STIMULUS CONTROL IN FIXED RATIO MATCHING-TO-SAMPLE[1]

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Pigeons were maintained on a fixed ratio (FR 9) schedule of reinforcement for correct matching-to-sample responses. Included in the test situation was a vertical array of lights, illuminated in relation to the successive steps of the fixed ratio. All five subjects showed regular decrements in matching errors across the sequence of unreinforced responses within the ratio cycle. In the form of a randomly introduced probe, the stimulus situation (array of lights) appropriate to having seven of the FR 9 steps already completed was occasionally introduced at the beginning of an FR cycle. Reinforcement followed the illumination of the two remaining lights by two correct matches. The number of errors in this probe condition was sharply lower than the errors characteristic of the first two steps of the basic FR 9.

When maintained with reinforcement for every n^{th} response (fixed-ratio), behavior frequently varies cyclically between successive reinforcements. For a color matching-to-sample situation, Nevin, Cumming, and Berryman (1963) report increases in the relative frequency of correct matches across the unreinforced sequences of a fixed ratio (FR). Variations in such properties of response as peak force, duration, and time integral of force have also been noted in FR behavior (Mintz, 1962; Notterman and Mintz, 1965). When the schedule of reinforcement requires a particular variation of the response to be emitted, the probability of this subclass has been shown to increase systematically across the unreinforced response sequences in FR cycles (Birch, 1964; Notterman and Mintz, 1965). The rate of response may also vary cyclically when performance is maintained with fixed ratio reinforcement. The pause and run pattern is a well-known characteristic of FR behavior. If a change in some exteroceptive stimulus is correlated with the steps of the ratio, changes in response rate across the unreinforced sequence tend to be pronounced (Ferster and Skinner, 1957).

Interpretation of the cyclical behavior produced by FR has been sought in differential control of the response by stimuli (exteroceptive or internal) correlated with the response sequence. This experiment examines cyclical FR performance in a color-matching situation with the probabilities of "correct" responding brought under direct exteroceptive stimulus control.

METHOD

Subjects

Five adult male White Carneaux pigeons were maintained at approximately 80% of free-feeding body weight. All had histories of color-matching behavior.

Apparatus

The test chamber was a triangular enclosure formed with a wall extending between opposite vertical edges of a 2-ft cube. The aluminum wall contained three response keys, feeder access, speaker for masking noise, blower outlet, and stimulus light array. The two sides and the roof were transparent Plexiglas, the flooring wire mesh.

The three response keys were 1⅜-in. square translucent panels, all centered 9⅞ in. above the flooring. Adjacent edges of the keys were 2 in. apart. Feeder access was directly below the center key, its bottom edge 3⅝ in. above the flooring.

The stimulus light display (Catania and Gill, 1964) consisted of a vertical line of 10 white jewel lamps, the bottom one centered 3 in. above the floor and the others spaced 1 in. from center to center. The line of lamps

was 11 in. to the right (viewed facing the keys) of the mid-point of the center key. White noise and the sound of the blower provided sound masking.

During the experiment, the test chamber was on continuous public display in the Exhibit Center of the Time-Life Building in New York City. The base of the test chamber was 4½ ft above the floor of a wide, 9-in. high platform holding the entire apparatus. This served to minimize distraction of the subjects, as the chamber was somewhat above and remote from viewers.

Procedure

The first matching trial began with the bottom lamp of the vertical array illuminated and the center key illuminated either red or green, each color having a 0.5 probability. A response on the center key immediately (within 25 msec) extinguished the center key light and illuminated the side keys, one red and the other green. The two side-key combinations each had a 0.5 probability, statistically independent of the center key color. All probabilities were instrumented with a Scientific Prototype 4020J probability generator.

A response to the side key of matching color (correct match) advanced the ratio count one step and illuminated the next higher light in the stimulus array. Illumination of the center key for the next trial was delayed 350 msec after a correct match. A response to the side key of contrasting color (incorrect match) delayed for 6.0 sec the start of the next trial. During the delays following either correct or incorrect matches, none of the response keys was illuminated.

Reinforcement occurred immediately upon completion of the ninth correct match and simultaneously with the onset of the tenth light. Key lights were not illuminated during reinforcement but the 10 display lights stayed on until reinforcement was complete. Immediately after reinforcement the center key light was illuminated for the first trial of the next FR sequence.

The baseline procedure was conducted daily for 8½ weeks, each bird working on alternate days during the final seven weeks. Each bird was run for 150-to-300 FR cycles with a 2.6-sec (except 3.2 sec for S10) period of feeder availability for reinforcement on its alternate days

of running. This procedure allowed the birds to receive all feeding in the test apparatus. The feed used for reinforcement was a standard mixture of 50% Kaffir, 40% Vetch, and 10% Hemp.

During the final week of running the basic procedure was modified. An occasional probe was introduced which involved resetting the FR to the eighth rather than the first step immediately after a reinforcement. Thus, two correct matches (FR 2 probe) remained for reinforcement and only the top two display lights were not illuminated. The FR 2 probes were introduced on a random schedule, approximately one probe per eight cycles.

RESULTS

The relative frequency of errors is analyzed for each step of the FR 9 cycles for the last few days before the FR 2 probe was introduced. Errors were recorded in terms of the number of match-attempts made for an advance to the next step of the FR cycle. Thus, ordinal steps of the FR reflect correct matches; the error frequencies reflect errors in achieving that step. The number of observations for each step ranged from 500-to-799 for this sample of stable performance. During the probe days, errors for FR 9 were recorded in the usual fashion, and additionally for the two steps of the FR 2 probes. For the five birds the number of FR 2 probes ranged from 72-to-105; the basic FR 9 occurred from 498-to-650 times.

Figure 1 shows the relative frequency of errors under the three conditions: baseline performance; baseline performance during sessions with probes; and performance in the FR 2 probes. All five birds show the same characteristic function for the baseline performance. The error curves resemble simple decay functions, asymptotic below 5% for every subject. In the initial step, every subject falls in the 20%-to-30% error range for baseline FR 9 performance. There does not appear to be any systematic effect of the probe on the baseline FR 9 error frequencies. However, some flattening of the error function is suggested for S19.

The probe data provide an interesting contrast to the baseline performance. Location of this data along the abscissa is somewhat arbitrary. In terms of the well-established sequence
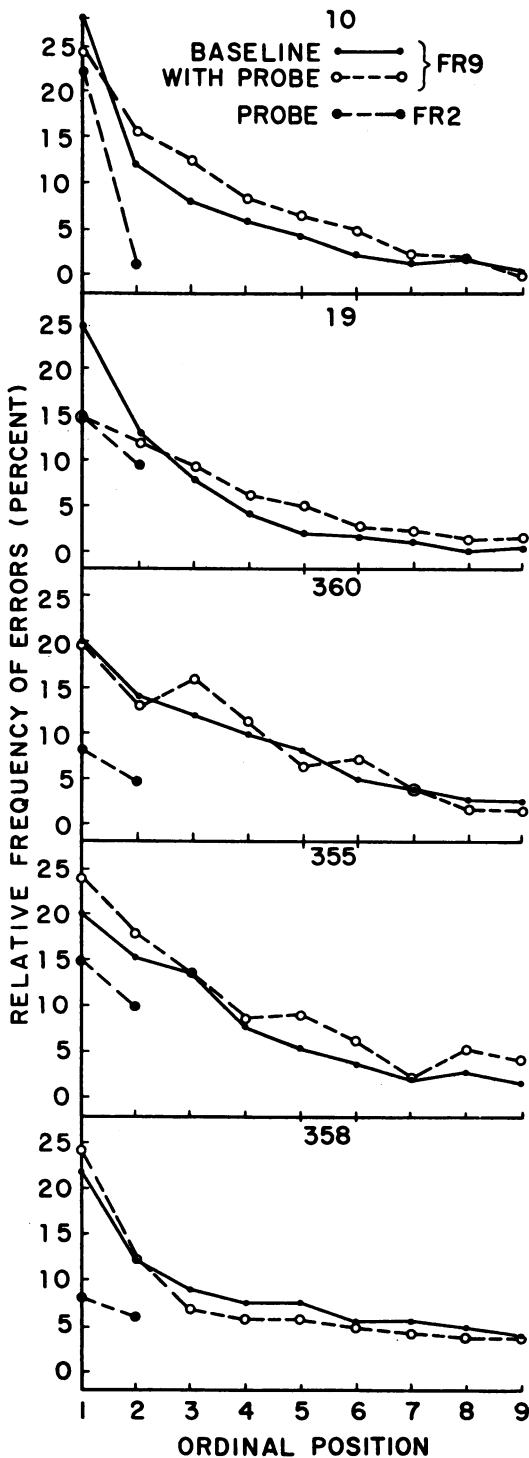
Fig. 1. Error frequency as a function of the ordinal position of the FR step for five subjects.

of behavior, the two steps of the FR 2 probe are the first steps of the baseline FR 9, and errors characteristic of these steps might be expected. However, these responses occurred in the presence of an exteroceptive stimulus correlated, over a long training period, with the last two steps of FR 9. It is clear that the matching behavior on the FR 2 probes is influenced by the correlated array of lights. Although none of the probe behavior exactly replicates the final two steps of FR 9, it is evident that the errors in probe behavior differ from performance characteristic of the first two steps of FR 9.

DISCUSSION

The baseline performance of FR 9 largely replicates the findings of Nevin, Cumming, and Berryman (1963) who used a similar procedure but without the correlated light array. Although the present subjects displayed generally fewer errors, it is impossible to say whether the correlated light array or other procedural differences underscore this behavioral difference. However, the comparison suggests that the potentially adverse conditions of the experimental environment did not produce manifestly adverse experimental control.

The distinctive feature of the data is the influence of the FR 2 probe. Providing stimuli correlated with the final two steps of FR 9 produced errors more appropriate to later steps rather than the initial steps of the FR run. The data suggest something like a multiple reinforcement schedule with the FR 2 component potentially established, although not specifically trained, during FR 9 training with the correlated light array. During the baseline procedure the subjects regularly encountered a situation in which all but the top two lights were illuminated and two correct matches produced reinforcement. The distinction between this and the probe rests only with the antecedent stimulus complex. In FR 9, a chain of matching responses and unit increments of light precede the FR 2 condition; in the probes, reinforcement is the immediate antecedent.

Ferster and Skinner (1957) provide numerous illustrations of affecting performance appropriate to a particular portion of an FR sequence by introducing a stimulus previously correlated with that portion. The present

study suggests that such findings are appropriate to matching errors as well as response rate.

The data reported by Nevin et al. (1963) include FR 3, FR 6, and FR 9 schedules. For each of these three schedules their subjects went from a high to a low error frequency across the unreinforced response sequence. Their data show a high likelihood of error for the first step of the FR, regardless of how many subsequent steps are required. Similarly, the step corresponding to reinforcement displays few errors regardless of the length of the sequence. Their data for variable ratio 3 (VR 3) show few errors, further suggesting that the regular (and presumably discriminable) sequence of unreinforced responses that must occur in an FR schedule is essential to a gradient of matching errors.

Notterman and Mintz (1965) report a progressive increase in the relative frequency of responses meeting an elevated effort (time-integral of force) criterion over the course of unreinforced FR responses. In their study the increase in the relative frequency of "correct" response could be interpreted as an increase in accuracy as reinforcement is approached. However, Notterman and Mintz entertain the possibility that their subjects were simply responding in the more vigorous fashion characteristic of extinction, with the increase in frequency of responses meeting the criterion being merely coincidental. The present study, and data reported by Nevin et al. (1963), suggest that an increase in accuracy may be a better interpretation. Birch (1964) provides further evidence that the "cor-rectness" of response systematically increases across the sequence of responses in FR.

The present probe data provide fairly conclusive evidence that the probability of a correct match was partially controlled by the correlated light array. Conformity to the requirements for reinforcement was most likely when cues related to proximal reinforcement were present. When a specified unit of behavior is measured on an occurrence basis, weak control is seen as nonresponse, the momentarily effective stimuli implicitly cueing some other behavior. An interesting feature of the matching situation is that the variations of discriminative control in FR include a substantial range in which control is great enough to produce the behavior comprising a match attempt, yet not great enough to produce a correct match.

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