DISCRIMINATIVE FUNCTIONS BASED ON A DELAY IN THE REINFORCEMENT RELATION¹

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Pigeons were shown to come under discrimination control when the S^D and S^A were temporally separated from reinforcement and non-reinforcement. S^D and S^A consisted of distinctive key illuminations presented separately. Responding on an FR 5 in the presence of S^D or S^A produced a third stimulus containing a schedule requirement. If this third (or interpolated) stimulus was preceded by S^D , responding in its presence produced reinforcement followed by a time-out (TO). If, on the other hand, the third stimulus was preceded by S^A , responding produced TO alone. In this fashion, the same stimulus and the same response requirement were imposed between S^D and the reinforcement as between S^A and the TO. In Experiment I, the schedule employed during the interpolated stimulus was FR; in Experiment II, FI. Discrimination reversal was accomplished in both experiments.

A problem of current and historical interest has been the assessment of the effects of separating important behavioral events in time. A prior stimulus can be separated temporally from the response over which it has some control, or a response may be followed after a substantial length of time by a reinforcer. There are a number of arrangements by which a period of delay can be introduced between the terms of the three-term contingency, stimulus, response, and reinforcement which are normally employed as contiguous events.

Normally a delay, however utilized, is imposed between terms in the contingency whose relation has been already established without a delay. For instance, Dews (1960) showed the effects of delaying reinforcement for behavior that had been maintained by immediate reinforcement. Similarly, Blough (1959) imposed

a delay between the disappearance of the sample illumination and the appearance of the illumination of the match keys on a matching-to-sample performance previously established under zero delay. Blough showed that such a complex discriminative performance could survive delays up to 10 sec, the efficiency normally declining as a function of the length of the delay unless distinctive superstitious chains of behavior followed each type of sample illumination during the delay.

Less well explored is the problem of establishing a discrimination when the delay is imposed initially rather than on a discrimination previously formed. The procedure of the present research was to establish such a discrimination whereby the reinforcement associated with S^D and non-reinforcement associated with S^A were delayed from the outset of training by the imposition of a third stimulus, common to and following both S^D and S^A . In addition, the temporal and/or behavioral properties of the delay represented by this third (or interpolated) stimulus were determined by a schedule in effect during this stimulus; the schedule delivered reinforcement (followed by a TO) if the S^D preceded the stimulus, or produced TO directly if S^A preceded the stimulus.

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METHOD

The general plan of both experiments was to present the animal with one of two possible

key colors. Five responses on the lighted key in either condition changed the illumination to a third color, which will be called the interpolated stimulus. In the presence of this stimulus a schedule was in effect, the terminal response of which produced either reinforcement followed by a period of blackout (TO) or the blackout period alone, depending upon which of the two colors appeared on the key before the interpolated stimulus. Following the blackout periods, the probability of the recurrence of either sequence was .5 (Gellerman, 1933).

A Mechner (1959) diagram is presented in Fig. 1 to show the usual arrangement between components in this discrimination procedure. The schedule in effect during S_3 (the interpolated stimulus) is indicated in block form allowing for the differences between experiments.

For a given experiment, the middle components (those containing S_3) of both sequences were identical. Thus S_1 was correlated with reinforcement followed by TO and S_2 with TO alone but only across the delay imposed by the same middle component.

Before the imposition of the discrimination procedure, approximately 60 hr of training were given each bird on a non-discriminative or baseline procedure. When both S_1 and S_2 of Fig. 1 are replaced by a single key color, then, not only are the middle (interpolated) components identical but also the first components. This resembles percentage reinforcement (Ferster and Skinner, 1957, p. 67), for a

single sequence or chain and represents the non-discriminative baseline requirement which was employed before any discrimination was attempted. The function of the baseline procedure was to establish a stable performance on a requirement similar to that demanded under the discrimination and thus provide a smooth transition to the discrimination procedure.

Subjects

Four male white Carneaux pigeons, retired breeders, 4 or 5 yr old were maintained at approximately 75% of their free-feeding body weights. Two were used in each of the two experimental procedures.

Apparatus

A standard, commercially available experimental chamber containing a two-key response panel (Grason-Stadler, E 1184J) was used. A 7-w lamp behind a diffusing glass window illuminated the entire chamber. Extinguishing this and the key lamps was used as the time-out (TO) procedure. A response key of translucent plastic with an associated electrical contact required a minimum force of approximately 15 g for operation. Behind the key were three lamps with colored filters and lenses to project colored light to transilluminate the key. When a fourth key condition was needed, the key was not illuminated from behind and the chamber light provided the only illumination. Access to grain accompanied by illumination of the grain aperture and extinction of chamber and key lamps provided reinforcement.

EXPERIMENT I

In this experiment, fixed-ratio schedules were used in the interpolated stimulus. Bird 2 and Bird 3 were used.

Procedure

For Bird 3, the baseline procedure consisted of two identical FR 60s in the presence of a green key producing reinforcement followed by a 30-sec TO or, on a .5 probability, TO only. For the discrimination procedure, a white light replaced the green illumination for the first five responses of the reinforced ratio, and a red key illumination was present during the first five responses of the non-rein-

Fig. 1. A Mechner diagram showing the deployment of major variables in the two experiments. The upper sequence shows the relation of S_1 to reinforcement (followed by TO) where responses in S_1 produce S_2 , the completion of the schedule requirement in S_2 producing reinforcement. The lower sequence shows the relation of S_2 to non-reinforcement (TO only) through an identical sequence. The schedule requirement in S_2 is the same for both sequences for a given experiment and is shown in block form to allow for the differences in the type of schedule used in the two experiments described in the text. The recycling arrow shows the recurrence of .5 probability of either sequence following TO.

forced ratio. The remaining 55 responses in either case were made in the presence of the green illumination. The minimal "delay" represented by this ratio was approximately 13-14 sec. Stimulus reversal consisted of presenting the red illumination during the first five responses of the reinforced ratio with the white illumination in the corresponding early segment of the unreinforced ratios. Session duration for this animal was 1½ hr throughout the experiment.

For both birds in this experiment, the illumination of the key during all of the baseline performance became the interpolated stimulus under the discriminative requirement. The requirements for Bird 2 are functionally equivalent to those for Bird 3, but with several procedural differences. The baseline procedure consisted of an FR 50 on the left key with the key in a non-illuminated condition. The terminal response of the ratio produced a green illumination on the right hand key; a single response on this key either produced reinforcement or continued the green light for an additional 3 sec. Both conditions were followed by a 20-sec TO. The additional key had no functional significance except to delay slightly the animal's contact with reinforcement and non-reinforcement. For this animal, the discrimination was imposed by illuminating the left key with red during the first five responses of the reinforced ratio, with the remaining 45 responses occurring on the same key in a non-illuminated condition. Similarly, the first five responses on the non-reinforced ratio were made with the key white. The remaining 45 responses were made as before with the key in a non-illuminated condition. A minimal delay represented by the ratio was approximately 11 sec. The switch to the right key occurred as in the baseline procedure with the response on that key responsible for the actual imposition of the final contingency. The stimulus reversal for Bird 2 consisted in having the white illumination present during the first five responses of the reinforced ratio and the red light similarly in the first five responses of the non-reinforced ratio. Sessions were from 1 to 4 hr with a 1½ hr average.

Results

The transition from the baseline to the discrimination procedure was remarkably smooth for both animals. Although this was their first

contact with the red and white illuminations, they responded immediately in the presence of either. The stimulus change involved in imposing the discriminative procedure presented no problems. Both birds showed a discernible discrimination after approximately 5-7 hr of training on this procedure (about 250 trials). Reversal for both subjects was at the same FR values and evidenced a progressive reversal of rate. Figure 2 shows portions of the cumulative recordings for Bird 3. In the upper left portion, all of the recorded segments of the ratios containing white illumination during the first five responses are shown together for session 6. The diagonal marks in this case indicate reinforcement since white = S^D followed by the TO period. The point at which the key illumination changes from white to the green (interpolated stimulus) is not shown but occurred after the fifth response of each ratio. In the lower left portion are the collected segments for this same session which contain the red stimulus for the first five responses of each ratio. The diagonal marks here indicate the direct occurrence of TO at the completion of the ratio. The dual recordings for session six show the degree of discriminative performance obtained. The pausing during the red light (S^A) seems to account for the major differences between the two records; the terminal ratio responding following either white (S^D) or red (S^A) illuminations being very similar. In most cases the rates during the green interpolated stimulus are identical, the exception being an occasional slight curvature following the offset of the red light (S^A). Starting with session 7, the functions of the red and white stimuli were reversed with the red illumination now in the first five responses of the reinforced ratio. The records on this first day of the reversal, however, still reflect the contingencies of the preceding sessions. Eight days later, (session 15), the effects of the reversed contingencies can clearly be seen. Two complete segments from each are enlarged and shown in the inset in the lower right corner of this figure. The heavy diagonal lines were drawn to show the offset of the white light in the segments marked A and the offset of the red light for the segments marked B. A slight curvature is evident following the offset of the white light (now the S^A). More typically the rate following the S^A is undisturbed; as are

Fig. 2. Cumulative records for one pigeon. The left segment shows performance during session 6 in which the white stimulus served as an S^D and the red stimulus as an S^A for the first five responses of the chain. The second link of the chain consisted of an FR 55 in the presence of an identical third stimulus following either the S^D or S^A . The diagonal pips indicate the delivery of reinforcement followed by a TO when the white stimulus (S^D) served as the first link, and TO alone when the red stimulus (S^A) served as the first link. The right section shows the first session (7) and the final session (15) in which the red stimulus served as an S^D and the white as an S^A . The insert in the lower right corner shows enlarged segments of cumulative records from session 15. The large diagonal pips indicate the offset of the S^D and S^A and the onset of the stimulus which followed both.

those following the S^D in the segments marked B. No differences in topography were noted during terminal ratio runs. For both birds the differences occurred during, and occasionally, just subsequent to the offset of the S^A and consisted of behaviors usually regarded as "emotional". The slight scalloping noted above is usually evidence of wing flapping, cooing, *etc.*, which is interspersed with pecks on the key.

EXPERIMENT II

In this experiment, FI schedules were used in the interpolated stimulus. Bird 4 and Bird 5 were used in the experiment.

Procedure

The baseline procedure for both animals consisted of an FR 5 in the presence of a green key illumination which produced a non-illuminated key. With the key in a non-illuminated condition, an FI schedule was in effect, the terminal response of which produced either 4-sec access to grain followed by 30-sec TO or TO alone. Each sequence had a .5 probability of occurrence. The initial FI value

for Bird 4 was 20 sec, for Bird 5, 30 sec. The discrimination procedure was initiated by substituting white and red key colors for the green illumination during the FR 5. White light illuminated the key during the FR which produced the FI which terminated in reinforcement followed by a TO, while red illumination preceded the FI, of which the terminal response produced TO only. The FI value for both birds was increased before reversal of the discrimination, and the reversal was obtained at these higher values. The value of the FI for the reversal procedure for Bird 4 was 40 sec and for Bird 5, 60 sec. Reversal consisted of reversing the functions of the red and white key illuminations.

Results

As was true of the ratio animals, the transition from the baseline to the discrimination procedure was made without noticeable disruption of performance. In Fig. 3, the dual recordings for session 15 represent the last session for which the FI value (during the interpolated stimulus) was 30 sec. The value of the interval during the interpolated stimulus was increased to 60 sec beginning with

Fig. 3. Cumulative records for one pigeon. The upper recordings show performance during session 15 in which the white stimulus served as an S^D and the red as an S^A for the first five responses of the chain. The second link of the chain consisted of FI 30 sec in the presence of an identical third stimulus following either S^D or S^A. The diagonal pips indicate the delivery of an S^B followed by a TO when the white (S^D) served as the first link, and TO alone when the red (S^A) served as the first link. Session 22, immediately below, shows the performance after the schedule requirement in the presence of the third stimulus had been changed from FI 30 sec to FI 60 sec. The bottom section shows the first session (23) and the final session (85) in which the red stimulus served as S^D and the white as S^A.

session 16 (not shown) in anticipation of the stimulus reversal. Session 22, as shown, is the last session before reversal. The first day of reversal (session 23) still clearly reflects the original contingencies. Session 85 reflects the discrimination based on the reversal functions of the stimuli.

While it took approximately 50 sessions to reverse the discrimination (more for Bird 4), part of this was due to an overall depression of rate which reduced severely the number of "trials". Both subjects showed this depressed rate, as excessive pausing during both the red and white key illuminations, while the rate of responding following a stimulus appeared to be unaffected. The duration of the magazine cycle was increased from 4 to 6 sec for both animals (Bird 4 session 52, session 55 for Bird 5) and within a few sessions, the overall rate was greatly improved.

Despite the fact that Bird 4's FI values were always shorter than those of Bird 5, this subject was consistently slower to develop a clear discriminative performance in the original discrimination and on the reversal. In regard to the original contingencies, a clear discriminative performance did not develop until the interval was increased to FI 30 sec then FI 40 sec in anticipation of the reversal.

Both birds exhibited a considerable amount of superstitious behavior during the interpolated intervals; this was observed both during control (baseline) sessions and during discrimination and reversal sessions. Bird 4, for instance, had developed a rather elaborate superstitious chain consisting of a vigorous craning of the neck, even to the point of partially losing balance, while Bird 5 consistently pecked at a spot a short distance to the right of the response key. Both birds were observed after a discriminative performance was assured and these superstitious behaviors were essentially the same when preceded by S^D or S^A . Usually such behavior was interspersed with pecks on the key and gave way gradually to the terminal rate. Where rate differences prevailed following the S^D and S^A , this usually reflected the slowness with which the bird returned to the key following the end of S^A .

DISCUSSION

In two experiments, pigeons were shown to come under discriminative control when the

S^D and the S^A were temporally separated from reinforcement and non-reinforcement. In Exp I this separation or delay was defined by a ratio schedule in the presence of a third stimulus. In Exp II an interval schedule was similarly employed and allowed the demonstration of sizable temporal delay (up to 60 sec on reversal) for this type of discrimination. A study employing 10-sec fixed intervals in a similar fashion has previously been reported by Myers (1958). These and the present results can be contrasted to similar discriminations where lack of acquisition or marked deterioration attend the imposition of a delay.

It is obvious that a relation involving a delay is less efficiently generated than those involving a more immediate correlation between important events. Beyond this, however, the sources of contribution of a delay to the weakened relation are not easily separated. In many cases where a delay is imposed, the major effect might be ascribed most simply to the decreased frequency of reinforcement or to combined affects of this and other features of the experimental procedures in establishing or maintaining a discrimination.

For instance an earlier study by Grice (1948) attempted to form a visual discrimination (white vs black) when rats were detained in identical gray delay chambers following a choice. Grice reported no success when the delay exceeded 5 sec, even when the animals were run in excess of 1000 trials. In contrast, delays of the same order of magnitude, or larger, were obtained in the present study in Exp I where the fixed-ratio schedule determined the length of the delay and where the discrimination was accomplished in far fewer than 100 conventionally determined trials. Session 6 (in Fig. 2), shows the degree of discrimination for one animal after less than half this number.

A major difference in experimental procedures was the use in the present instance of successive presentation of S^D and S^A rather than the multiple choice used by Grice. Under such conditions of choice, the possibility exists of a choice based on position alone, or of a color at a position which is maintained by intermittent reinforcement. Aside from its function as a delay as such, the use of a delay may accentuate such "preferences". Where the response (or discrimination) was solely positional (right or left) and thus free of such

confounding relations, Perkins (1947) found that a correct choice was acquired when the delay following either the reinforced or non-reinforced choice was as long as 2 min. Undoubtedly similar differences hold when a delay is imposed on an established performance. Changes in independent variables have been noted to reinstate "spurious solutions" such as position or color preferences under matching to sample (Skinner, 1950; Cummings and Berryman, 1961).

In a recent study, where delays were imposed on an already established matching-to-sample performance, Blough (1959) found occasions where unique superstitious behaviors tended to "mediate" the discrimination across the delay. The present experiments failed to reveal any similar mediation. Observations of the animals during the present research indicated some general features of behavior under the two types of schedules used. Ratios seemed to hold the topography of the response virtually constant both within and between conditions. Except for the continuance of some emotional behaviors following the S^A after the discrimination has formed, no differential topographies following the prior stimuli were noted. This seemed to apply even to the manner in which an animal held its head or stood while running off the ratio. Fixed-intervals, like other interval schedules, tend to encourage behaviors which constitute pauses in the criterion response of key-pecking. Although behavior other than pecking the key figured prominently throughout the interval in Exp II, no differences in the topography of this behavior were noted during an interval component, whether the interval followed an S^D or an S^A .

So far as the present study is concerned, the lack of observation of differential superstitious behaviors is certainly not definitive except in regard to highly visible chains such as those reported by Blough. It does not preclude subtle behavioral changes which could have occurred and escaped detection. Certainly the schedule requirement in effect during the delay period makes demands on only a small segment of the behaviors during the delay

which could extend the effectiveness of a prior stimulus. One advantage of the uses of schedule requirements is that the type of very distinct chains as noted by Blough can be more thoroughly explored or eliminated by the imposition of such requirements.

One limiting feature of the present methodology should be mentioned. While large and persistent differences in rates could be obtained with all animals in both experiments, the S^A rate has never been seen to drop to a zero level. Since the possibility of obtaining an S^D sequence is contingent upon the completion of the S^A sequence, this relation was probably responsible for keeping the S^A responding from deteriorating further. While such a relation is more remote than the one under investigation, it necessarily works in a direction opposite to that desired and limits the minimum S^A rate which the method can produce.

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