THE BISECTION OF A SPATIAL INTERVAL BY THE PIGEON

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Pigeons pecked two response keys to move a white dot until it was equidistant from two other dots on a screen. Continuous records of dot position showed the effects of reinforcement and stimulus parameters upon the accuracy with which the dot was positioned. The method may prove useful for studying the perception of distance in non-human organisms.

In the psychophysical method of "tracking", the subject, human or animal, continuously varies the value of some stimulus parameter. In typical studies, subjects have varied the intensity of a visual or auditory stimulus up and down across absolute threshold (Békésy, 1947; Blough, 1958). The method is efficient, since the subject tends to present itself with stimuli close to critical values. Also, it permits recording of changes through time, such as might be caused by adaptation, drugs, *etc.* As yet, however, little work has been done either to demonstrate the use of the method in new situations, or to investigate parameters that affect the accuracy of the tracking performance.

This paper describes a tracking method for measuring a pigeon's performance of a simple, one-dimensional spatial discrimination. The bird adjusted a small spot of light to be equidistant between two other spots. Continuous records of the spot position show where the point of equidistance was judged to be and reveal the effects of changes in reinforcement and stimulus parameters. The method is designed for situations where the subject re-

ports, in effect, "longer than", "shorter than", "farther than", and so on.

METHOD

Subjects

Six adult male White Carneaux pigeons were used. The four used in most of this study had previous experience in a hue generalization experiment. The other two, used only in the attempt to train without fading (see below), were experimentally naive. The subjects were maintained at 80% of free-feeding weight.

Apparatus

The birds worked in an experimental chamber divided into two sections by a panel. Figure 1 shows the arrangement of the stimulus screen, response keys, and reinforcement magazine on this panel. Two relays mounted on the back of the panel gave distinctive clicks when the response keys were operated. The keys were illuminated from behind by neon bulbs (NE2) and were shielded to prevent any leakage to the stimulus window.

An optical system projected three white dots upon the ground-glass stimulus screen, which was otherwise dark. The dots were 2 mm in diameter and were arranged on a horizontal line, with the two end dots fixed at 46 mm between centers. The middle dot could move back and forth between the other two. The end dots were provided by the image of a metal slide with two small holes fixed in one pathway of the optical system; the middle dot was the image of a hole in a movable slide in a second optical pathway. The chart drive of a Varian recorder followed the movement of the

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Fig. 1. The experimental chamber. The stimulus screen is located 35 mm behind the response keys. The stimuli appeared as white dots on the darkened screen, and the remainder of the chamber was dark, save for the response keys, which were dimly lit from below.

center dot through time. The experimental sessions were programmed by a series of relays, steppers, and timers. (See Blough, 1957, 1958 for further details on visual tracking methods with pigeons.)

Procedure

Four birds were first trained to eat quickly upon presentation of the food hopper, and then to peck either of the two keys. Food reinforcement was contingent upon appropriate key-pecking. Specifically, if the middle of the three dots on the stimulus screen were to the left of center, pecks on the right-hand key brought reinforcement on a variable-interval schedule. If the middle dot were to the right of center, pecks on the left key brought reinforcement. Regardless of the position of the middle dot, pecks on the right key moved the dot toward the right, and pecks on the left key moved the dot toward the left. Thus, only pecks that moved the dot toward the center of the display were reinforced; once the dot crossed the center, the bird had to switch keys in order to obtain reinforcement.

The dot did not move continuously with each peck, since the stimulus drive did not start and stop rapidly enough. During train-

ing, the dot moved one 1.6-mm step after every tenth response. Later, after experimental variations in step size (see *Stimulus excursion* below), the apparatus was permanently set to move the dot 0.8 mm after each fifth response. Direction of motion was controlled by the last peck; if the fifth response were on the left key, the dot moved left, if on the right key, the dot moved right. Stops prevented the middle dot from approaching either end dot closer than 10 mm.

Two reinforcement contingencies were used to enhance stimulus control. The first was intended to make reinforcement unlikely if the bird switched randomly from key to key. An add-subtract counter advanced one count for each incorrect response (i.e., for each response that moved the dot away from the center of the display). Correct responses subtracted from this total. Given that the variable-interval contingency was satisfied, a response brought reinforcement only if the add-subtract counter stood at zero. Thus, for example, if the bird had emitted six incorrect pecks, seven correct pecks would be necessary to yield food. (A limit of 10 incorrect responses was allowed to register "against" the bird.) This procedure operated to enhance control because responding to the correct key built up no "positive balance" of responses while responding to the incorrect key accumulated a "negative balance". Hence, random responding to the two keys would tend to keep the bird with a negative balance and prevent reinforcement. It should be noted, however, that this contingency neither forces the bird to move the spot back and forth across the center line, nor delays reinforcement substantially after every error. (For example, a single error followed by two correct responses could sometimes produce reinforcement.)

A second procedure arranged specific differential reinforcement for attention to the stimulus. On a 1-min variable-interval schedule, a red filter dropped into the light beam leading to one of the three dots. When any dot turned red, responses would neither move the middle dot nor bring reinforcement for 6 sec. If responses occurred during this S— period, the period was extended; it terminated 6 sec after the last response. Thus, if responding continued after a dot had turned red, the pigeon might undergo a prolonged period of non-reinforcement. On the other hand, a bird that

attended to the dots only had to pause on the average of once a minute for 6 sec before continuing. Since any dot might turn red, their selection was random, the bird had to watch them all. Records of response during S— periods showed how well the bird was attending to the spots.

A fading technique (Terrace, 1966) was also used to generate control by the position of the middle dot. Early in training, a 1.0 log unit, neutral density filter was placed in the pathway to the middle dot, so that when this dot was to the left of center its brightness equalled that of the outer dots, but when it was to the right of center it was 1.0 log unit dimmer. Thus, pecks on the right key brought reinforcement when this dot was at full brightness, and pecks on the left key brought reinforcement when the dot was dim. The birds rapidly learned this task. The filter was then changed to a less dense value (0.7 log unit) and training continued. The discrimination was retained at a high level as the density of the filter was reduced over a considerable number of training sessions. Finally, the last filter (0.1 log unit) was removed, and the response remained under the control of spatial cues alone.

During the fading sessions just described, the variable-interval contingency was added to the reinforcement schedule and gradually lengthened to VI 1-min. The final baseline conditions were reached after approximately 80 daily 1.5-hr sessions.

Following the training just described, certain reinforcement and stimulus parameters were systematically varied, in order to check on possible artifacts and to find the best conditions for further use of the method. For

clarity, these procedural changes and their effects will be described together. Table 1 summarizes the sequence of experimental procedures.

RESULTS

A typical chart record for part of a day's session appears in Fig. 2. The jagged line records the subject-controlled movement of the middle dot on the stimulus display. Middle and end dots are drawn to scale. Vertical lines indicate the true center of the display, and the mechanical limits on dot movement. Thin vertical lines also mark each 3.2 mm of movement from center. Crossings of these lines on the chart records were counted, and the resulting frequency distribution, shown at the top of Fig. 2, was used to generate numerical estimates of the variability and central tendency of the track. For example, in Fig. 2, the line did not reach "–12.8" at all, crossed "–9.6" four times, "–6.4" fourteen times, and so on. These counts were transformed into percentages, and a mean and standard deviation were calculated for each session.

The mean showed how much the track deviated from the center of the display. For example, in Fig. 2, the mean is –0.8 mm. This shows that the bird tracked slightly to the left of true center during the period shown. Because of the symmetry of the situation, it was not expected that means would deviate systematically from center, and they did not. However, again as expected, with more variable tracks, the mean was generally farther from center than with less variable tracks.

Variability in the track was estimated by the standard deviation of the distribution shown

Table 1
Sequence of Experimental Procedures

<i>Number of Sessions</i>	<i>Procedure</i>	<i>Details</i>
80	Training	Magazine and key train; build up to VI 1-min; fade center dot to full brightness.
36	Vary dot excursion	5 sessions at 1.6 mm; 5 at 4.9; 5 at 0.8; 7 at 0.8; 7 at 4.9; 7 at 0.8.
1	Recenter dot in extinction	---
30	Vary reinforcement schedule	10 sessions at VI 1-min; 10 at VI 2-min; 10 at VI 1-min.
30	Vary reinforcement duration	5 sessions at 3 sec; 7 at 6 sec; 6 at 3 sec; 7 at 6 sec; 5 at 3 sec.
30	Vary reinforcement schedule	4 sessions at VI 1-min; 4 at VI 2-min; 6 at VI 2-min; 12 at VI 4-min; 6 at VI 1-min.
4	Remove center dot	1 session dot in; 1 out; 1 in; 1 out.

Fig. 2. A portion of a record from one session. The stimulus dots are represented to scale. The middle dot moved one 0.8-mm step after each fifth response. The distribution above shows the frequency with which the track crossed each scale line on the tracking record. Dashed lines indicate one standard deviation on either side of the mean.

in Fig. 2. A low standard deviation indicated tracking within a narrow range on either side of the central value. The standard deviation of the track in Fig. 2 was approximately 5 mm. Most of the results below are expressed in terms of standard deviation, but this measure may be misleading unless its limitations are recognized. Though very significant changes were registered, the standard deviation varied over an apparently small range. A deviation of 4 mm indicated a relatively precise track, while records yielding a standard deviation of as much as 6.5 mm usually gave no indication of stimulus control. Even on good days, the deviation scores did not reach low values because short periods of wandering to one side of the display contributed large increases to the deviation score. The score could rise little above 6.5 because, when stimulus control was lost, dot movement was limited to a maximum

of about 13 mm in either direction, and with random wandering, the dot tended to cross the center lines more frequently than the lines toward the edge.

Reinforcement Variables

The present procedure shares with others the possibility that reinforcement itself may provide discriminative cues (Blough, 1966; Jenkins, 1965). To investigate the influence of this effect in the present experiment, all subjects were tested in the following way. While the bird was eating, the reinforcement circuit was disconnected and the middle dot was moved to its left or right extreme. All of the birds returned the dot to the center of the display from both left and right extremes. This indicated that reinforcement cues were not necessary to the tracking performance. However, none of the birds moved the dot directly back, with no incorrect responses. It is also of interest that most of the birds stopped responding, sometimes for 30 sec or more, after the dot was moved to one side. This "surprise" reaction indicated that dot position did affect the bird's behavior.

Reinforcement schedule. Although reinforcement itself did not seem to serve a discriminative function, it was of course necessary to maintain the spatial discrimination. If reinforcement failed for more than a few minutes, as happened due to apparatus failure on a few occasions, stimulus control was lost. Yet, for many applications, it would help to have the birds working for relatively infrequent and brief reinforcement. The effects of decreasing reinforcement density and changing its amount were therefore investigated.

An experimental variation of reinforcement schedule was run in three series as follows: (1) 10 sessions each of VI 1-min, VI 2-min, and return to VI 1-min; (at this point, the reinforcement duration study described next intervened, see Table 1); (2) four sessions each of VI 1-min, VI 2-min, and return to VI 1-min; (3) six sessions of VI 1-min, 12 sessions of VI 4-min, then six sessions of VI 1-min. The amount of food consumed, both per unit time and in total, was kept roughly constant in these series by lengthening access to the food magazine with the longer VI schedules. The duration of reinforcement was 3 sec on VI 1-min, 6 sec on VI 2-min, and 12 sec on VI 4-min.

In all cases, the longer the average interval of the VI schedule, the more variable was the tracking performance. The standard deviation of the pre- and post-test VI 1-min baseline was almost the same for all three series: 5.4, 5.3, and 5.4 mm were the respective means. VI 2-min gave a score of 5.9 mm on both series, while VI 4-min gave 6.5 mm. An ABS analysis of variance (Winer, 1962) showed that both VI 2-min scores differed from the VI 1-min baseline with $p < 0.005$, and VI 4-min differed with $p < 0.001$. As pointed out above, the 6.5-mm score for VI 4-min was in the range associated with either little or no stimulus control.

Reinforcement duration. It is possible that the adjustment of reinforcement amount used in the schedule experiment just described might alone have influenced the results. To check this, the duration of reinforcement delivered on VI 1-min was altered in a series of sessions. Again the procedure was to establish a baseline VI 1-min performance, double the reinforcement duration for seven days, re-establish baseline, run another seven days doubling duration, then obtain a final baseline. Altogether this involved 30 daily sessions with each subject. The double reinforcement sessions were in other respects identical to the baseline sessions, except that to avoid satiation the birds were tested for 45 min instead of the baseline 90 min.

The variability of performance during the double reinforcement sessions differed in no significant way from that of either the whole baseline sessions or performance in the first 45 min of the baseline sessions.

Stimulus Variables

It was shown above that reinforcement did not seem to be significant as a discriminative stimulus controlling the birds' tracking behavior. It was not demonstrated, however, that reinforcement played no role in controlling the behavior, or that a sort of apparent "track" might result from random responding to the two keys, or from other behavior patterns not under discriminative control. For further information on these matters, two birds were tested with the moving middle dot absent from the stimulus display. The red S— intervals continued, those scheduled for the middle dot being transferred randomly to the two remaining dots. The design included one base-

line session, a test session with the middle dot absent, a second baseline session, and a second test session.

Removal of the middle dot resulted in a large increase in variability for both birds. The mean control standard deviation of each was 4.7 mm; this increased to 6.5 mm in one bird and 6.6 mm in the other when the middle dot was missing.

Stimulus excursion. The mechanical parts that moved the middle dot could not keep up with the pigeon's pecking, so a 1:1 ratio of movement to response was impossible. As already mentioned, a ratio of 10 responses to one 1.6-mm step was arbitrarily established during training. The following experiment attempted to determine the most suitable length of stimulus movement for good tracking. Three excursions were used: the one used in training (10 pecks/1.6 mm), a smaller (5 pecks/0.8 mm), and a larger (30 pecks/4.9 mm). In each case, the number of pecks required corresponded approximately to the number that the average bird would emit during the time the dot moved the given distance. Three birds had five days at 1.6 mm, five at 4.9 mm, and five at 0.8 mm. For a partial replication, they continued with seven days at 0.8 mm, seven days at 4.9 mm, and another seven days at 0.8 mm.

Records from the largest and smallest excursions from one bird are shown in Fig. 3. It is evident that, although the track sometimes wanders, the small excursion record describes a rather consistent positioning of the middle dot near the center of the stimulus display. With the large excursion, on the other hand, there is no evidence of stimulus control. The track often runs into the stops at the left and right extremes. The standard deviations for the two records are respectively 3.7 and 6.4 mm.

Mean results showed that variability increased with step size. The mean standard deviations for the three step sizes, from large to small, were 6.9, 6.1, and 5.5. An analysis of variance showed the effect of step size significant with $p < 0.001$. In the replication, the results were very similar, with the small step S.D. of 5.2, and large of 6.8 mm.

Importance of fading. Two birds were trained as described in the Procedure section, except that the fading technique was not employed. The birds were given 40 sessions after

Fig. 3. Sample records from one bird showing a performance with the 0.8-mm stimulus step (above) and the loss of stimulus control with the 4.9-mm step (below).

they had reached the final reinforcement conditions, but they never reached the performance levels of the other birds; their deviation scores varied around 6 mm.

DISCUSSION

The results presented above indicate that pigeons can track the position of a point in a visual display, but that under the present conditions this is a difficult task. The task took a good many sessions to learn, and the performance was rather sensitive to several parameters of the situation. Optimal results were maintained by a high frequency of reinforcement and by a close link between the pigeon's responses and the dot motion that they caused. Although even a perfectly tracking bird would necessarily produce a wider track with the coarse 30 pecks to 4.9-mm movement than with the five pecks to 0.8-mm movement, it is not clear why the large step should result in the loss of control exemplified in Fig. 3. This loss of control tended to occur within a few minutes of a switch from small to large step, and to recover with equal rapidity upon return to the small step size. These observations suggest that a tight feedback loop between re-

sponses and stimuli should be maintained in future tracking studies.

Contributing to the variability of the records was a strong tendency to switch keys. This tendency might have been much stronger, were it not for the "penalty for incorrect responses" that discouraged random switching. Other investigators have found that chaining between two keys makes stimulus control difficult to obtain, in the absence of a changeover delay or similar contingency (Catania, 1966; Blough, 1966). Evidence that this was important in the present situation came on several occasions when the add-subtract counter controlling the changeover penalty failed. When this happened, the first correct response after switching keys was reinforced, if the VI contingency had been met. Again in these cases, stimulus control was lost within a few minutes and regained with almost equal rapidity when the contingency was reinstated.

In its present form, the method is potentially useful for the study of spatial discriminations. For precise measurements, further reduction in variability would be helpful, and there is no reason to believe that refinements of the procedure could not bring this about.

It is important to bear in mind that the pigeon was not actually pecking at the dots. Many investigators have found that responding directly to the discriminative stimuli results in optimal control (*cf.*, Woodworth and Schlosberg, 1954, p. 584). If ways could be found to have the subject directly move the adjustable part of the stimulus display, quicker learning and stronger control might be achieved.

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