to remain close to 50%, although there was some variability, including temporary incongruent differentiation. Sample congruence scores near 50% were nearly always the result of a strong preference for one or the other sample location.

A third dependent variable of interest was the “shaping score”, which is a measure of the extent to which the choice of comparison stimulus was a function of the chosen sample position. The shaping score was calculated as the percent of comparison choice responses that were congruent with the sample-position response, regardless of whether the sample response was congruent or the comparison response was correct. Thus it was possible for the shaping score to be quite large while choice accuracy and sample differentiation were still at chance. For example, if a bird in Group MTO-color comparisons had been trained in Phase 2 to peck the top red sample then choose the red comparison and to peck the bottom green sample then choose

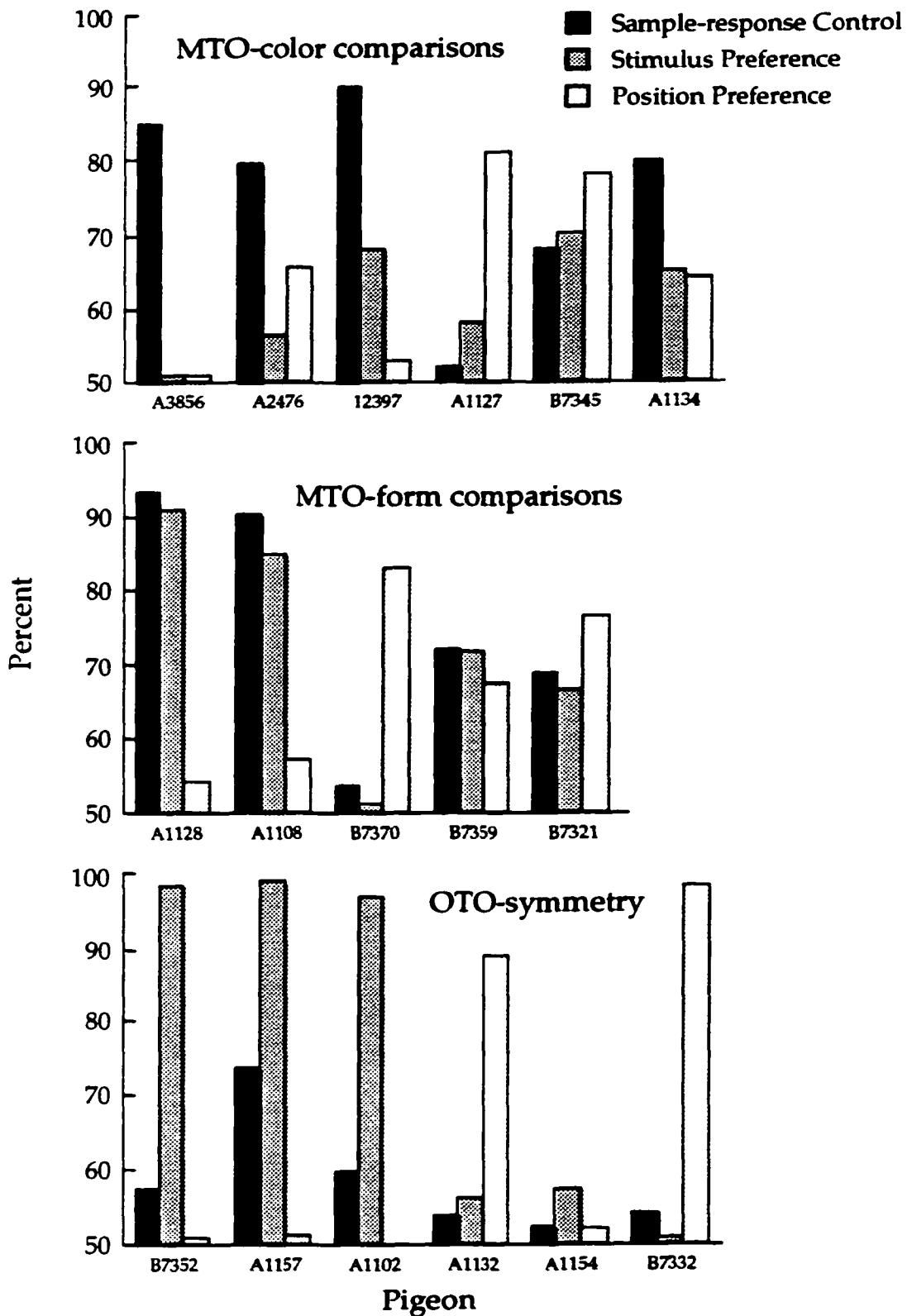
the green comparison, then pecks to either the top cross or the top circle in Phase 3 might be more likely to be followed by the choice of red, and pecks to the bottom of either form might be more likely to be followed by the choice of green. It should be noted that while it is rhetorically convenient to use the term "shaping score" or "shaping effect", these terms refer to a correspondence between different behaviors performed by the subject, not to any contingency intentionally imposed by the experimental design. Figure 8 shows the shaping score for each bird over the blocks of five sessions. Shaping scores for the MTO birds were generally much higher than for OTO birds. It is particularly noteworthy that several of the MTO birds had high shaping scores from the very first session of Phase 3, which indicates that the differential reinforcement effect preceded acquisition of the task. However, before declaring this a "real" effect, each bird's behavior must be examined in more detail, since a high shaping score could result as an artifact of strong preferences for one sample position and one comparison stimulus. In this not-too-unlikely scenario, if the preferred sample position and the preferred comparison stimulus happened to be congruent, this would yield a shaping score of 100%, even though it is not clear that this represents the type of differential reinforcement of sample-specific responding hypothesized by Saunders and Williams (1998), but might better be described as a merely chance concatenation of two response preferences. However, if it could be shown that responses to the other sample position, even if rare, were usually followed by choice of the alternative comparison, then this would provide



**Figure 3.** Percent of trials in which the comparison choice was congruent with the sample response for each pigeon over blocks of five sessions of Phase 3 training with cross and circles forms as sample stimuli.

good evidence that the choice of comparison stimulus was influenced by the location of the sample response.

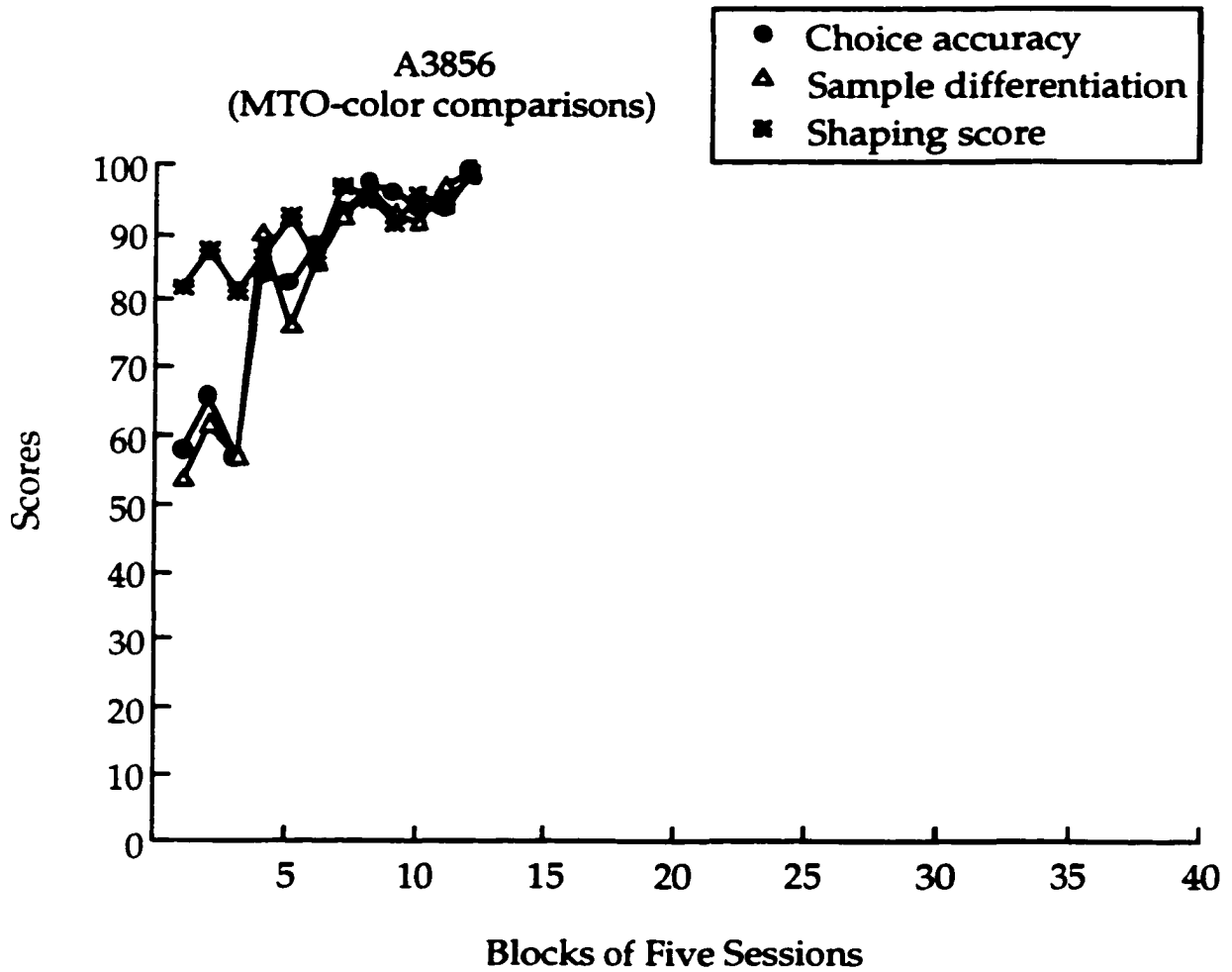
Prior to the acquisition of accurate matching performance, pigeons may employ one of a variety of strategies for choosing a comparison stimulus (Cumming & Berryman, 1965). One common strategy is to always choose the comparison on one side (position preference). Another strategy is to always choose the same comparison, regardless of which side it appears (stimulus preference). A third possible strategy in the present experiment is to choose one comparison following a top sample response and the other comparison following a bottom sample response, in correspondence with the sequence learned in Phase 2 (sample-response control, i.e., the shaping effect). Figure 9 shows the prevalence of each of these strategies for each bird during the first 10 sessions of Phase 3. If control by the sample response was greater than control by a stimulus preference alone, then it can be concluded that there was a real shaping effect beyond a merely chance combination of sample position and comparison stimulus preferences. There was a real shaping effect for six of the MTO birds (A3856, A2476, 12397, A1134, A1128, and A1108). Even when the shaping effect was not much stronger than the stimulus preference, as was the case for A1128, it can be concluded that the shaping effect was real. In these cases, sample responses were usually directed to one sample location, followed by choice of the congruent comparison stimulus. However, on occasion, the alternate sample location was chosen, and this was then followed by choice of the alternate comparison stimulus as well. The



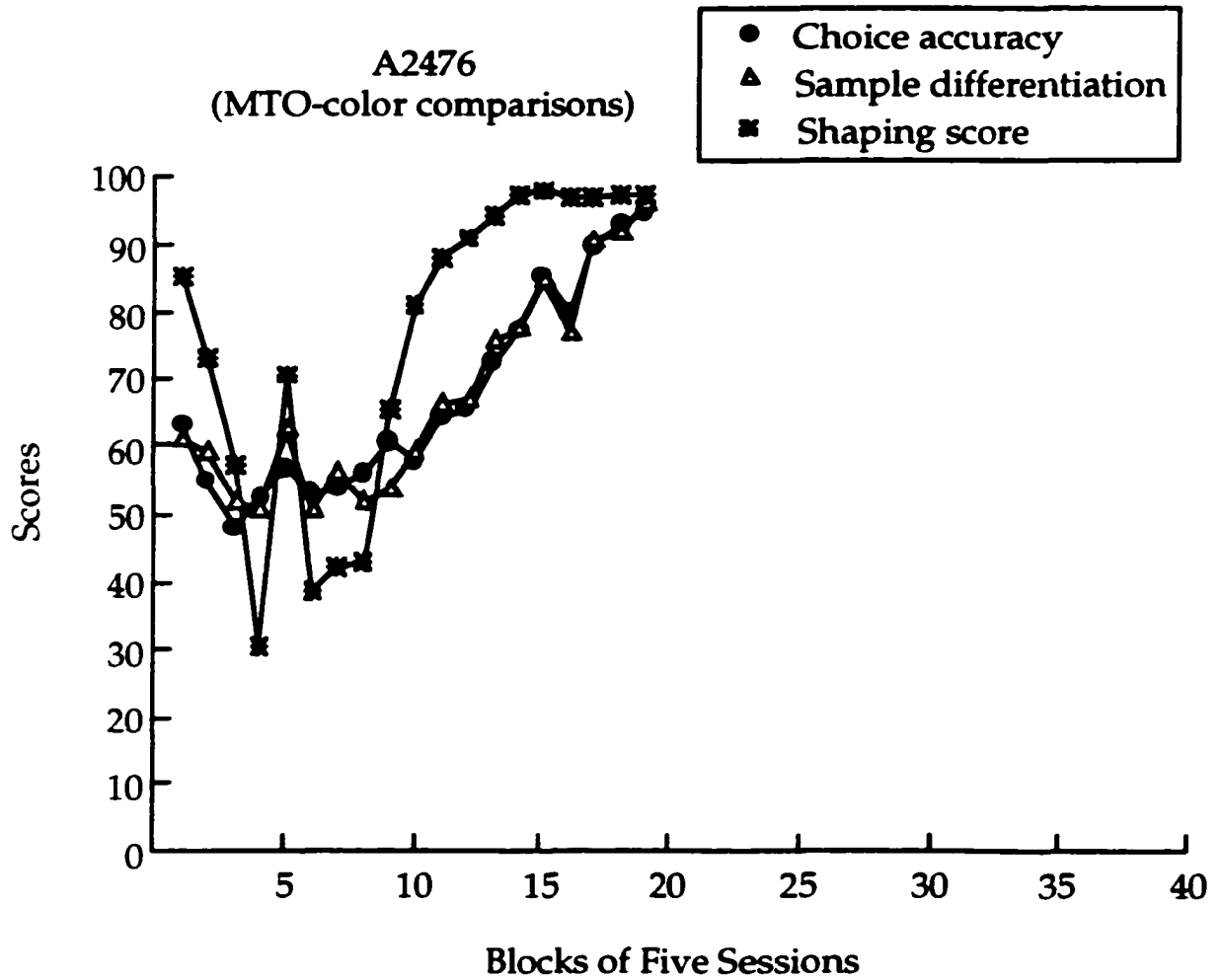
**Figure 9.** Percent of comparison choices in the first ten sessions of Phase 3 (form samples) that corresponded to each of three "strategies".

consistent coincidence of these two events, even where each was rare, provides strong evidence that the location of the sample response determined which comparison stimulus was subsequently chosen. None of the OTO birds demonstrated a controlling relationship between the sample response location and subsequent comparison choice. A stimulus preference was dominant for three of the OTO birds, and a position preference was dominant for other two.

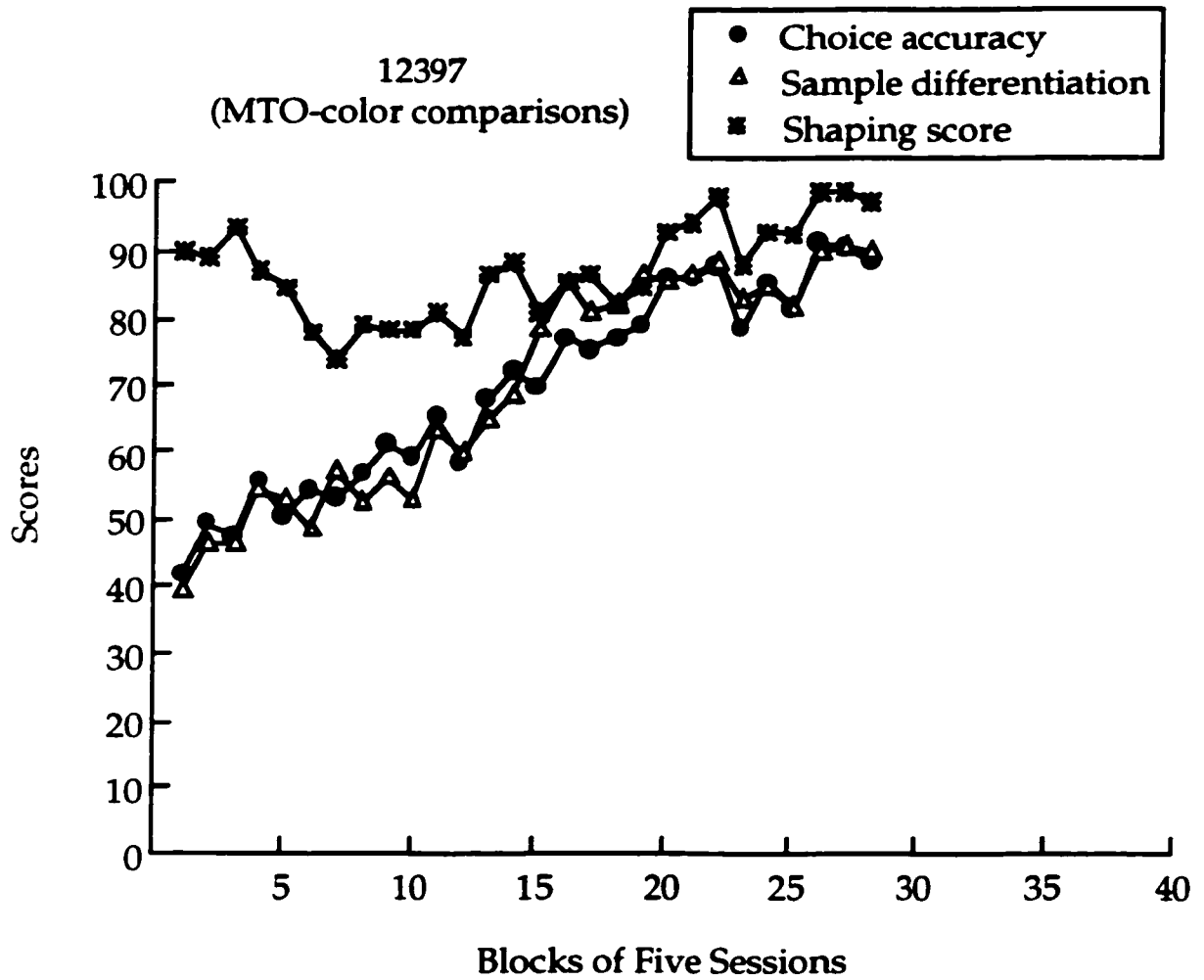
The relationship between the three variables discussed above (choice accuracy, sample-response differentiation, and the shaping score) can be appreciated more readily by examining each bird's performance individually (see Figures 10–26). These figures provide a graphic narration of acquisition of the Phase 3 matching task. Certain commonalities can be seen in the performances of MTO birds A3856, A2476, 12397, A1128, and A1108 (see Figures 10–14). They all had a strong inclination to choose one comparison following a top sample response and the other comparison following a bottom sample response, and that inclination typically remained pronounced throughout Phase 3 training (except for a period of time from Session 6 to Session 47 for A2476, when a red preference dominated). It is important that in these five cases, the shaping effect was apparent well before the acquisition of accurate matching or sample-specific behavior, a necessary condition for it to qualify as a mechanism underlying the emergence of sample-specific responding. It is also apparent that choice accuracy and sample-response differentiation increased in parallel. This is actually a



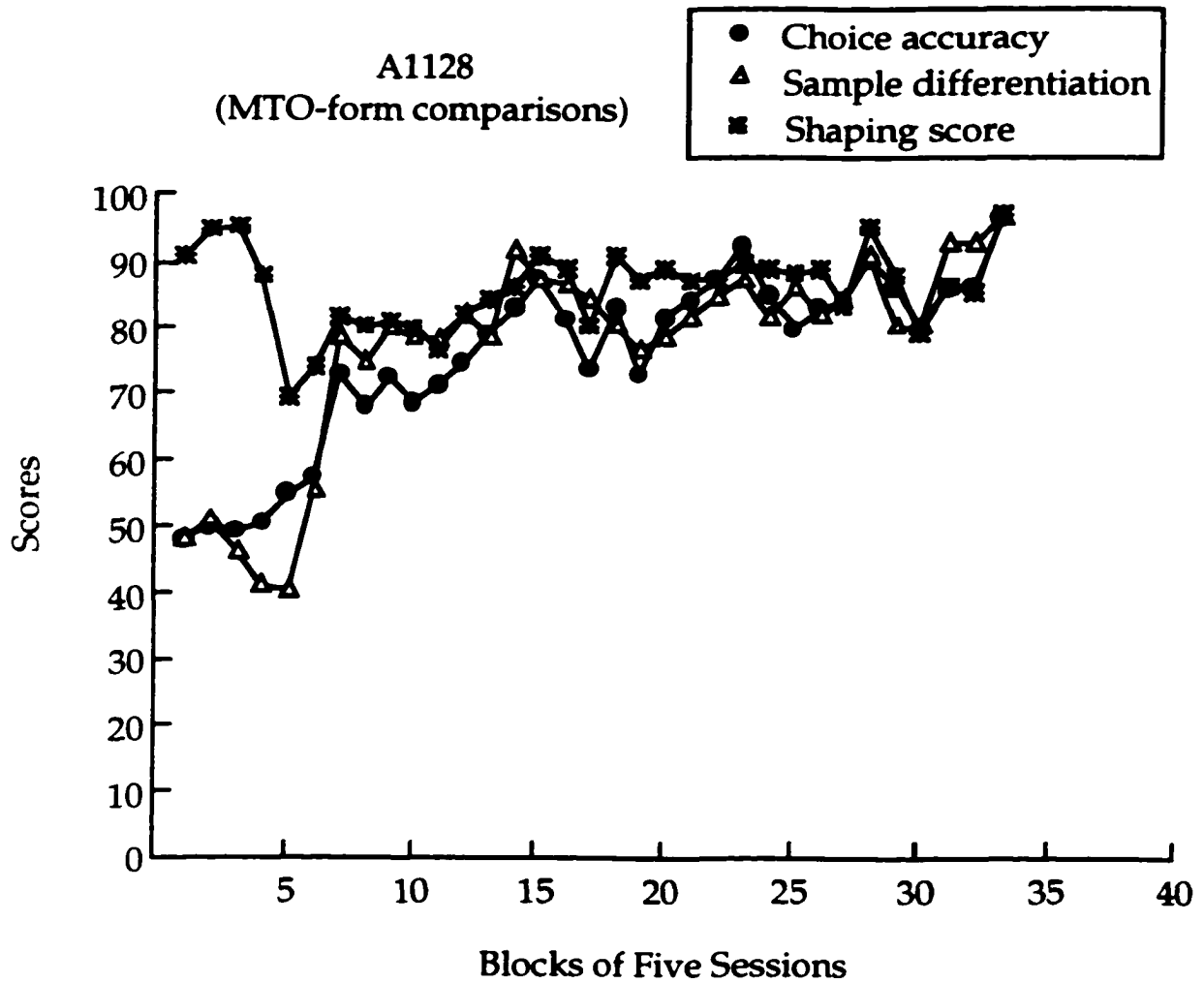
**Figure 10.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A3856.



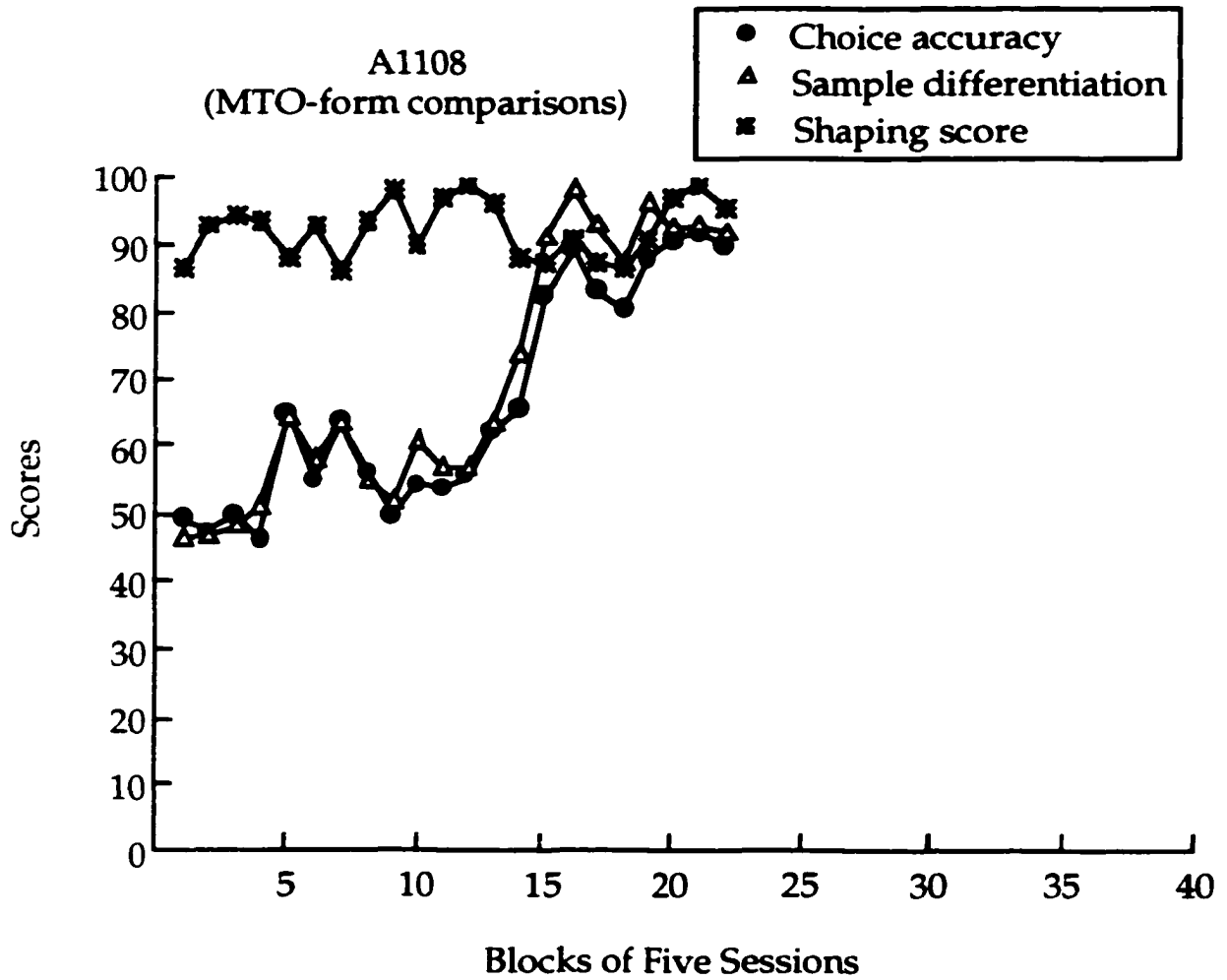
**Figure 11.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A2476.



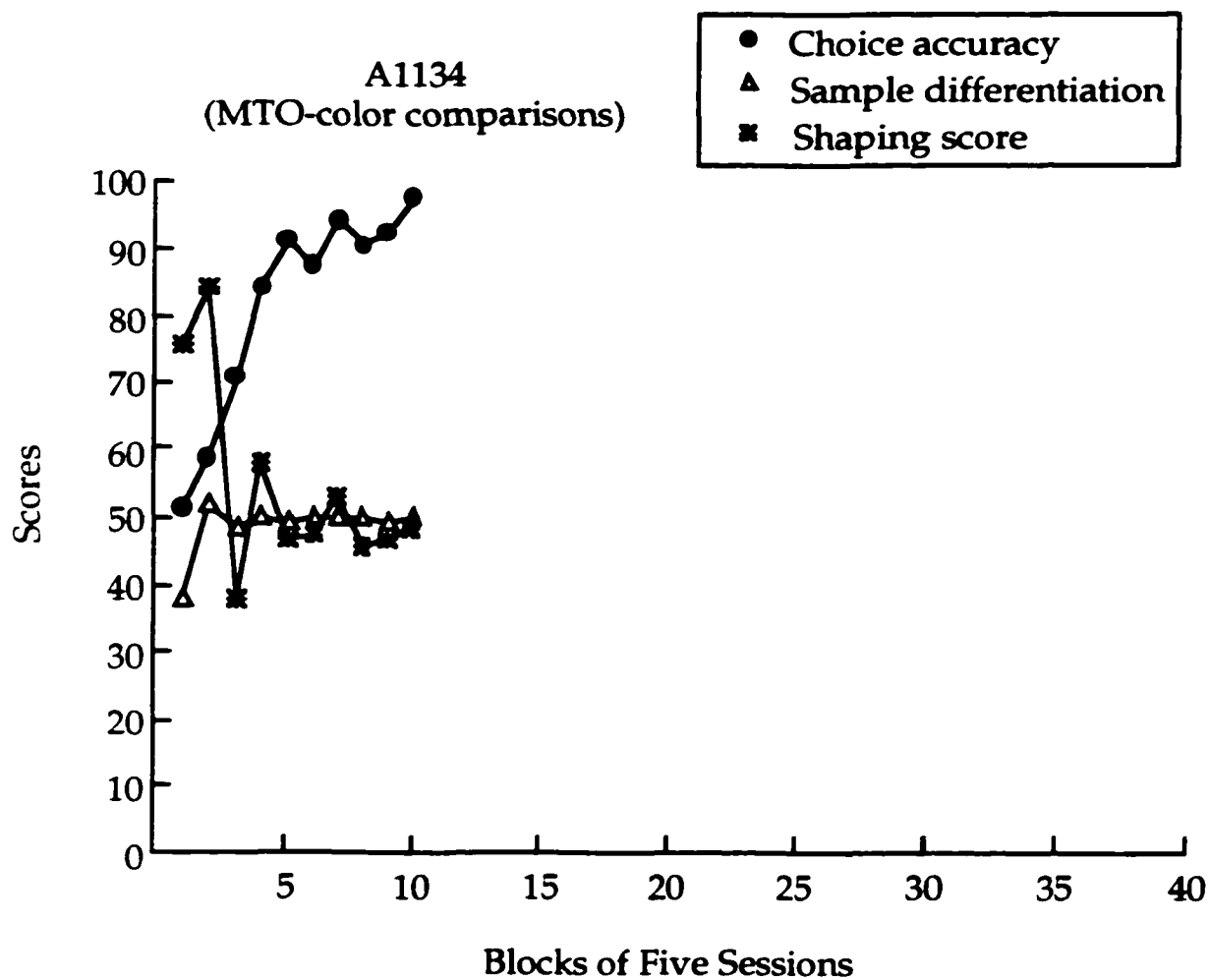
**Figure 12.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon 12397.



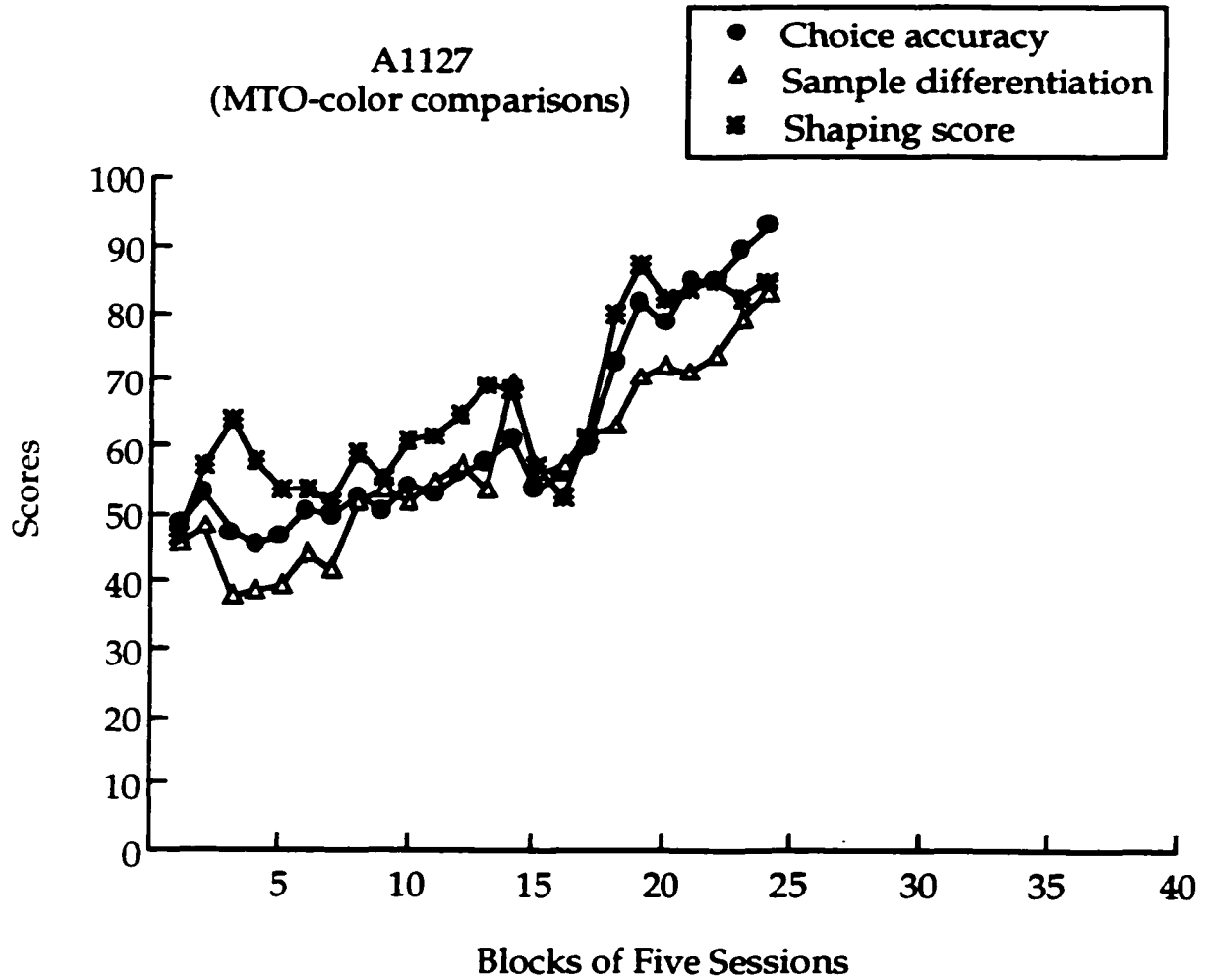
**Figure 13.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1128.



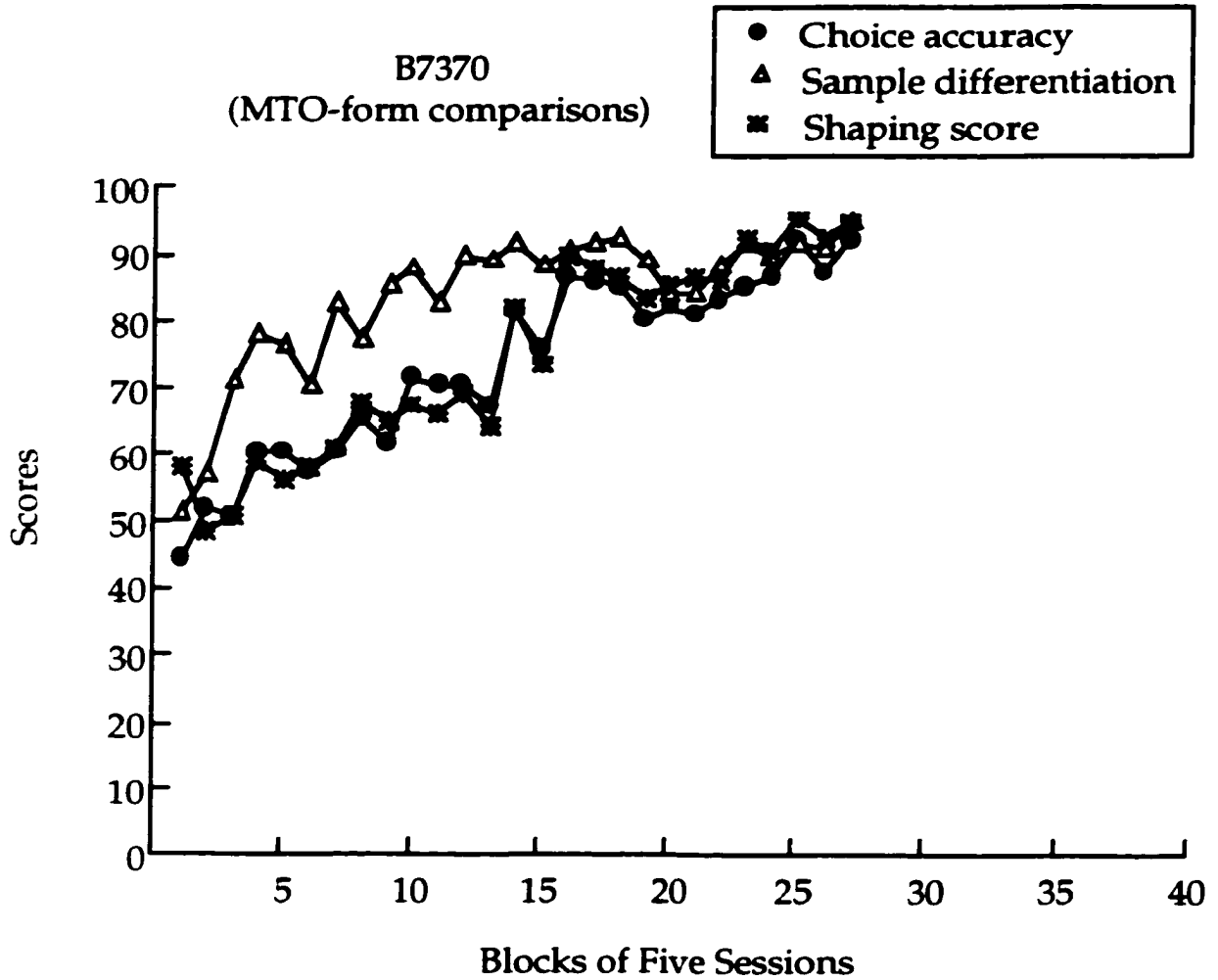
**Figure 14.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1108.



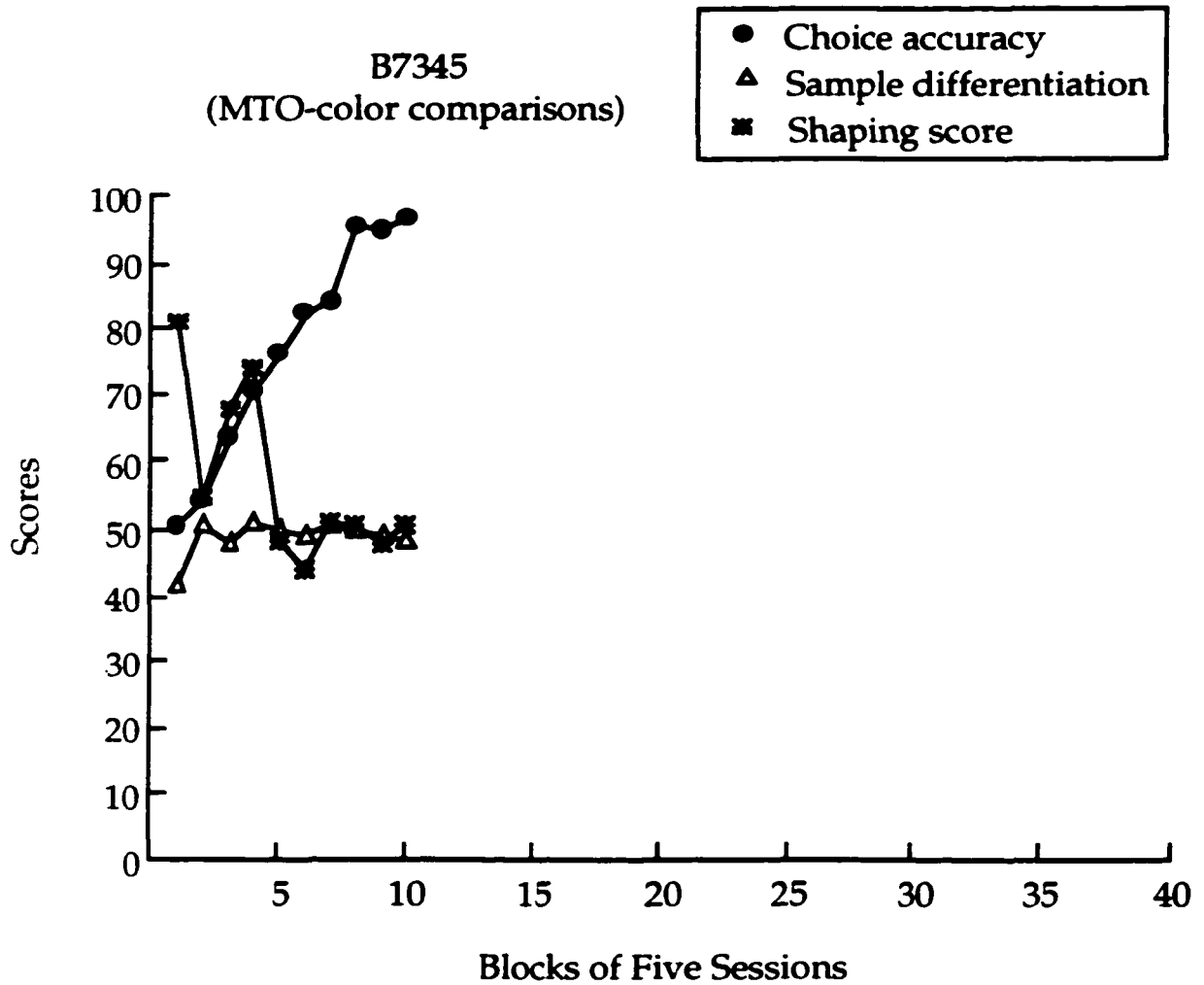
**Figure 15.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1134.



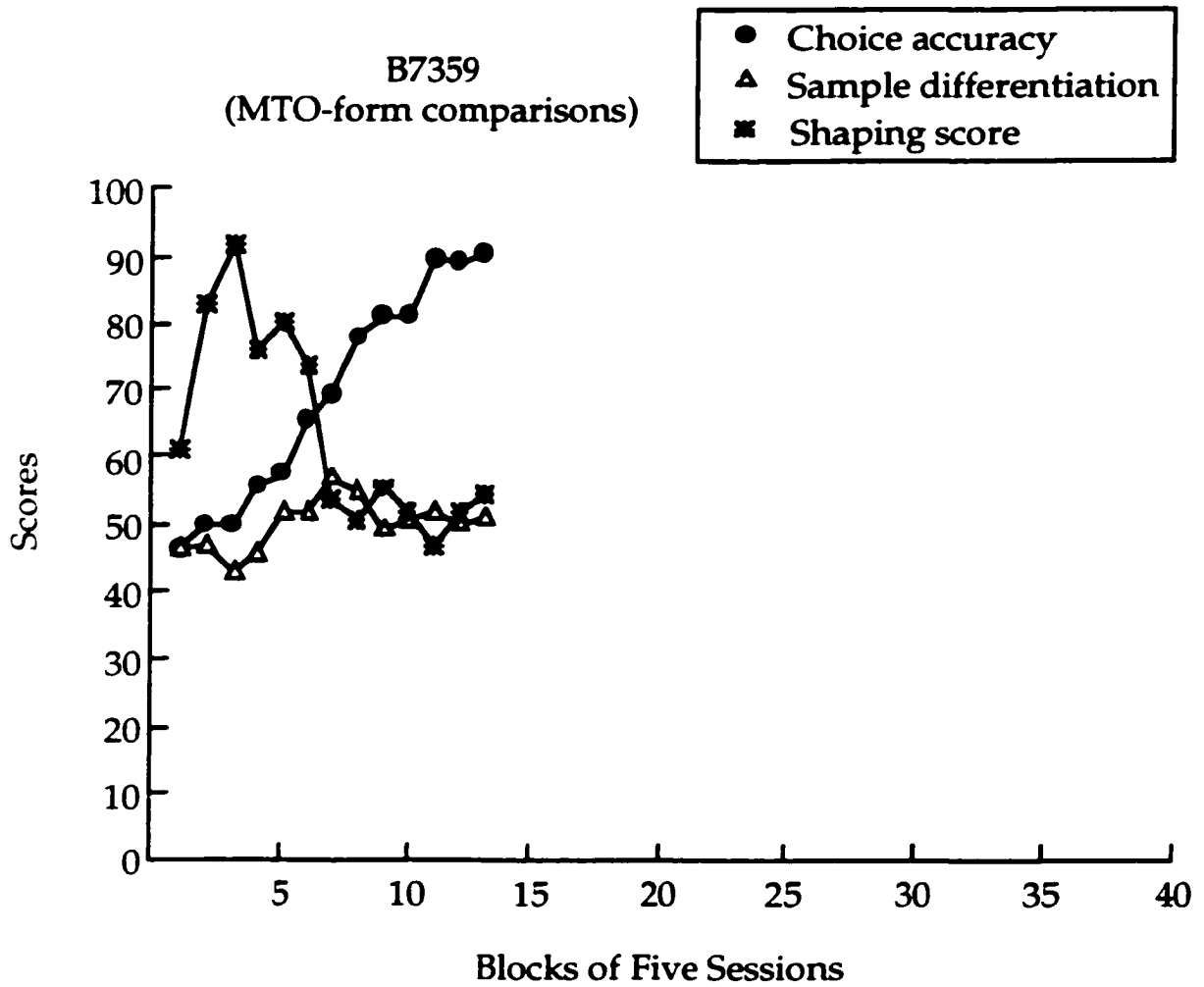
**Figure 16.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1127.



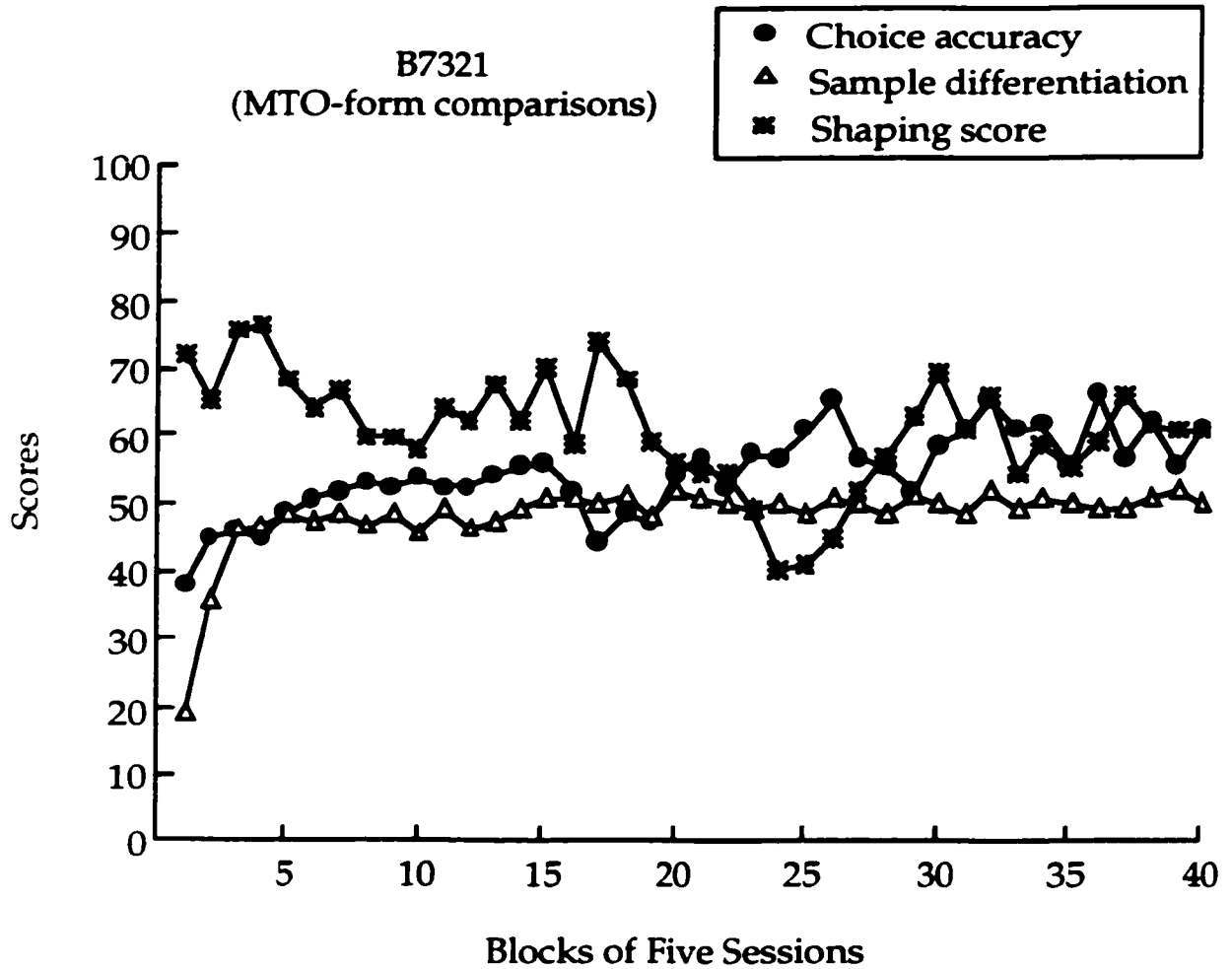
**Figure 17.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon B7370.



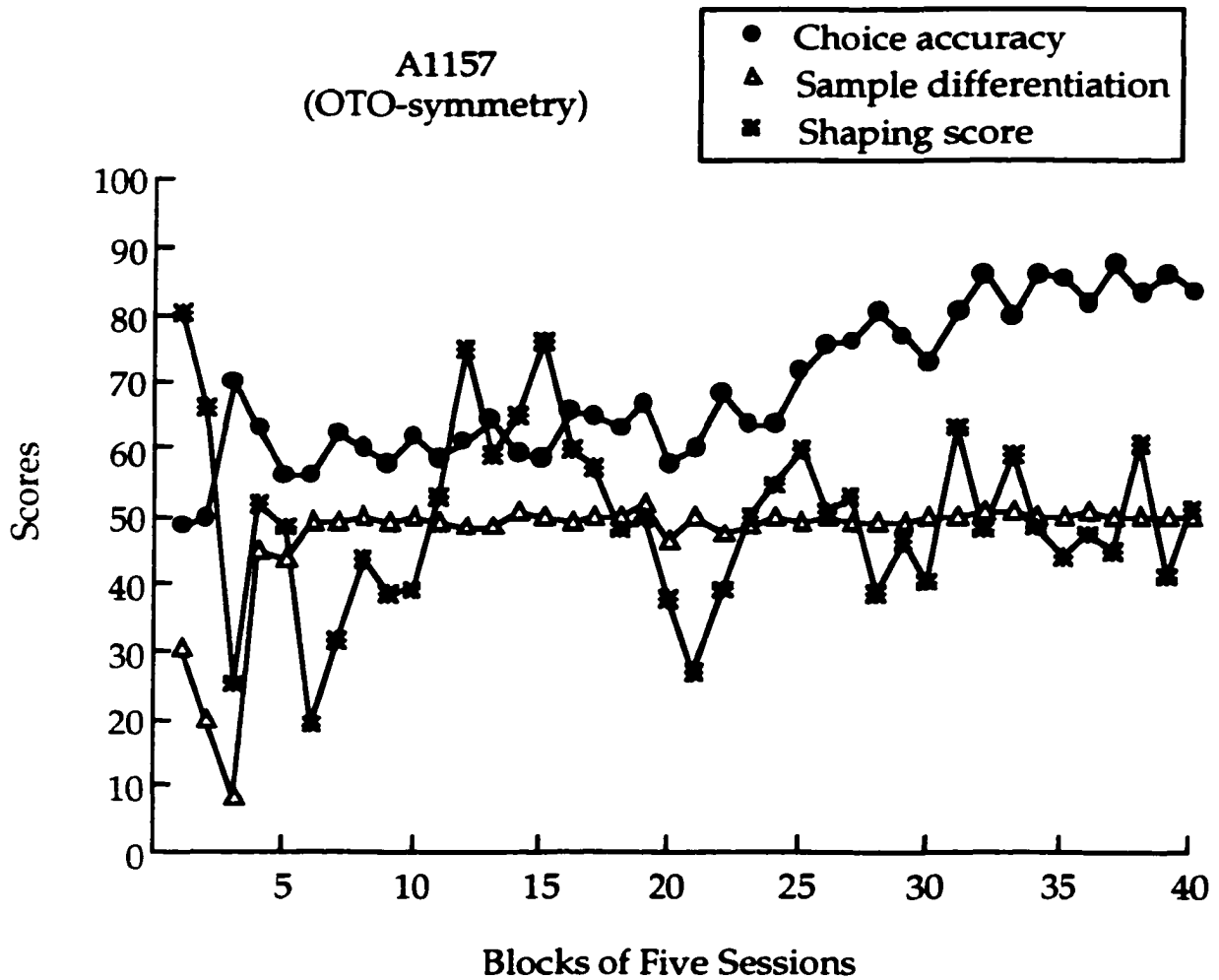
**Figure 18.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon B7345.



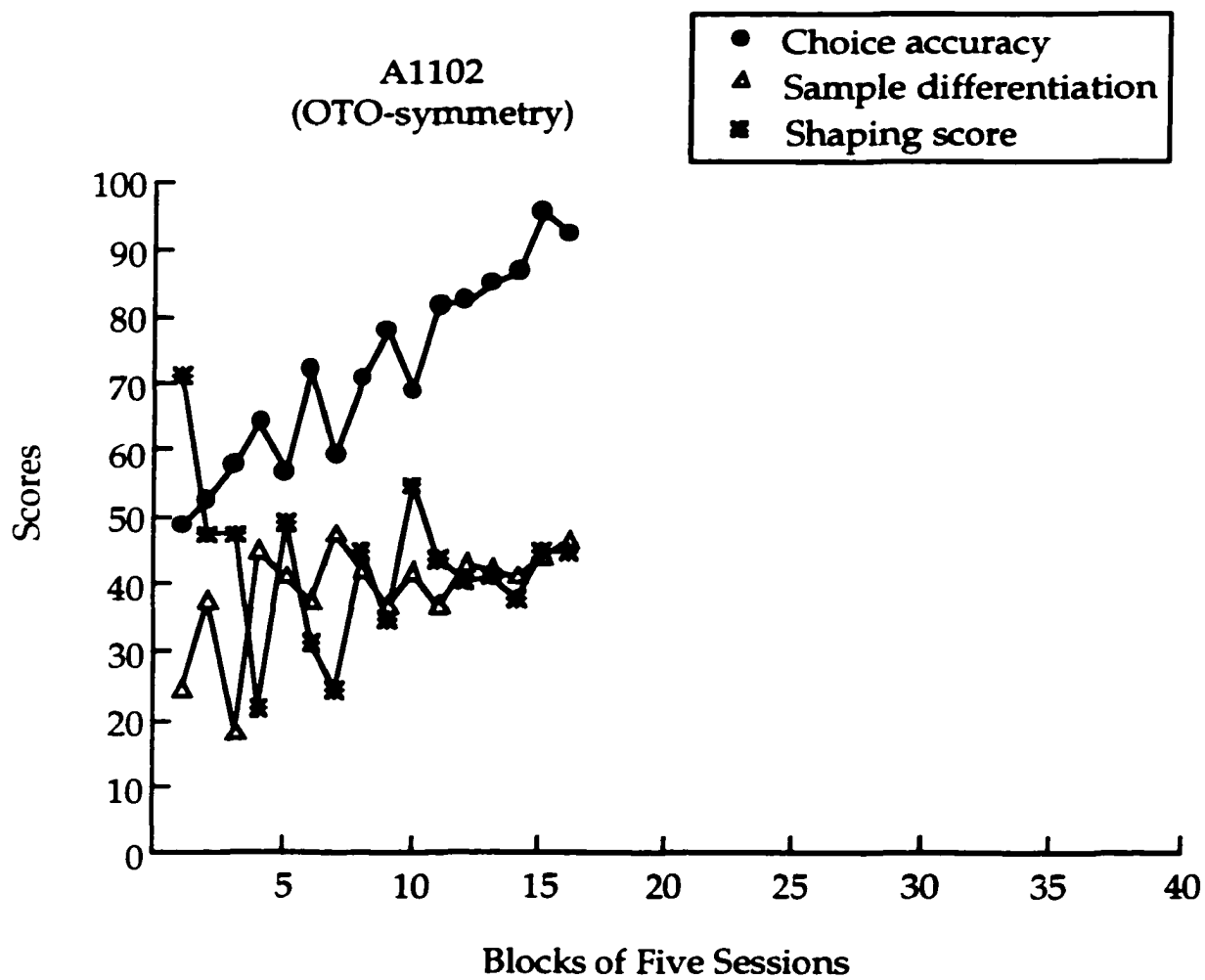
**Figure 19.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon B7359.



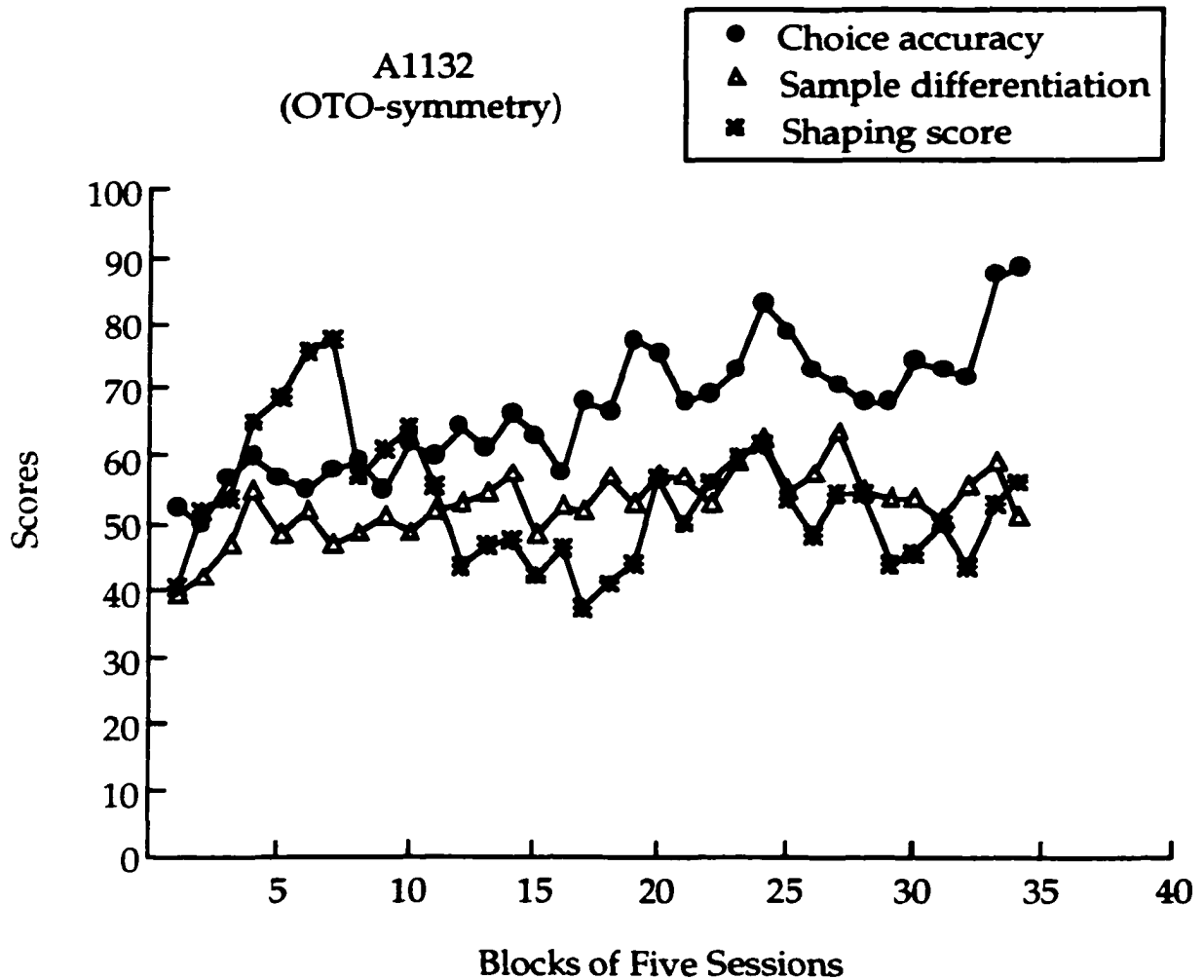
**Figure 20.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon B7321.



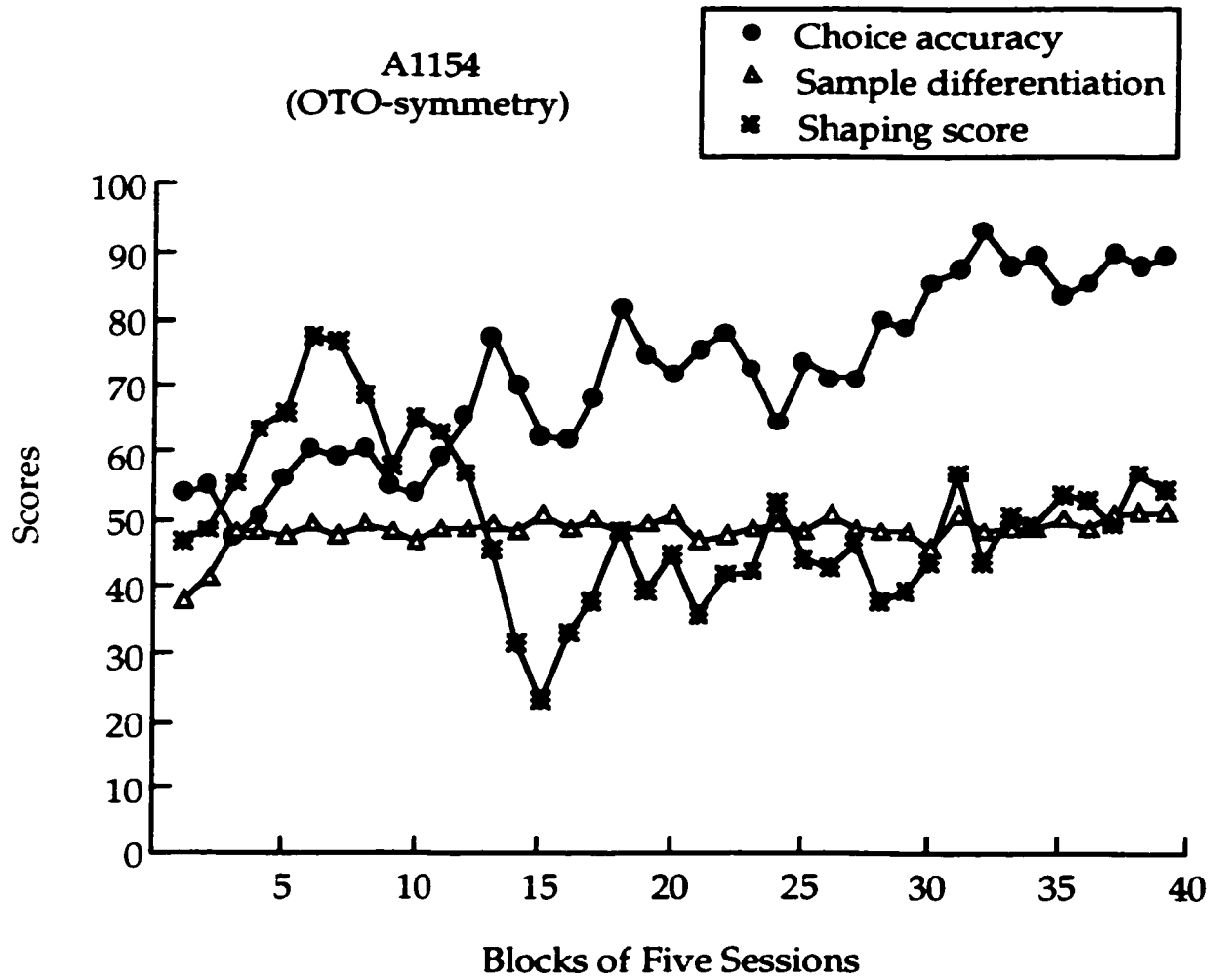
**Figure 21.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1157.



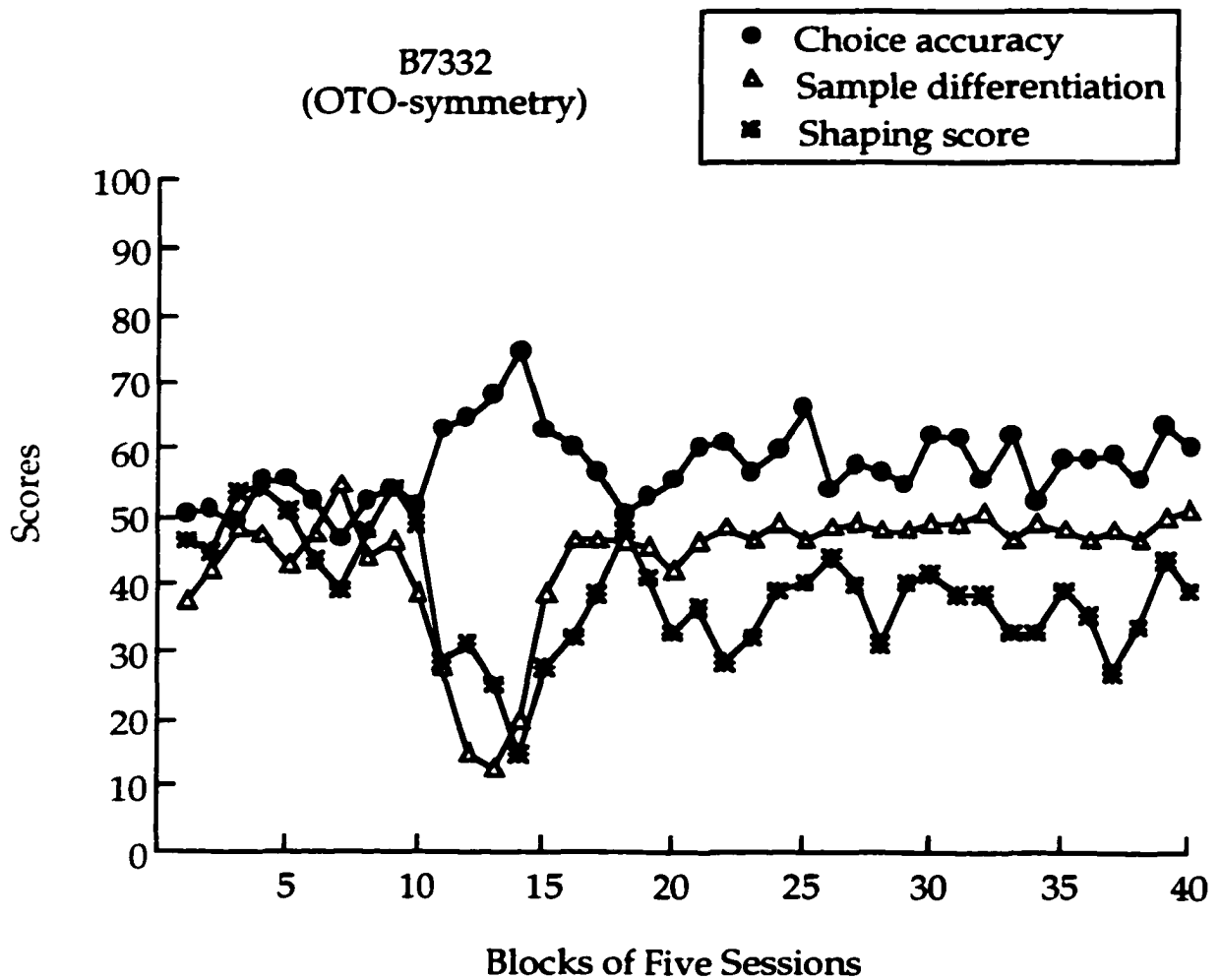
**Figure 22.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1102.



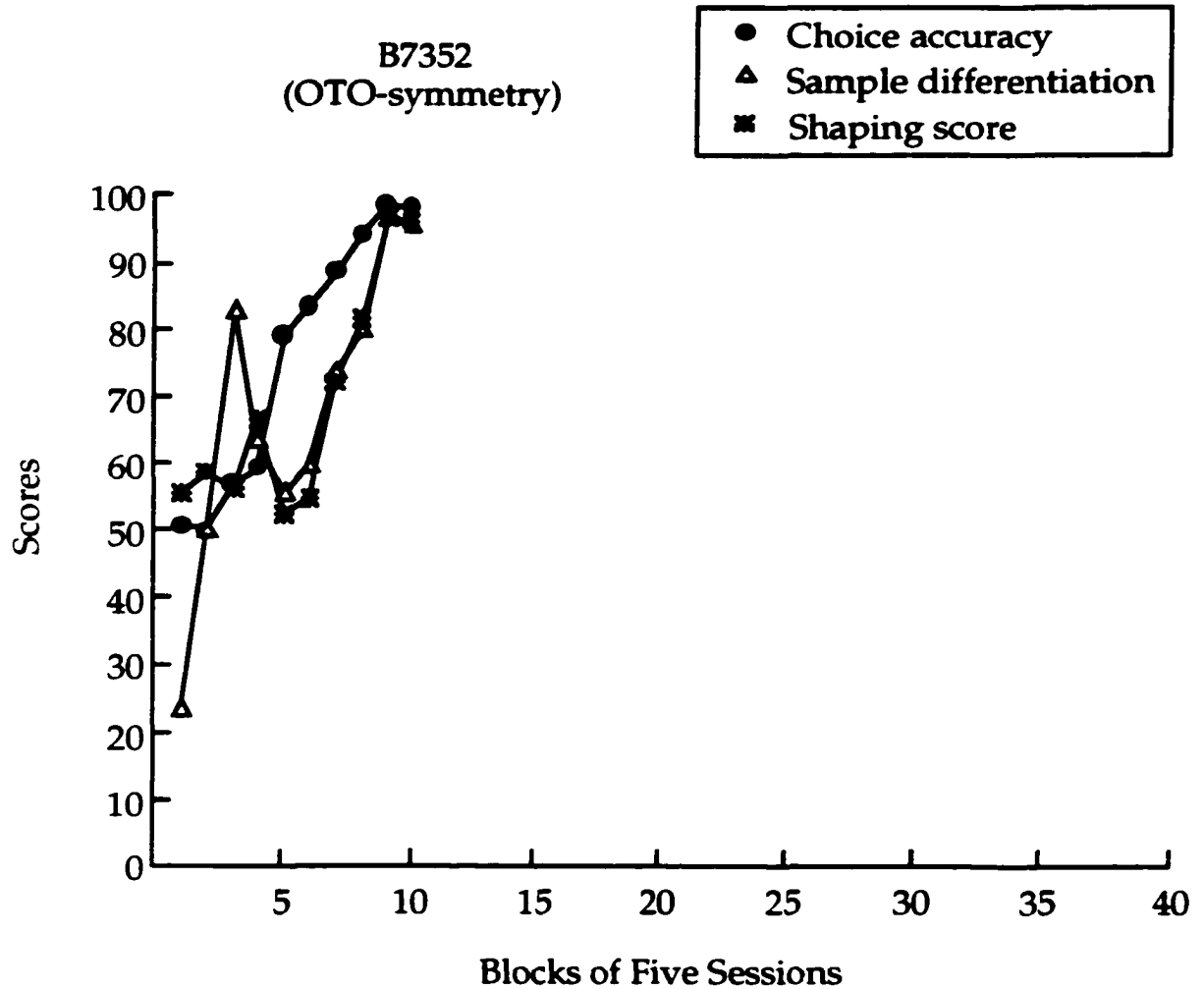
**Figure 23.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1132.



**Figure 24.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon A1154.



**Figure 25.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon B7332.



**Figure 26.** Percent scores for the variables measured in Phase 3 of Experiment 1 on form sample trials, for pigeon B7352.

mathematical certainty: Given a large shaping score, any increase in sample-response congruence would have to result in greater accuracy. In fact, although each pairwise combination of these three variables is independent in principle, as a triad they are entangled such that if any two of them are large, the third must also be large. Therefore, it is difficult to say whether increasing sample-response differentiation drove increases in chance accuracy or vice-versa. However, the presence of the shaping effect provides a mechanism whereby sample-specific responding could be expected to develop, so it is tempting to conclude that matching accuracy developed as a by-product of increasing sample differentiation.

The remaining MTO birds showed different patterns of acquisition. For A1134 (see Figure 15), there was evidence that comparison choice was a function of sample-response location (a high shaping score) during the first 10 sessions, but differentiated sample behavior did not develop (this bird nearly always chose the top sample after Session 9), and the shaping effect vanished as the bird began to learn the matching task. A1127 and B7370 (see Figures 16 and 17) developed congruent sample-specific responding, but it is not clear how this behavior was produced. A1127's comparison choices were dominated by a right position preference through the first 85 sessions, resulting in near-chance levels of all three dependent measures. Near the end of training, the position preference gradually gave way to a combination strategy: choose green following a circle sample, and choose in accordance with the sample response location following a cross sample. Because sample-

response congruence was high for cross samples and somewhat poorer for circles, this led to choice accuracy that was higher than the sample differentiation or shaping scores. It cannot be concluded that learning of the task was mediated by differential reinforcement of sample-specific behavior, but this may have played a role, if only on cross-sample trials. In the case of B7370, sample-specific behavior developed early and independently of accuracy or a shaping effect. Choice accuracy and the shaping effect subsequently increased in lock-step. While it is possible that choice accuracy developed independently of sample behavior, and the shaping score followed as a mere mathematical artifact, it is at least as likely that the bird eventually learned to base its comparison choices on the sample response location, thereby driving the increase in choice accuracy. The remaining three MTO birds, B7345, B7359, and B7321 (see Figures 18–20), never developed overt sample-specific behavior, and there was little indication of a shaping effect beyond the artifactual variety attributable to stimulus preferences. The appearance of a strong shaping effect during the first 30 sessions for B7359 is primarily due to the combination of a top preference and a circle preference. When the circle preference disappeared in Session 30, so did the shaping effect. The fluctuations in the shaping score apparent in B7321's data reflect reversals of weak preferences for one or the other comparison stimulus. It is of some interest that B7345 and B7359, despite evidently learning the matching task in a different manner than many of the other MTO birds,

learned very quickly. B7321, however, never performed much better than chance.

Oddly, all OTO birds began Phase 3 training by spontaneously differentiating their sample responding in the incongruent direction, although the differentiation was slight in some cases. In the case of A1157 (see Figure 21), incongruent sample-specific responding was especially pronounced during Sessions 11 through 15, and comparison choice was correlated with with sample-response location such that accuracy increased a bit. This could be referred to as an inverted shaping effect. However, the effect didn't last as a strong top sample preference took over and was never abandoned. The comparison preference shifted between green and red, causing the shaping score to fluctuate. A1102, A1132, and A1154 (see Figures 22–24) had essentially similar patterns of behavior, with the initial incongruent sample-specific behavior quickly giving way to a fairly strong preference for either the top or the bottom sample position, regardless of which form it was. The shaping effect that appeared during Sessions 19–34 for A1132 is not clearly attributable to stimulus preferences alone, but it had no apparent effect on sample responding or choice accuracy. In contrast, the high shaping scores that appear early in A1154's training were clearly due to a red preference, and the low shaping scores that followed were due to a green preference. For B7332 (see Figure 25), incongruent sample-specific responding re-emerged beginning in Session 48, which was followed by a strong inverted shaping effect. These behaviors combined to raise choice accuracy, but sample-

specific responding inexplicably disappeared by Session 76, permanently replaced by a bottom preference. The weak inverted shaping effect that remained throughout the rest of training appears to be a real effect, not attributable to stimulus preferences, but comparison choice was mostly dominated by a left preference, and accuracy generally remained close to 60%.

Finally, B7352's results deserve particular consideration, since this was the only bird in Group OTO-symmetry that differentiated its sample responding (see Figure 26). Like the other OTO birds, B7352 initially differentiated its sample responding in the incongruent direction, which lasted for five sessions in this case. During the next five sessions, sample responding was undifferentiated, with no strong top or bottom preference. During this time, there was a strong preference for the red comparison, resulting in chance accuracy and shaping scores. Sample responding began to differentiate in the congruent direction in Session 11, but changed to a bottom preference by Session 19. There was some indication of a shaping effect from Session 12 to Session 20, when it disappeared. Choice accuracy rose beginning in Session 21, and apparently without any influence from a shaping effect or sample-specific behavior. Beginning in about Session 32, sample-specific responding and the shaping effect re-emerged, this time in the congruent direction. It is not clear whether the development of these behaviors contributed to choice accuracy, which was already quite high by this time, or whether perhaps the increase in accuracy somehow fueled the development of either sample differentiation or the shaping effect. It does seem likely,

however, that sample-specific responding was the primary of the latter two effects, and the increase in the shaping score was an artifactual consequence, since the probable effect of spontaneous development of sample-response control of comparison choice would have been a reduction of choice accuracy rather than a perfectly concurrent increase in sample-specific behavior.

In summary, of the ten MTO birds that eventually learned the Phase 3 task, seven developed stable congruent sample-specific responding (see Table 2). Of these, the shaping effect was apparent from the outset for five birds. For the other two, the shaping effect was not clearly responsible for the sample differentiation, although it may have played a role late in the phase. Only one of the six birds for which the shaping effect was strong at the outset failed to develop sample-specific behavior. Of the five OTO birds that learned the Phase 3 task, sample-specific responding emerged in one, after choice accuracy had reached high levels and without any apparent differential reinforcement.

### **Discussion**

This experiment successfully replicated the essential components of the Manabe et al. (1995) experiments, albeit with a different species performing a different sample observing response. The hypothesis that emergent sample-specific behavior would appear for MTO birds, but not for OTO birds, was generally supported, with the one notable exception of a OTO bird that also developed sample-specific responding.

Manabe et al. (1995) identified three characteristics of naming behavior. Two of these, differential responding to different stimuli and arbitrariness of

Table 2

**Summary of Experiment 1 Results (Phase 3 Form Sample Task)**

	MTO (N=11)	OTO (N=6)
• Learned the task	10	5
• Sample congruence	7	1
• Shaping effect	6	0
• Shaping & congruence	5	0

the responses, are common to other types of operant behavior. The criterion characteristic is that names have a referential quality that allows them to be used in the absence of the named object. While Manabe et al. equate this referential quality with "emergent use", it is not at all evident that a naming response that is emitted in the absence of the named stimulus must in fact refer to that stimulus. Saunders and Williams (1998) have identified two possible routes whereby responses of this kind might emerge, without necessarily referring to the stimulus to which they were originally conditioned. One possibility is that given a restricted repertoire of behaviors, the target behavior might emerge by chance. In the case of matching-to-sample with two different observing responses, there are only four possible outcomes: (a) Response A is performed in the presence of both samples, (b) response B is performed in the presence of both samples, (c) sample A controls response A and sample B controls response B, or (d) sample A controls response B and sample B controls response A. Only one of these possibilities (c) would give the appearance of referential behavior, but since it is one of only four possibilities, it might not be a terribly unlikely chance outcome. The other possible route that could lead to seemingly referential behavior is adventitious differential reinforcement of the target behavior, as described in the introduction above. This account is particularly germane to the present experiment.

Both the naming hypothesis and the adventitious differential reinforcement hypothesis predict the emergence of sample-specific behavior

for the MTO birds in this experiment, so the fact that several of MTO birds produced that outcome does not differentiate between the theories. Other aspects of the performances favor the adventitious differential reinforcement account, however. For the sake of rhetorical clarity, the following arguments consider a specific arrangement of stimuli and response requirements and omit other trial types and alternative arrangements that ensued from counterbalancing. It should be understood that the arguments apply equally well to all trial configurations that were actually presented in the conditions under consideration.

The naming hypothesis explains the performance of the MTO-color comparisons birds that developed sample-specific behavior in the following way. In Phase 2, a top response was conditioned to the green sample and in Phase 3 an association was learned between the cross sample and the green comparison. Once the Phase 3 association developed, presentation of the cross sample elicited a prospective representation of the green comparison. This prospective representation was manifested as the appropriate naming response for green. This account predicts that accurate matching would have to be a prerequisite for emergent sample-specific behavior, and the frequency of congruent sample-specific responses should not exceed the frequency of correct comparison choices. In fact, sample differentiation typically developed in lockstep with choice accuracy, making it impossible to say which was prior to the other.

A slightly different explanation is required for sample differentiation by the MTO-form comparisons birds. According to the naming hypothesis, in Phase 2 the top response to the green stimulus might have become associated with the correct comparison that followed (the cross in this example), either because of the contiguity between the sample response and the comparison choice or because of the mapping of the green sample onto both the top response and the cross comparison. Then when the cross was presented as a sample in Phase 3, the top-cross association manifested itself in a symmetrical fashion, such that the cross produced the top response. From this account, it might be expected that sample-specific behavior would appear at the outset of Phase 3, since experience with the Phase 3 contingencies appears to be unnecessary. However, this did not happen. Typically, sample differentiation developed gradually over a period of several sessions, suggesting that it was shaped during Phase 3, rather than a reflection of an extant association. Notice also that the fundamental notion of the naming hypothesis—that the top response refers to the green stimulus, even in its absence—has become quite strained in this analysis, since the green stimulus is not part of any of the trials introduced in Phase 3.

The adventitious differential reinforcement hypothesis parsimoniously explains sample differentiation among both groups of MTO birds in the following manner. During Phase 2, the top response that was conditioned to the green sample also at least partly controlled the subsequent choice of the green comparison (cf., Cohen, Brady, and Lowry, 1981; Urcuioli, 1985; Urcuioli

& Honig, 1980). At the beginning of Phase 3 training, either the top or the bottom cross might be chosen on any given cross-sample trial, at first due to chance or a spontaneous preference on the part of the bird. If the top cross was chosen, then the green comparison was also chosen, since top responding was already a discriminative cue for choosing green. Since this resulted in reinforcement, the entire cross-top-green chain was reinforced, so that top responding became more frequent in the presence of the cross sample. On the occasions when the bottom cross was pecked, red was more likely to be chosen, which resulted in non-reinforcement, thereby extinguishing the cross-bottom-red chain. This account obviously predicts the presence of a strong shaping effect—the quantitative index of adventitious differential reinforcement—prior to the emergence of sample-specific responding, which was in fact the typical result. This account also predicts the observed lockstep progression of choice accuracy and sample differentiation. Since the correct comparison choice was already being made following congruent sample responses, all that was necessary was enough repetition for congruent sample responses to become more frequent, at which time a corresponding increment in choice accuracy automatically ensued.

Group OTO-symmetry provides a more direct test of the competing hypotheses, since they make very different predictions regarding the likelihood of emergent sample-specific behavior. According to the naming hypothesis, sample differentiation was extremely probable, since all of the ostensibly important processes described for MTO-color comparisons and

MTO-form comparisons birds converged in the OTO-symmetry condition. Thus, top responses to the cross sample in Phase 3 could emerge either as a prospective reference to the impending green correct comparison or as a symmetrical instantiation of an association created in Phase 2 between the top response and the cross comparison. The adventitious differential reinforcement hypothesis makes the opposite prediction. Since the two matching tasks did not share common comparison stimuli, there was no opportunity in Phase 2 for sample response location to become a discriminative cue for choosing a particular comparison introduced in Phase 3. Thus, adventitious differential reinforcement would not be expected, and therefore neither would sample-specific responding be expected. The adventitious differential reinforcement hypothesis was clearly supported by the five OTO birds that failed to develop sample-specific behavior.

The exceptional results of B7352, however, cannot be accounted for by adventitious differential reinforcement as it was measured in this experiment. It is possible that in this case sample responses were truly referential. Other possibilities cannot be ruled out, however. It is not too hard to imagine that, given the limited set of possible sample behavior patterns, differentiation could emerge as a form of "superstitious" behavior (Skinner, 1948). During the period of time when B7352 was just beginning to master the Phase 3 matching task, it nearly always chose the bottom sample. However, on rare occasions, the top circle was pecked, and this was almost always followed by the correct choice of the red comparison. Thus, responses to the

top circle were serendipitously reinforced, which may have resulted in an increase in these responses. Once even a modicum of sample differentiation was established, it may have contributed to the rapid acquisition of the matching task by providing an additional discriminative cue (cf., Eckerman, 1970), which would have further reinforced sample differentiation (cf., Blough, 1959). This account is admittedly speculative and *ad hoc*.

Manabe et al. (1995) claimed that it was “hard to avoid the conclusion that something more than standard conditioning processes underlies the emergent relations demonstrated in (their) experiments” (p. 126). The present results suggest the opposite. It seems likely that standard conditioning processes do underlie these emergent behaviors. In fact, backward chaining seems to provide the best model of Phase 3 learning. Backward chaining is a technique for training a fixed sequence of responses (a response chain). Training begins by reinforcing the response that will be the last response in the chain, then other responses are added to the front of the chain, one at a time, each being reinforced by the opportunity to advance to the next “link” in the chain (see Mazur, 1994, for more details). While it is usually assumed that matching-to-sample involves the learning of stimulus relations between the sample and the correct comparison, it seems that in the Phase 3 task, the pre-existing response-comparison relation merely required the addition of an appropriate sample-response association to form a chain. For some of the MTO birds, this was shaped by differential reinforcement, since congruent sample responses led to correct choices, while incongruent sample responses

led to incorrect choices. It is entirely possible that there was no direct association between the samples and the comparisons that was not mediated by the response that linked them together. As an illustration of this, consider A3856's training. During Phase 2, A3856 learned to choose the green comparison following a top response and the red comparison following a bottom response. In Phase 3, these terminal links continued to be performed in the presence of the form samples—top responses were still followed by the choice of green and bottom responses by red, as evidenced by the high shaping score. All that needed to be learned in Phase 3 were the additional links of choosing the top cross sample and the bottom circle sample in order to connect to the correct terminal link.

These findings may also have important implications for the concept of common coding, lending support to the contention that transfer effects following many-to-one matching-to-sample training (e.g., Urcuioli et al., 1989; Urcuioli et al., 1995) are also mediated by unobserved sample-specific responses produced by adventitious reinforcement (Saunders et al., 1996). Experiment 2 was designed to provide additional evidence pertaining to this issue.

## **Experiment 2: Emergent Sample-Specific Behavior and the Common Coding Effect**

The results of Experiment 1 were characterized by considerable variability. Seven of the birds that received many-to-one training developed congruent sample-specific behavior, but four others did not. The common coding literature is characterized by this same kind of intersubject variability. For example, Urcuioli et al. (1989, Experiment 2) trained pigeons on a many-to-one task in which hue samples (red and green) and line orientation samples (horizontal and vertical) were mapped onto line orientation comparisons. Following this training, the hue samples were mapped onto new form comparisons (circle and dot). Then the line orientation samples were tested with the new form comparisons. During the first session of this transfer test, comparison choices that were congruent with the previously trained mappings ranged from near chance to 95%, with 7 of the 12 birds showing at least some transfer.

Since it has been theorized that this transfer effect (the common coding effect) is mediated by covert sample-specific responses (or “codes”) shared by the samples mapped onto one comparison (Saunders et al., 1996; Urcuioli, 1996), it would be interesting to see if the variability in the results reported in Experiment 1 corresponds to the variability that is generally discovered in common coding experiments. Therefore the birds used in Experiment 1 were

trained on a new symbolic matching-to-sample task, with the green and red samples from Experiment 1 mapped onto new comparisons (a yellow star and a blue triangle, respectively). This new training was conducted every other session, and training identical to the Phase 3 training of Experiment 1 was conducted during the alternate sessions. After acquisition of the new task, the cross and circle samples were tested for transfer to the new comparisons in a single-session test. It was hypothesized that the birds that developed sample-specific behavior in Phase 3 of Experiment 1 would perform at higher levels of accuracy in the transfer task, due to the availability of sample-specific behavior to serve as the mediating response (or common code).

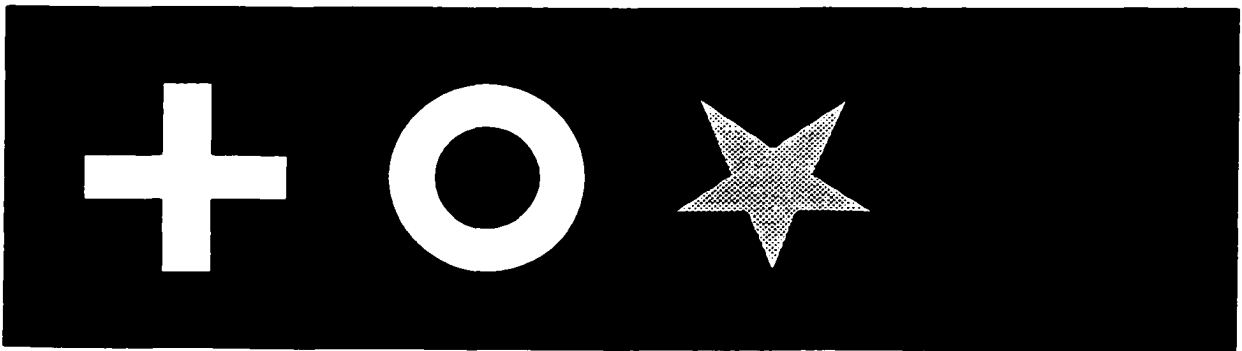
## **Method**

### **Subjects and apparatus**

The 15 pigeons that successfully learned all of the matching-to-sample tasks in Experiment 1 were used in this experiment. Each bird began Experiment 2 immediately upon completion of its role in Experiment 1. The same apparatus used in Experiment 1 was also used here.

### **Procedure**

**Training.** The birds received two kinds of training sessions on alternate days. Even numbered sessions consisted of training identical to Phase 3 of Experiment 1. Odd numbered sessions consisted of new symbolic matching-to-sample training, with new comparison stimuli: a yellow star and a blue triangle (see Figure 27). The yellow star was the correct choice following the sample consisting of a pair of green fields and the blue triangle was correct



**Figure 27.** Form stimuli (cross, circle, yellow star, and blue triangle) used in Experiment 2.

following red for all birds. These samples were the same as those used in Experiment 1, and top/bottom differential sample behavior was required in the same manner as in Experiment 1. The outcomes for sample responses errors and correct and incorrect comparison choices were also the same as in Experiment 1. Odd numbered sessions consisted of 48 trials, and training was continued until correct comparison choices were made at least 90% of the time over a period of four successive sessions.

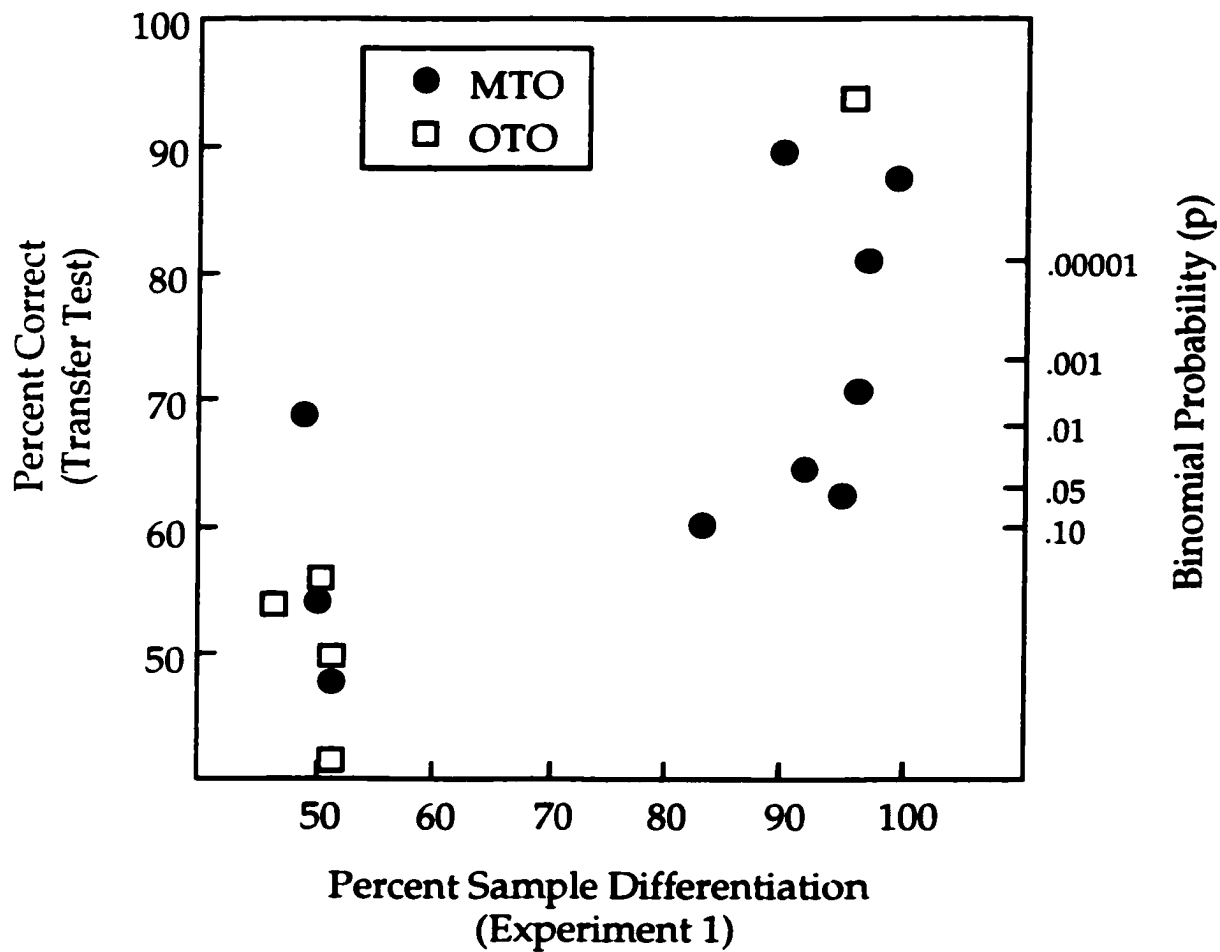
**Transfer test.** Each bird's transfer test was done on the day after achievement of the training criterion. The transfer test consisted of a single session of 48 trials, with the cross pair and the circle pair as samples and the yellow star and blue triangle as comparisons. Sample-specific responding was not required. The samples were mapped onto the comparisons in a manner that was congruent with Experiment 1 training. For example, for birds in which green and cross samples had been mapped onto the green comparison in Experiment 1, the cross sample was mapped onto the yellow star (which was matched with green in the training phase) in this test. Correct choices were reinforced, and incorrect choices resulted in blackout.

### **Results and Discussion**

All of the birds easily mastered the matching task that they received on odd numbered training sessions. As expected, there was considerable intersubject variability in the results of the transfer test. Also as hypothesized, the birds that developed sample-specific behavior to the form samples in Experiment 1 generally performed better in the transfer test. Figure 28 shows

this correlation. By plotting the percent of congruent sample responses during the last five-session block of Experiment 1 on the abscissa, the results of Experiment 1 are also neatly summarized here. It can clearly be seen that the birds separated into two distinct categories in Experiment 1—those that developed sample-specific responding and those that did not. It should be noted that sample-specific responding to the form samples did not diminish for these birds during Experiment 2 training, and it was evident for each subject during the transfer test to a degree similar to that obtained in Experiment 1. None of the birds that failed to develop sample-specific responding in Experiment 1 developed it during the course of Experiment 2.

Choice accuracy during the transfer test is shown on the ordinate of Figure 28, with cumulative binomial probabilities shown on the right border. Five of the eight birds with sample-specific behavior performed at levels significantly greater than chance, and the remaining three performed at borderline significance levels. Particularly notable, again, is the performance of B7352, whose transfer test accuracy of 93.8% exceeded that of any of the MTO birds. This finding of positive transfer following symmetry training is unprecedented with pigeons, and might have seemed mysterious had the mediating sample-specific behavior not been overt. It would appear that positive transfer is common following many-to-one training because this provides conditions that are favorable to the development of congruent sample-specific behavior, which serves to mediate the positive transfer. This behavior, if developed via other means, is nevertheless just as effective in



**Figure 28.** Each pigeon's choice accuracy during the Experiment 2 transfer test as a function of its terminal extent of congruent sample-specific responding in Experiment 1.

mediating positive transfer performance. It must also be conceded, though, that for at least some of these birds, sample response location was not the only factor that determined choice, or accuracy would have been even higher in several cases.

Figure 28 also shows that those birds that did not differentiate their sample behavior also generally did not show any positive transfer. The one exception, B7345, chose correctly on 68.8% of the transfer trials, which could indicate that there was an implicit common response (or a common code) that mediated transfer performance. This argument runs the risk of becoming tautological, however, in the sense that every instance of positive transfer is taken as evidence of common coding, and common coding is defined only as hypothetical process that produces positive transfer. The great advantage of the method developed by Manabe et al. (1995) and elaborated here is that the derived stimulus control results in an explicit, observable behavior, making it possible to determine the conditions under which it occurs and the effects that it mediates.

If the sample-specific behavior that was produced in Experiment 1 does in fact serve the role of the common code that mediates transfer in Experiment 2, then its exposure does not undermine the concept of common coding, rather it provides a plausible mechanism whereby the code is generated. Furthermore, evidence of a behavioral mediator does not exclude the possibility or potential importance of a central representation. An

observable behavioral manifestation, however, should prove useful for bringing the code into a realm where it can be investigated more readily.

## **Chapter 4: General Discussion**

Matching-to-sample, the prototypical procedure for investigating conditional discrimination learning in animals, generates behavior that is not as straightforward as it might appear. One might be tempted to assume that pigeons solve identity matching-to-sample by learning a rule such as “choose the matching stimulus”. This would be an incorrect assumption, as several studies have shown that pigeons fail to transfer matching performance to novel stimuli (e.g., Cumming & Berryman, 1965; Farthing & Opuda, 1974; Holmes, 1979), except perhaps after extended training with a very large number of stimuli (Wright, Cook, Rivera, Sands, & Delius, 1988). One might then be tempted to assume that the learning involves specific associations between the stimuli present during training (e.g., “if red sample, choose red comparison, etc.”). This account might not be wrong, but it is certainly incomplete, as it neglects consequential factors such as the role of the incorrect comparison and, of greater relevance to the present context, the role of sample responses.

The experiments reported here indicate that emergent sample-specific behavior is a fairly common outcome of many-to-one matching-to-sample training, which provides conditions that frequently result in adventitious

differential reinforcement of the emergent behavior, as suggested by Saunders and Williams (1998). The contention (Saunders, Williams, & Spradlin, 1996) that derived sample-specific behavior of this sort mediates transfer in the common coding paradigm was also supported. The finding that sample behavior can mediate transfer is not new (e.g., Urcuioli & Honig, 1980). Neither, of course, is the finding that many-to-one training generates conditions that favor positive transfer of one set of samples to new comparisons after explicit training of the other samples onto the new comparisons (e.g., Urcuioli et al., 1989). One contribution of the present experiments was the exposure of the derived common code (which had precedent in the experiments of Manabe et al., 1995), such that it could be observed and measured directly prior to transfer testing, rather than inferred after the fact from positive transfer performance. The explication of this effect was also furthered by the direct observation of adventitious differential reinforcement, as hypothesized by Saunders (1998), and the relationship between that process and emergent sample-specific behavior, which suggests that the former was the cause of the latter. While Manabe et al. (1995) should be given credit for developing the procedure for demonstrating emergent sample performances, some of their interpretations are called into question by the present findings. Little support was found for the notion that the sample responses operate like names, emitted in prospective anticipation of the stimuli to which they refer.

Other authors have made similar claims based on transfer effects following many-to-one training. Zentall et al. (1993) advanced the argument that substitutability of commonly coded samples provides partial evidence of formal stimulus equivalence. According to Sidman and Tailby (1982), stimulus equivalence can be demonstrated by showing the existence of three properties: reflexivity, symmetry, and transitivity. Thus if a certain relation between A and B is trained, then the reflexivity is demonstrated if the same relation is emergent between A and A, and between B and B. Symmetry requires the emergence of the same relation in the reverse direction (i.e., between B and A). Transitivity can be demonstrated by training an additional relation between B and C, then showing the emergence of the same relation between A and C. Zentall et al. note that the many-to-one procedure trains a relation between sample A and comparison C and between sample B and comparison C, which produces an emergent relation between sample A and sample B (as evidenced by the transfer results). This is said to demonstrate transitivity, since the emergent relation is mediated by C. It also demonstrates symmetry, as C could only operate as a mediator if a backward association exists between it and at least one of the samples. However, these relations must emerge spontaneously, without being explicitly trained (Sidman & Tailby, 1982). If the substitutability of samples is the result of a common response shaped by adventitious differential reinforcement, as appears to be possible in the many-to-one paradigm, then these arguments cannot be upheld.

At this time, caution must be exercised in extrapolating these results to other experimental paradigms, including other many-to-one experiments. There were some important methodological differences between the present experiments and other many-to-one experiments that might limit the generalizability of the conclusions reached here. The most obvious difference is that sample-specific responding is typically not explicitly trained to either pair of sample stimuli. This would seem to reduce the likelihood of differentiation developing at all, since it would have to develop spontaneously for one set of samples before it could be shaped onto the other set.

Another important difference is that the sets of training relations that constitute the many-to-one mapping are ordinarily introduced simultaneously, rather than training one before adding the other. Order effects such as this may be very important, as evidenced by the failure of one-to-many matching-to-sample to produce any evidence of common coding, even though the relations that are ultimately trained before the transfer test are identical to many-to-one training, except that they are trained in a different order. Urcuioli et al. (1995) trained 12 pigeons on a many-to-one task and 12 pigeons on a comparable one-to-many task. In the one-to-many task, one set of samples was mapped onto two sets of comparisons in the initial training phase. Then in the next phase, a new set of samples was mapped onto one of the comparisons sets. Then the new set of samples was tested with the other comparison set. Despite the fact that the two phases of training

involved all of the same stimulus relations that were trained in the many-to-one paradigm (but in a different order), no transfer was apparent for the one-to-many group in the test phase. Urcuioli (1996) speculates that one-to-many training doesn't produce common coding because the impossibility of knowing which set of comparisons will be presented blocks the possibility of developing a prospective representation, which he believes constitutes the common code in the many-to-one task. However, there are other possibilities that don't require the postulation of referential or anticipatory codes. In one-to-many training, the second set of samples is not introduced until the reassignment phase (the last phase before the transfer test). This means that the second set of samples are never presented in the same session with the first set, which might reduce the subject's tendency to emit sample responses that had become conditioned to the first set of samples. If sample-specific responding was required for the first set of samples, and the opportunity to make these same responses was clearly available when the second samples were presented (as with the bipartite sample stimulus fields used in the present experiment), then congruent sample-specific behavior might be shaped in the same manner as observed in the present experiment. If congruent sample-specific behavior did develop in this manner, then it should also mediate positive transfer in the test phase. These issues and others will have to be resolved empirically.

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