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The Role of Physical Identity of the Sample and
Correct Comparison Stimulus in
Matching-to-Sample Paradigms

by

Angelo J. Santi

A thesis submitted to
the Faculty of Graduate Studies
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

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Department of Psychology
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Ottawa, August, 1976

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Abstract

The purpose of the present research was to assess the role which physical identity of the sample and correct comparison stimulus plays in the discriminative behavior established by a matching-to-sample paradigm. In order to accomplish this, pigeons were trained to perform a discrimination in which the rule for reinforcement could be described as involving a higher-order conditional discrimination. For example, if a vertical line was presented on the response keys, then selection of the comparison stimulus which was the same as the color of the sample stimulus was reinforced, but if a horizontal line was presented, then selection of the comparison stimulus which was different in color from the sample was reinforced. Since stimuli were compounds of line tilt and color, there were two different types of trials which allowed for assessment of the role of physical identity. On one trial type (MTS), the sample and correct comparison were similar on both the line tilt and color dimension, while on the other trial type (MMTS), the sample and correct comparison were similar on the line tilt dimension but different on the color dimension.

In the first experiment, acquisition and performance of this task was examined using red and green colors and line tilts of 0° and 90°. In addition, transfer of training was

assessed by substituting blue and yellow for red and green. During acquisition and transfer, there was a tendency for some subjects to exhibit higher accuracy on one trial type than the other. A detailed analysis of the data revealed that these overall differences in accuracy were a result of either differences in the point at which correct responding began to develop to a specific stimulus configuration, or from interactions which occurred during the development of correct responding. Following transfer, the original red and green colors were reintroduced. During this recovery phase, two birds exhibited consistently higher accuracy on MTS trials than on MMTS trials. However, a detailed data analysis revealed that this difference was primarily a result of poorer performance on one particular MMTS stimulus configuration. Since all birds did not reveal sustained differences in MTS-MMTS accuracy and since the differences that were observed were often specific to one particular stimulus configuration, it was not possible to conclude that physical identity of the sample and correct comparison stimulus played a significant role in this experiment.

In the second experiment, stimulus control gradients were obtained by varying the angularity of the lines. The purpose of obtaining these gradients was to derive additional information regarding the role of physical identity. The gradients were very orderly and similar for all birds. They

failed to reveal any bias toward or away from the physically identical comparison stimulus, since the gradients revealed the greatest slope change between 45° and 22.5° regardless of whether 0° was correlated with reinforcement for responding to the matching or mismatching comparison. Overall, the data of both experiments suggest that physical identity between the sample and correct comparison stimulus does not play a significant role in the discriminative behavior established by a matching-to-sample paradigm.

The data were also discussed in terms of the relationship between extra center key pecks and the initial mismatching preference; the method by which, the point at which, and the dimension along which stimulus generalization is assessed; and the relationship of the present research to studies which attempt to teach animals to use instructional stimuli.

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Table of Contents

	<u>Page</u>
I. INTRODUCTION	1
II. REVIEW OF MATCHING-TO-SAMPLE AND MISMATCHING-TO-SAMPLE RESEARCH	4
II.1 Comparisons of simultaneous matching-to-sample and mismatching-to-sample	4
II.2 Variables affecting the acquisition of matching-to-sample	11
II.3 Transfer of training in matching-to-sample	16
II.4 Delayed matching-to-sample	36
II.5 Response requirements to the sample	43
II.6 Schedule control of matching-to-sample	49
III. THE ROLE OF PHYSICAL IDENTITY OF THE SAMPLE AND CORRECT COMPARISON STIMULUS IN MATCHING-TO-SAMPLE PARADIGMS	55
IV. EXPERIMENT I	60
IV.1 Method	60
IV.2 Results	66
IV.3 Discussion	96
V. EXPERIMENT II	105
V.1 Method	105
V.2 Results	107
V.3 Discussion	115
VI. GENERAL DISCUSSION AND CONCLUSIONS	117
REFERENCES	126

List of Tables

	<u>Page</u>
Table 1 Stimulus configurations employed during training	64
Table 2 The number of sessions on which various types of accuracy differences were observed during training	71
Table 3 Overall response biases exhibited during the first session of training	76
Table 4 Response latencies (in seconds) to left (L) and right (R) side keys during the last three sessions of chaining	77
Table 5 Number of sessions preceding the occurrence of sustained above-chance levels of performance on both MTS and MMTS trials	87
Table 6 The number of sessions on which various types of accuracy differences were observed during transfer	89
Table 7 Overall response biases exhibited during the first session of transfer	91
Table 8 Extra center key pecks and responses to the mismatched comparison during the first session of transfer	92
Table 9 Percent position bias to the left comparison key for the three probe stimuli during stimulus control testing	114

List of Figures

	<u>Page</u>
Figure 1 Percent correct on MTS and MMTS trials for birds P1, P4, P2 and P3 during training	67
Figure 2 Percent correct on MTS and MMTS trials for birds P5, P6, P8 and P7 during training ...	68
Figure 3 Percent correct on MTS and MMTS trials for all birds during the correction procedure and the removal of this procedure	70
Figure 4 Choice behavior in the presence of each of the 8 stimulus configurations prior to and during the transition to above-chance accuracy for birds P1, P5 and P7	79
Figure 5 Choice behavior in the presence of each of the 8 stimulus configurations prior to and during the transition to above-chance accuracy for birds P8, P4 and P6	80
Figure 6 Choice behavior in the presence of each of the 8 stimulus configurations prior to and during the transition to above-chance accuracy for bird P2	81
Figure 7 Percent correct on MTS and MMTS trials for birds P1, P5 and P7 during transfer sessions and the recovery sessions	85
Figure 8 Percent correct on MTS and MMTS trials for birds P4, P6 and P8 during transfer sessions and the recovery sessions	86
Figure 9 Choice behavior in the presence of each of the 8 stimulus configurations during the transition phase of transfer testing for birds P1, P5 and P7	94
Figure 10 Choice behavior in the presence of each of the 8 stimulus configurations during the transition phase of transfer testing for birds P8, P6 and P4	95

	<u>Page</u>
Figure 11 Choice behavior in the presence of each of the 8 stimulus configurations during the recovery phase for birds P4 and P6	97.
Figure 12 Percent correct on MTS and MMTS trials for all birds during sessions of intermittent reinforcement and stimulus control testing	108
Figure 13 Choice behavior in the presence of each of the 8 stimulus configurations during sessions of intermittent reinforcement for birds P6, P8 and P4	110
Figure 14 Gradients of stimulus control for line orientation	111
Figure 15 Percent choice of the comparison stimulus appropriate to a 0° orientation as a function of angularity	113

I. INTRODUCTION

Stimulus control refers to the extent to which changes in the physical characteristics of antecedent stimuli control different rates of responding or different response probabilities. Most of the research concerned with stimulus control has centered on discriminations which are based on variations along a simple stimulus dimension. For example, responding in the presence of a green light is reinforced, while responding in the presence of a red light is never reinforced. Such a discrimination has been termed an absolute discrimination and can be contrasted with discriminations based on more complex stimulus relations. These are referred to as conditional discriminations since the reinforcer is not contingent simply upon the presence or absence of a particular stimulus but rather on the relationship of one stimulus to another stimulus.

Investigations of conditional stimulus control have frequently made use of a matching-to-sample or mismatching-to-sample paradigm with pigeons used as subjects. The procedure employed on a typical trial in 3-key operant chamber is as follows: a particular stimulus value (e.g. a red light) is projected onto the center key. This is referred to as the standard or sample stimulus. When the pigeon pecks the

center key, stimuli are projected onto the side keys. Usually, one of the stimuli is the same as that projected onto the center key, while the other differs from it (e.g. a red light on the right side key and a green light on the left side key). The stimuli projected onto the side keys are referred to as comparison stimuli. A response to either of the side keys results in the removal of the stimuli from all 3 keys. A correct response, in a matching-to-sample paradigm, would be the selection of the comparison stimulus which is identical to the standard or sample stimulus. A correct response, in a mismatching-to-sample paradigm, would be the selection of the comparison stimulus which is different from the standard or sample stimulus. A reinforcer is delivered following a correct response, while a blackout (i.e. chamber completely dark) typically follows an incorrect response.

The purpose of the first experiment presented in this dissertation is to assess the role which physical identity of the sample and correct comparison stimulus plays in the performance and transfer of conditional discriminations when a within-subjects procedure is employed. In order to accomplish this, pigeons were trained to perform a discrimination in which the rule for reinforcement could be described as involving a higher-order conditional discrimination. That is, the reinforcement contingency for responding in the presence of values on one stimulus dimension is contingent upon the rela-

tionship between values of stimuli on a second dimension. For example, if a vertical line is present on the response keys, then selection of the comparison stimulus which is the same as the hue of the standard or sample stimulus would be reinforced, but if a horizontal line is presented, then selection of the comparison stimulus which is different in hue from the standard would be reinforced.

In a second experiment, the dimensional stimulus control generated by a higher-order discrimination procedure was examined in order to determine whether orderly gradients of stimulus control can be obtained with such a procedure. In addition, these gradients should provide information regarding the role of physical identity of the sample and correct comparison stimulus.

Prior to a more detailed exposition of the rationale for these experiments, a general review of the empirical literature on matching-to-sample and mismatching-to-sample relevant to this dissertation will be undertaken. The review will focus primarily on infra-human research. A reading of the entire review is not necessary in order to understand the rationale underlying these experiments. The reader so inclined may go directly to section III after reading sections II.1 to II.3.

II. REVIEW OF MATCHING-TO-SAMPLE AND MISMATCHING-TO-SAMPLE RESEARCH

Matching-to-sample experiments can be classified into two types depending upon whether the sample stimulus is present or absent during illumination of the comparison stimuli. If the sample stimulus remains on after the comparison stimuli are presented, then it is referred to as simultaneous matching-to-sample. If the sample stimulus is removed prior to the presentation of the comparison stimuli, then it is referred to as delayed matching-to-sample. The delay between sample stimulus offset and comparison stimuli onset can be of various durations. Zero-delay matching-to-sample refers to the situation in which comparison stimuli are presented immediately after the sample stimulus is offset.

II.1 Comparisons of simultaneous matching-to-sample and mismatching-to-sample

This section will be primarily concerned with a comparison of the acquisition and performance of simultaneous matching-to-sample (MTS) and mismatching-to-sample (MMTS). A research question which has received considerable attention in this area is whether the requirement that the subject select the comparison stimulus which corresponds physically with the sample stimulus has a special status. That is,

are there acquisition or performance differences between MTS and MMTS which might be due to the different conditional relations between stimuli and reinforcement in these two paradigms?

Skinner (1950), in a paper dealing with the necessity for certain types of learning theories, suggested that matching-to-sample could be used as an experimental paradigm to investigate the "higher mental processes" which transcend single responses or single stimulus-response relationships. He believed that these experiments could be formulated in terms of the discrimination of stimuli, the establishment of various sequences of responses and so on. In this paper, he reported that MTS was no easier to establish than MMTS when pigeons were used as subjects and red and green lights served as stimuli. However, Ginsburg (1957) also used pigeons, but found that MMTS required fewer trials to reach a criterion of 80% correct than did MTS. He speculated that this result may have been due to the use of a correction procedure. In his study, in both MTS and MMTS, if the incorrect comparison stimulus was responded to, the stimulus configuration would remain the same until a correct response was made. Thus, on incorrect trials all pigeons were reinforced for responding to one color after a response to the other color. This type of training could be expected to interfere with MTS behavior but possibly facilitate MMTS behavior.

In view of these contradictory findings, Cumming and Berryman (1965) compared the acquisition of MTS and MMTS without a correction procedure. The acquisition functions which they obtained displayed the following three properties (i) four of six MMTS subjects performed at above chance levels of accuracy (70%) on the first day of acquisition, while all of the MTS subjects performed at chance levels (50%); (ii) the overall group acquisition function for MMTS subjects demonstrated a slower rate of improvement than for MTS subjects; and (iii) the terminal level of accuracy attained by MTS subjects as a group was higher than that attained by MMTS subjects. The early superior performance of MMTS subjects was not obtained by Tombaugh and Marshall (1974) who used a different type of pretraining than Cumming and Berryman (1965). They established a sequence of responding from the center key to the side key prior to the introduction of the MTS and MMTS procedures and without delivery of primary reinforcement for center key responding. Under these conditions, both MTS and MMTS subjects began acquisition from chance levels of accuracy. The failure to pretrain center-side key response chains probably also accounts for the fact that presolution position preferences were slight during MMTS training but very marked during MTS training in the Cumming and Berryman (1965) study.

Even though MTS and MMTS subjects began acquisition from comparable levels in the Tombaugh and Marshall (1974)

study, it was still observed that MTS subjects had a faster rate of acquisition and a slightly higher level of terminal performance than MMTS subjects. It is important to note that in both studies (Cumming and Berryman, 1965; Tombaugh and Marshall, 1974) three colored lights (i.e., red, green and blue) served as stimuli in all possible combinations. Thus for each sample stimulus there would be four possible stimulus configurations: RRG, GRR, RRB and BRR. If pigeons acquired a set of stimulus-response chains in MTS and MMTS paradigms, then the poorer performance of MMTS subjects in these studies could be due to the greater number of rules or chains which they had to learn. A MTS subject would require one rule to master the stimulus set above: "If the sample is red, then peck the red comparison". A MMTS subject would require two rules: "If the sample is red, then peck the green comparison" and "If the sample is red, then peck the blue comparison". This hypothesis is supported by studies which have demonstrated that, when pigeons are trained on either MTS or MMTS with only 2 sample stimuli, there are no differences in either the rate of acquisition or the terminal levels of performance (Zentall and Hogan, 1974; Zentall and Hogan, 1976). However, when 4 sample stimuli are employed, matching performance is clearly superior to mismatching performance at the end of training (Zentall and Hogan, 1974).

These data suggest that pigeons learn a set of specific "if ... then ..." rules, with the physical identity between a sample and the correct comparison stimulus having no special status. The assessment of what pigeons learn in matching-to-sample experiments will be considered in more detail in the section on transfer of training. In addition, the relationship between "What is learned?" and "The role of physical identity" will be considered further. At this point, it would be appropriate to consider additional evidence which suggests that physical identity has no special status in matching-to-sample paradigms. These data derive from a study of symbolic matching-to-sample.

In symbolic matching-to-sample, the sample stimulus is neither physically identical to the correct comparison (as in MTS) nor physically identical to the incorrect comparison (as in MMTS). Rather, the sample stimulus bears an arbitrary relation to the comparison stimuli. For example, a red sample may specify responses to a vertical line on the comparison keys as correct, while a green sample may specify responses to a horizontal line. Using these two stimulus dimensions, Carter and Eckerman (1975) compared two MTS tasks, line-line matching and hue-hue matching, with two symbolic MTS tasks, hue-line and line-hue matching (where the first term designates the sample stimulus dimension and the second term the comparison dimension). They found that hue-hue

matching was most rapidly acquired, while line-line matching was the most difficult task. Hue-line and line-hue matching were of intermediate difficulty, with hue-line matching easier than line-hue matching.

Carter and Eckerman (1975) conceived of the matching-to-sample task as consisting of a successive discrimination between samples across trials and a simultaneous discrimination between comparisons on a given trial. Support for this account was derived from a comparison of the performance of subjects given matching training to that of subjects trained on simple successive and simultaneous discriminations. They had shown that acquisition of line-line matching took 4.5 times longer than acquisition of hue-line matching. Since these tasks differed only with respect to the discriminability of samples and since a simple successive discrimination between lines was acquired with a rate 4.5 times longer than the same task with hues, they concluded that rates of acquisition for hue-line and line-line matching differed as a function of the discriminability of one sample from another and not of a difference between identity and non-identity matching per se. It was also demonstrated that groups having line comparisons took 2.5 times as long to learn as groups having hue comparisons. These results led Carter and Eckerman (1975) to conclude that the rate of acquiring either matching or symbolic matching was a function of the discriminability between sample

stimuli and between comparison stimuli, with the former having a greater influence.

The studies reviewed thus far strongly support the claim that physical identity of the sample and correct comparison stimulus has no special status, nevertheless it has been reported that MTS performance is more easily disrupted by the drug sodium pentobarbital at low doses than MMTS performance (Berryman, Cumming, Nevin and Jarvik, 1964; Nevin and Liebold, 1966). In the Berryman et al., study, the effects of sodium pentobarbital (at 5.0, 7.5, 10.0 and 12.5 mg/kg) were examined on (a) zero-delay matching-to-sample, (b) simultaneous mismatching-to-sample, and (c) variable delay matching-to-sample. It was observed that the effects of this drug on zero-delay MTS was almost identical to those on simultaneous MTS which had been reported earlier by Berryman, Jarvik and Nevin (1962). In addition, a greater dose of sodium pentobarbital was required under simultaneous MMTS conditions to produce an accuracy decrement comparable to those obtained under zero-delay MTS conditions. Since simultaneous and zero-delay MTS performances were similarly affected by the drug and both were more affected than simultaneous MMTS performance at comparable drug dosages, Cumming and Berryman (1965) argued that MTS and MMTS may require qualitatively different types of behavior. In the studies by Berryman et al., (1962; 1964), three key colors were used. However, using a single pigeon, Nevin and

Liebold (1966) replicated these drug effects in a within-subjects design, even though only two key colors were used (hence equating the number of stimulus-response rules to be learned). The study by Nevin and Liebold will be considered in more detail in section III since their procedures and results led to the research reported in this dissertation. However, at this point, it should be emphasized that unlike the data reviewed earlier in this section, the data on drug sensitivity suggest that the physical identity of sample and correct comparison stimuli may play a special role in the discriminative behavior established via a matching-to-sample procedure. It is not presently clear how this discrepancy can be reconciled.

II.2 Variables affecting the acquisition of matching-to-sample

In addition to assessing the role of physical identity, researchers have attempted to determine how various factors such as the sample response requirement, the nature of the stimuli, and the length of the intertrial interval affect acquisition and performance of simultaneous matching-to-sample. The effects of requiring different numbers of responses to the sample stimulus will be reviewed in detail in section II.4. It is sufficient at this point to note that increasing the sample response requirement can enhance accuracy in simul-

taneous matching-to-sample when varied within-subject (Santi, Tombaugh and Defalco, 1976). With regard to the nature of the stimuli employed in matching-to-sample experiments, it has been repeatedly demonstrated that acquisition and performance (in pigeons, at least) on the color dimension is superior relative to the angularity dimension (Maki and Leuin, 1972; Maki and Leith, 1973; Carter and Eckerman, 1975). Finally, Holt and Shafer (1973) have indicated that matching acquisition can be affected by the length of the intertrial interval. They demonstrated that when a zero second intertrial interval was used, pigeons failed to acquire matching. However, intertrial intervals greater than zero seconds did not block matching acquisition. Furthermore, it was shown in this study that switching to an intertrial interval of zero seconds from higher values resulted in a performance decrement.

A ~~com~~ of studies have attempted to determine something about the nature of matching-to-sample acquisition. For example, Rodewald (1974) analyzed the acquisition data from a matching-to-sample procedure in which pigeons matched three hues, and he found evidence of all-or-none learning. That is, prior to attaining a criterion of 90% correct matching, there was no evidence of learning since the number of correct responses in halves of precriterion sequences did not differ significantly. In addition, prior to the last error, a Bernoulli sequence of responses was found, which indicated independence

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of trial-by-trial performance. Also, the number of errors and specific sequences of errors and successes in each four-trial block prior to the last error were binomially distributed. It is important to note that Rodewald (1974) selected the schedule parameters (e.g. response requirement to the sample, correction procedure, intertrial interval) to maximize the rate of acquisition and set the occasion for all-or-none acquisition to occur. Obviously, his conclusions would be much more forceful if all-or-none learning were found under conditions fostering slow acquisition.

In order to assess the development of stimulus control in matching-to-sample, Barrera and Eckerman (1972) chose to examine the preacquisition response latencies to comparison stimuli. The rationale of this analysis was that latency increases to the incorrect comparison stimulus might be indicative of control by the sample stimulus and the relation between the sample and the incorrect comparison stimulus. The matching-to-sample task involved three hues and no center key response was required. The comparison stimuli were presented two seconds after sample stimulus onset. The findings could be summarized as follows: (i) total daily latency increases were correlated with the development of matching behavior, (ii) 3 out of 8 birds had marked position preferences and their response latencies to the incorrect stimulus when presented on the preferred side increased prior to and during the

first day of above chance matching accuracy, (iii) stimulus control did not develop simultaneously for all 3 sample stimuli, (iv) the remaining 5 birds had a combination of position and color preference but they also exhibited latency increases prior to the elimination of inaccurate hypotheses or during the shift from chance levels of accuracy. The main conclusion derived from this study was that the sample stimulus began to control behavior before matching accuracy started to rise. While Barrera and Eckerman also concluded that matching acquisition was the product of a gradual, continuous process, they did not make clear what aspect of their data supported such a conclusion.

It might be appropriate at this point to note that both the Barrera and Eckerman (1972) study and the Rodewald (1974) study indicated that an examination of the performance of a subject in the presence of each sample stimulus separately was a worthwhile level of data analysis. Along with other investigators (Cumming and Berryman, 1965; Cohen, Looney, Brady and Aucella, 1976), they presented data which revealed that while one sample stimulus may be matched perfectly, another may only be matched at chance levels.

Finally, it should be mentioned that two studies (Cumming, Berryman, Cohen and Lanson, 1967; Cohen, 1969) have demonstrated that extinction of matching-to-sample behavior

produces a characteristic reduction in the rate of matching with no decrement in matching accuracy. A similar effect can be obtained by the satiation of experimental animals performing in a delayed matching-to-sample task (Cumming, Berryman and Nevin, 1965). However, Grimm (1970) has shown that matching accuracy can be reduced if in addition to the non-reinforcement of correct responding, the reinforcer is made contingent upon responses to the sample stimulus alone.

The research reviewed in the two preceding sections suggests that training in a MTS paradigm results in pigeons acquiring a set of specific "if ... then ..." rules, with the physical identity between a sample and the correct comparison stimulus having no special status. However, the differential sensitivity of MTS and MMTS performance to sodium pentobarbital is difficult to reconcile with this point of view. The acquisition of simultaneous MTS has been shown to be affected by sample response requirements, the nature of the stimulus dimension and the length of the intertrial interval. Depending on the particular values selected for these and other parameters, matching-to-sample acquisition could proceed in an all-or-none fashion or it could unfold as a gradual, continuous process. Finally, several studies have indicated that examining matching performance in the presence of each sample stimulus separately is a worthwhile level of data analysis.

II.3 Transfer of training in matching-to-sample

A quick survey of introductory textbooks in learning will reveal that transfer of training is usually covered in the section dealing with verbal learning while the topic of stimulus control or generalization and discrimination is covered in the section on instrumental and classical conditioning. Transfer of training is a concept which refers to the effects which performance on one type of task has on the performance of a different task or of the same task after changes have been introduced. Stimulus control, on the other hand, refers to the degree to which variations in the physical characteristics of antecedent stimuli control different rates of responding or different response probabilities. While transfer of training and stimulus control experiments are conceptually related (Brown, 1965), there are certain methodological differences. In matching-to-sample experiments the methodological difference centers on whether the novel stimuli introduced during testing are reinforced or not. If the novel stimuli are reinforced, we typically have a transfer design, and the concern is with establishing whether acquisition occurs more rapidly with the novel stimulus set than with the set of original stimuli. If the novel stimuli are not reinforced, we typically have a stimulus control design. These designs can be of two types. In one type (transient designs) testing is done in extinction. That is, both the original training sti-

multi and novel stimuli are nonreinforced. The other type of testing involves a steady-state design, in which the original training stimuli continue to be reinforced intermittently while novel stimuli are randomly presented without reinforcement. In stimulus control designs, the concern is with deriving gradients of stimulus generalization. Since transfer of training and stimulus generalization can be equated conceptually, research dealing with them will be incorporated in the present section.

In the preceding section, research was reviewed which suggested that training in a MTS paradigm resulted in pigeons acquiring a set of specific "if ... then ..." rules. The question of what pigeons learn in acquiring discriminations such as MTS and MMTS can be more directly approached by the use of a transfer of training paradigm. There are at least three kinds of learning which can occur in these situations. (1) Pigeons could learn a discrimination for each specific stimulus configuration employed during MTS or MMTS training. A stimulus configuration is a specific spatial arrangement of a set of stimuli on the left, center (sample stimulus) and right response keys. For example, given the configuration red-red-green, the pigeon would learn to respond to the left key, but given the configuration green-red-red, the pigeon would respond to the right key. (2) Pigeons could learn a set of stimulus-response chains or "if ... then ..." rules based on

the specific sample stimuli employed during matching training. For example, in MTS the rule could be: "If the sample is red, then peck the red comparison". (3) Pigeons could learn a generalized matching concept: "Respond to the comparison stimulus which is the same as the sample stimulus". Conceptual behavior consists of generalization within a concept or stimulus class and discrimination between stimulus classes. A stimulus class consists of a set of stimuli having some common property which can be a physical property or a more abstract property. In a MTS paradigm, the abstract property of "sameness" based on the relationship between the sample and comparison stimulus would have to control behavior in order for a generalized matching concept to be exhibited.

Prior to reviewing the literature on transfer of training, it should be pointed out that the question: "What do pigeons learn in MTS paradigms?" can be addressed independently of the question: "Does physical identity have a special status?". As already indicated, transfer of training paradigms can be used to directly address the former question. However, the role of physical identity can be established by comparing MTS to MMTS performance or MTS to symbolic MTS performance under conditions where other factors such as numbers of rules to be learned have been equated. While the methodology employed to answer these questions may be somewhat independent, there is no guarantee that the answers to the ques-

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tions will be independent. That is, it may be that if physical identity does have a special role, then what is learned in a MTS paradigm may differ from what is learned in a MMTS paradigm. On the other hand, it is possible that regardless of whether pigeons learn a configuration specific response or a stimulus-response chain or a generalized matching concept, there may still be an effect due to the physical identity of the sample and correct comparison stimulus which cannot be attributed to other factors.

The initial research on the transfer of training of MTS, MMTS and zero-delay MTS was performed by Cumming, Berryman and their students. In their first study, Cumming and Berryman (1961) trained pigeons in a MTS paradigm with three sample colors: red, green and blue. After 22 days of training, yellow was substituted for blue. This did not affect MTS performance on trials in which red and green served as sample or comparison stimuli, or on trials in which yellow was a comparison stimulus only. However, when yellow was the sample, performance dropped to chance levels on the first day of transfer. It was noted that on these trials the birds reverted to a position preference and did not simply revert to responding to the previously reinforced hue.

Berryman, Cumming, Cohen and Johnson (1965) gave similar 3 hue training in a MMTS paradigm. Again yellow was sub-

stituted for blue, after 20 days of mismatching. On the first day of transfer with yellow as the sample, performance was at chance levels when the comparison was red (54%) and at a very high level when the comparison was green (96.5%). When red or green were sample stimuli and yellow was a novel comparison, performance was at an intermediate level (59% and 70% respectively). This finding prompted Berryman et al. (1965) to conclude that MMTS performance in pigeons involved the acquisition of a conditional discrimination in which the sample stimulus signalled which comparison stimulus to approach rather than signalling which comparison stimulus to avoid.

Finally, Cumming, Berryman and Cohen (1965) again substituted yellow for blue after 42 sessions of zero-delay MTS were completed. On the first day of transfer, with yellow as a comparison stimulus only, two birds maintained their levels of accuracy while another bird improved slightly. On trials with yellow serving as both a sample and a comparison stimulus, the performance of all birds fell below chance.

Cumming, Berryman and Cohen (1965) accounted for their results in terms of a coding hypothesis. According to this hypothesis, the subject makes an implicit, covert response to each sample stimulus. Responses to the comparison stimuli are presumably under the control of these implicit coding responses rather than being exclusively determined by the proper-

ties of the sample stimulus. The notion of a coding response was derived from the work of Lawrence (1963) who suggested that coding responses are a product of both sensory input and organismic factors such as the conditioning state of the organism, response bias and so on. The assumption that responses to the comparison stimuli are mediated by coding responses appears to be necessary in a delayed MTS paradigm since the sample stimulus is physically absent when the comparison response is made. The possibility that coding responses also operate in simultaneous MTS is suggested by the finding that pigeons, after training on simultaneous MTS, exhibit above chance levels of accuracy when they are first exposed to delays of 0,1 or 2 seconds (Berryman, Cumming and Nevin, 1963). The coding hypothesis is compatible with the notion that pigeons learn specific stimulus-response chains since both accounts suggest that matching consists of one problem for each sample stimulus employed.

The transfer data from the Cumming et al., (1965) study is explained in terms of the coding hypothesis by assuming that when a novel sample stimulus is introduced, it will not have associated with it an appropriate coding response. In this situation, Cumming et al., propose that the subject may make any one of the coding responses already available to it. The coding response which is made can be determined from the distribution of responses to the comparison stimuli.

In their study, when the novel sample stimulus, yellow, was introduced, a coding response appropriate to one of the old samples (red, green, blue) was available. It appeared that, in this study, a coding response appropriate to red was made to the novel yellow sample. On trials where yellow was both a sample and a comparison and red was the other comparison (YYR = the first letter refers to the sample and the underlined letter refers to the correct comparison stimulus), performance was initially quite poor (17%) and did not rise above chance levels until Day 4. This could be accounted for by assuming that yellow was coded "red" when it was the sample stimulus, but was discriminated from red when it was a comparison stimulus. In addition, this would mean that on YYR trials, the coding response-comparison response sequence which had previously been reinforced (choose "red" after making the coding response "red") would now be extinguished. This would lead one to expect a performance decrement on trials where red was both a sample and comparison stimulus and yellow was a comparison stimulus only (RRY). An accuracy decrement was observed on these trials which only recovered once accuracy on YYR trials improved. Unfortunately, not enough data were presented in the study of simultaneous matching to determine whether there was a similar relationship between YYR trials and RRY trials (Cumming and Berryman, 1961). Cumming et al. (1965) also reported that during transfer on YYG trials performance

was near chance levels while for GGY trials accuracy remained high. Both of these results are in line with the coding hypothesis as outlined above.

It should be noted that this analysis in terms of the coding hypothesis does not exclude the stimuli present in the choice phase from having some control over matching performance. In fact, the coding explanation proposed by Cumming et al. requires that these stimuli function as discriminative stimuli. The reason for this is that extinction of the "choose red" after making the coding response "red" sequence on YYR trials affects performance on RRY trials but not RRG trials. Hence the birds must be able to discriminate those situations in which the "red"- "red" sequence is reinforced from those in which it is extinguished on the basis of the stimuli present in the choice phase.

Further support for the coding hypothesis derives from a study of zero-delay MTS (Kamil and Sacks, 1972), in which pigeons were trained with only 3 of 4 possible stimulus configurations (RRG, RGR, GRG). The fourth unused configuration (GGR) was used to assess transfer effects. A high degree of negative transfer was observed with subjects tending to choose red on the right during GGR transfer trials. These results were interpreted, by Kamil and Sacks, as indicating that subjects had learned to respond on the basis of color following red samples and on the basis of position following a green

sample. An alternative interpretation could be made in terms of the previous reinforcement history of the subject. That is, during training subjects received 2/3 of their reinforcements following a response either to the right key or the red comparison stimulus. In a second experiment, following similar three-configuration matching training, the subjects were given position preference tests in which the comparison stimuli were identical and neither matched the red or green sample. It was found that all subjects exhibited greater right position preferences following green samples (GRR or GWW) than following red samples (RGG or RWW) during testing. However this is not all that surprising since subjects were only reinforced for responding to the right key in the presence of the green sample during training while responding in the presence of the red sample was reinforced on both the left and right key. Kamil and Sacks (1972) viewed their results in terms of the coding hypothesis and postulated that each coding response was a discriminative stimulus which exerted control over choice responses made in its presence. Both the acquisition and transfer data from this study also suggested that, for pigeons, matching consisted of the separate acquisition of a stimulus-response chain or rule for each sample stimulus.

Farthing and Opuda (1974) have published data from a series of studies which they contend supports the hypothesis that pigeons in a matching-to-sample paradigm acquire a set of

specific stimulus-response chains, rather than a general matching concept or a set of discriminations based on specific stimulus configurations. A simultaneous MTS paradigm was employed in which pigeons were initially trained with either color or form stimuli and then shifted to stimuli on the other dimension. Prior form-matching appeared to result in better performance during the first six sessions of color matching relative to a group of subjects without prior matching experience. As pointed out by the authors, this result does not indicate the transfer of a generalized matching concept, since performance on the first session of color matching was at chance levels for the group with prior form-matching. It was suggested that the transfer group had acquired "generalized attention" to the stimuli on the response keys.

In a second experiment, after extensive training with both color and form matching, the birds were tested with novel stimuli or novel combinations of familiar colors and forms in separate sessions. As earlier experiments had shown (Cumming and Berryman, 1961; Cumming et al., 1965), performance was only disrupted when a novel stimulus was used as a sample stimulus but not when it was used as an incorrect comparison stimulus. Novel stimulus configurations involving familiar form and color stimuli did not result in any performance decrements. These results led Farthing and Opuda to conclude that: (i) matching

in pigeons does not depend simply on the learning of discriminations to specific stimulus configurations and (ii) the failure of a novel incorrect comparison to disrupt matching is not a result of the pigeon's tendency to choose a familiar comparison stimulus over a novel comparison stimulus.

The first conclusion was based upon the finding that matching was not disrupted by novel stimulus configurations involving familiar stimuli. This finding also indicated that pigeons do not simply tend to choose a familiar comparison stimulus if presented with a new configuration of stimuli. If such a tendency was operative, according to Farthing and Opuda, one would expect a random selection of the two equally familiar comparisons. Obviously, this did not occur. Hence, Farthing and Opuda concluded that the failure of a novel incorrect comparison stimulus to disrupt matching was not a result of the pigeon's tendency to choose a familiar comparison over a novel comparison. Overall, the results supported the hypothesis that pigeons learn matching-to-sample by acquiring a set of specific stimulus-response chains.

Generalization gradients during the acquisition, transfer and extinction of matching-to-sample have been obtained by Cohen (1969), who used a novel two key procedure with pigeons. In the presence of the sample, a peck at the side comparison key changed the stimulus on that key. When the sample stimulus and comparison stimulus matched, a response to

the sample was reinforced. At the end of acquisition training, for most of the pigeons generalization gradients derived from the several comparison stimuli were peaked at the correct comparison values. When new samples were added to those already available, many subjects displayed a broadening of the gradients for the old samples. Hence, unlike earlier studies of transfer with three-key MTS, subjects showed a decrement in accuracy with old samples, after new samples were introduced. The reason for this difference is not clear. One possibility mentioned by Cohen (1969) is that in her study two new samples were introduced, while in previous studies only one new sample was substituted. Alternatively some other aspect of the procedural differences between this and earlier studies may be responsible for the results. Cohen (1969) also reported that in most cases the new sample gradients were peaked at the old comparison values on the first session of transfer. The previous reinforcement history of the pigeons in the presence of the old comparison stimuli may have strongly contributed to these transfer effects.

In an attempt to make coding responses overt, Eckerman (1970) required that pigeons execute sample-specific observing responses. The sample stimulus was presented on a wide key so that the location of observing responses for the two sample stimuli could be manipulated. There were 3 groups of birds for which the locus of the observing responses to the

two sample stimuli was separated by 0, 3 or 6 inches. The task was one of symbolic matching since colored samples determined which of two line comparison stimuli (0° and 90°) were correct. Eckerman (1970) found that the speed of acquisition of symbolic matching was directly related to the degree of separation in the location of observing responses. He then attempted to assess the generalization of the observing response (3 new sample colors) and the conditional discrimination (3 new comparison line tilts) during extinction. It was found that both observing-response location and comparison responding showed the greatest change within the same region of the wavelength continuum. His next experiment basically attempted the same thing except that a maintained generalization test procedure was used and only the training comparison stimuli were used. That is, training trials were intermittently reinforced (VR3), while test trials were never reinforced. Maintained testing produced more orderly and homogeneous performances than the extinction test procedure. Once again both observing response locus and the pattern of comparison choice shifted abruptly from that appropriate for 506 nm to that appropriate for 583 nm. These were the two training wavelengths.

A general summary of the studies of transfer and stimulus control of MTS reviewed thus far might be helpful. All of these studies indicated that pigeons did not acquire a gener-

alized matching concept, at least not with the procedures presently used. Most studies suggested that specific stimulus-response chains with some form of a coding response to the sample stimulus was the basis of matching for this organism. However, evidence for the coding hypothesis was not very compelling. The problem of stimulus generalization (or lack of it) among comparison stimuli and the prior reinforcement history of test stimuli must also be considered. In fact, the differential history of reinforcement associated with comparison stimuli may account for the failure of generalization between samples (Cohen, 1969) and between sample and comparison stimuli (Cumming et al., 1965)

Recently several studies have been reported which claim to have demonstrated that pigeons can acquire a generalized concept of matching. One approach, employed by Zentall and Hogan (1974; 1975; 1976), has been to train pigeons initially on either MTS or MMTS and then to substitute novel stimuli during transfer with the task remaining the same as during training (Nonshifted: MTS to MTS or MMTS to MMTS) or changing to the opposite task (Shifted: MTS to MMTS or MMTS to MTS). The rationale of this approach is that if pigeons do learn some "abstract" concept such as "same" and/or "different" during MTS or MMTS training, then nonshifted groups should learn the second task faster than the shifted groups. Since this effect may be explained by simple stimulus generalization

when transfer stimuli are on the same dimension as training stimuli, Zentall and Hogan (1974; 1975; 1976) employed an orthogonal dimension during transfer. In all of their studies, Zentall and Hogan found that nonshifted subjects performed significantly better than shifted subjects. However, the locus of this transfer effect varied from study to study. Sometimes it appeared only on the first transfer session but not after (Zentall and Hogan, 1974, Experiment II; Zentall and Hogan, 1975, Experiment I) and sometimes only after the first transfer session (Zentall and Hogan, 1974, Experiment I; Zentall and Hogan, 1975, Experiment II; Zentall and Hogan, 1976). Furthermore, in most cases, the difference between nonshifted and shifted groups could not be spoken of as if they were main effects, since there were significant interactions between training task and transfer task which Zentall and Hogan rather consistently misinterpreted. For example, in the first experiment reported by Zentall and Hogan (1975), the transfer data (first session) showed positive transfer for nonshifted MMTS subjects, no transfer for nonshifted MTS subjects or subjects shifted from MTS to MMTS, and finally negative transfer for subjects shifted from MMTS to MTS. In the second experiment of Zentall and Hogan (1974), the transfer performance over sessions indicated best performance by nonshifted MMTS subjects and shifted MTS-MMTS subjects, intermediate performance by nonshifted MTS subjects and poorest performance by shifted MMTS-

MTS subjects. These interactions do not permit one to conclude that nonshifted groups perform better than shifted groups since one shifted group (MTS-MMTS) performed at least as well and sometimes better than certain nonshifted groups. Hence these data do not provide clear evidence for abstract concept learning in pigeons.

Evidently, no clear demonstration of pigeons learning a generalized matching concept has been possible when a 3-key MTS procedure is employed. However, given other training procedures, evidence for generalized matching has been obtained. Urcuioli and Nevin (1975) have argued that the failure of pigeons to transfer matching to novel hues might result from pigeons not learning to refrain from pecking the nonmatching key during standard 3-key MTS training. If pigeons were given explicit training not to peck nonmatching hues, presumably matching would transfer to novel hues. A modified MTS procedure was employed, in which only one comparison key was lighted after an observing response to the sample on the center key. In the presence of a matching hue, comparison key pecks were reinforced. But in the presence of a nonmatching hue, the pigeon was required to refrain from pecking for 4.8 seconds. Pecks to the nonmatching hue reset the 4.8 second delay interval. If the pigeon refrained from pecking the nonmatching hue for 4.8 seconds, the nonmatching hue terminated and the matching hue appeared on the other comparison key. Three

hues (red, green and yellow) were used during acquisition. During transfer tests, two novel hues (blue or violet) were substituted individually or together for one or two of the training hues. Since this procedure precluded a choice response, latency to peck the comparison key was used as the dependent variable.

Urcuioli and Nevin (1975) found that latencies to the novel comparison hue were shortest when a novel matching hue appeared as a sample and did not differ from baseline matching latencies. However, when a novel hue appeared as either a sample or comparison in a nonmatching combination, latencies increased as a direct function of the separation between the novel hue and the nonmatching hue on the ordinal hue continuum. These data were interpreted as evidence that the pigeons had learned two general rules: "if side-key hue same as center-key hue, peck side key" and "if side-key hue different from center-key hue, do not peck side key". While the first rule generalized completely, the second rule revealed more of a gradient of generalization.

Note that Zentall and Hogan (1974; 1975; 1976) and Urcuioli and Nevin (1975) were actually trying to demonstrate the concept of matching at different levels. Zentall and Hogan were more ambitious in that they were attempting to demonstrate a general concept of "sameness" and/or "difference"

which was independent of the specific stimulus dimension used in training. On the other hand, Urcuioli and Nevin were attempting to demonstrate a generalized matching concept which was independent of the specific stimulus set but not the stimulus dimension employed during matching training. This attempt is closely related to the research of Honig (1965) and Malott, Malott, Svincki, Kladder and Ponicki (1971) in that these researchers have shown that the behavior of pigeons can be controlled by a dimension based on stimulus differences.

Honig (1965) trained pigeons in a two key situation to peck one key if there was no wavelength difference between two keys and the other key if wavelengths differed by 40 nm. After considerable training, novel wavelength pairs separated by various amounts were presented during generalization testing along with the training wavelengths. All subjects revealed orderly gradients along the dimension of wavelength difference. They also gave evidence of having learned the concepts of sameness and difference since new wavelength combinations involving differences larger than 40 nm showed performance improvements.

Mallott et al. (1971) also examined the generalization of stimulus sameness and difference. They employed a split-key technique, in which the two halves of a response key could be independently illuminated with a particular color. The

dependent variable was response rate. If response rate was higher when the colors on the two halves matched than when they did not match, then a matching discrimination was said to have occurred. Generalization of this matching discrimination was obtained after training with 4 matching stimuli, but not after training with only 2 matching stimuli. This suggested to Mallott et al. (1971) that increasing the number of matching stimuli in training may increase the probability that a matching discrimination will generalize. However, Cohen's (1969) results were not in accord with this, since generalization of matching failed to occur following training with 2 or 4 sample wavelengths. Procedural differences make it difficult to account for this discrepancy.

Prior to summarizing the literature on MTS transfer, a study by Sacks, Kamil and Mack (1972) should be noted. This study was partly concerned with the transfer of zero-delay MTS from red and green to blue and yellow hues. The number of responses to the sample was manipulated between subjects such that either an FR40, FR20, FR10 or FR1 was required prior to illumination of the comparison stimuli. The response requirement for each group was the same during transfer as it had been during original training. On the very first transfer session, pigeons exposed to a sample requirement of FR10 or higher demonstrated above-chance matching. Above-chance matching on the first transfer session has never been reported elsewhere in the

literature, probably because only a single response is usually required to the sample stimulus. These results led Sacks et al. to suggest that FR sample response requirements may increase the strength of the mediating events which control the choice response. However, Cumming, Berryman and Cohen (1965) failed to find any facilitative effects of increasing the sample response requirement from FR1 to FR5 on the 13th session of transfer in zero-delay MTS. If one assumes that FR sample requirements function simply to increase the strength of coding responses, it is difficult to account for this result. Further research is needed which examines transfer of training with different sample response requirements.

The research surveyed in this section indicated that pigeons trained in a 3-key MTS paradigm did not show any evidence of having learned a generalized matching concept. Much of the data obtained with the 3-key MTS paradigm suggested that specific stimulus-response chains were acquired. However, demonstrations of the control of behavior by the dimension of sameness-difference has been possible when either a 2 key or 1 split-key procedure is used and response latency or response rate is the dependent variable. It has been suggested (Urcuioli and Nevin, 1975) that giving pigeons explicit training not to peck nonmatching hues is the crucial feature determining whether matching behavior will transfer to novel stimuli.

II.4 Delayed matching-to-sample

Delayed matching-to-sample refers to an experimental paradigm in which the sample stimulus is removed prior to the presentation of the comparison stimuli. At present, this paradigm is being employed to study various aspects of short-term memory in pigeons (Roberts, 1976), monkeys (D'Amato, 1973; Mason and Wilson, 1974) and dolphins (Herman, 1975). The acquisition of delayed matching by pigeons was first reported by Berryman, Cumming and Nevin (1963). The following seven experimental conditions were presented in a random order: simultaneous, zero delay, 1, 2, 4, 10 and 24 seconds delay. An FR5 was required on the sample before comparison stimuli were presented. The extreme position habits characteristic of the acquisition of simultaneous matching were not observed. Animals tended to make 75% of their responses to one key or the other. After 9 sessions, the birds were still at chance levels of accuracy. Berryman, Cumming and Nevin (1963) then exposed all the birds to simultaneous matching alone. This resulted in all birds adopting a complete position preference which declined as simultaneous matching was acquired. The birds were then returned to the variable-delay procedure and above chance performance on most delays was obtained. After 60 sessions, the performance in the experimental conditions could be ranked from best to worst in the order of simultaneous, zero, 1, 2, 4, 10 and 24 seconds.

Cumming and Berryman (1965) also examined the acquisition of zero-delay without prior simultaneous training, and observed the following: (i) a very gradual increase in matching accuracy; (ii) most birds exhibited major reversals in accuracy during acquisition; and (iii) position preferences were not as strong as those observed in simultaneous matching but these preferences did increase prior to the acquisition of zero-delay matching.

An interesting question posed by studies of delayed matching is: "What controls correct responding in the absence of the sample stimulus?". Conditioned reinforcers, in the form of proprioceptive stimuli, have been implicated in studies of delay of reinforcement (Spence, 1947; Grice, 1948) as have behavioral chains (Ferster, 1953; Verhave, 1959). Berryman, Cumming and Nevin (1963) did not observe any specific superstitious behavioral chains which might act to mediate the delay interval. However, Blough (1959) has observed these chains.

In Blough's (1959) study, pigeons were required to match-to-sample a flickering or steady light. He employed these stimuli rather than hues to reduce the likelihood of a delayed response based on colored after-images. No response was required to the sample, which was illuminated for 1 second. Following training on zero-delay matching, various de-

lays of from 0 to 10 seconds were introduced. For two birds matching accuracy was a decreasing function of the delay duration. These birds exhibited a single stable response pattern during the delay interval. For the other two birds, accuracy and delay duration were not as consistently related. The reason for this appeared to be superstitiously conditioned behavioral chains in the delay interval which were differentiated according to the sample which had been presented. These behavior chains appeared to control choice responses and variations in the topography of the chains contributed to the variability in matching accuracy at various delay durations. Perkins, Lydersen and Beaman (1972), who also studied the acquisition of variable delay matching-to-sample (2, 4 and 6 sec.), found that only one of three subjects displayed increasing levels of accuracy after extensive training. For this subject, different behavioral chains were observed in the presence of each sample stimulus.

Smith (1967), in an experiment partially concerned with delayed matching, required pigeons to peck the center-key in order to terminate the delay interval. Smith reasoned that this would reduce the likelihood of superstitious behavior chains developing during the delay period. In his study, he observed decreasing accuracy as a function of delay duration. The stimuli used were vertical and horizontal bars and an FR20 was required to the sample stimulus before it was

offset.

Despite a considerable number of procedural differences all four of the studies reviewed above obtained similar functions between response accuracy and delay duration. After delays greater than 7-10 seconds, most of the pigeons responded at or very near chance matching levels. Some interesting comparative data are available in this regard, since delayed matching experiments have also been conducted with monkeys, dolphins and children as subjects. A number of studies of delayed matching with capuchin monkeys has been carried out by D'Amato and his students (D'Amato, 1973). The stimuli which these studies typically used were square, triangle, vertical line and red disk. In most of the studies, a trial was subject initiated by completion of an FR 15. This presented the sample stimulus which was terminated when a response (panel press) was made to it. Correct responses were followed by one CIBA pellet and incorrect responses were followed by a 1-minute timeout.

D'Amato and O'Neill (1971) found that darkness during the retention interval resulted in better performance than normal chamber illumination. This replicated a similar effect reported by Etkin (1972) with a 24 sec. delay interval. However, D'Amato and O'Neill (1971) have obtained this effect with delays as long as two minutes. This result indicated that

earlier studies which found poor performance in delayed matching of stumptail monkeys with delays of 30 sec.

(Jarrard & Moise, 1970) were not tapping the structural limits of short-term memory but rather had merely not employed optimal experimental conditions. In the D'Amato and O'Neill (1971) study, with a delay of 120 seconds, three monkeys performed between 50 and 60% correct with the houselight on during the delay interval, while with the houselight off the range in performance between the monkeys was 58-80% correct. All four types of stimuli used were similarly affected by this treatment. Furthermore, the effect was not a result of the houselight off condition constituting a change in the sequence of events on a trial. The facilitation was obtained even when the houselight was off during all phases of a trial sequence except during intertrial periods.

Mello (1971) reported that rhesus monkeys could perform in a delayed matching task with delays up to 3 minutes. Interestingly, the experimental chambers were completely dark except for illumination by the experimental stimuli. This study indirectly discounts a source of interference which D'Amato (1973) did not explicitly recognize. That is, non-differential houselight conditions during the retention interval and intertrial interval.

It has also been shown that delayed matching-to-sample performance can be affected by manipulations of auditory input

as well as houselight conditions. Worsham and D'Amato (1973) found that auditory input in the form of white noise during the delay interval did not affect the delayed matching of visual stimuli. However, when the auditory input was a recording of the vocalizations which occurred in the monkey colony room, performance was facilitated at long delay intervals.

While monkeys appear unable to acquire auditory delayed matching (D'Amato, 1973), this does not appear to be true for the bottlenose dolphin. Herman and Gordon (1974) used training and testing procedures for the dolphin which differed considerably from those employed in studies with pigeons and monkeys. These procedures included the use of fading methods, the playback of S^+ or S^- following a response, the successive presentation of comparison stimuli, and the use of a complex chain to establish control over listening behavior. The stimuli used were rather complex sounds formed by pairing between or within six sound classes, e.g. unmodulated pure tones, pulse modulated tones, frequency modulated tones, etc. During training, 21 unique problems were given with delays progressively increasing up to 18-sec. Then, the dolphin was tested on 346 delayed matching problems with the duration of long delays gradually increasing over testing. The sample and comparison stimulus durations were 2.5 sec. The reinforcer was 34 g. of smelt and a noncorrection procedure was

used. The majority of errors on trial 1 of a new problem occurred within the first third of the 346 problems. The errors appeared to be independent of the delay intervals (1-15 sec.) for the first 121 problems. Over the remaining 225 problems a progressive improvement of matching accuracy was observed. In fact for 169 of these problems, there were no errors in matching on trial 1. Even with a delay of 120 sec. 5 out of 6 new samples were correctly matched on the first trial. Herman and Gordon (1974) interpreted the data as evidence that the dolphin has the ability to form a generalized concept of matching.

One other interesting aspect of this study was the development of emotional responding during long delays (60-120 sec.). Herman and Gordon (1974) speculated that this may have occurred because of the contrast between short and long delays within a set over successive problem blocks. Most of the studies with monkeys employed a constant delay throughout a block of trials (D'Amato, 1973) and no emotional responding was reported.

Finally, one very important point which Herman and Gordon (1974) stressed pertains to the procedures which they employed and the goals of comparative psychology. They pointed out that in order to determine the maximum skill level which a species can achieve on a given learning task, one must

select or develop conditions of stimulus control favorable to the species under test. In some respects the experimental procedures may differ considerably, as they do between the dolphin and monkey DMTS studies. However, in some situations the same or similar experimental procedures may be found effective with very different species.

In summary, the studies dealing with delayed matching-to-sample in various species have all demonstrated that accuracy is related to the length of the delay interval. It is important to realize that a host of experimental parameters such as type of apparatus, the nature of the stimuli and the type of pretraining and so on are significant factors in determining the limits of delay for an organism.

II.5 Response requirements to the sample

The phrase "response requirements to the sample" refers to the number of responses which must be made to the sample stimulus before the comparison stimuli are presented. This variable has attracted the interest of researchers since it provides an operational definition for increased attention (Mello, 1971) and in certain contexts has been interpreted as increasing the strength of a memory trace (Roberts, 1972). The importance of a response requirement to the sample stimulus was demonstrated by Eckerman, Lanson and Cumming (1963). They reported that acquisition of MTS was faster when a re-

sponse to the sample stimulus was required relative to a condition in which a response to the sample was not required. In addition, the removal of the response requirement after performance had stabilized produced a substantial decrease in the accuracy of responding. Zentall, Hogan and Holder (1974) found that requiring 4 responses to the sample stimulus in mismatching-to-sample greatly facilitated the learning of this task relative to a condition in which there was no response required to the sample. Thus, it appears that sample response requirements are an important variable to be considered in MTS and MMTS paradigms.

Research on the effects of fixed ratio sample requirements in MTS paradigms has produced equivocal results. Cumming, Berryman and Nevin (1963) observed that an FR5 sample requirement did not facilitate the acquisition of simultaneous matching. Cumming, Berryman and Cohen (1965) changed the sample requirement from FR1 to FR5 on the 13th day of transfer training and found that a reduction in accuracy of responding occurred. More recently, Sacks, Kamil and Mack (1972) examined the effects of FR sample requirements on zero-delay matching-to-sample with 1, 10, 20 or 40 responses required to the sample before the comparison stimuli were presented. An increased speed of acquisition as a direct function of FR sample requirements was obtained. In addition, increasing the number of required sample responses facilitated perfor-

mance in both delayed matching and a transfer task in which 2 novel hues were introduced. As Sack et al. (1972) noted, the difference in results could be accounted for in two ways. First, the FR requirement employed by Berryman et al. (1963) may have been too small to produce facilitative effects. Second, basic differences between simultaneous and zero-delay matching may exist, such that increased FR sample requirements affect performance in the latter but not in the former.

In order to assess which of these factors was responsible for the earlier reported differences, Santi, Tombaugh and Defalco (1976) examined simultaneous and zero-delay matching in pigeons with the number of responses required to the sample varied within-subjects such that either 1, 6 or 36 responses were required prior to illumination of the comparison stimuli. When the stimulus dimension was line orientation, the simultaneous matching birds performed more accurately on trials with a response requirement of 6 than on trials with a requirement of 1 or 36. The zero-delay subjects failed to demonstrate any acquisition in over 90 sessions. When the zero-delay birds were switched to a simultaneous matching procedure, they only demonstrated acquisition on trials requiring 36 responses to the sample. In a later phase of the research, all subjects were trained under simultaneous matching with the stimulus dimension being colour. On this dimension, the functional relationships between accuracy and sample response requirement

exhibited a much greater degree of reliability and generality. For all subjects, matching accuracy was monotonically related to the number of sample responses required on a trial: the greater the number of responses, the higher the accuracy. This research clearly demonstrated that sample response requirements can enhance accuracy in simultaneous matching-to-sample when varied within-subject. However, the value of the response requirement which produced maximal accuracy appeared to be complexly determined by the experimental history of the subject and the difficulty of the task.

It has been suggested that the facilitative effects of sample response requirements may be due to increased exposure to the sample stimulus. Maki and Leuin (1972) have shown that the duration of the sample stimulus in zero-delay matching can affect response accuracy. Roberts and Grant (1974) experimentally controlled sample duration and found that accuracy increased as a negatively accelerated function of presentation time. However, Cohen, Looney, Brady and Aucella (1976) have recently examined differential sample response schedules in simultaneous matching-to-sample. They obtained facilitative effects of differential sample-schedule requirement (i.e. DRL 3 sec. for one sample and FR16 for the other) relative to a nondifferential sample-schedule requirement (i.e., DRL 3 sec. to both samples or FR 16 to both samples) which they argued could not be attributed to increased sample duration. It

should also be recalled that Santi, Tombaugh and Defalco (1976) reported higher accuracy for simultaneous matching subjects early in training when 6 responses were required to the sample relative to 1 or 36 responses. These results are also difficult to account for simply in terms of increased sample duration.

In the studies reviewed thus far, except for the study by Cohen, Looney, Brady and Aucella (1976) the response-requirements were independent of the sample stimulus presented. Lydersen and Perkins (1974) compared the acquisition of zero-delay matching in three groups of pigeons. In the first group, the response requirement was dependent on the value of the sample stimulus. That is, an FR8 was required to the red sample and an FR16 was required to the green sample. In a second group, the same response requirements were independent of the value of sample stimulus. In a third group, the sample-key color was irrelevant and the subject was required to chose the red comparison following FR8 and the green comparison following FR16. Compared to the first two groups, acquisition of matching by the third group was slow and irregular. Lydersen and Perkins (1974) also found that the asymptotic level of accuracy was higher and attained more rapidly in Group 1 than in Group 2. In the transfer phase of this study, Groups 1 and 2 were essentially shifted to a symbolic matching task since vertical and horizontal lines replaced the

red and green samples only and the subjects were required to match colors to lines." Again, Group 1 subjects acquired the task more rapidly than subjects in Group 2. This result suggested that for Group 1 subjects, the FRs functionally acted as part of the sample.

Only one study has required more than one response in the choice phase of a matching-to-sample experiment. This study was performed by Zentall, Hogan and Holder (1974) and involved a comparison of mismatching-to-sample and "true oddity". The difference in these tasks is that in "true oddity" there is no sample stimulus. The subjects in a "true oddity" experiment are presented with a set of stimuli and must choose that stimulus which differs from those in the remainder of the set. In comparing the performance of pigeons in mismatching-to-sample (with no response requirement to the sample) to "true oddity", Zentall et al. found that increasing the response requirement in the choice phase improved performance on the MMTS task but not on the "true oddity" task. In fact, pigeons were not able to acquire the "true oddity" task.

In summary, response requirements to the sample have produced facilitative effects in simultaneous and zero-delay matching-to-sample as well as simultaneous mismatching-to-sample. The determinants of this effect have not been clearly established. It may be due to the increased time of

sample stimulus exposure. However, there are other factors which may be responsible such as differential patterns of responding, increased response effort, attentional factors, etc. More research is also needed to assess the effects of response requirements during the choice phase of MTS experiments. This research may eventually be found to be linked to work on a related conditional discrimination paradigm:- non-spatial delayed alternation. Williams (1971) found that use of an FR response requirement in the choice phase of nonspatial delayed alternation facilitated both the acquisition and transfer of this task. Williams attributed the FR effect to the pigeon's propensity to respond on subsequent trials to the stimulus value reinforced on the last trial. Larger FRs presumably enabled the subjects to correct this type of error. To the extent that perseveration exists in the MTS paradigm, it can be assumed that FR requirements in the choice phase of this paradigm will have similar facilitative effects.

II.6 Schedule control of matching-to-sample

As with simple responses such as key pecking, more complex responses such as matching have been shown to be affected by the schedule of reinforcement with which they are associated. One advantage of examining schedule effects with matching-to-sample responding rather than simple key pecking is that it allows for more than just the rate and pattern of

responding as dependent variables. It also allows for a measure of accuracy of responding. Ferster (1960) demonstrated that schedule control of matching could be established using a zero-delay paradigm. Primary reinforcement occurred only when the schedule requirement was met and each matching response was followed by delivery of a conditioned reinforcer (.2 sec. illumination of the magazine light). A between-trials correction procedure was employed and incorrect responses were followed by a 1 second timeout. Ferster found that when matching was reinforced on a fixed-ratio (FR) schedule, accuracy increased as the FR value increased from FR1 or CRF to FR15 and FR20.

The highest rates of responding were obtained with small FRs, as with simpler responses such as key pecking. The larger FRs produced typical FR response patterning with pausing after reinforcement being followed by an abrupt shift to responding at the terminal FR rate. The size of the FR that the birds were able to sustain was smaller for matching than for simple keypecking. Ferster also found that with fixed-interval schedules (FI) a scallop was not produced until the birds were exposed to a multiple FIFR. The multiple FIFR brought matching behavior under stimulus control with performance in the 2 components corresponding to that which occurred when only a single component was available.

With regard to incorrect or S^{Δ} responses Ferster noted two interesting effects. First, overall there was less incorrect responding on ratio than interval schedules. Second, the S^{Δ} levels in successive quarters of 10-minute FI periods revealed that the most accurate matching occurred in the last quarter of the FI period and the least accurate responding in the second quarter.

Ferster's work was extended by Nevin, Cumming and Berryman (1963). They assessed the effects of various schedules of ratio reinforcement on matching performance. Contrary to Ferster's results, they obtained a decrement in matching behavior when subjects were shifted from an FR1 to an FR3. The effect of increasing the ratio from 3 to 10 produced equivocal results in that two birds displayed a slight improvement while one bird displayed a slight decrement. A number of procedural differences could account for this discrepancy.

Nevin et al. did, however, replicate the pause-run behavior characteristics of FR reinforcement. They also noted that errors tended to occur immediately after reinforcement on FR schedules with accuracy increasing as the ratio progressed. This did not occur with VR reinforcement, since high accuracy was obtained regardless of the position within the VR. Nevin et al. also observed a direct relation between the time taken to complete the response requirement to the sample

(FR5) and the ordinal trial number. That is, as the ratio progressed, the time to complete the sample-response requirement decreased and the accuracy of matching increased.

Mintz, Mowrer and Weinberg (1966) examined the fixed ratio reinforcement of matching with changes in an exteroceptive stimulus correlated with the steps of the ratio. Although there were generally fewer errors displayed by subjects in this study than in the Nevin et al. study, a similar function relating errors to ordinal position in the ratio was obtained. Specifically, error frequency was a decreasing function of position in the ratio. Mintz et al. also found that when the stimulus conditions associated with the last two steps of the FR were randomly presented immediately after reinforcement, the accuracy obtained on these two trials was more appropriate to later trials than the initial trials of the FR run. The exteroceptive stimuli, therefore, had gained some control over matching accuracy.

Studies dealing with fixed interval schedules have also demonstrated that post reinforcement stimuli consistently correlated with nonreinforcement come to control lower rates of responding and lower levels of accuracy. Both Ferster (1960) and Clark and Sherman (1970) found an increased rate of matching responses and a higher level of accuracy near the end of the FI interval relative to that at the beginning.

Boren and Gollub (1972) investigated the accuracy of

matching performance under single FI, chained FI and FI schedules with an added clock (i.e. exteroceptive stimulus changes correlated with time since the last reinforcer). The accuracy of matching within the simple FI and the FI with added clock decreased from the beginning of the interval to some point in the middle and then increased until the end of the interval. With the chained FI schedules, accuracy changed within the components. The level of accuracy decreased during the first component, stayed at an intermediate level during the middle component, and increased throughout the terminal component. Boren and Gollub (1972) also found that regardless of the type of FI, matching accuracy was lowest at intermediate rates of responding and highest at either low rates or high rates.

The schedule control of matching behavior has also been studied with children ranging in age from 4 to 7 years by Davidson and Osborne (1974). They found that with FR schedules for zero and 2-sec. delay matching, children displayed the greatest number of errors immediately after delivery of the reinforcer. With VR schedules, a similar pattern was not observed. While with pigeons the number of errors decreased as the ratio progressed, with children the major effect was a decrease in the number of errors from the first position to the remaining positions. With FI schedules for zero-delay, the children produced the greatest number of errors in the second

quarter of the interval. VI schedules with similar frequencies of reinforcement produced error patterns which were unsystematic. Davidson and Osborne (1974) found that errors were related to response rate, as had Boren and Gollub (1974). In addition, they pointed out that in both studies this effect may be related to the degree of rate change across the interval in addition to, or independent of, the relative response rate. In the Davidson and Osborne study, while rates in the second quarter of the FI were intermediate to rates in other quarters, the greatest change in response rate occurred between the first and second quarter.

In summary, then, the pattern of occurrence of a matching response is a function of the schedule of reinforcement associated with it. This has been shown for both human and nonhuman organisms.

III. THE ROLE OF PHYSICAL IDENTITY OF THE SAMPLE AND CORRECT COMPARISON STIMULUS IN MATCHING-TO-SAMPLE PARADIGMS

As indicated earlier, this section will consider the study by Nevin and Liebold (1966) in more detail and will proceed to outline the rationale for the present research. It will be recalled that research reviewed previously (Section II.1) suggested that pigeons trained in a MTS paradigm acquired a set of specific "if ... then ..." rules, with the physical identity between the sample and correct comparison stimulus having no special status. However, the differential sensitivity of MTS and MMTS performance to disruption by sodium pentobarbital is difficult to reconcile with this point of view. The failure to obtain differences between MTS and MMTS when the number of rules is equated (Zentall and Hogan, 1974; Zentall and Hogan, 1976) does not necessarily preclude physical identity from playing a role in the acquisition, performance and transfer of matching-to-sample. The expression of an effect attributable to physical identity may depend upon the sensitivity of the design with which it is measured. The most powerful comparison of the acquisition, performance and transfer of matching and mismatching would derive from a within-subject design in which potential confounding with other variables is

eliminated. This would necessitate equating the number of stimulus-response chains to be learned during acquisition and also minimizing the problems associated with previous reinforcement history during transfer testing.

A procedure for comparing MTS and MMTS within-subject was suggested in a study by Nevin and Liebold (1966). They attempted to establish higher-order stimulus control over matching and mismatching performances. In their study, they trained a single pigeon to a high level of accuracy on MTS and then introduced reinforcement for MMTS. MTS and MMTS trials were cued by the presence or absence of a yellow houselight and alternated in blocks of 25 trials. Since reinforcement for matching alternated with nonreinforcement for matching (or reinforcement for mismatching) every 25 trials, it could have been the context provided by the reinforcement-nonreinforcement sequence which controlled performance rather than the discriminative properties of the yellow pilot light. While Nevin and Liebold found no differences between MTS and MMTS in terms of terminal performance levels, they did replicate the differential sensitivity of MTS performance to disruption by sodium pentobarbital. They also found that after 10 sessions of transfer of training (blue and yellow were substituted for red and green), accuracy was much higher on MTS trials than on MMTS trials. However, these transfer test results may have been confounded by their training procedure; matching was

trained first to a high level of accuracy before mismatching trials were introduced. It is possible, that when confronted with new stimuli during transfer, the pigeon simply responded on the basis of the performance which had been established first.

A variation of the procedure employed by Nevin and Liebold (1966) was used in the following research because it afforded the opportunity to assess the role which physical identity of sample and correct comparison stimuli play in the performance and transfer of a conditional discrimination when examined within-subject. In order to accomplish this, pigeons were trained to perform a discrimination in which the rule for reinforcement could be described as involving a higher-order conditional discrimination. For example, if a vertical line is present on the response keys, then selection of the comparison stimulus which is the same as the color of the sample stimulus would be reinforced, but if a horizontal line is presented, then selection of the comparison stimulus which is different in color from the sample would be reinforced.

The nature of the stimulus control function which results from exposing a pigeon to such a paradigm, does not necessarily have to reflect the experimenter's rule for reinforcement. In order to speak of higher-order conditional stimulus control as a behavioral process, it must be clearly demon-

strated that stimulus control of functional classes of stimulus-response relations, such as matching and mismatching has been established. In the example above, the line orientation would have to exhibit a "selective" or "instructional" function that momentarily strengthens a particular discrimination such as matching or mismatching. While Nevin (1973) has claimed that his earlier experiment (Nevin and Liebold, 1966) demonstrated higher-order conditional stimulus control in the pigeon, it is clear that the source of confounding mentioned earlier does not allow one to conclude that an exteroceptive discriminative stimulus had control over MTS and MMTS performance.

With regard to the present research, it was not anticipated that higher-order conditional stimulus control would necessarily develop. That is, rather than line orientation exhibiting an "instructional" function, it is more likely that both line tilt and color will form a stimulus compound that will function as a unitary discriminative stimulus. The important point to note however is that the status of physical identity can still be determined. From the viewpoint of line tilt and colors forming stimulus compounds, we can see that there are still two different types of trials: those trials in which the sample and correct comparison are similar on both the line tilt and color dimension and those trials in which the sample and correct comparison while similar on the line

tilt dimension are different on the color dimension. While the stimulus compounds are physically identical in the first type of trial, they are not so in the second type. These two types of trials were presented in a random sequence in the following studies. Acquisition and performance on this task were examined using red and green colors and line tilts of 0° and 90° in Experiment I. In addition, transfer of training was assessed by substituting blue and yellow colors for red and green. Such a procedure eliminates confounding in terms of the number of rules to be learned and previous reinforcement history. In Experiment II, stimulus control gradients were obtained by varying the angularity of the lines. This should provide additional information with regard to the status of physical identity since symmetrical gradients would be expected if physical identity played no role, whereas asymmetrical gradients could reflect a bias toward or away from the physically identical comparison stimulus, depending on the nature of the asymmetry.

IV. EXPERIMENT I

The first experiment examined the acquisition, performance and transfer of discriminative behavior established via a procedure which could be termed a higher-order conditional discrimination procedure.

IV.1 Method

Subjects: Eight experimentally naive White Carneau pigeons, without prior experimental histories, were maintained at 80% of their free-feeding weights. They were not studied on days that their weights exceeded or fell below $80\% \pm 15$ grams.

Apparatus: Four Lehigh Valley key pecking chambers were used. Each chamber was enclosed in a plywood box insulated with acoustical ceiling tile. Masking noise and ventilation was provided by two 100-CFM Dayton blowers located on the left side wall and back wall, respectively of each apparatus and holding box. The three translucent (Perspex) response keys were all 2.54 cm. in diameter. The stimuli used (red, green, yellow or blue and a white line with an orientation of 0° , 22.5° , 45° , 67.5° or 90° from horizontal) could be projected on the reverse side of the translucent key by an In-Line Digital Unit. Directly below this key

was a 5.08 cm. square aperture that provided occasional access to a hopper filled with mixed grain. General illumination was provided by a houselight located above the center response key. All experimental contingencies and response measures were programmed and recorded by a PDP-8I digital computer located in a separate room.

Procedure:

Preliminary training. The eight birds were adapted to the experimental chambers and trained to eat out of the hopper. They were then trained to respond to either of the two side keys by means of an "autoshaping" procedure. Red and green lights were presented an equal number of times on both the right and left keys. The side key remained illuminated for 8 seconds if no response occurred and terminated with 3 seconds access to grain. If a response to the illuminated key occurred within the 8 seconds, the reinforcer was delivered immediately and the key light terminated. Each session of autoshaping consisted of 144 trials with an intertrial interval of 25 seconds. Six birds pecked the key on more than 90% of the trials by the third session of autoshaping. Two birds, P1 and P8, who failed to key peck by the third session of autoshaping, were handshaped to peck the key.

The next phase involved the training of a response chain. Red and green lights were again used as stimuli in this phase. A trial began with illumination of the center key. A response to this key illuminated one of the side keys while the center key remained on. On one half of the trials, the left side key was illuminated and on the other half of the trials, the right side key was illuminated. In addition, the side key matched the sample (center) key on half the trials and mismatched on the remainder. A response to the side key offset the center and side keys and was followed by 3 seconds access to mixed grain (reinforcer). Center key responses which occurred after side-key illumination had no programmed consequences. Each session consisted of 144 trials with an intertrial interval of 15 seconds. This phase of training was continued for 6 sessions, by which point all subjects showed a stabilization of response latencies to the center key and left and right key.

Conditional discrimination training. With the initiation of training, the red and green lights were presented with a line tilt of 0° or 90° superimposed on them. One of the side keys was illuminated with a color which was the same as that on the center key, while the other side key was illuminated with a color different from that on the center key. The line orientation which was superimposed on all response keys signalled

whether a response to the matching color or a response to the mismatching color was correct. For half of the subjects, the 0° line was correlated with reinforcement for responding to the color which matched that on the center key, while the 90° line was correlated with reinforcement for responding to the color which mismatched that on the center key. This relationship was reversed for the remaining subjects. Since the red and green stimuli were counterbalanced over the left and right keys and the superimposed line tilt was 0° or 90°, eight different stimulus combinations resulted. These are presented in Table 1. Each day's session consisted of 144 trials. Eighteen blocks of 8 trials made up the 144 trials, with each block consisting of a random sequence of the 8 trials shown in Table 1.

A trial was conducted as follows. The center key was illuminated with a line tilt superimposed on a colored background. A response to this key resulted in the presentation of the appropriate stimuli on both of the side keys. A peck to the correct side was followed by 3 seconds access to grain, while a peck to the incorrect side was followed by a 3 second blackout (i.e., all lights in the experimental chamber were turned off). A 15 second intertrial interval followed either reinforcement or Blackout.

Four birds (P1, P2, P3 and P4) were originally given the training described above. After 60 sessions of training,

TABLE 1
STIMULUS CONFIGURATIONS EMPLOYED DURING
TRAINING

Orientation of Line Superimposed on all Keys	Left Key	Center Key	Right Key
0°	Red Green Red Green	Red Red Green Green	Green Red Green Red
90°	Red Green Red Green	Red Red Green Green	Green Red Green Red

all except P3 had acquired. A correction procedure was introduced for all 4 subjects at this point and continued for 25 sessions. During this phase, an incorrect response on any trial was followed by a 3 second blackout and a repetition of that trial (same stimulus configuration). The trial was repeated until a correct response was recorded. Even with the correction procedure, P3 failed to acquire. In addition, P2 died as a result of a laboratory accident during this phase. Because of this, an additional four naive birds (P5, P6, P7 and P8) were trained in accordance with the procedures previously described. After 50 sessions of conditional discrimination training, all except P7 had acquired. Again a correction procedure was introduced for 25 sessions and P7 acquired the task. As a result, six birds were able to continue in the experiment. For three subjects (P1, P5, P7) a line orientation of 0° was correlated with reinforcement for responding to the matching color, while 90° was correlated with reinforcement for responding to the mismatching color. This was reversed for P4, P6 and P8.

Following the 25 sessions of the correction procedure, an additional 5 sessions of training was given without the correction procedure. These 5 sessions served as a baseline prior to introduction of the transfer task.

Transfer Training. During transfer, blue and yellow were substituted for red and green. These two novel hues were intro-

duced during transfer to reduce problems associated with previous reinforcement history when familiar and novel colors are both presented during transfer. Other than the change in color, the procedure during transfer was exactly the same as during original training. All subjects were given 50 sessions of transfer.

Recovery of original performance. Following transfer, all subjects were returned to the original conditions of training. That is, red and green lights were substituted for blue and yellow. This was done for two reasons. First, to determine what effects a change in stimuli would have even though the birds had learned to respond appropriately to them. Secondly, to once again examine steady-state performance on this conditional discrimination. This phase was terminated after 15 sessions.

IV.2 Results

Overall level of accuracy during training. Accuracy data, during the 60 sessions of training for P1, P2, P3 and P4 and the sessions of training for P5, P6, P7 and P8 prior to the introduction of a correction procedure are shown in Figures 1 and 2 respectively. For ease of presentation, trials in which the sample and correct comparison were similar on both line tilt and color dimensions will be referred to as MTS trials, while those in which the sample and correct comparison

FIGURE 1. Percent correct on MTS and MMTS trials for birds P1, P4, P2 and P3 during training.

FIGURE 2. Percent correct on MTS and MMTS trials for birds P5, P6, P8 and P7 during training.

were similar on the line tilt dimension but different on the color dimension will be referred to as MMTS trials. As can be seen in the figures, six birds (P1, P4, P2, P5, P6, P8) acquired the task prior to introduction of a correction procedure. Chance levels of performance for both MTS and MMTS trials is at 50%. According to a simple binomial model ($N=72$, $p=.5$), performance on each type of trial would have to be at or above 61% correct in order to reject the hypothesis that the bird was performing at chance levels (i.e., one-tailed test, $p<.05$) for a given trial type. If one looks at the number of sessions required before performance on both MTS and MMTS trials rises to at least 61% and never again falls below this value, it will be seen that there is considerable variability between birds: P1 required 16 sessions, P5 and P8 required 22; P6 required 38; P2 required 44 and P4 required 47. However, all of these subjects were able to attain accuracy levels of 80% correct or higher.

A consideration of the data for the first session of training reveals that accuracy on MMTS trials was higher than on MTS trials for all subjects, however, the magnitude of the effect varied. It should be noted that P8 did not begin responding until session 6, but showed the effect during this session. These accuracy differences between MTS and MMTS trials will be considered in more detail shortly.

FIGURE 3. Percent correct on MTS and MMTS trials for all birds during the correction procedure and the removal of this procedure.

TABLE 2

THE NUMBER OF SESSIONS ON WHICH
VARIOUS TYPES OF ACCURACY DIFFERENCES
WERE OBSERVED DURING TRAINING

Subject	Type of Accuracy Difference		
	MTS > MMTS	MTS < MMTS	MTS = MMTS
P1	35	15	0
P2	26	30	4
P4	24	32	4
P5	32	9	9
P6	16	21	13
P7	24	23	3
P8	15	19	16

Figure 3 presents data obtained following the introduction of the correction procedure. It can be seen in the lower left hand corner of this figure that P7 acquired the discrimination following introduction of the correction procedure and attained an accuracy level of 90-100% correct. The other subjects (P1, P5, P4, P6, P8) exhibited high levels of performance during this phase. Removal of the correction procedure did not disrupt accuracy in any subject. As indicated earlier in the method section only 6 subjects (P1, P5, P7, P4, P6, P8) remained in the experiment at this point, since P3 failed to acquire the discrimination even with the correction procedure and P2 died as the result of a laboratory accident during this phase.

With regard to terminal levels of performance (i.e., the last 5 sessions of training without a correction procedure), no consistent large differences in accuracy on MTS and MMTS trials were observed. However, P4 and P5 did show a slightly higher overall level of accuracy (5-10%) on MTS trials. For all other subjects, the average level of accuracy on MTS and MMTS trials differed by less than 5 percent.

Table 2 indicates the number of sessions in which accuracy on MTS trials was greater than, less than or equivalent to accuracy on MMTS trials prior to introduction of the correction procedure. A sign test (two-tailed, $p < .05$) performed on these data revealed that for P1 and P5 there were

significantly more sessions in which accuracy was higher on MTS trials than on MMTS trials. For all other subjects, there was no statistically significant difference.

The training data prior to introduction of the correction procedure was examined further by assuming that observations of accuracy differences between MTS and MMTS trials were randomly ordered over sessions. A runs test was then performed to determine whether there were time trends or bunching (i.e., too few runs) which would suggest a lack of independence in the order in which these differences were obtained. When this test was performed on the training data prior to introduction of the correction procedure, it was found that subjects P1, P2, P4 and P6 exhibited an ordering of accuracy differences which departed from randomness (one-tailed test, $p < .05$). For P1 there was a tendency for MTS accuracy to be higher than MMTS accuracy from sessions 14 to 20 (during which acquisition was taking place) and also from sessions 34 to 46. For P2, higher accuracy on MMTS trials was observed from session 6 to session 24, while for P6 a similar difference was observed from sessions 1 to 6. P6 also exhibited higher accuracy on MTS trials from session 36 to 44 (during which acquisition was taking place). The presence of time trends in the data of P4 was not as clear as for the other subjects. A runs test failed to reveal significant departures from randomness for the data of P3, P5, P8 and P7 during training. This was also true for the data of P7 following the introduction of the correction procedure.

Nevertheless, even though there was no statistically significant departure from randomness, there were some observable time trends in which MTS accuracy was higher than MMTS accuracy for P5 (sessions 18 to 33 of training) and P7 (session 1 to 9 during the correction procedure). In addition, for P8, MMTS accuracy was higher than MTS accuracy from session 23 to 30 of training.

In order to specify the locus of these accuracy differences a more detailed analysis of performance on this conditional discrimination task was undertaken. The detailed analysis should also reveal the nature of the response biases or preferences which existed prior to acquisition.

Detailed analysis of performance during training. The detailed analysis of performance, to be outlined, involved a consideration of choice behavior in the presence of each of the 8 stimulus configurations individually. A stimulus configuration is a specific spatial arrangement of a set of stimuli on the left, center and right response keys. This detailed analysis will commence with the first session of training, since all subjects, except P8, exhibited higher accuracy on MMTS trials than on MTS trials during this session. Following this, a detailed analysis of performance during the transition period will be presented. The transition period is defined as those sessions over which performance changes from chance levels to

above chance levels of accuracy. Once again, according to a simple binomial model ($N=72$, $p=.5$), performance on each type of trial would have to be at or above 61% correct in order to be significantly above chance (one-tailed test, $p<.05$). The data for the transition period were examined in detail because several subjects revealed differences in MTS-MMTS accuracy during these sessions and also because it afforded a closer look at the dynamics of acquisition.

Choice behavior in the presence of each stimulus configuration was considered for session 1 of training and certain biases were observed. These biases were classified as a preference for position, color, or the relation between the sample and comparison stimulus responded to. The response biases exhibited are presented in Table 3. A value of 50% indicated no bias and the Binomial Test ($N=144$, $p=.5$) required that the bias be $50\pm 9\%$ in order to reject the null hypothesis that there was no bias (two-tailed test, $p<.05$). Table 3 indicates that there was a statistically significant position bias to the left key for P1, P2, P3 and P5 and a strong bias to the right key for P4. The position biases were closely related to response latencies obtained during the last 3 days of chaining which are presented in Table 4. Note that the subjects with a significant position bias also have consistent and large differences in response latencies to the left and right key during these sessions relative to the two

TABLE 3
OVERALL RESPONSE BIASES EXHIBITED DURING
THE FIRST SESSION OF TRAINING

Type of Bias	S U B J E C T						
	P1	P2	P3	P4	P5	P6	P7
Position: Left Key Choice	91.6*	92.3*	60.4*	21.5*	96.5*	50.6	43.0
Color: Red Comparison Choice	54.1	56.2	56.9	52.0	49.3	50.6	65.2*
Relation: Mismatched Comparison Choice	55.5	54.9	60.4*	53.4	50.6	68.7*	62.5*

NOTE: Value of 50±9% indicates a significant departure from no bias according to the Binomial Test (two-tailed).

* $p < .05$.

TABLE 4

RESPONSE LATENCIES (IN SECONDS) TO LEFT (L) AND RIGHT (R)
SIDE KEYS DURING
THE LAST THREE SESSIONS OF CHAINING

Ses- sions	S U B J E C T													
	P1		P2		P3		P4		P5		P6		P7	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R
1	.96	1.52	.86	1.07	.87	1.12	1.37	.80	1.00	2.89	1.11	1.17	1.68	1.40
2	.89	1.19	.89	1.12	.75	1.19	1.22	.73	1.12	2.01	1.29	1.08	1.28	1.27
3	.80	1.52	.91	1.02	.82	1.22	1.31	.77	1.28	2.20	1.42	1.07	1.57	1.66

subjects (P6 and P7) who do not show a significant position bias.

In addition to position biases, Table 3 reveals that only one subject (P7) exhibited a color bias, while 3 subjects (i.e., P3, P6 and P7) exhibited a bias to the mismatched comparison. It should be noted that mismatching biases were never as extreme as the position biases. Furthermore in the case where a subject showed more than one type of bias (i.e. P3 and P7), it was not certain which was the "actual" bias. For example, the subject may have had a bias to the red comparison when it mismatched the sample, but had no bias when the red comparison matched the sample. In such a case, choice behavior was jointly determined by the two types of bias.

A detailed analysis of transition behavior is presented in Figures 4, 5 and 6. The analysis involved a consideration of choice behavior in the presence of each of the 8 stimulus configurations individually. Each configuration was presented 18 times in a session and so the maximum number of correct responses for each configuration was 18. Each stimulus configuration has a unique designation in the figures which indicates the position and color of the correct comparison stimulus along with its relation (identity or difference) to the sample stimulus. The position of the correct comparison is represented by the line joining the symbols: right key - solid lines; left key - dashed lines. The color of the correct comparison is represented by the

SESSIONS

FIGURE 4. Choice behavior in the presence of each of the 8 stimulus configurations prior to and during the transition to above-chance accuracy for birds P1, P5 and P7.

FIGURE 5. Choice behavior in the presence of each of the 8 stimulus configurations prior to and during the transition to above-chance accuracy for birds P8, P4 and P6.

DESIGNATION OF CORRECT COMPARISON STIMULUS FOR EACH STIMULUS CONFIGURATION	
○---RRG	△---RRG
○---GRB	△---GRB
●---GGR	△---GGR
●---RGG	△---RGG
POSITION } RIGHT ---; LEFT ----	
COLOR } RED (R)-UNSHADED GREEN (G)-SHADED	
PHYSICAL IDENTITY } MTS-CIRCLE; MMTS-TRIANGLE

FIGURE 6. Choice behavior in the presence of each of the 8 stimulus configurations prior to and during the transition to above-chance accuracy for bird P2.

shading of the symbols: red - unshaded; green - shaded. The physical identity of the sample and correct comparison is represented by the shape of the symbols: MTS - circle; MMTS - triangle. For example, the following designation O--- would represent the stimulus configuration in which the correct comparison is red on the left key and physically identical to the sample stimulus (i.e., matching). The designation ▲— would represent the configuration in which the correct comparison is green on the right key and not physically identical to the sample stimulus (i.e., mismatching).

An examination of Figures 4, 5 and 6 revealed that each bird had a unique pattern of responding to the 8 stimulus configurations employed. Prior to the transition to above chance performance, five of the seven subjects exhibited extreme position preferences. In these figures, position preferences are indicated by a complete separation of dashed lines from solid lines. For birds, P1, P5, P8, P4 and P2, these preferences were evident very early. For P6, the position preference developed over the first 5 sessions as the mismatching bias dropped out. The only bird which failed to exhibit a position preference prior to acquisition was P7. The data for P7 from the beginning of training until acquisition occurred, revealed no clear preferences except for the slight color and mismatching bias on session 1 as previously noted. The data for P3 are not presented since this bird

persisted in positional responding and failed to acquire.

The transition from a position preference to above-chance levels of accuracy showed a great degree of configurational specificity. There are three aspects of this specificity which are worth noting. First, while correct responding was developing to one particular stimulus configuration, other configurations were characterized by position responding. Second, the switch to the correct comparison on the nonpreferred side seemed to be in terms of the color of the correct comparison on that side for birds P2, P5, P6 and P4. Third, the improvement in performance as a result of switching to the correct comparison on the nonpreferred side was correlated with a decrement in performance for configurations in which the correct comparison was on the preferred side (for birds P2, P5, P1 and P8). The data of P2 displayed in Figure 6 would serve as the best example of these various aspects of transitional performance. P2 began to respond appropriately to the GGR configuration on session 6 or 7; to the GRR configuration on session 18; to the RGG configuration on session 29 and to the RRG configuration on session 31. In naming these stimulus configurations, the colors on the left, center and right keys are listed respectively and the correct comparison color is underlined.

Note that P2 switched to the correct red comparison stimulus on the right before switching to green regardless of

the type of trial involved (i.e., matching or mismatching). This can also be seen in the data of birds P5, P6 and P4. However, in the case of P4, it was a switch to the correct green comparison on the left which preceded a switch to the correct red comparison on the left. The third aspect of transitional behavior which P2's data illustrates is that while performance has improved for GGR and GRR configurations, it has deteriorated for GGR and GRR configurations. Similar types of interactions can be seen for P5, P1 and P8. P4, P7 and P6 did not demonstrate these interactions.

Overall level of accuracy during transfer. Accuracy data for the last 5 sessions of training, the 50 sessions of transfer and the 15 sessions of return to training conditions are presented in Figures 7 and 8. If the data for the first session of transfer are examined, two effects can be seen. First, performance has deteriorated markedly relative to the last 5 sessions of training. Secondly, accuracy on MMTS trials are higher than on MTS trials for all subjects except P1.

During the initial sessions of transfer, responding was at chance levels or dropped to chance levels prior to the development of consistent above chance performance (i.e., performance at or above 61% correct). All birds acquired the transfer task faster than the original training task. This is illustrated in Table 5. For all birds, sustained levels of accuracy at or above 61% correct on both types of trials

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MICROCOPY RESOLUTION TEST CHART
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FIGURE 7. Percent correct on MTS and MMTS trials for birds P1, P5 and P7 during transfer sessions and the recovery sessions.

FIGURE 8. Percent correct on MTS and MMTS trials for birds P4, P6 and P8 during transfer sessions and the recovery sessions.

TABLE 5

NUMBER OF SESSIONS PRECEDING THE
OCCURRENCE OF SUSTAINED ABOVE
CHANCE LEVELS OF PERFORMANCE
ON BOTH MTS AND MMTS TRIALS

Subject	Training	Transfer
P1	16	9
P5	22	14
P7	55	15
P4	47	25
P6	38	23
P8	22	8

occurred considerably earlier during transfer than during original training. The terminal levels of accuracy achieved during the transfer phase were equivalent to those attained during initial training for P1, P5, P7 and P8. However, they were somewhat lower for P4 and P6.

Table 6 indicates the number of sessions in which accuracy on MTS trials was greater than, less than or equivalent to accuracy on MMTS trials during transfer. A sign test performed on these data (two-tailed, $p < .05$) revealed that for P5 and P6 there were significantly more sessions in which accuracy was higher on MTS trials than on MMTS trials, while the opposite was found for P1. For P7, P4 and P8, no statistically significant differences were obtained. A runs test was then performed on the transfer data to determine whether the sequence of accuracy differences between MTS and MMTS trials departed from randomness over sessions. Significant departures from randomness were found for P7 ($z = -2.95$, $p < .05$), P4 ($z = -3.18$, $p < .05$) and P6 ($z = -3.75$, $p < .05$). For these birds, then, there were statistically significant time trends in the MTS-MMTS accuracy differences observed. For P7, accuracy on MMTS trials was higher than on MTS trials from session 3 to 16. For P6 and P4, accuracy was higher on MTS trials than on MMTS trials from sessions 12 to 28 and from sessions 38 to 50 respectively. The data for P1, P5 and P8 failed to reveal any statistically significant departures from randomness. A

TABLE 6

THE NUMBER OF SESSIONS ON WHICH
VARIOUS TYPES OF ACCURACY DIFFERENCES
WERE OBSERVED DURING TRANSFER

Subject	Type of Accuracy Difference		
	MTS>MMTS	MTS<MMTS	MTS=MMTS
P1	15	29	6
P5	32	13	5
P7	21	25	4
P4	26	22	2
P6	37	8	5
P8	16	26	8

more detailed analysis of performance during transfer is presented in the next section.

Detailed analysis of performance during transfer. The nature of the response bias exhibited by the birds in the first session of transfer is presented in Table 7. Once again, in order to reject the hypothesis of no bias, a value of $50 \pm 9\%$ is required by the Binomial Test ($N=144$, $p=.5$, two-tailed test). Four of the birds had a single major bias. P7 and P6 exhibited a position bias, while P1 had color bias. P4 had a bias to respond to the mismatched comparison. P8 demonstrated a position and color bias while for P5 all three types of biases were significant. In the case of P5 it was observed that the bias to respond to the left key was strong on all configurations except YYB configurations regardless of trial type.

Since two birds (P4 and P5) did exhibit a significant mismatching bias, it seemed relevant to determine whether this bias was related to extra center key pecks. Fortunately, during the first session of transfer, the number of trials on which extra center key pecks occurred was available for analysis. These data are presented in Table 8 along with the number of trials on which the mismatching comparison was selected. The two birds (P4 and P5) with a significant mismatching bias made extra center key pecks on very few trials (i.e., 5 or less). In addition, one bird (P7) that made extra center key pecks on virtually every trial failed to exhibit a significant mismatching bias.

TABLE 7

OVERALL RESPONSE BIASES EXHIBITED DURING
THE FIRST SESSION OF TRANSFER

Type of Bias	S U B J E C T					
	P1	P5	P7	P4	P6	P8
Position: Left Key Choice	48.6	67.3*	8.3*	49.3	73.6*	84.7*
Color: Red Comparison Choice	98.6*	34.0*	51.3	47.9	49.3	59.7*
Relation: Mismatched Comparison Choice	50.9	63.2*	51.3	63.2*	56.9	55.5

NOTE: Value of 50±9% indicates a significant departure from no bias, according to the Binomial Test (two-tailed).

* $p < .05$.

TABLE 8

EXTRA CENTER KEY PECKS AND RESPONSES TO
THE MISMATCHED COMPARISON DURING THE
FIRST SESSION OF TRANSFER

BIRD	Number of Trials With Extra Center Key Pecks (Maximum 144)	Number of Trials With a Response to the Mismatched Comparison (Maximum 144)
P1	4	72
P5	4	91
P7	141	74
P4	5	91
P6	3	82
P8	48	80

A detailed analysis of transition behavior during transfer is presented in Figures 9 and 10. Once again, each stimulus configuration has a unique designation which indicates the position and color of the correct comparison along with its relation (identity or difference) to the sample stimulus. The process of acquisition during transfer was similar to that observed during original training. Prior to the transition to above chance levels of performance (61% correct or higher) all six birds exhibited clear position preferences. For birds, P1, P5, P8, P6 and P4, the preference was for the left key, while for P7 it was for the right key. The position preference shown by P1 from session 8 to 12 was preceded by a color preference from session 1 to 4.

Once again, as was the case for training data, the improvement in performance as a result of the switch to the correct comparison on the nonpreferred side showed a large degree of configurational specificity and was correlated with a decrement in performance on configurations in which the correct comparison was on the preferred side. For some birds, the increments and decrements between stimulus configurations were unambiguously related. For example, P8 demonstrated an improvement on BBY trials during sessions 5, 6 and 7 which was obviously correlated with a decrement on BYY trials over these sessions. However, when there were dramatic interactions on all trials such as for P7 it was much more difficult

FIGURE 9. Choice behavior in the presence of each of the 8 stimulus configurations during the transition phase of transfer testing for birds P1, P5 and P7.

SESSIONS

FIGURE 10. Choice behavior in the presence of each of the 8 stimulus configurations during the transition phase of transfer testing for birds p8, p6 and p4.

to specify directly which configurations were interacting.

Analysis of performance during recovery of original perfor-

mance. Following transfer, the original colors used during training (i.e., red and green) were substituted for blue and yellow. The overall average performance during this phase is shown in Figures 7 and 8 along with the transfer data.

For birds, P4, P8, P5 and P7, the return to red and green stimuli was followed by a decrement in performance relative to both the last five sessions of transfer and the last 5 sessions of original training. This decrement was quickly overcome and all subjects except P6 attained levels of performance equivalent to those observed during the last 5 sessions of original training. A Sign Test was performed on the recovery data for each subject. It was found that for P4 and P6 there were a significant number of sessions in which MTS accuracy was higher than MMTS accuracy (two-tailed test, $p < .05$). A detailed breakdown of the responding of these birds is presented in Figure 11. For both birds, the poorer performance on MMTS trials was primarily a result of difficulty with the RRG stimulus configuration.

IV.3 Discussion

The training, transfer and recovery data of this study were marked by instances of either a transitory or sustained overall superiority of performance on either MTS or MMTS

FIGURE 11. Choice behavior in the presence of each of the 8 stimulus configurations during the recovery phase for birds P4 and P6.

trials. A detailed analysis of the data was undertaken to determine whether this effect was reliable for all stimulus configurations of a particular trial type or a result of averaging performance over all of the 8 stimulus configurations involved. It was observed that the overall differences in accuracy were a result of either differences in the point at which correct responding began to develop to a specific stimulus configuration, or from interactions which occurred during the development of correct responding, or from consistently poorer performance on one particular stimulus configuration. Since sustained overall MTS-MMTS accuracy differences were not observed for all birds and since the nature of the observed MTS-MMTS accuracy differences was such that they were specific to one stimulus configuration, it is not possible to conclude that physical identity of sample and correct comparison stimulus played a significant role in the discriminative behavior established by this matching-to-sample paradigm. In this regard the present results are in agreement with those reported by Skinner (1950), Zentall and Hogan (1974; 1976) and Carter and Eckerman (1975), while they partially conflict with those reported by Nevin and Liebold (1966).

Nevin and Liebold (1966) found no differences between MTS and MMTS in terms of terminal performance levels, however they did find that after 10 sessions of transfer of training accuracy was much higher on MTS trials than on MMTS trials.

In the present study during transfer two subjects had higher accuracy on MTS trials, one subject had higher accuracy on MMTS trials and three subjects revealed no statistically significant differences. There were many procedural differences between the two studies which could account for these differences. At present though, there are no reliable transfer of training data which indicate a special role for the physical identity of sample and correct comparison stimuli.

However, it is certainly striking that during the first session of original training and transfer, accuracy was higher on MMTS trials than MTS trials for most birds. A detailed analysis of responding indicated a significant bias to respond to the mismatched comparison for 3 of 7 birds during the first training session and for 2 of 6 birds in the first transfer session. While this is not strong evidence for a role of physical identity in matching-to-sample, it needs to be considered further because it has been shown in between-subject designs that on the first day of training MMTS birds display superior performance to MTS birds. This effect has been regarded as an artifact of pretraining procedures in which responding to all 3 keys or only the two side keys is reinforced (Berryman, Cumming, Cohen and Johnson, 1965; Zentall and Hogan, 1974). As a result, when MTS or MMTS training is begun, responses to the center key are not followed by the reinforcer. Presumably, as a result of this, the strength of

responding to the particular stimulus on the center key declines. Hence, when the bird eventually responds to a side key, it tends to select the side key illuminated with a stimulus different from that on the center key.

Data presented by Tombaugh and Marshall (1974) suggested that if a sequence of responding from the center key to the side key was established during pretraining, then both MTS and MMTS subjects begin acquisition from chance levels of performance. While a similar pretraining procedure was employed in the present study, performance on MTS and MMTS trials was not equivalent during the first session of training or transfer. In addition, data obtained during the first session of transfer failed to reveal a relationship between the number of trials on which extra center key pecks occurred and the number of trials on which the mismatched comparison was responded to on the side key. The two birds (P4 and P5) with a significant mismatching bias in this session made extra center key pecks on very few trials (5 or less). These data do not support the explanation offered for the initial superiority of MMTS birds on the initial session of training. The relationship between pretraining procedures, extra center key pecks and responding to the mismatched comparison needs to be more carefully examined in future studies. It may be that the mismatching bias exhibited on the first session of training reflects a special role of physical identity which is not an

artifact of pretraining or other variables.

The magnitude of the MMTS bias observed during the first training and transfer session must be kept in perspective however. Position biases are more common and stronger than the MMTS biases obtained. In addition, it was observed that even if a MMTS bias existed in the first session it dropped out and was usually replaced by a position habit prior to acquisition. This has not been the case in studies of matching-to-sample and mismatching-to-sample which employed a between-subject design. In these studies (Berryman et al., 1965; Zentall and Hogan, 1974), the above chance accuracy of MMTS birds was maintained and acquisition proceeded from this level. This is not very surprising since in a between-subject design, MMTS subjects are always reinforced for a mismatching response.

The data of the present study provided a very close look at the dynamics of matching-to-sample acquisition. Most subjects exhibited an extreme position preference prior to acquiring the task. This type of systematic presolution behavior has been reported in other studies of matching-to-sample with pigeons (Cumming and Berryman, 1965; Eckerman, 1970; Lydersen and Perkins, 1974; Cohen, Looney, Brady and Aucella, 1976). It has also been reported that pigeons presented with a simple simultaneous discrimination problem initially adopt a position habit. Hall (1974) reported that mastering this

problem involves learning to peck the nonpreferred side under certain conditions. Similar response strategies appear to be operative in the acquisition data of the present experiment. However, when acquisition did occur it was frequently specific to particular stimulus configurations. That is, while correct responding was developing to one particular configuration, other configurations were still characterized by a position preference. This phenomenon of accurate matching on some configurations while position responding on others has also been reported in the literature (Cumming and Berryman, 1965; Cohen et al., 1976). In addition, it was observed that the development of correct responding to one configuration was often accompanied by a decrement in correct responding to other configurations. This interaction could be more accurately described as an improvement in performance for configurations in which the correct comparison was on the nonpreferred side, accompanied by a decrement in performance for configurations in which the correct comparison was on the preferred side. Kamil and Sacks (1972) have reported similar interactions. While the complexities of matching-to-sample acquisition have been clearly demonstrated by the present data, it is still unclear exactly what variables determine: (i) when acquisition will occur (ii) on what configuration(s) it will first become apparent and (iii) what configurations (if any) will exhibit interactions.

It is clear that line orientation did not develop control over a generalized concept such as matching or mismatching. It appears as though line tilt and color functioned as a unitary discriminative stimulus. When blue and yellow were substituted for red and green during transfer, performance dropped to chance levels. If the line tilts were discriminative stimuli for matching and mismatching responses, then the novel stimuli should have been responded to appropriately from the beginning of transfer. The present data indicate that pigeons learned either a discrimination for each specific stimulus configuration or a set of specific stimulus-response chains based on compound stimuli. Thus, the results are congruent with those obtained in other studies employing a 3-key MTS paradigm since they show no evidence of pigeons having learned a generalized matching concept (Cumming and Berryman, 1961; Berryman et al., 1965; Cumming, Berryman and Cohen, 1965; Farthing and Opuda, 1974). There was some evidence of savings however, since consistent above-chance levels of accuracy occurred earlier during transfer than during original training.

Finally, it should be noted that a transfer design such as the one employed in the present study may not be the most sensitive procedure for determining what pigeons learn in matching-to-sample experiments. This is suggested by data from the recovery phase which demonstrated that a performance

decrement can occur following a change in the stimuli used in a 3-key MTS paradigm even though the birds have learned to respond appropriately to the stimuli. It may be that other transfer procedures would be more likely to result in appropriate responding to "novel" stimuli. For example, responding to the original training stimuli could be intermittently reinforced and "novel" stimuli introduced as probe trials.

V. EXPERIMENT II

The preceding experiment failed to reveal any special role for physical identity of sample and correct comparison stimulus during the training, transfer and performance of discriminative behavior established via a higher-order conditional discrimination procedure. In the present experiment, stimulus control gradients were obtained by varying the angularity of the lines. The purpose of obtaining these gradients is to derive additional information with regard to the status of physical identity. Symmetrical gradients would be expected if physical identity played no role, whereas asymmetrical gradients could reflect a bias toward or away from the physically identical comparison stimulus, depending on the nature of the asymmetry.

V.1 Method

Subjects and Apparatus: The six pigeons that completed all phases of Experiment I served as subjects in this experiment. The apparatus is the same as that described for Experiment I.

Procedure:

Intermittent reinforcement. During this phase, sessions consisted of 288 trials (36 randomized blocks of the 8 different types of trials). One of every 4 of these trials was ran-

domly selected as a reinforcement trial. On reinforcement trials, a correct response was followed by 3 seconds access to mixed grain, while an incorrect response was followed by a 3 second blackout. The 72 reinforcement trials which occurred in a session consisted of 9 randomized blocks of 8 different types of trials. On regular trials, during which no reinforcement was available, a response to the side key (correct or incorrect) was followed immediately by an intertrial interval of 15 seconds. A similar intertrial interval was employed following reinforced trials. The background colors and superimposed line tilts used during this phase were the same as during original training in Experiment 1: Red and green lights and line tilts of 0° and 90° . Intermittent reinforcement was continued for 10 sessions prior to stimulus control testing.

Stimulus control testing. During stimulus control testing, 72 probe trials were added to the 288 trials of intermittent reinforcement. Every fifth trial was a probe trial. On these trials, one of 3 probe line tilts (22.5° , 45° or 67.5°) was presented along with a red or green light on the center key. A response to the center key resulted in illumination of the side keys with the same probe line tilt and appropriate color backgrounds. Following a response to a side key, all key lights were turned off and a 15 second intertrial interval began. Reinforcement was not available on probe trials.

The 72 probe trials consisted of 24 presentations of each of the 3 line tilts. Each probe line tilt was tested 6 times on each of the 4 different stimulus configurations of 2 colors. For each probe line tilt the proportion of responding to the matching color or mismatching color was determined. Stimulus control testing was conducted for 5 sessions.

V.2 Results

Intermittent Reinforcement. The overall accuracy of performance during the 10 sessions of intermittent reinforcement and the 5 sessions of stimulus control testing is presented in Figure 12. For subjects P1, P5 and P7 very high and stable levels of accuracy were maintained on both MTS and MMTS trials during intermittent reinforcement and stimulus control testing. For P4, P6 and P8 the accuracy levels were somewhat lower and more variable. In addition, these birds tended to show somewhat higher accuracy on MTS trials than on MMTS trials in a number of sessions during intermittent reinforcement. However, during stimulus control testing there was little accuracy difference between MTS and MMTS trials (i.e., less than 10%), except for P4 during session 5 of testing.

Since P4, P6 and P8 had lower levels of accuracy and more sessions in which MTS-MMTS accuracy differences were greater than 10%, a detailed analysis of responding was under-

FIGURE 12. Percent correct on MTS and MMTS trials for all birds during sessions of intermittent reinforcement and stimulus control testing.

taken. These data are presented in Figure 13. Note that for P6 the stimulus configuration in which green was the correct mismatching comparison on the right (RRG) contributed most to the overall difference between MTS and MMTS trials. For P8 and P4, the MTS-MMTS accuracy differences could not be attributed to any one mismatching configuration. Furthermore, even though birds, P6 and P8 have had extensive training on the discrimination there was still a tendency for positional responding to be evident in their data. That is, P6 generally performed more poorly on configurations in which the correct comparison stimulus was on the right key. The data for P8 revealed that as performance improved on trials in which the correct comparison was on the right key from sessions 5 to 9 there was a deterioration in performance on trials in which the correct comparison was on the left.

Stimulus control testing. Gradients of stimulus control for line orientation are presented in Figure 14. For birds P1, P5 and P7, an orientation of 90° from horizontal was correlated with reinforcement for responding to the mismatching color while 0° was correlated with reinforcement for responding to the matching color. This relationship was reversed for birds P4, P6 and P8. In Figure 14, the dependent variable is the percent choice of the comparison stimulus which is the same color as the sample stimulus (i.e., matching). This variable is plotted as a function of the angularity of the

DESIGNATION OF CORRECT COMPARISON STIMULUS FOR EACH STIMULUS CONFIGURATION	
○---RRG	△---RRG
○---GRR	△---GRR
○---GGR	△---GGR
○---RGG	△---RGG
POSITION } RIGHT ---, LEFT ----	
COLOR } RED (R) - UNSHADED	
GREEN (G) - SHADED	
PHYSICAL IDENTITY } MTS - CIRCLE, MMTS - TRIANGLE

SESSIONS

FIGURE 13. Choice behavior in the presence of each of the 8-stimulus configurations during sessions of intermittent reinforcement for birds P6, P8 and P4.

FIGURE 14. Gradients of stimulus control for line orientation.

line presented on all three keys. The figure shows for each bird that as the orientation correlated with reinforcement for matching responses on the color dimension was varied, there was a decreasing tendency to select the matching comparison. Only the gradient for P5 exhibited a slight departure from monotonicity. While these gradients were averaged over 5 testing sessions, they were still quite representative of the individual gradients obtained for each test session.

The averaged gradients for the two groups of birds are presented in the right hand panel of Figure 14. It can be seen that for both groups the greatest change in gradient slope was between orientations of 45° and 22.5° regardless of which orientation (i.e. 0° or 90°) was correlated with reinforcement for matching responses. The similarity in gradients for both sets of birds can be seen most clearly if the group functions are plotted in the same graph, in terms of the choice of the comparison stimulus which is appropriate for an angular orientation of 0° . This has been done in Figure 15.

Since the gradients may have been affected by the development of position preferences when probe stimuli were presented, an analysis of position bias to the left key in the presence of each probe stimulus was undertaken. The results of this analysis are presented in Table 9. In general, position preferences were very slight for all subjects regardless of the nature of the probe stimuli. According to the Bino-

FIGURE 15. Percent choice of the comparison stimulus appropriate to a 0° orientation as a function of angularity.

TABLE 9

PERCENT POSITION BIAS TO THE LEFT
 COMPARISON KEY FOR THE THREE
 PROBE STIMULI DURING STIMULUS
 CONTROL TESTING

Probe Stimuli	S U B J E C T					
	P1	P5	P7	P4	P6	P8
67.5°	45.0	44.6	52.5	45.0	55.0	38.4*
45°	55.0	54.7	59.2	53.7	57.5	40.8
22.5°	55.9	53.0	55.9	47.5	65.9*	48.4

NOTE: Value of 50±10% or more indicates a significant departure from no bias according to the Binomial Test (two-tailed).

*p<.05.

mial Test ($N=120$, $p=.5$; two-tailed), only two significant departures from no bias were found. P8 exhibited a moderate right key bias in the presence of the 67.5° probe, while P6 exhibited a moderate left key bias in the presence of the 22.5° probe.

V.3 Discussion

The present data reveal that very orderly gradients of stimulus control along the angularity dimension can be obtained by training pigeons in what might be termed a higher-order conditional discrimination procedure. These gradients fail to reveal a bias toward or away from the physically identical comparison stimulus, since the gradients for both groups of birds revealed the greatest slope change between 45° and 22.5° regardless of whether 0° was correlated with reinforcement for responding to the matching or mismatching comparison. It appears as if the birds in this study responded to orientations of 90° , 67.5° and 45° as belonging to one set and to orientations of 22.5° and 0° as belonging to another set.

In order to claim that a particular stimulus dimension controls behavior one must clearly show that changes in stimulus value along this dimension will result in changes in response probability (Terrace, 1966; Honig, 1970). Clearly, this study demonstrated that line orientation controlled the

tendency to select the matching or mismatching comparison. One might interpret the present results as supporting the suggestion that the pigeons' behavior was under stimulus control characterized by the following rule: if line orientation is 0° (or 90°) select the matching comparison, but if line orientation is 90° (or 0°) select the mismatching comparison. However, stating the nature of the stimulus control rule in this fashion is clearly misleading if it is taken to imply that line orientation controls a particular discrimination such as matching or mismatching. The previous study demonstrated that line orientation did not initially control appropriate responding to novel stimuli during the transfer phase. The data of both of the present studies can be parsimoniously interpreted as indicating the pigeons learned either a discrimination for each specific stimulus configuration or a set of specific stimulus-response chains based on compound stimuli in which the physical identity of sample and correct comparison stimulus played no special role. However, there was a tendency for less accurate performance on MMTS trials during the intermittent reinforcement phase of Experiment 2. This suggests the possibility that a role for physical identity of sample and correct comparison stimulus may be more readily observed if the difficulty of the task is increased.

VI. GENERAL DISCUSSION AND CONCLUSIONS

The purpose of the present research was to assess the role which physical identity of the sample and correct comparison stimulus plays in the discriminative behavior established by a matching-to-sample paradigm. While some research has failed to obtain differences between MTS and MMTS when the number of rules to be learned is equated (Zentall and Hogan, 1974; 1976), other research has reported differences in transfer and in susceptibility to drug effects (Nevin and Liebold, 1966). A within-subject design was employed in the present research to assess the role of physical identity. Pigeons were trained to perform a discrimination in which the rule for reinforcement could be described as involving a higher-order conditional discrimination. For example, if a vertical line was present on the response keys, then selection of the comparison stimulus which was the same as the color of the sample stimulus was reinforced, but if a horizontal line was present, then selection of the comparison stimulus which was different in color from the sample was reinforced. The stimuli used in this research were thus compounds of line tilt and color. As a result there were two different types of trials which allowed for assessment of the role of physical identity. On one trial type (MTS), the sample and correct comparison were similar on both the line tilt and color dimension, while on the other trial type

(MMTS), the sample and correct comparison were similar on the line tilt dimension but different on the color dimension.

In the first experiment, the acquisition, transfer and recovery of the discriminative behavior required by this experimental paradigm was studied. For some subjects, during acquisition and transfer there was a tendency for accuracy to be higher on one trial type than the other. A detailed analysis of the data revealed that these overall differences in accuracy were a result of either differences in the point at which correct responding began to develop to a specific stimulus configuration, or from interactions which occurred during the development of correct responding. During the recovery phase, subjects P4 and P6 exhibited consistently higher accuracy on MTS type trials than on MMTS type trials. However, a detailed analysis of their data for this phase revealed that this difference was primarily a result of poorer performance on one particular MMTS stimulus configuration. Since all birds did not reveal a sustained overall MTS-MMTS accuracy difference and since the MTS-MMTS accuracy differences that were observed were often specific to one particular stimulus configuration, it is not possible to conclude that physical identity of the sample and correct comparison stimulus played a significant role in this experiment. Data obtained during the intermittent reinforcement phase of the second experiment suggested that increasing the difficulty of

the task might increase the probability of observing an effect of physical identity. During the intermittent reinforcement phase of this experiment, birds P4, P6 and P8 exhibited a higher accuracy on MTS trials than on MMTS trials. However, it should be noted that this effect was not maintained during stimulus control testing. In addition, these 3 birds received training in which an orientation of 90° signalled MTS trials and 0° signalled MMTS trials. None of the birds, for which an orientation of 0° signalled MTS trials and 90° signalled MMTS, exhibited a significant overall MTS-MMTS accuracy difference during the recovery phase of experiment 1 or the intermittent reinforcement phase of experiment 2.

In the second experiment, very orderly gradients of stimulus control along the angularity dimension were obtained. These gradients failed to reveal a bias toward or away from the physically identical comparison stimulus, since the gradients for all birds revealed the greatest slope change between 45° and 22.5° regardless of whether 0° was correlated with reinforcement for responding to the matching or mismatched comparison.

Overall, the data of both experiment 1 and 2 suggest that physical identity between the sample and correct comparison stimulus does not play a significant role in the discriminative behavior established by a matching-to-sample paradigm.

This conclusion is similar to that reached by Carter and Eckerman (1975), however it differs from that reached by Cumming and Berryman (1965) and Nevin and Liebold (1966). Cumming and Berryman (1965) found differences in presolution behavior, in the rate of MTS and MMTS acquisition, and in the susceptibility of MTS and MMTS performance to disruption by sodium pentobarbital. The differences in presolution behavior were probably a result of above-chance accuracy by MMTS birds on session 1, with acquisition proceeding from this level as a result of repeated reinforcement for a mismatching response. In the present research, no differences in presolution behavior as a function of trial type were observed. The bias to respond to the mismatched comparison on session 1 of training in both the Cumming and Berryman (1965) study and the present study remains to be accounted for. This bias may be a result of pretraining procedures and extra center key pecks. However, further research is necessary to establish the reason(s) for the mismatching preference.

The differences in rate of acquisition of MTS and MMTS reported by Cumming and Berryman (1965) appears to be a result of the greater number of stimulus-response chains to be learned in a MMTS paradigm. Both the present research and that reported by Zentall and Hogan (1974) failed to demonstrate differences in the rate of MTS and MMTS acquisition when the number of stimulus-response chains is equated.

While the comparisons between MTS and MMTS performance made by Cumming and Berryman (1965) were based on independent groups of pigeons, both the present research and that of Nevin and Liebold (1966) allowed for a comparison based on a within-subjects design. The procedure employed by Nevin and Liebold (1966) did not permit a comparison of MTS and MMTS performance during acquisition. However, they did report that after 10 sessions of transfer to novel key colors, accuracy was higher on MTS trials than on MMTS trials. The present research failed to replicate this effect in all subjects. Only two (P5 and P6) out of six subjects showed such an effect during transfer. Thus, one cannot cite transfer results as reliable evidence for a special role of physical identity in matching-to-sample paradigms.

There remains some data which could still be used to support the contention that physical identity of sample and correct comparison has a special role in matching-to-sample paradigms. These data derive from studies by Berryman, Cumming, Nevin and Jarvik (1964) and Nevin and Liebold (1966). Both of these studies demonstrated that with increasing doses of sodium pentobarbital, MTS accuracy is reduced to a greater extent than MMTS accuracy. At present, these results cannot be accounted for. However, it would be worthwhile to examine the effects of sodium pentobarbital on the discriminative behavior established by the procedure employed in the present

research since it does not have the methodological weaknesses that were inherent in the Nevin and Liebold (1966) study.

The present research indicated that a change in one component (i.e. color) of the compound stimuli during transfer led to little evidence of generalization since accuracy fell to chance levels and reacquisition occurred with the novel colors. However, when a change in the other component (i.e. lines) of the compound stimuli was made during stimulus control testing, there was evidence of stimulus generalization since responding to these novel line tilts changed in an appropriate and orderly fashion. The birds did not revert to positional responding in the presence of novel stimuli during stimulus control testing. These data could be a result of any of the following: (i) the method by which stimulus generalization is assessed; (ii) the point at which stimulus generalization is assessed; and (iii) the stimulus dimension along which generalization is assessed. In order to determine which factor was responsible for the data obtained in the present research certain empirical studies could be undertaken.

Birds could be trained with red and green colors but then rather than substituting blue and yellow for red and green as in the transfer phase of the present research, a stimulus control testing procedure could be used. That is, the birds could be given intermittent reinforcement on trials involving red and green colors with probe trials on blue and

yellow inserted. If appropriate responding occurred on the probe trials involving novel stimuli, then it would appear that the method of assessing generalization was the critical factor.

A different design would be employed to assess whether the timing of generalization testing was critical. In this research, stimulus control testing on the line tilt dimension would be conducted immediately after initial training with the red and green colors. If stimulus control gradients similar to those obtained in the present research were found, then it would be clear that the present results were not simply due to the order in which transfer and stimulus control was assessed.

Finally, one could use color as the "instructional" stimulus dimension with "matching" or "mismatching" on the line tilt dimension. An examination of transfer on the angularity dimension as well as stimulus control testing along the color dimension would be helpful in determining whether there was some dimensional specificity to the effects observed in the present research. It may be even more advantageous to remove the "instructional" stimulus from the response key. For example, tones of varying frequency or the presence vs. absence of a tone could be used to signal matching vs. mismatching trials. This may decrease the probability that birds will learn the task by responding to compound stimuli.

While the experimental paradigm employed in the present research was developed primarily to examine the role of physical identity of the sample and correct comparison stimulus in matching-to-sample paradigms, it does bear a relationship to studies which attempt to teach animals to use instructional stimuli. The distinction between dimensional and instructional stimulus control has been made by Goldiamond and Dyrud (1968). While the former refers to control by a stimulus dimension over behavior, the latter refers to environmental control over which dimension controls behavior. From the experimenter's viewpoint all studies in this sphere involve conditional discriminations. For example, pigeons could be taught to peck or not peck at different key colors depending on the presence or absence of a vertical line or tone. The exact procedures vary from study to study but in all of the research reported thus far the "instructional" stimulus involves the control of a simple discrimination (Heineman, Chase and Mandell, 1968; Boneau and Honig, 1964; Yarczower, 1971; Wilkie, 1973; Born, Snow and Herbert, 1969). The present research differs from these in that, at the procedural level, the instructional stimulus involves control of a conditional discrimination.

Research involving the use of instructional stimuli has attracted two well-deserved criticisms. The first concerns the distinction between dimensional control and instruc-

tional control. Gilbert (1969) has argued that both forms of control are interrelated and that the kind of control which a dimension exhibits may only depend on the role of that dimension in the experimenter's definition of the situation. Because of this, there has been a tendency to use terms such as "stimulus control over stimulus control" (Gilbert, 1969) or "multi-dimensional stimulus control" (Wilkie, 1973) as opposed to instructional stimulus control. The second criticism directed toward this research relates to whether instructional stimulus control has been empirically demonstrated. Riley and Leith (1976) suggested that animals may merely be learning a number of simple habits to different compound cues in these paradigms. The data generated by the present discrimination procedure were also interpreted as indicating that the birds had learned simple responses to compound stimuli. Whether there are experimental procedures which would result in the kind of complex form of stimulus control that could be unambiguously interpreted as "instructional" is an open empirical question.

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