CONDITIONAL DISCRIMINATION WITH AMBIGUOUS STIMULI

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Five pigeons learned a two-key conditional discrimination. When background color on both keys was red, pecks on the key with a horizontal line produced food. When the color was green, pecks on the key with a vertical line produced food. During part of the experiment, color was presented on only one of the keys. It was found that accuracy was higher when color was combined with the line stimulus correlated with nonreinforcement. In another part of the experiment, color was presented on both keys but a line was present only on one. Accuracy was higher when the line accompanied the nonreinforced option than when the line accompanied the reinforced option. Superior performance when the combined stimuli were displayed on the nonfood key may be explained by the association of different components of the compound stimuli with reinforcement or as the result of rules pigeons follow in solving conditional discriminations.

Key words: conditional discrimination, ambiguous stimulus, key peck, pigeons

It is clear that subjects' discriminations between simultaneously-present stimuli can be based either on approach of the positive stimulus or on avoidance of the negative stimulus, or both. Experimenters have sometimes sought to assess these potentially operative relations through the use of ambiguous stimuli. The procedures in those experiments have consisted of two types of trials: In one type, the positive stimulus was contrasted with (or presented opposite) the ambiguous stimulus; in the other type, the negative stimulus was contrasted with (or presented opposite) the ambiguous stimulus. The ambiguous stimulus was the same regardless of which of the other stimuli made up the second member of the pair. Responses on the positive stimulus were reinforced on "positive vs. ambiguous" trials, and responses to the ambiguous stimulus were reinforced on "negative vs. ambiguous" trials.

Most of the original research on this problem was done with primate subjects. It soon became apparent that the results of these studies depended on the stimuli that were used. When primates chose between stereometric objects, they always performed more accurately on negative vs. ambiguous trials than on positive vs. ambiguous trials (Boyer & Polidora,

1972; Boyer, Polidora, Fletcher, & Woodruff, 1966; Fletcher & Garske, 1972; Fletcher, Grogg, & Garske, 1968; Leary, 1958), but when two-dimensional stimulus displays were used, accuracy was better on positive vs. ambiguous trials (Boyer et al., 1966; Fletcher & Bordow, 1965; Thompson, 1954).

More recently, there have been several experiments with pigeons as subjects. Richards (1973) conditioned pigeons to make a two-key discrimination in which the positive, negative, and ambiguous stimuli were all uniform colored fields. He found accuracy was better on negative vs. ambiguous than on positive vs. ambiguous trials. In a second study, Richards and Marcattilio (1975) reinforced every correct response during positive vs. ambiguous trials and varied the number of correct responses required for reinforcement on negative vs. ambiguous trials. Once again, they found that when all correct responses were reinforced, pigeons showed better discrimination on negative vs. ambiguous trials. However, when a ratio requirement was introduced on negative vs. ambiguous trials, all subjects eventually responded more accurately on positive vs. ambiguous trials.

The most recent work with pigeons was done by Hall (1980). He was able to show that accuracy could be better on either positive vs. ambiguous or negative vs. ambiguous trials, depending on the type of ambiguous stimulus

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used. When a horizontal line was the positive stimulus, a vertical line the negative stimulus, and a uniform red field the ambiguous stimulus, discrimination was best on positive vs. ambiguous trials. In a second experiment, the same positive and negative stimuli were used, but a cross was the ambiguous stimulus. The pigeons then showed better discrimination on the negative vs. ambiguous trials.

Just as the ambiguous-stimulus procedure has been used in the study of simple choice discrimination, this technique has also been used to examine conditional discrimination. In the original conditional-discrimination procedure introduced by Lashley (1938), the conditional stimulus was presented as a background for the choice stimuli. There were two stimuli present on every trial. Rats served as subjects; their jumping at an inverted triangle on a black background was reinforced, but jumping at an upright triangle on a black background was not. When a striped background was used, choosing the upright triangle was reinforced, and choosing the inverted triangle was not. It is clear that in problems of this kind, a display of either the positive or negative compound on one side and only the background (i.e., ambiguous) stimulus on the other could be sufficient for accuracy to be maintained. It also may be possible for a subject to maintain accuracy when both choice stimuli are shown but when the conditional, or background, stimulus is presented with only one of them. If accuracy were maintained only when the positive stimulus compound was present, it would show that the subject was simply discriminating presence vs. absence of this stimulus compound. On the other hand, if the subject solved the conditional discrimination when only the negative stimulus compound was present, it would indicate that the discrimination was based on presence vs. absence of the negative stimulus compound. If accuracy were maintained under both conditions, it would indicate that subjects could discriminate the presence or absence of either stimulus compound.

Carter and Werner (1978) recently reviewed the literature describing conditional discriminations in pigeons. They pointed out that the most common procedure for studying conditional discrimination is matching to sample, which differs in many ways from Lashley's (1938) original method. However, they con-

cluded that on the basis of the published data it seemed that pigeons' behavior conforms to an "*S^p* rule." This meant that pigeons discriminated presence vs. absence of a stimulus resembling the previous sample stimulus when confronting the set of comparison stimuli. Carter and Werner (1978) rejected the possibility that pigeons make conditional discriminations by avoiding negative stimuli. Their conclusion suggested that pigeons should perform more accurately when the positive and ambiguous stimuli were presented together than when the negative and ambiguous stimuli were presented together. The present experiment addresses that prediction.

METHOD

Subjects

Five pigeons were maintained at 80% of their free-feeding weights for the course of the experiment. No subject had served in any other experiment.

Apparatus

The experimental chamber (BRS-Foringer) was 50 cm long by 35 cm high. The front wall contained two response keys, 3 cm in diameter, located 25 cm above the grid floor and 7.5 cm from each side wall. The food hopper was located behind a 5 by 4 cm opening centered on the midline of the front wall. Two lamps (GE 757) mounted behind a 7.5 by 35 cm piece of white Plexiglas at the top of the front wall served as a houselight. The intensity of the houselight was 14.7 m^l, as measured by an SEI photometer. An Industrial Electronics Engineers in-line display unit was mounted directly behind each response key. Tape readers, electromechanical switching equipment, and counters were located in an adjacent room.

Procedure

Key pecking was shaped during the first session, and every key peck was reinforced during the next three sessions. The conditional-discrimination procedure was introduced during the fifth session.

In the conditional-discrimination procedure, both keys were dark between trials. During a trial the color backgrounds on both keys were the same and could be either red or green. A horizontal white line was superimposed on the background color on one key, a vertical

white line on the other. When the background was red, a response on the key with the horizontal line turned off the stimuli on both keys and allowed 4-sec access to the feeder. A response on the vertical line also turned off both stimuli but did not produce reinforcement. Instead, there was a 20-sec timeout (TO) during which the houselight was turned off and the chamber remained in total darkness. When the background color was green, a response on the key with the vertical line was reinforced, and a response on that with the horizontal line was followed by a timeout.

If the preceding trial ended with reinforcement, either the red or green colors could be presented on the next trial. The position of the lines could either remain the same or change. If the preceding trial had ended with a timeout, the same stimuli were presented on the next trial. Regardless of the number of successive trials on which the subject responded incorrectly, the same stimuli were presented on the following trial until the subject made a correct response. Each session continued until the subject had earned 32 reinforcers, and this procedure continued for 17 sessions.

At that time the procedure was changed so that reinforcement occurred once for an average of four correct responses; that is, correct responses were reinforced on a variable ratio four (VR 4). On trials when the correct response did not produce reinforcement, the stimuli on both keys were turned off for 1 sec while the houselight remained on. After the 1-sec interval, either a new, or the same, pair of stimuli could be presented. Each error was still followed by a 20-sec timeout and the restoration of the same stimulus pair after the timeout. Each of these sessions continued until the subject had earned 24 reinforcers and there were 23 such sessions (Sessions 18 to 40).

During the next 10 sessions (Sessions 41 to 50), a horizontal line was presented on one key and a vertical line on the other during every trial. However, the background color,

which served as the conditional stimulus, was displayed on only one key. The choice stimulus (i.e., the horizontal or vertical line) on the same key as the colored background was the positive stimulus on half the trials, and the negative stimulus on the remaining trials. For example, there might be a trial in which a vertical line was shown on the left key, and a horizontal line on a red background was displayed on the right key. On that trial a response on the key with the horizontal line would be reinforced. However, if there were a horizontal line on one key and a vertical line on a green background on the other, a response on the latter key would be reinforced. Thus, a line alone was an ambiguous stimulus. If the color-line compound on the second key was a positive stimulus, a response to the line was not reinforced and the trial was called a positive vs. ambiguous trial. When the color-line compound on the second key was a negative stimulus, a response to the line was reinforced and the trial was called a negative vs. ambiguous trial. Table 1 shows the stimuli that were presented on both types of trials.

The colored background was displayed on the left key half the time and on the right key half the time, as were the positive and negative choice stimuli.

Every correct response was reinforced during the next six sessions (Sessions 51 to 56), and each session continued until the subject had earned 32 reinforcers. There were no other changes in procedure and the conditional stimulus was still presented on only one key. During the next six sessions (Sessions 57 to 62), the schedule of reinforcement was again VR 4 and each session lasted until the subject had earned 24 reinforcers. Finally, during Sessions 63 to 68, each correct response was again reinforced, and each session continued until the subject had earned 32 reinforcers.

The next block of six sessions (Sessions 69 to 74) was used to reestablish a level of baseline accuracy. The colored background that

Table 1
Stimuli Present During Positive vs. Ambiguous and Negative vs. Ambiguous Trials

<i>Positive vs. Ambiguous Trials</i>		<i>Negative vs. Ambiguous Trials</i>	
Positive Stimulus	Ambiguous Stimulus	Negative Stimulus	Ambiguous Stimulus
Horizontal line on red field	Vertical line	Vertical line on red field	Horizontal line
Vertical line on green field	Horizontal line	Horizontal line on green field	Vertical line

served as a conditional stimulus appeared on both keys on every trial; a horizontal line appeared on one key and a vertical line appeared on the other. Each session continued until the subject had earned 32 reinforcers. The vertical line was still the correct stimulus when the background was green, and the horizontal line was the correct stimulus when the background was red.

For the next 24 sessions the conditional background stimulus was present on both keys during each trial, but a line was present on only one key. Regardless of the background color that was present, the vertical line was displayed on half the trials and the horizontal line was displayed on the remaining trials. Each line was presented on the left and right key equally often. The presentation of a colored field on one key and a positive color-line compound on the other key was called a positive vs. ambiguous trial. On these trials, a response to the compound stimulus was correct. On other trials, a colored field was presented on one key and a negative color-line compound was presented on the second. These were called negative vs. ambiguous trials, and on them a response to the colored field was reinforced. Obviously, the colored field was an ambiguous stimulus because responses to it would, or would not, be reinforced, depending upon the stimulus present on the other key. Table 2 shows the stimuli that were presented on both types of trials.

During the first six of these sessions (Sessions 75 to 80), each correct response was reinforced and the session continued until the subject had received 32 reinforcers. The reinforcement schedule was VR 4 during the next six sessions (Sessions 81 to 86) and the number of reinforcers per session was reduced to 24. Another block of six sessions (Sessions 87 to 92) followed in which every correct response was reinforced and the subject received a total of 32 reinforcers per session. Finally, there was a last block of six sessions (Sessions 93 to 98) in

which the schedule was VR 4, and the session ended when the subject had received 24 reinforcers.

RESULTS

Since subjects were shifted to a VR-4 schedule before their performances had stabilized at the beginning of the experiment, it is impossible to be sure what effect the change in schedule would have had on a well-learned conditional discrimination. The data shown in Figure 1 are based on the results of the first trial with any particular pair of stimuli. If a subject made an error on this first trial, the subsequent reinforcer it earned on the next, or later trials, with the same stimuli was not used in computing accuracy. Similarly, if a subject responded incorrectly on two or more trials with the same stimuli, only the first error was used in computing accuracy. This procedure was followed throughout the analysis of results. Figure 1 shows the effect of shifting to VR 4, and, as can be seen, two subjects, 1172 and 7267, suffered a sharp drop in accuracy. However, the remaining subjects seemed to show little change in accuracy when the schedule was changed. When performance during the next 28 sessions is examined, it is seen that the two subjects whose accuracy decreased when the schedule was changed ultimately stabilized at 80 to 90% accuracy. The three remaining subjects all stabilized at levels of accuracy that exceeded 90%.

When the background color was removed from one key, all the subjects showed an immediate decrease in accuracy. However, there were large differences in accuracy on positive vs. ambiguous compared to negative vs. ambiguous trials. Figure 2 shows that during eight of the first 10 sessions, Pigeon 7267 responded more accurately on positive vs. ambiguous trials. Pigeon 11775 responded more accurately on positive vs. ambiguous trials during the first four sessions but was more

Table 2
Stimuli Present During Positive vs. Ambiguous and Negative vs. Ambiguous Trials

Positive vs. Ambiguous Trials		Negative vs. Ambiguous Trials	
Positive Stimulus	Ambiguous Stimulus	Negative Stimulus	Ambiguous Stimulus
Horizontal line on red field	Red field	Vertical line on red field	Red field
Vertical line on green field	Green field	Horizontal line on green field	Green field

Fig. 1. Each pigeon's accuracy during the first 40 sessions of conditional discrimination is shown above. Every correct response was reinforced during the first 17 sessions. Correct responses were reinforced on a VR-4 schedule during Sessions 18 to 40.

Fig. 2. Each pigeon's accuracy during positive vs. ambiguous and negative vs. ambiguous trials is shown above. The schedule of reinforcement for each block of sessions is noted above the horizontal axis.

accurate on negative vs. ambiguous trials during the next six sessions. The remaining three subjects responded more accurately on negative vs. ambiguous trials. The only other subject that was more accurate on positive vs. ambiguous trials during even one of these 10 sessions was 1172.

Each correct response was reinforced during the next six sessions. There was no consistent change in accuracy as a result of the change in schedule. However, all subjects now tended to respond more accurately on negative vs. ambiguous trials. As Figure 2 shows, this was true in at least four of the six sessions for every subject.

The schedule was changed to VR 4 for the next block of six sessions. Once again, there was no consistent change in the overall level of accuracy, but subjects continued to respond correctly on a larger percentage of negative vs. ambiguous trials. No subject failed to show this effect on fewer than four of these six sessions.

During the last block of sessions shown in Figure 2, every correct response was again reinforced. Subject 7944 no longer showed any systematic difference in accuracy on negative vs. ambiguous trials compared to positive vs. ambiguous; however, the other four pigeons still responded more accurately on negative vs. ambiguous trials in at least five of the six sessions. As had been the case previously, the change did not have an effect on accuracy that was consistent among the five birds.

Over the entire set of 28 test sessions during which the color was presented on only one of the keys, all subjects had more sessions in which accuracy was higher on negative vs. ambiguous trials. Pigeon 7267 showed the effect more weakly than any other subject but still was more accurate on the negative vs. ambiguous trials during 18 sessions. Pigeons 11775 and 7944 were more accurate on these trials in 19 and 20 sessions, respectively. Pigeons 3572 and 1172 showed the effect most strongly and were more accurate on these trials in 26 and 27 sessions, respectively.

The data were also examined for other identifiable sources of errors. Accuracy was comparable on those trials with red backgrounds and green backgrounds. Nor did it matter whether the line that was positive was horizontal or vertical. However, Pigeons 1172 and 3572 made well over 90% of their errors dur-

ing these sessions by responding on the left key. These were the subjects which had the greatest difference in accuracy between positive vs. ambiguous trials and negative vs. ambiguous trials. Apparently, position preferences were much more pronounced on positive vs. ambiguous trials since these were the trials on which most errors occurred. The other three pigeons also showed slight position preferences, but made only 60 to 70% of their errors on one key. In addition, one subject, 7267, seemed to switch slowly from left to right and back to left during the course of these sessions.

The results were also examined to see if particular stimulus compounds were correlated with differences in accuracy. A comparison was made of the two types of negative vs. ambiguous trials: those in which a red-vertical compound was on one key and a horizontal line on the other, and the second type in which a green-horizontal compound was on one key and a vertical line on the other. All subjects showed differences in day-to-day performance on the two types of trials, but there was no consistent pattern, either between subjects or for an individual subject over sessions, which indicated that one type of trial was more discriminable than the other. There were also two types of positive vs. ambiguous trials: those in which a red-horizontal compound was on one key and a vertical line on the other, and a second type in which a green-vertical compound was on one key and a horizontal line on the other. Once again, there were no consistent differences in accuracy when performances on the two types of positive vs. ambiguous trials were compared.

Colored backgrounds and lines were displayed on both keys during the next six sessions. The reason for including all the stimulus components was to see whether baseline accuracy had undergone any change. As can be seen in Figure 3, all the birds responded correctly on more than 90% of the trials during at least five of the six sessions. Baseline accuracy was still quite high.

A line was displayed on only one of the keys during the next 24 sessions. Colored backgrounds were always displayed on both keys. Every correct response was reinforced for the first six sessions. The schedule was then changed to VR 4 for six sessions; every correct response was reinforced for the next six sessions, and the schedule was changed to VR 4

for the final six sessions. Figure 4 shows that there was no consistent improvement, or decrease, in accuracy as the schedule was changed over blocks of sessions. However, there was a large difference between accuracy on trials when the compound stimulus was negative compared to trials on which the compound stimulus was positive. Figure 3 shows that accuracy was usually much better when the compound stimulus was negative; in other words, the pigeons were more accurate on negative vs. ambiguous trials. During at least four of the first six sessions in which only one line was present, all subjects responded correctly more often when the negative stimulus was the color-line compound. When the schedule of reinforcement was reduced to VR 4 during the next block of six sessions, each subject had a higher percentage of correct responses on negative vs. ambiguous trials in at least five sessions. The same effect was apparent during the third block of six sessions when every correct response was reinforced. Each subject made the correct response more often on negative vs. ambiguous trials in at least five of these

sessions. The schedule of reinforcement was again changed to VR 4 during the final block of six sessions. At this time Pigeon 11775 suddenly stopped responding more accurately on negative vs. ambiguous trials. The remaining subjects continued to show greater accuracy on negative vs. ambiguous trials during at least five of the six sessions.

Considering the entire set of 24 sessions during which only one line was displayed, all subjects had many more sessions in which they more often responded correctly on negative vs. ambiguous trials than on positive vs. ambiguous trials. Pigeons 11775 and 1172 showed this difference in 19 sessions, Pigeons 7944 and 7267 in 22 sessions, and Pigeon 3572 in 23 sessions. The data also showed persistence of the position preferences the birds had demonstrated earlier.

Performances were also examined to see if there was any difference in accuracy as a function of the particular stimuli. There were two types of negative vs. ambiguous trials: one in which a red-vertical compound was displayed on one key and a red field on the other, the

Fig. 3. Each pigeon's accuracy during positive vs. ambiguous and negative vs. ambiguous trials is shown above. The schedule of reinforcement for each block of sessions is noted above the horizontal axis.

second in which a green-horizontal compound was displayed on one key and a green field on the other. No consistent differences in accuracy were found. There were also two types of positive vs. ambiguous trials: a red-horizontal compound on one key and a red field on the other, and in the second type, a green-vertical compound on one key and a green field on the other. Again, accuracy was unrelated to the particular stimulus combinations.

DISCUSSION

The most important point to be made as a result of the present study is that pigeons can maintain a conditional discrimination when only a portion of the complete stimulus set is displayed. Although it has been demonstrated previously that pigeons could choose correctly when an ambiguous stimulus was one of two options in a simple choice discrimination (Hall, 1980; Richards, 1973; Richards & Marcattillio, 1975), it had not been known whether they could also perform a conditional discrimination in which an ambiguous stimulus was used on one side of the simultaneously-presented pair. Moreover, the ambiguous stimulus in previous studies was physically different from both the positive and negative stimuli. In this experiment the ambiguous stimulus was one component of the compound positive or negative stimulus. This suggests that the functional properties of the ambiguous stimulus may play a greater role than its physical characteristics.

The present experiment also showed that pigeons could respond at better than chance levels regardless of whether the positive or negative compound was displayed on any given trial. If it is assumed that pigeons solve conditional discriminations by following rules, as Carter and Werner (1978) suggested, then these pigeons must have learned rules that allowed them both to approach the positive stimulus and avoid the negative. When background color was shown on one key, it might have been possible for the pigeons to use a rule that was associated only with the positive line stimulus, regardless of which key displayed color. However, when only one line was displayed, the positive line stimulus did not appear on half the trials. Therefore, it is difficult to see how the subject could have chosen it if this were the controlling relation.

By the same token, the negative line stimulus was absent on half the trials, and it is not clear how a rule based on avoidance of the negative stimulus would allow a subject to avoid a stimulus that was not present.

Although the subjects discriminated at better than chance levels on both types of trials, they were more accurate on negative vs. ambiguous trials. That suggests that if rule following were involved in this two-choice conditional-discrimination problem, the pigeons learned rules that allowed them to avoid the negative stimulus more efficiently than they learned rules for approaching the positive stimulus. It is not clear why pigeons should learn to avoid the negative stimulus in this situation, whereas Carter and Werner (1978) have concluded that they probably learned to approach the positive stimulus in the standard matching-to-sample procedure.

An alternative explanation of the superior performance of these pigeons on the negative vs. ambiguous trials could be based on the view that the background colors served as both conditional stimuli and parts of the compound stimuli between which subjects choose. Consider the first series of test sessions in which the conditional color stimulus was displayed on only one of the keys. During a session, responding to a vertical and a horizontal line was reinforced equally often. But, the green background was displayed on only half the trials and was on the same key as the positive vertical line on only half of those. Thus, a response on a key on which a green background was displayed could be reinforced on only one quarter of the trials. For exactly the same reasons a response to a key on which a red background was displayed could be reinforced on only one quarter of the trials. However, during both green-background trials and red-background trials, the positive stimulus was displayed on the key that had no background color half the time. Therefore, half the potential rewards could be earned by pecking the key without a colored background.

Since accuracy was well above chance levels for all subjects in virtually all sessions, the pigeons must have been making the conditional discrimination correctly on most trials. Nevertheless, if the pigeons were affected by different probabilities of reinforcement associated with each of the color stimuli, as well as with the absence of a colored background, they should

have been more likely to make an error by responding to the key on which no color was displayed. Such a preference would have produced an increase in the probability of a correct response when the colored conditional stimulus was on the same key as the negative choice, and a decrease in accuracy when the color was on the same key as the positive choice. This process could account for superior performance on negative vs. ambiguous trials.

A very similar analysis could be applied to those sessions in which only one of the choice stimuli was displayed. For example, a red conditional stimulus was shown on both keys on half the trials in each session. The positive horizontal line was shown on only half of these trials, and therefore reinforcement could be produced by responding on the horizontal line on only one quarter of the trials in a session. By the same token, the green conditional stimulus was displayed on half the trials, and the vertical line was shown on half of these. Therefore, responses on the vertical line could have been reinforced on only one quarter of the trials. It is apparent that approximately half its reinforcers must have been produced by responses on the key on which no line was displayed. If the subject then developed an increased probability of responding on the key without a line when discriminative control was poor, it would have led to increased accuracy on negative vs. ambiguous trials and to decreased accuracy on positive vs. ambiguous trials. Once again, that was the observed result.

This component analysis is similar to hypotheses that have been offered by Berch (1974), Hall (1980), and Leary (1958) to explain the role of the ambiguous stimulus in simple choice discrimination. Each of them sought to explain the observed behavior in terms of interacting generalizations among the positive, negative, and ambiguous stimuli and

the different response strengths conditioned to each one.

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Received December 29, 1981

Final acceptance September 17, 1982