The relation between response and attentional shifts in pigeon compound matching-to-sample performance

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Pigeons' pecks to the two elements of spatially separated compound samples were observed during matching-to-sample performance. An attentional biasing procedure was used in which the birds were tested on a subset of the information contained in the sample (either one of the two dimensions or one of the two sample key locations) for a large number of sessions. This procedure resulted in a greater proportion of sample pecks to the positively biased (tested during biasing) sample attribute. Increases in accuracy on the positively biased attribute as well as decreases in accuracy on the negatively biased (not tested during biasing) attribute were also found. However, not all of the shifts in matching accuracy could be explained by the shifts in pecking behavior.

In the compound matching-to-sample (MTS) task, a sample stimulus is presented that contains information about which of the test stimuli is to be selected (pecked) in a subsequent two-alternative choice. A peck to the test stimulus that matches a dimensional value contained in the sample results in access to food reinforcement. During exposure to a typical compound sample, pigeons acquire information that allows them to perform accurately on tests in which a choice must be made between the two values of either of the dimensions (e.g., line orientation or color) contained in the sample. Research using this task has led to the hypothesis that pigeons divide a limited processing capacity between the dimensions of the sample stimulus or, under different conditions, selectively process one dimension at the expense of the other (see Riley, in press, Riley & Leith, 1976, and Riley & Roitblat, 1978, for reviews). A possible alternative to the central attentional mechanism that has been inferred from these experiments, however, is differential receptor or body orientation to the elements of the compound samples, at least when they are spatially separated. The present experiment examines whether overt receptor orientation is sufficient to account for changes in matching accuracy to the elements of the compound in a MTS pro-

cedure or whether a more central attentional process needs to be invoked.

Although it is difficult to directly assess where a pigeon is looking during the presentation of the sample, its pecking is easily observed. Since the mobility of pigeons' eyeballs in their sockets is very limited (Walls, 1942), it is very likely that pecking is a good indication of visual orientation. Thus, an understanding of the relationship between the spatial distribution of pecks and matching accuracy serves as an important step in understanding the mechanism of selective processing in conditional discriminations.

While pecking the discriminative cue is not necessary to control responding in some tasks (e.g., Wright & Sands, 1981), there is a large body of evidence suggesting that pecking the sample is accompanied by improved accuracy in matching tasks (e.g., Eckerman, Lanson, & Cumming, 1968; Maki, Gillund, Hauge, & Siders, 1977; Sacks, Kamil, & Mack, 1972). However, while increases in the sample FR requirement in MTS are accompanied by increases in matching accuracy, it is not clear to what extent this effect is actually due to increases in sample duration which typically correlate with higher FR requirements, rather than to the number of pecks per se (Maki et al., 1977). In any case, sample pecking may reflect important receptor orienting behavior and possibly more central processes.

Two recent findings make an understanding of the role of peck location in compound MTS particularly important. First, we have found that increasing the spatial separation of the two elements of a compound sample increases the selective processing of the elements by pigeons (Cook, Riley, & Brown, 1982; Lamb & Riley, 1981). If pecking directed at the to-be-matched stimulus facilitates matching perfor-

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mance, then the effect of spatial separation may be a function of an increased difficulty of pecking both elements when they are spatially separated, resulting in decreased performance on both elements (Lamb & Riley, 1981) or good performance on one dimension and poor performance on the other (Cook et al., 1982). Second, Lamb and Riley (1981) observed that compound samples that are configured such that both dimensional elements are contained within the same stimulus event (e.g., a colored line of some orientation) are matched at a level that approaches or equals element samples. This effect might be due to the fact that, for such samples, a single stimulus can be observed (pecked) that contains information about both dimensions.

The following experiment was designed to reveal whether changes in the distribution of pecks to the elements of compound samples can account for changes in matching accuracy on those elements. The locations of pecks on the sample key were recorded, and matching accuracy was measured under baseline conditions, with tests occurring from both sample dimensions, as well as during a biasing procedure similar to that used by Leith and Maki (1975). The biasing consisted of prolonged training phases in which birds received tests on a subset of the information contained in the sample and no tests on the remaining subset. Such biasing, if Leith and Maki's results were repeated, would result in an increase in accuracy on the sample attribute tested during the biasing treatment, accompanied by a decrease in accuracy on the attribute that was never tested during the biasing procedure, when measured subsequent to biasing.

Comparisons of matching accuracy before and after biasing, when only trials with similar or equivalent numbers of pecks to the relevant sample attributes are compared, would reveal whether such changes in matching accuracy occur without corresponding shifts in the distribution of pecks to the sample attributes. If changes in matching accuracy are directly indexed by changes in sample pecking behavior, there should be no differences in accuracy before and after biasing when comparisons are restricted to trials with equivalent sample pecking behavior. If, however, accuracy shifts are at all independent of changes in sample pecking location, then increases in accuracy on the biased attribute, and decreases on the untested attribute, would be expected even when only trials with similar sample pecking behavior are compared.

METHOD

Subjects

The subjects were two Silver King pigeons (No. 45 and No. 46) that had had extensive experience with the stimuli used (see Lamb & Riley, 1981). They were maintained at 75% of their free feeding weights and had access to water and grit in their home cages.

Apparatus

The experiment was conducted in a three-key operant chamber measuring 37.7 cm in height, 31.2 cm in depth, and 36.4 cm across the front and back walls. The inside of the chamber was painted flat black, with the exception of one Plexiglas side wall, which served as the door. A hole (approximately 6.5 cm square) was cut in the top of the chamber so that the birds could be observed by the experimenters. The keys (BRS/LVE Model 121-16) were 23.4 cm above the wire mesh floor. The center key measured 3.3 cm square. The round side keys were 2.6 cm in diameter, and their distance from the center key (center to center) was 10.4 cm. The food hopper (BRS/LVE Model 1110) opening, through which the subjects received mixed grain reinforcement, was 6.5 cm square and 15.6 cm below the center key. Stimuli were back-projected onto the keys by Kodak slide projectors (Model E-2) through a series of beam splitters and lenses. The onset and offset of stimuli on the center key was accomplished with high-speed shutters (Uniblitz Model 214LOA0T5H), with rise and fall times of 1.3 and 2.3 msec, respectively. Stimuli on the side keys were presented using Uniblitz Model 26LOA3X5 shutters, with rise and fall times of 1.6 and 2.6 msec, respectively. The apparatus was in a windowless room that had been painted flat black. A Data General Nova-2 computer, located in an adjacent room, controlled experimental events and collected accuracy data.

Stimuli

All the samples were compound stimuli, equivalent in form, but slightly larger than those used in the "Far" condition of Lamb and Riley (1981). They consisted of a line element and a color element, presented on the center key, one in the upper-left corner of the center key and the other in the lower-right corner (hereafter referred to as "upper" and "lower" quadrants, respectively). The line element was composed of three $.6 \times .12$ cm parallel white lines separated by .12 cm (edge to edge). On half of the trials, these lines were oriented vertically, and on the other half, they were oriented horizontally. The color element was a $.6 \times .6$ cm square that was red (Kodak wratten filter No. 24) on half of the trials and orange (Kodak wratten filter No. 16) on the other half. Thus, on any given trial, the sample had one of two values on each of the dimensions of color and line orientation. The elements were .6 cm from the two closest edges of the key and were separated from each other by 2.1 cm (center to center). Test stimuli consisted of one element, which was proportional but 2.5 times as large as the sample elements and centered on the test key. Thus, the color test stimuli were 1.6 cm square, and the line tests were three $.3 \times 1.5$ cm lines separated by .3 cm.

Procedure

The birds were not run for several months following the conclusion of the experiments reported in Lamb and Riley (1981). In preparation for the present experiment, the birds were retrained in the compound MTS procedure.

The sequence of trial events in this retraining and in the experiment was as follows. Each trial began with the illumination of the center key by a white light. This warning signal remained on for 10 sec or until a single peck. If no peck occurred, the trial was initiated again after a 10-sec ITI. Following a peck to the warning signal, the sample stimulus was presented; it remained on for 20 pecks (FR 20). Completion of the FR requirement extinguished the sample, and the test stimuli were then immediately presented on the two side keys. A single peck to the test key that matched a value presented in the sample resulted in 1.8-sec access to mixed grain. Test stimuli remained on for 5 sec from onset if an incorrect response or no response occurred. The trial was repeated if there was no response. On any given trial, both test stimuli were from the same dimension. The tested dimension was varied randomly from trial to trial, as were the location of the dimensions on the sample key (upper or lower quadrant) and the side (left or right) of the correct test key, with the constraint that equal numbers of all possible trial types be presented in each 32-trial block.

In preparation for the experiment, the birds first matched line elements, with the key location of the line alternating between sessions. Five blocks per day were presented. After a performance criterion of 85% correct for 3 consecutive days had been attained for each key position, sessions of color samples were presented on alternate days, with the location of the color element constant within a session but alternating between color sessions. After the same criterion was met for both line and color sessions, the elements were no longer presented and the sessions consisted only of the compounds to be used in the experiment. Five blocks per day were run for 5 days, followed by 20 days of sessions containing three blocks. During the experimental phases described below, the birds received two blocks per session, and one session per day, unless otherwise noted.

The experiment consisted of two phases. During each phase, the birds were first given sessions containing tests from both dimensions and both sample key quadrants ("baseline sessions"). These were followed by sessions in which tests always came from only one dimension, or from the dimension occupying one of the sample key quadrants ("biasing sessions"). The attribute (color, line, or one of the two quadrants) biased in each case was chosen to be the one that the bird pecked at the least during the preceding baseline sessions. The series of biasing sessions was followed by three baseline sessions. The sequence of experimental conditions is summarized in Table 1.

The birds first received three baseline sessions. Two of the experimenters observed sample pecking behavior through the opening in the top of the chamber. The sample key was divided into four equal quadrants for the purposes of these observations, two of which were the upper-left and lower-right quadrants in which the sample stimuli were presented and two of which never contained stimuli (the upper-right and lower-left quadrants). The set of all quadrants pecked, as well as the one quadrant that was the target of the largest number of pecks, was judged by each of the observers. Trials on which only one of the elements was pecked were termed "simple" response trials. Those on which both elements received one or more pecks, were termed "complex" response trials. In either case, the observers judged which of the key quadrants received the majority of pecks. This quadrant was defined as "dominantly pecked." The observers were chosen unsystematically from among the four experimenters during biasing sessions, although the observers and dyads of observers were counterbalanced over the baseline sessions.

The baseline sessions were followed by biasing sessions during which tests of only one dimension, or the information contained in only one of the two key quadrants, occurred. Dimensional values and sample key quadrants are referred to as sample "attributes" in what follows. The sample attribute tested during the biasing sessions of a phase is referred to as the "positively biased" attribute, and the attribute not tested is referred to as the "negatively biased" attribute.

During the biasing sessions of Phase 1, one bird (45) was tested only on the line dimension, although the sample contained both color and line values. Bird 46 was tested only on the dimension that appeared in the lower quadrant of the key. Thus, it received either dimension of test, with the dimension tested on a given trial determined by the position of the stimulus elements on the sample key. Bird 45 received 54 days of biasing with two blocks per day, except for Days 22-49, during which it was given four blocks per

day due to the slow rate at which both its accuracy and pecking behavior changed. Bird 46 received two blocks per day for 50 days. The pecking behavior of the birds was observed by one observer for the first 30 and last 3 days of biasing. During the period in which Bird 45 was given four blocks per day, only the last two blocks were observed.

The biasing sessions were followed by three baseline sessions. This allowed for an evaluation of the effects of biasing on accuracy on the attribute that had not been tested during biasing. The pecking behavior of the birds was observed by two observers during these sessions.

Following the completion of Phase 1, the subjects were retrained in the baseline condition for two blocks per day until their performance appeared to have stabilized (approximately 40 days). The birds were then observed for three baseline sessions. This was followed by 51 sessions of biasing, during which Bird 45 received tests only on the dimension appearing in the upper quadrant. Bird 46 received tests only on the color dimension. The birds were observed by a single observer approximately every third session during biasing, except for the final three consecutive sessions, which were observed by two observers. Three baseline sessions followed, with two observers each session.

RESULTS

Interrater Reliability

Interrater agreement for each two-observer session was determined for two measures of pecking behavior: the set of quadrants containing stimuli that received pecks and the quadrant that received the most pecks. During the first baseline phase, the observers agreed on 96% of the trials on which quadrant received the most pecks. For Bird 45, the range was 98% to 100%, and for Bird 46 the range was 84% to 100%. The observers agreed 93% of the time (ranges—Bird 45, 86%-100%; Bird 46, 84%-100%) on which of the two quadrants containing stimuli received any pecks. Interrater reliability was similarly high for the other sessions using two observers. Because of the high interrater reliability scores, the pecking behavior data for each day are those of only one observer, determined randomly with the constraint that each observer's judgments be used in proportion to the number of sessions he had observed.

Initial Baseline Results

The analyses we report (with the exception of the last analysis) include both simple response trials (on which only one quadrant was pecked) and complex response trials (on which more than one was pecked). Thus, the trials were categorized in terms of pecking behavior according to which sample attribute was dominantly pecked on a given trial. Initially, we report analyses of performance during the three pre-biasing baseline sessions of Phase 1. These are of special interest because they are uncontaminated by the biasing procedure. Virtually all pecks were directed to the quadrants containing stimuli. Bird 45 directed a majority of its sample pecks to the lower quadrant during 65% of the trials, whereas Bird 46 pecked the upper quadrant dominantly on most trials (89%). Both birds pecked the color element of the com-

Table 1
Sequence of Experimental Procedures

Phase 1				
Bird 45	Baseline	Line Biasing	Baseline	Retraining
Bird 46	Baseline	Lower Quad Biasing	Baseline	Retraining
Phase 2				
Bird 45	Baseline	Upper Quad Biasing	Baseline	
Bird 46	Baseline	Color Biasing	Baseline	

pound dominantly on the majority of the trials (Bird 45, 85%; Bird 46, 61%).

Percentage correct for each 32-trial block was calculated for each of two trial types, (1) those on which the tested attribute had been dominantly pecked, and (2) those on which the tested attribute had not been dominantly pecked. Table 2 shows the percent correct for color and line tests as a function of whether or not the tested sample attribute had been dominantly pecked. An analysis of variance (ANOVA) (dimension of test $\times$ pecking behavior $\times$ subjects) was conducted on these scores. In this and all other ANOVAs reported, the residual error term was used. Differences in degrees of freedom for similar ANOVAs are due to missing cells. The analysis confirmed that accuracy was higher when the tested dimension had received the majority of sample pecks than when it had not [$F(1,40)=21.5$, $p < .001$]. Matching accuracy was higher on color tests than on line tests [$F(1,40)=11.7$, $p < .01$]. The main effect of subjects was not significant, nor were any interactions ($ps > .05$), although visual inspection of the data suggests that both birds performed above chance on color tests, but not on line tests, when the tested element was not dominantly pecked.

Effects of Biasing

In the following section, data from the biasing procedures are described. The effect of biasing is examined in subsequent sections by comparing behavior before and after biasing.

Biasing sessions. Figure 1 shows pecking behavior and matching accuracy during biasing. Bars display the percentage of trials on which the positively biased attribute was dominantly pecked. Matching accuracy on the positively biased attribute is shown separately for those trials on which it had been dominantly pecked during sample presentation and those trials on which it had

Figure 1. Matching-to-sample accuracy and distribution of sample pecking during the biasing sessions of the experiment. Bars indicate the percentage of trials on which the biased attribute was dominantly pecked. Filled circles show matching accuracy when the testing attribute was dominantly pecked. Open circles are from trials with dominant pecking to the other sample attribute. Phase 1 data are shown in blocks of six sessions, except for the last block, which is from the three sessions prior to the termination of biasing. There were 21 days of biasing before the final block for Bird 45 and 17 days for Bird 46 which are not represented because of the lack of pecking-behavior data. Phase 2 data are shown in blocks of 4 observation days, each of which represents approximately 12 days of biasing, with the exception of the last block, which consists of the final 3 consecutive days of biasing.

not. In the case of Bird 45 in Phase 1, for example, the bars refer to the percent of trials on which lines (the positively biased attribute), as opposed to color, was the dominantly pecked dimension of the sample, the filled circles show matching accuracy on line tests when line was the dominantly pecked sample attribute, and the open circles show accuracy on line tests when the bird had pecked dominantly at color. In general, the proportion of sample pecking directed at the positively biased attribute, as well as matching accuracy on that attribute, increased over the course of biasing.

Pecking behavior. In order to evaluate the effect of biasing on pecking behavior, pecking behavior during the baseline sessions preceding biasing was compared with pecking behavior during the baseline sessions following biasing. Differences in the percentage of trials on which the biased attribute was dominantly pecked before and after biasing can be seen in Figure 2. For each bird, an ANOVA (pre- vs. postbiasing $\times$ phase) was conducted, using the percentage of trials in each 32-trial block on which the biased attribute was dominantly pecked. Bird 45 dominantly pecked the biased dimension on a greater proportion of trials following biasing than it had before [$F(1,20)=492.1$, $p < .001$]. There was an interaction between the biasing effect and phase [$F(1,20)=4.5$, $p < .05$], the result of biasing having a greater effect in Phase 2. Analyses of simple main effects confirmed that the increases in pecks to the biased attribute was significant for both Phase 1 [$F(1,20)=201.4$, $p < .001$] and Phase 2

Table 2
Matching Accuracy During Initial Baseline Sessions

	PC	n	PC	n
	Simple Responses			
	Pecked		Not Pecked	
Bird 45				
Color	92	77	79	14
Lines	79	14	53	76
Bird 46				
Color	98	48	50	12
Lines	73	15	47	49
	Complex Responses			
	Pecked Dominantly		Pecked Nondominantly	
Bird 45				
Color	100	5		0
Lines		0	33	6
Bird 46				
Color	92	12	92	24
Lines	65	23	44	9

Note—PC = percent correct.

Figure 2. Changes in sample pecking as a result of biasing. The percentage of trials on which the biased attribute was dominantly pecked is shown before and after the biasing sessions.

[$F(1,20) = 295.1$, $p < .001$]. Bird 46 also pecked more at the biased attribute following biasing [$F(1,20) = 107.5$, $p < .001$], with the effect of biasing greater in the second phase than in the first [$F(1,20) = 23.0$, $p < .001$]. Again, analyses of simple main effects revealed that the increases were significant in both phases [Phase 1, $F(1,20) = 15.5$, $p < .001$; Phase 2, $F(1,20) = 114.8$, $p < .001$].

Matching accuracy. Figure 3 shows matching accuracy before and after biasing as a function of biasing treatment and pecking behavior. In general, the closed circles joined by solid lines lie above the open circles joined by solid lines; the same holds true for the closed and open circles joined by dotted lines. This confirms the correlation between sample pecking and matching accuracy seen in the initial baseline phase. The other obvious effect shown in Figure 3 is that the solid lines, representing matching accuracy on the positively biased dimension, rise from pre- to postbiasing, whereas the dotted lines, representing accuracy on the negatively biased attribute, fall. These facts are summarized in the statistical analyses that follow.

An ANOVA was performed on the data of each bird for each phase using percent correct during the 12 pre- and postbiasing blocks. These analyses compared matching accuracy before biasing with accuracy following biasing (pre vs. post). In addition to this factor, accuracy when the tested dimension was dominantly pecked during sample presentation was compared with accuracy when it was not dominantly pecked (pecking) and accuracy on the positively biased dimension was compared with accuracy on the negatively biased dimension (biasing). Thus, a differential effect of biasing on matching accuracy for the positively and negatively biased sample attributes would be revealed by a pre vs. post $\times$ biasing interaction.

The F ratios obtained in these ANOVAs are shown in Table 3. The two most important effects are the

main effect of pecking and the interaction between the factor of pre vs. post accuracy and biasing. As can be seen, in three out of four cases, accuracy was higher when the tested dimension received the majority of pecks than when it did not. In all four cases, a significant pre vs. post $\times$ biasing interaction was obtained, due to the decreases in accuracy on the negatively biased attribute and/or the increases in accuracy on the positively biased attribute seen in Figure 3.

Analysis of simple response trials. A theory that attributed the changes in matching accuracy produced by biasing to changes reflected by pecking behavior would predict no changes in accuracy when trials with equivalent pecking behavior were compared. The fact that accuracy changes as a result of biasing for the various trial types shown in Figure 3 argues against such a theory. Thus, the data contain support for attentional effects that cannot be attributed to changes associated with pecking behavior. However, because of the nature of our measure of pecking behavior (most and least frequently pecked), we cannot say with precision whether these changes are independent of changes in the relative frequency of pecks to the relevant quadrants. For Bird 46 in Phase 1, for example, the increase in matching accuracy on the dimension shown in the lower quadrant, even when the upper quadrant was dominantly pecked (open circles joined by solid line), might be related to an increase in lower quadrant peck frequency from a very low proportion (say, 0, 1, or 2 pecks in 20) to a moderate rate (say, 7, 8, or 9 pecks in 20). Even so, the trial would have been categorized the same in both cases.

Figure 3. Changes in matching accuracy as a result of biasing. Percent correct is shown before and after biasing. Solid lines connect scores for the positively biased attribute. Dashed lines connect scores for the negatively biased attribute. Filled symbols represent trials on which the tested attribute was dominantly pecked during sample presentation. Open symbols represent trials on which the tested attribute was not dominantly pecked.

Table 3
F Ratios for Analysis of the Effects of Biasing on Matching Accuracy

Effect	Phase 1		Phase 2	
	Bird 45 F(1,39) =	Bird 46 F(1,35) =	Bird 45 F(1,39) =	Bird 46 F(1,38) =
Pre vs. Post	1.1	3.0	0.0	0.5
Biasing	0.0	38.2†	3.5	19.2†
Pecking	41.9†	30.2†	10.6**	0.1
Pre vs. Post × Biasing	4.7*	4.9*	6.9*	9.8**
Pre vs. Post × Pecking	1.5	21.9†	1.0	4.7*
Pecking × Biasing	0.2	3.3	0.1	0.0
Pre vs. Post × Biasing × Pecking	0.5	0.9	0.5	0.0

* $p < .05$. ** $p < .01$. † $p < .001$.

A stronger test of the role of pecking behavior in changes in matching accuracy comes from an examination of a special class of trials, namely, those on which only one of the quadrants containing stimuli received any pecks. Since the pecking behavior of the birds is more precisely known in the case of these simple response trials, they allow for comparisons of pre- and postbiasing accuracy that are relatively unaffected by changes in pecking behavior. Pre- to postbiasing accuracy changes theoretically could be examined for four trial types: (1) trials on which the positively biased attribute received all 20 sample pecks, (2) those on which it received no sample pecks, (3) trials on which the negatively biased attribute received all 20 sample pecks, and (4) trials on which it received no pecks. However, because the positively biased attribute was chosen to be the one which the bird pecked least, there were very few trials on which it was pecked exclusively prior to biasing. Similarly, there were very few trials on which the negatively biased attribute received no pecks prior to biasing. Therefore, statistical analyses of changes in accuracy on simple response trials could be performed only on trials on which the positively biased attribute was tested after receiving no pecks and trials on which the negatively biased attribute received all 20 sample pecks. Table 4 shows pre- and postbiasing accuracy on simple response trials when the positively biased attribute was tested after receiving no sample pecks. Table 5 shows corresponding data for trials on which the negatively biased attribute was tested after receiving all 20 sample pecks. Inspection suggests that performance shifts for these simple response trials depend on whether a key location or a dimension served as the biased attribute.

ANOVAs were performed on simple response trial accuracy data using the percent correct scores from the three prebiasing sessions and the three postbiasing sessions. The two levels of the treatment factor were: accuracy on the positively biased attribute when it was not pecked at all and accuracy on the negatively biased attribute when it was pecked exclusively. Because of the scarcity of simple response trials, and the apparent difference between positional and dimensional biases, the data for both positional

biases (Bird 45 in Phase 2 and Bird 46 in Phase 1) were combined, as were the data from dimensional biases (Bird 45 in Phase 1 and Bird 46 in Phase 2). This resulted in an approximately equal contribution of scores from each bird and each phase.

A treatment × pre vs. post × bias type (positional or dimensional) ANOVA revealed a significant triple interaction [$F(1,40) = 14.5$, $p < .001$] due to the fact that there was a treatment × pre vs. post interaction only in the case of the positional biases. This was confirmed by separate treatment × pre vs. post ANOVAs performed for each bird in each phase. There was a treatment × pre vs. post interaction, due to an increase in performance on the positively biased attribute when it was not pecked and/or a decrease in performance on the negatively biased attribute when it was pecked, for Bird 46 in Phase 1 [$F(1,8) = 85.5$, $p < .001$] and for Bird 45 in Phase 2 [$F(1,8) = 13.7$, $p < .01$], but not for Bird 45 in Phase 1 or Bird 46 in Phase 2.

DISCUSSION

The data suggest four conclusions. (1) Pecking at an element of a compound stimulus is accompanied by improved matching accuracy on tests of that element. (2) Extended testing on a subset of the information contained in the sample results in an increase in pecking at the biased attribute. (3) Such biasing results in increased matching accuracy on the positively biased attribute as well as decreased accuracy on the negatively biased attribute. (4) At least in the case of positional biasing, some of the changes in matching accuracy occur without corresponding changes in the distribution of sample pecks.

The results demonstrate a relationship between the location of pecking and accuracy in MTS; accuracy is higher when pigeons are tested on the attribute that received the majority of pecks during sample presentation. This fact, which is generally true before, during, and after biasing, is consistent with the view that more pecks (in the form of higher sample FR requirements) produce better retention (Maki et al., 1977; Sacks et al., 1972). However, since the present finding is correlational in nature, the data do not rule

Table 4
Accuracy on the Positively Biased Attribute Before and After Biasing on
Trials With No Pecks to the Positively Biased Attribute

Subject	Positively Biased Attribute	Prebiasing PC	Postbiasing PC
Phase 1			
Bird 45	Lines	52.6 (n = 76)	54.3 (n = 35)
Bird 46	Lower Quad	49.1 (n = 59)	100.0 (n = 14)
Phase 2			
Bird 45	Upper Quad	62.6 (n = 83)	85.0 (n = 20)
Bird 46	Color	87.5 (n = 64)	82.3 (n = 17)

Note—PC = percent correct.

Table 5
Accuracy on the Negatively Biased Attribute Before and After Biasing on
Trials With Pecking Exclusively to the Negatively Biased Attribute

Subject	Negatively Biased Attribute	Prebiasing PC	Postbiasing PC
Phase 1			
Bird 45	Color	92.2 (n = 77)	82.9 (n = 35)
Bird 46	Upper Quad	92.1 (n = 59)	63.2 (n = 14)
Phase 2			
Bird 45	Lower Quad	96.1 (n = 77)	69.2 (n = 26)
Bird 46	Line	69.5 (n = 59)	72.2 (n = 18)

Note—PC = percent correct.

out the contribution of other factors. For example, higher matching accuracy on a particular dimension results in stimuli of that dimension's being followed by food more often than are stimuli of the other dimension. As is well known, when a stimulus element is consistently paired with a greater probability of reinforcement than are other elements, that element is pecked more often (e.g., Jenkins, 1973; Hearst & Jenkins, 1974). Roberts and Grant (1978) have argued that such elicited pecking plays a role in MTS.

Either or both of these factors could have played a role in the changes in pecking behavior that resulted from the biasing treatments. One explanation for these changes is that pecking a stimulus element increases retention of that stimulus element, thereby increasing matching accuracy. During biasing, pigeons respond to the contingency between increased pecking to the positively biased attribute and increased matching accuracy by increasing the proportion of sample pecks to that attribute. On the other hand, biasing produces large changes in the stimulus-food pairings described above. When a bird was biased to color, for example, only color test stimuli preceded the delivery of food. It is reasonable to assume, therefore, that color test stimuli became conditioned stimuli in the same way that signals in an autoshaping procedure do (Brown & Jenkins, 1968). Since the elements of the sample from the positively biased dimension differed only in size from the corresponding test stimuli, generalized pecking to the elements of that dimension might be expected. In the

case of positional biasing, the description of such hypothesized conditioned stimuli is more complex. All four dimensional elements are pecked more when they appear in the positively biased key location and less when they appear in the negatively biased location. Consequently, each CS would have to be described as a compound of the dimension appearing on the test keys and the location of its value on the preceding sample key.

Although biasing did result in an increase in pecking at the positively biased attribute, these changes in pecking behavior were not necessary for the observed changes in matching accuracy. Evidence for this conclusion comes from the increases in performance on the positively biased attribute, and corresponding decreases in performance on the negatively biased attribute, as a result of biasing, even when only trials with similar (all trials) or equivalent (simple response trials) pecking distributions are compared. The strongest evidence comes from the shifts in matching accuracy, as a result of biasing, on trials with all 20 sample pecks to the negatively biased (and tested) attribute and trials with no pecks to the positively biased (and tested) attribute.

The changes in accuracy observed show that some factor other than changes in the location of pecks must be responsible for at least some of the accuracy changes that resulted from biasing. One might imagine a pigeon pecking at one key quadrant while "looking" at the other, but, if true, this probably would not involve eye movements, given pigeons' lack of

eye socket mobility (Walls, 1942). Orienting to the positively biased attribute could conceivably occur prior to or in between pecks, although evidence from analyses of pigeons' pecking topographies suggest that at least two fixations are directed at the to-be-pecked stimulus prior to a peck (Goodale, 1983). Of course, some minimal amount of visual information must be obtained from sample attributes in order for them to be matched above chance. Thus, our subjects must have obtained information about attributes which they did not peck. The important point is that differences in the distribution of sample pecks are not sufficient to explain the differences in observed matching accuracy before and after biasing. Although it is possible that changes in more subtle forms of behavior, not measured by the present method, are responsible for the changes in matching accuracy, a more central attentional mechanism may provide a more parsimonious explanation for these data. For example, selection may occur at a memory encoding stage, which occurs after the detection and identification of stimuli and which is independent of receptor orientation. Whatever the nature of the attentional mechanism, our data indicate that "pecking at" and "attending to" are not identical. Increases in pecking at and attending to stimulus elements often occur together, but they need not. This conclusion is similar to that of Schrier and Povar (1982), who showed that visual scanning of stimuli during discrimination learning by monkeys, beyond that necessary to fixate on the stimulus, is helpful but not necessary for learning.

The data suggest that attentional shifts are more independent of shifts in sample pecking when attention is biased to a location on the pecking key than when attention is biased to a dimensional component of the sample. It is interesting to note that in the case of positional biases, it is possible to determine the location of the relevant (positively biased) attribute before it is actually presented on the key. This is not true for dimensional biases. On the other hand, there are only two possible correct test stimuli during dimensional biasing (the two values of the positively biased dimension), whereas four correct test stimuli are possible in the case of positional biases. The role of these variables in producing attentional effects deserves further study.

The present results confirm and extend those of Leith and Maki (1975), who also presented pigeons (experienced with matching both color and line orientation) with tests on only one of the two dimensions for extended periods of time and then reintroduced tests on the other dimension. They found decreased accuracy on the dimension not tested during biasing relative to elements from that dimension. Although their data were interpreted as indicating shifts in attention to the positively biased dimension, an alternative interpretation is possible. This hypothesis

would assume that the long-term "matching rules" (cf. Carter & Werner, 1978) that control test responding for the negatively biased attribute of the compound are forgotten as a result of disuse during the biasing procedure. For example, during line biasing, the bird may lose matching rules of the form "if the sample contained red, then peck the red test key" and "if the sample contained orange, then peck the orange test key." Alternatively, the long-term associations necessary for the use of "prospective" or "instructional" coding of information (see Grant, 1981; Riley, Cook, & Lamb, 1981) may be lost. However, the attentional shifts found in the present experiment in the two cases in which a key position rather than a dimension was biased are much harder to explain as the loss of such matching rules. These changes in matching accuracy cannot be attributed to a process that depends on the loss of long-term information about the relationship between values on a dimension and the correct comparison stimulus, since both dimensions were tested equally often during biasing. The present procedure demonstrates shifts in attention to a location on a pecking key, even though it is the contents of that location, rather than the location itself, that provides useful information.

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