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THE EFFECT OF INFORMATIVE FEEDBACK ON TEMPORAL TRACKING IN THE PIGEON[1]

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Pigeons emitted interresponse times that were reinforced if they fell between an upper and a lower bound ($t < \text{IRT} < t + t/10$). Brief stimuli followed each response; under some experimental conditions the color of these stimuli was correlated with whether the preceding interresponse time was longer or shorter than that specified by the schedule. Preliminary experiments indicated that these "feedback" stimuli acquired no discriminative properties even after prolonged training. A modified procedure, in which t varied cyclically throughout each experimental session, allowed the stimuli to acquire such properties: stimulus control was demonstrated under the training conditions, for two of the pigeons, and under transfer conditions for all three birds. A series of probe conditions, followed by a replication of the simple procedure using a multiple schedule, indicated that the controlling property of the stimuli was not the relation between stimuli, interresponse time, and value of t, but a variable determined by the interaction between the animals' responding and the cyclic procedure. This variable was probably the relative frequency of the less-frequent feedback stimulus.

CONTENTS

The behavior of pigeons can be brought under the control of a procedure that selectively reinforces responses terminating interresponse times (IRTs) lying between an upper and a lower limit (DRL LH schedules). Responding under these procedures typically falls considerably short of perfect effectiveness; the probability that a given response will be reinforced rarely exceeds 50%, and the "accuracy" of temporal discrimination, measured either as the variance of the distribution of IRTs or as the location of the modal IRT with respect to the reinforced interval, is not noticeably improved by requiring sharper discriminations of the animal. Thus, the results of Kelleher, Fry, and Cook (1959) indicate that a reduction in the limited hold (LH) on a DRL procedure tends to worsen temporal discrimination both by displacing the IRT mode towards shorter values and by increasing the variance of the IRT distribution.

The relative inability of the usual differential reinforcement procedures to improve temporal discrimination of this sort leads one to ask whether performance under DRL schedules represents some kind of absolute limitation upon animals' ability to discriminate time intervals. Is there anything about the DRL schedule itself which might artificially restrict animals' opportunity to exhibit accurate temporal discriminations? At least two potential limiting properties can be distinguished. (1) An experiment by Reynolds (1966) indicated that the ability to discriminate, *i.e.*, show behavior correlated with, a given time interval must be distinguished from the ability to inhibit responding for the duration of that interval. The enforced-pause aspect of the spaced responding procedure may thus be an irreducible limiting factor. (2) An adventitious property of DRL LH procedures, however, as they are usually scheduled, is the infrequency of informative feedback available to the animal. Most of the informative feedback on DRL LH schedules is associated with the reinforcement; reinforcement implies that the previous IRT was correct and the animal should continue to emit IRTs of this duration. An unreinforced response, on the other hand, implies only that the previous IRT was incor-

[1]This paper is dedicated to B. F. Skinner in his sixty-fifth year.

rect; it carries no indication either of the correct IRT or the direction in which future IRTs should change. Thus, the rate of informative feedback depends largely upon the rate of correct responses, which, in turn, depends on the frequency of informative feedback, and so on. It is conceivable that this circular process may artificially limit pigeons' performance in spaced responding situations, either in terms of the accuracy of performance for a given DRL requirement, or by setting an upper limit on the DRL value that can gain discriminative control over the modal interresponse time (*cf.* Staddon, 1965), or both.

Empirical investigation of the effects of "informative" stimuli poses a number of subtle methodological problems. At the simplest level, however, a situation is required where response-contingent stimuli are presented that are (a) correlated with the difference between the just-emitted IRT and the IRT required, and (b) are not correlated with reinforcement. These two conditions were satisfied by a procedure that briefly presented a red or a green key following IRTs that were too short or too long, respectively, in terms of a given DRL LH schedule. The presentations were brief because a correlation with reinforcement would have qualified the stimuli as either discriminative, or conditioned reinforcers, or both, and thus might have confounded the outcome.

Asymptotic performances were obtained with this procedure in a series of experiments involving DRL LH schedules with DRL values over the range of 8.8 to 30 sec and limited holds from 10% to 30% of the DRL value. In a number of ABA sequences no reliable differences between asymptotic IRT distributions obtained with and without feedback stimuli were found.

This failure implies either that (a) pigeons cannot utilize the information provided by feedback stimuli, or (b) some kind of shaping procedure is necessary to demonstrate control of behavior by feedback stimuli, or (c) the DRL LH contingencies used were not sufficient to produce stimulus control, *i.e.*, the birds obtained sufficient reinforcement without attending to the stimuli; (b) and (c) are of course not mutually exclusive.

Further exploration of this technique focused on (c), the "difficulty" of the procedure. The manipulation finally chosen involved shifting to a dynamic situation where, on *a priori* grounds, feedback might seem to be most useful. The situation involved a DRL *t* LH *0.t* schedule where the value of *t* changed systematically every 5 min, going through two cycles in a 2-hr experimental session. A series of transfer tests demonstrated clear control of responding by the feedback stimuli under these conditions, but indicated that the mechanism of control was not the obvious "speed up" or "slow down" effect intended. This conclusion was reinforced by a further experiment, using a more sensitive version of the original simple DRL LH procedure, that again failed to show any clear effect of the stimuli.

EXPERIMENT I: SEQUENTIAL STUDY OF FEEDBACK AND NO-FEEDBACK CONDITIONS[2]

METHOD

Subjects

Three adult, male, White Carneaux pigeons, maintained at 80% of their free-feeding weights, were used. These birds had been exposed to a variety of reinforcement schedules before the start of the experiment, including various exploratory procedures using feedback stimuli on DRL LH schedules.

Apparatus

The experimental chamber consisted of a standard 12- by 12- by 13-in. wire cage, one side of which was an aluminum panel on which a Gerbrands pigeon key and grain feeder were mounted. The translucent key was illuminated from behind by Christmas-tree lamps of various colors. These lamps also served as general illumination, both via the key and by reflection from the white-painted walls of the larger soundproofed enclosure containing cage and panel assembly. White noise masked most extraneous sounds. A force of at least 18 g was required to operate the key. Effective re-

[2]Experiment 1 is adapted from a thesis submitted to Harvard University in partial fulfillment of the requirements for the Ph.D. degree. The work was supported by grants from the National Science Foundation to Harvard University; preparation of this report was assisted by Grant MH 14194 from the National Institute of Mental Health. Reprints may be obtained from the author, Department of Psychology, Duke University, Durham, North Carolina 27706.

sponses produced an audible click from a relay behind the panel. During reinforcement (3-sec access to grain) the key lights were out and the magazine aperture was illuminated.

Scheduling was accomplished by a system of relays and timers. Responses were recorded on electric impulse counters and a cumulative recorder. IRT data were obtained by a graphic method first described by Blough (1963). The technique produces oscillograms in which each response is recorded as a dot; displacement of the dot along the ordinate is an exponential function of the preceding IRT and its displacement along the abscissa is proportional to the ordinal number of that response (*i.e.*, tenth, forty-fifth, *etc.*) within the session. The exponential time axis insures that responding that is random with respect to time will tend to produce a more or less uniform field of dots, whereas temporal discrimination, defined as a rising IRTs/Op function, will tend to produce clusters of responses around a given ordinate value. Thus, the data shown in Fig. 3 show a progressively changing temporal discrimination, since the ordinate value associated with clustering of responses shifts systematically through the experimental session.

Procedure

The schedule used throughout the experiment involved five DRL values, each one of the form: DRL *t* LH *0.t*-sec, *i.e.*, a 10% limited hold was used in all cases. These five values were presented in the following sequence (nominal values of *t* in sec[3]):

8; 10; 15; 20; 30; 30; 30; 20; 15; 10; 8.

Each component was in force for 5 min, independent of the number of reinforcements produced in the component; the scheduling timer did not stop during reinforcement. No differential stimuli, in the usual sense, were correlated with each value of the schedule and it must therefore be classified as a mixed DRL LH schedule of a cyclic rather than a random nature (cyclic DRL). Two cycles of this procedure constituted a session, which therefore lasted for 110 min. The session always started with the first 8-sec component. The 10% limited-hold aspect of the schedule was dictated by the need to hold to a reasonable level the number of reinforcements the animal could produce within the 2-hr session. Earlier experiments indicated that even a 20% LH allowed some animals to produce as many as 90 reinforcements within a 2-hr period. Under these conditions, tracking behavior deteriorated sharply.

The major independent variable was the presence or absence of feedback (FB) stimuli. There were two stimuli, a red and a green key light. In the FB condition a response on the key had one of three outcomes: (1) after an IRT shorter than the minimum IRT specified by the cyclic-DRL component then in force, the white key light changed to green for 1.6 sec, followed by a return to the white key light; (2) after an IRT within the limits prescribed by the schedule in force, the key lights were extinguished and the reinforcer presented. Following reinforcement, the white key light reappeared at reduced intensity (caused by interposing a 300-ohm resistor in series with the light) for 1.6 sec, after which it returned to its normal intensity; (3) after an IRT longer than the maximum (10% longer than the minimum) specified by the schedule, the white key light changed to red for 1.6 sec, followed by a return to white. All key lights were turned off for 35 msec (the duration of the response pulse) after every response, to allow time for switching of the scheduling equipment. A typical sequence of events is illustrated in Fig. 1. In the "no-feedback" (NFB) situation, the number of possible outcomes that could result from a response was reduced from three to two: reinforcement, on the one hand, or the 1.6-sec appearance of the white light at reduced intensity, on the other. The same stimulus occurred after reinforcement in both procedures. Thus, the only difference between the FB and NFB situation was that in the latter, the white light at reduced intensity took the place of both green and red key lights.

In the extinction conditions with feedback, responses terminating IRTs that would normally have been reinforced were followed by the feedback stimulus that followed the preceding IRT.

Two major dependent variables will be discussed: (1) IRT distribution as a function of time and schedule component; (2) rate of responding as a function of time within each

[3]The nominal values of *t* do not reflect its actual value in all cases; actual values were:

nominal *t* (sec)	8	10	15	20	30
actual *t* (sec)	8.5	11.0	16.3	20.9	30.6.

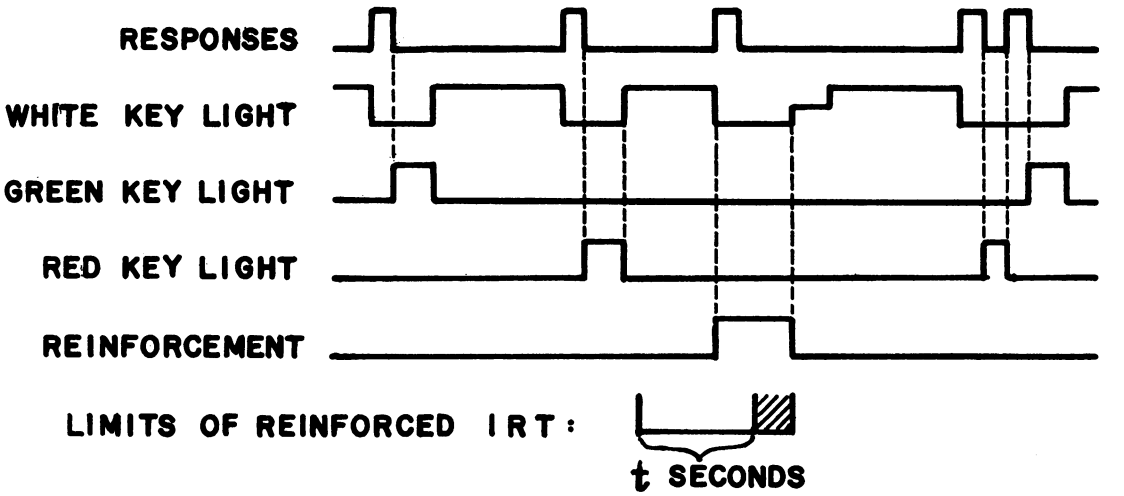

Fig. 1. The sequence of events following interresponse times greater than, less than, and within the reinforced IRT band. The effect of an IRT shorter than the 1.6-sec feedback stimulus duration is also shown. The time dimension is not to scale.

session; for this purpose the number of responses made during each of the eleven 5-min components during the second cycle of the session was recorded.

Table 1 shows the sequence of experimental conditions used. The first part of the experiment—Conditions 1 through 6—was designed to establish the existence of an effect of the feedback stimuli under both steady-state conditions and in extinction. The second part —Conditions 7 through 16—attempted to analyze further the mode of action of the stimuli by interpolating probe sessions separated by days under the basic feedback procedure.

Results

The major result of the experiment was demonstration of control of the cyclic pattern of responding developed under this procedure ("tracking" of the cyclic DRL) by the feedback (FB) stimuli. This control is clearly evident under steady-state conditions for two of the birds and in extinction tests for all three. The relevant steady-state data appear in Fig. 2 which shows response rate within each 5-min component during the second cycle of the session for Conditions 1, 3, and 5 (NFB-1, FB-1, and NFB-2). Both 186 and 106 show the ex-

Table 1

Condition	*Description*		*No. of Sessions (range)*
1	no feedback	(NFB-1)	32
2	extinction without feedback	(EXT NFB-1)	1
3	feedback	(FB-1)	21-25
4	extinction with feedback	(EXT FB-1)	1
5	no feedback	(NFB-2)	29
6	extinction without feedback	(EXT NFB-2)	1
7	feedback	(FB-2)	27
8	extinction during second cycle	(½ EXT)	1
9	feedback	(FB-3)	3
10	reversed feedback for 2nd cycle	(½ REV)	1
11	feedback	(FB-4)	5
12	reversed feedback and extinction	(½ REV + EXT)	1
13	feedback	(FB-5)	6
14	green feedback stimulus only	(GREEN)	1
15	feedback	(FB-6)	3
16	red feedback stimulus only	(RED)	1

Experimental conditions and number of sessions. The basic procedure throughout the experiment was a DRL *t* LH *0.t* schedule with *t* varying cyclically. Two cycles constituted a session.

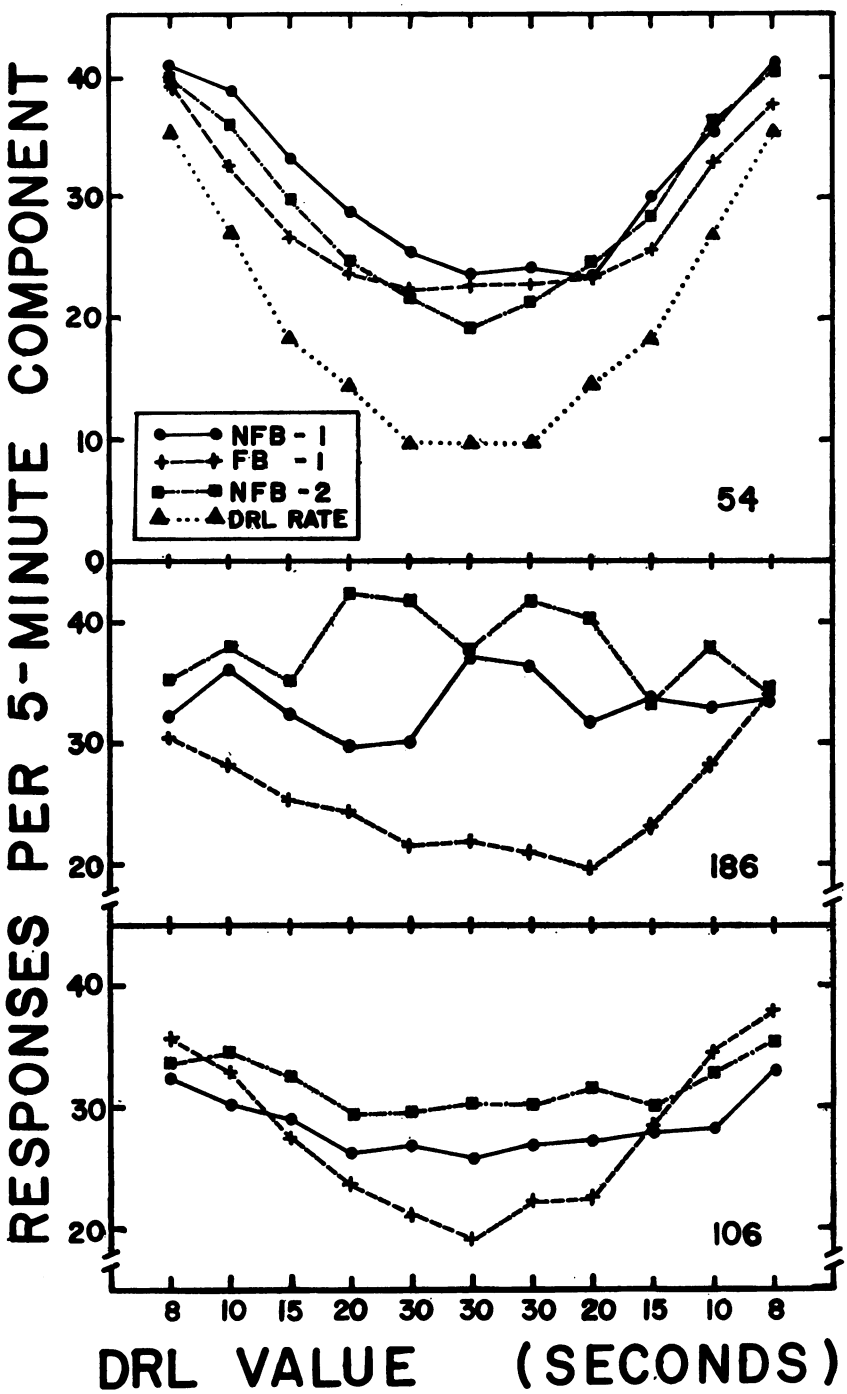

Fig. 2. Response rate in each component during the second cycle of the session for the first and second no-feedback (NFB-1 and 2) conditions and the first feedback condition (FB-1) for the three birds. Each point is the average of the last seven sessions under each condition. In this and all similar plots the rate in each component has been adjusted for the time taken by the reinforcement cycle. The curve labelled "DRL RATE" in the top panel indicates the number of responses that would be emitted in each component if every response terminated an IRT just long enough to qualify for reinforcement.

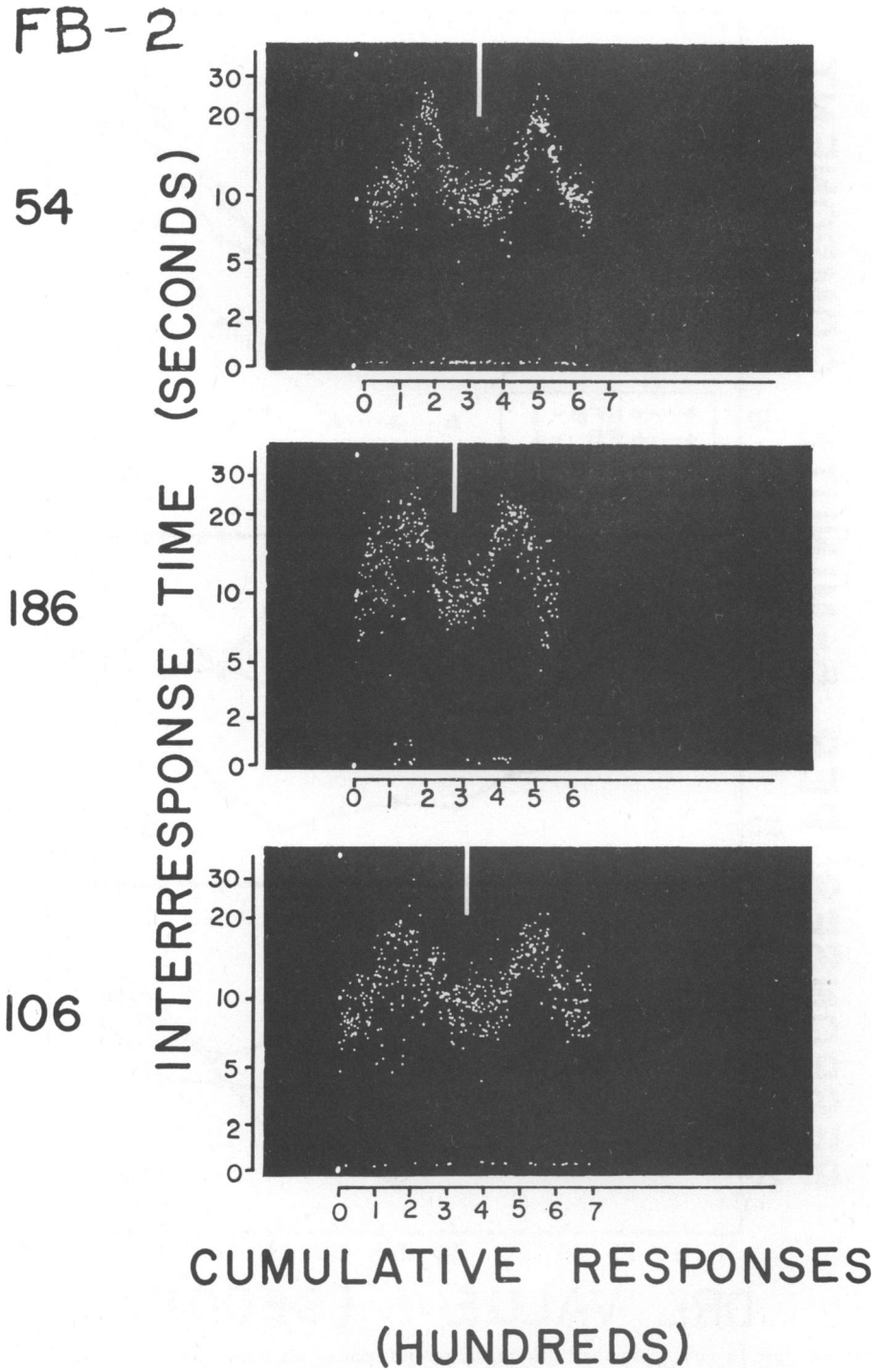

Fig. 3. Oscilloscope records for the last session under the second feedback condition (FB-2) for the three pigeons. Each point represents a response terminating an IRT given by the ordinate value. The ordinal number of the response is given by the value on the abscissa. Vertical white line at the top of each photograph indicates the end of the first cycle. See text for fuller discussion.

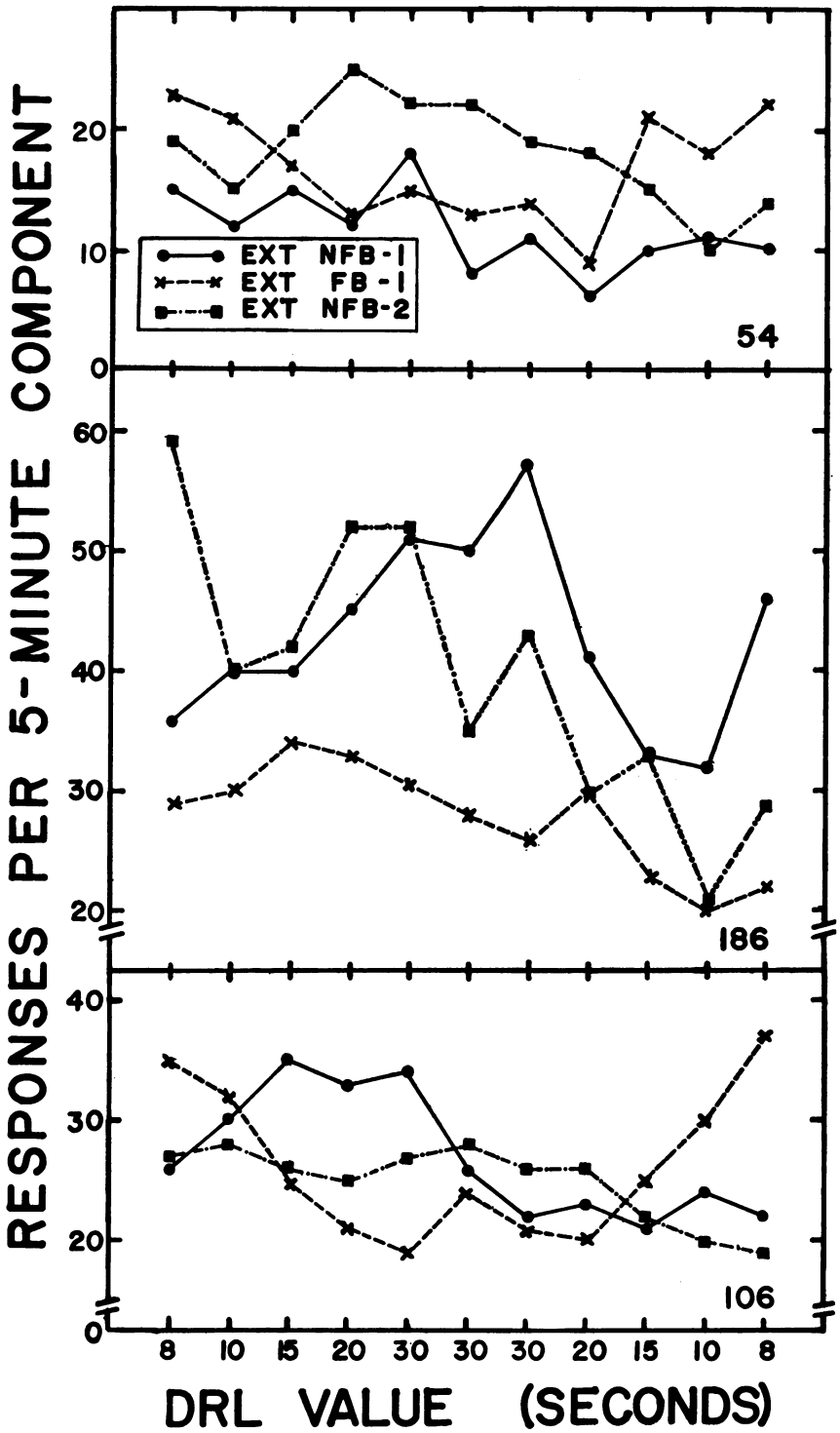

Fig. 4. Response rate in each component of the second cycle in extinction following feedback and no-feedback conditions; *i.e.*, in Conditions EXT NFB-1, EXT FB-1, and EXT NFB-2.

pected decline and increase in response rate as a function of time for the feedback condition, but to a lesser extent (106), or not at all (186), for either of the no-feedback conditions. Bird 54, however, tracked even without the aid of the feedback stimuli. The data in this figure indicate that the more proficient the bird was at this procedure, in terms of the regularity and amount of cyclic variation in the presence of cues both from reinforcement and the feedback stimuli, the less disruption was produced by removing the stimuli; *i.e.*, the same order of proficiency obtained both with and without feedback. Dot pictures taken for all these conditions indicate that the cyclic variations in response rate shown in Fig. 2 are due to systematic shifts in the modal IRT (*i.e.*, a change in temporal discrimination) rather than a nonselective change in the proportion of long *vs.* short IRTs such as that produced by extinction. A typical set of such dot pictures, taken from Condition 5 (the second feedback condition) is shown in Fig. 3.

The data shown in Fig. 2 might seem to suggest that Bird 54 was controlled solely by cues other than the feedback stimuli (*e.g.*, reinforcement, time since the beginning of the session, *etc.*). This conclusion is contradicted, however, by the results of the extinction sessions, which are depicted in Fig. 4 and 5. Figure 4 shows second-cycle response rate during extinction sessions with and without feedback following FB and NFB conditions, *i.e.*, EXT NFB-1, EXT FB-1, EXT NFB-2. All three pigeons show an effect of the feedback stimuli; in the case of Birds 54 and 106, the cyclic pattern of responding is disrupted by NFB and restored by FB, in the case of 186, responding occurs at a much lower rate in the feedback extinction condition, paralleling the results for this bird in the presence of reinforcement with and without feedback (Fig. 2).

The discriminative control exerted by the stimuli is even more apparent in the second-cycle conditions shown in Fig. 5. The relevant comparisons are between the ½ EXT condition, in which the feedback stimuli, but no reinforcement, occurred during the second cycle of the session, and the other two conditions in which the significance of the stimuli was reversed (*green* for "long", *red* for "short") but reinforcement was continued (½ REV), and the same condition without reinforcement (½ REV + EXT). Only in the ½ EXT condition is the normal cyclic pattern of responding preserved and indeed the birds' tracking behavior during this condition was at least as accurate as during the condition when both reinforcement and feedback were available.

The feedback stimuli clearly exerted control over some aspect of the tracking behavior of all three pigeons in this experiment. Given the scheduled relationship between the red and green key lights and the birds' responding, the simplest mode of control by the stimuli would appear to be upon the direction of change of interresponse time: following an IRT shorter than the DRL requirement, the subsequent IRT should be longer; following a too-long IRT, the subsequent IRT should be shorter. The most direct method for testing a mechanism of this sort was provided by the second-cycle conditions when the significance of the green and red stimuli was reversed. If the birds' tracking were controlled by a negative feedback mechanism of the type described, with the stimuli providing the feedback signals, the second-cycle reversal conditions (½ REV and ½ REV + EXT) should convert a negative feedback mechanism into a positive feedback one, leading either to runaway acceleration (shorter and shorter IRTs) or deceleration (longer and longer IRTs). Figure 5 shows that neither result occurred for any animal. Indeed, for the ½ REV condition the rate for the first four or five components of the condition showed less change than usual, contradicting predictions based upon an IRT-by-IRT feedback control mechanism. The results of the ½ REV + EXT condition are more equivocal for Birds 54 and 106, but in neither case do they provide clear support for the simple feedback view. Unfortunately, the results of the other two probe conditions, GREEN and RED, are similarly uninformative, agreeing only in that they fail consistently to support the feedback hypothesis. Thus, while response rate in the GREEN condition (green feedback stimulus following all unreinforced responses) was lower than for the RED condition for Birds 186 and 106, in accordance with the scheduled "too short" significance of green, the opposite was true of Bird 54, which in other respects adapted best to this situation. In general, the tracking of all three birds was more disrupted by RED than by GREEN, the difference being greatest for 186 and least for

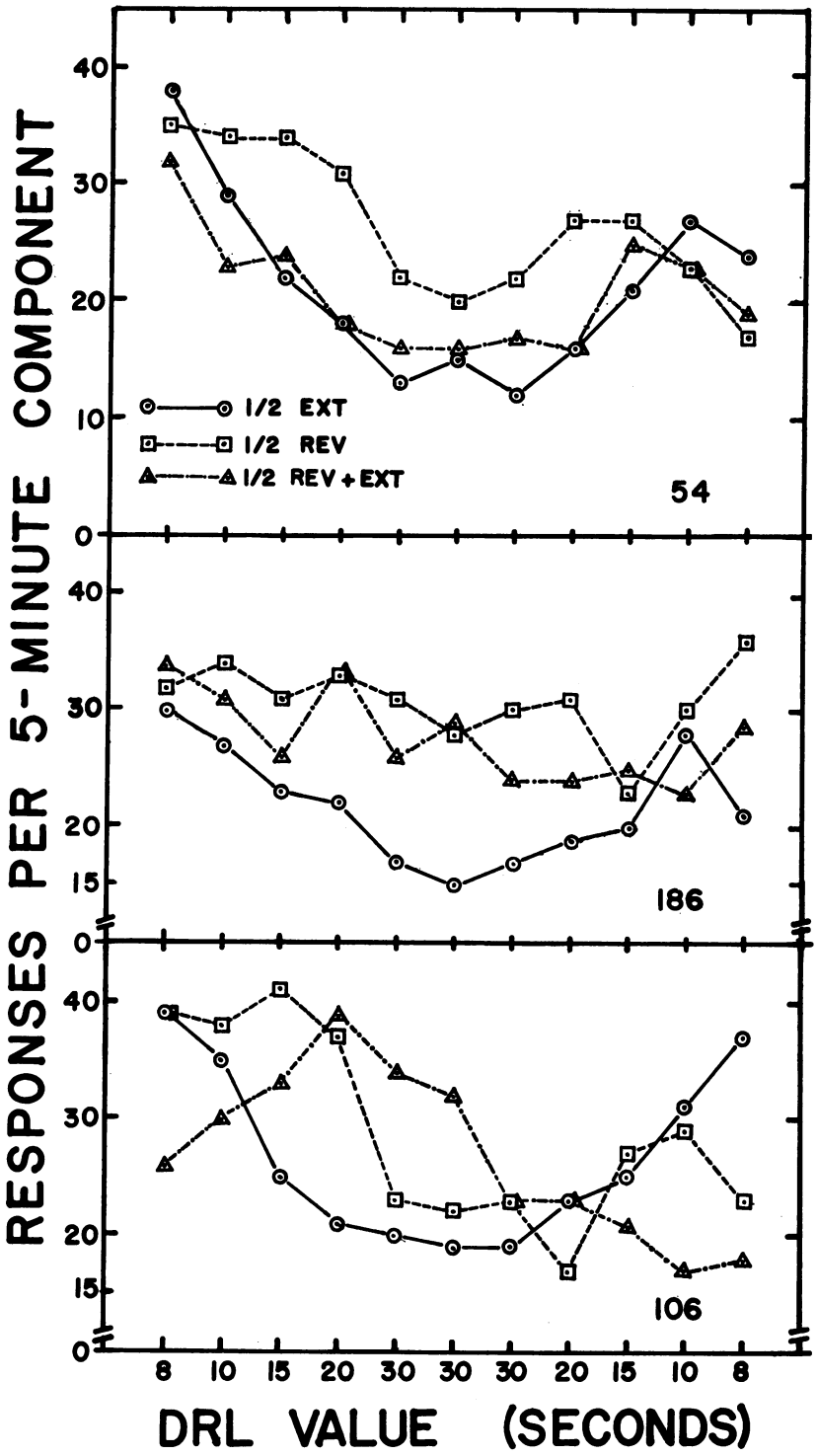

Fig. 5. Response rate in each component of the second cycle during the three second-cycle conditions: ½ EXT —extinction during the second cycle, feedback given; ½REV—reversed feedback during second cycle, reinforcement given; ½ REV + EXT—neither reinforcement nor feedback during second cycle.

54, again reflecting the order of proficiency of the birds at this task.

EXPERIMENT 2: FEEDBACK AND NO-FEEDBACK CONDITIONS WITHIN COMPONENTS OF A MULTIPLE SCHEDULE

After the cyclic DRL experiment, the possibility of discriminative control by feedback stimuli in the simple DRL LH situation was re-examined using a more sensitive procedure. In addition to four naive pigeons the two most proficient birds under the cyclic procedure (54 and 106) were used. This experiment thus constituted a test of whether or not their experience under the cyclic procedure allowed these birds to come under the control of feedback stimuli in the simple DRL LH situation. Two of the six pigeons showed small, idiosyncratic effects attributable to the feedback stimuli.

METHOD

Subjects

Six White Carneaux pigeons, four naive (223, 224, 225, 226) and two used in the previous experiment (54, 106) were maintained at 80% of their free-feeding weights.

Apparatus and Procedure

After one day of continuous reinforcement following key and magazine training for the four naive birds, all birds were exposed in the chamber of the previous experiment to 24 sessions of a DRL x LH y procedure with x and y varying from 5 sec and 1.5 sec, during early sessions, to 15 sec and 3 sec for the last 15 sessions. This was followed by 28 sessions when Birds 54, 106, 224, and 226 were exposed to DRL 15 LH 1.5-sec and Birds 223 and 225 to DRL 10 LH 1-sec.

Superimposed on this basic procedure was a two-component multiple schedule of feedback and no feedback. The components alternated at 5-min intervals and the first component of the session varied irregularly from day to day. Six cycles of this procedure constituted a session. During the feedback components, the same stimulus contingencies were in effect as in the feedback conditions in the first experiment, *i.e.*, a brief green or red stimulus following IRTs longer or shorter than the range specified by the DRL LH schedule. For Birds 54 and 106, green signified "short" and red "long", as in the previous experiment. For the other four birds the significance of the colors was counterbalanced: green signifying "short" for Birds 223 and 224, and *vice versa* for Birds 225 and 226. The duration of the feedback stimuli was 1.5 sec for the DRL 15 LH 1.5 birds and 1 sec for the others. During the no-feedback component of the multiple schedule, the key light was dimmed after each response by interposing a 500-ohm resistor in series with the white key light. This stimulus also followed reinforcement during the feedback component.

On the day following Session 19 of the series of DRL 15 LH 1.5-sec sessions, Birds 54 and 226 were given an extinction session with the multiple feedback–no-feedback contingency remaining in force. As with the feedback extinction conditions in the previous experiment, after IRTs that would have been reinforced, the feedback stimulus appropriate to the preceding (one-back) IRT was presented.

Separate IRT distributions, with 16 IRT cells having a width of 1.5 sec for the DRL 15 LH 1.5-sec conditions and 1 sec for the DRL 10 LH 1-sec conditions, were obtained for the feedback and no feedback components.

RESULTS

Figure 6 shows data for the last 14 days of the final condition of the experiment. Each point is the mean of 14 daily points. Each daily point represents the difference (NFB − FB) between the number of IRTs in a given cell in the no-feedback and feedback components respectively. Thus, the curves of Fig. 6 represent the mean difference between the IRT distributions with and without feedback. The small IRT distributions along the right column of Fig. 6 are 14-day means with and without feedback; they show typical DRL LH performances for all the birds. The difference curves show few significant deviations from zero, however. With the exception of Bird 223, and possibly Bird 106, there were negligible differences between the feedback and no-feedback IRT distributions. Bird 223 did show a small but consistent difference between the feedback and no-feedback distributions, with the feedback distribution showing fewer short (< 6 sec) IRTs and more long ($6 < \text{IRT} < 8$ sec) IRTs. Overall, however, the effect of feedback under these conditions was much less ap-

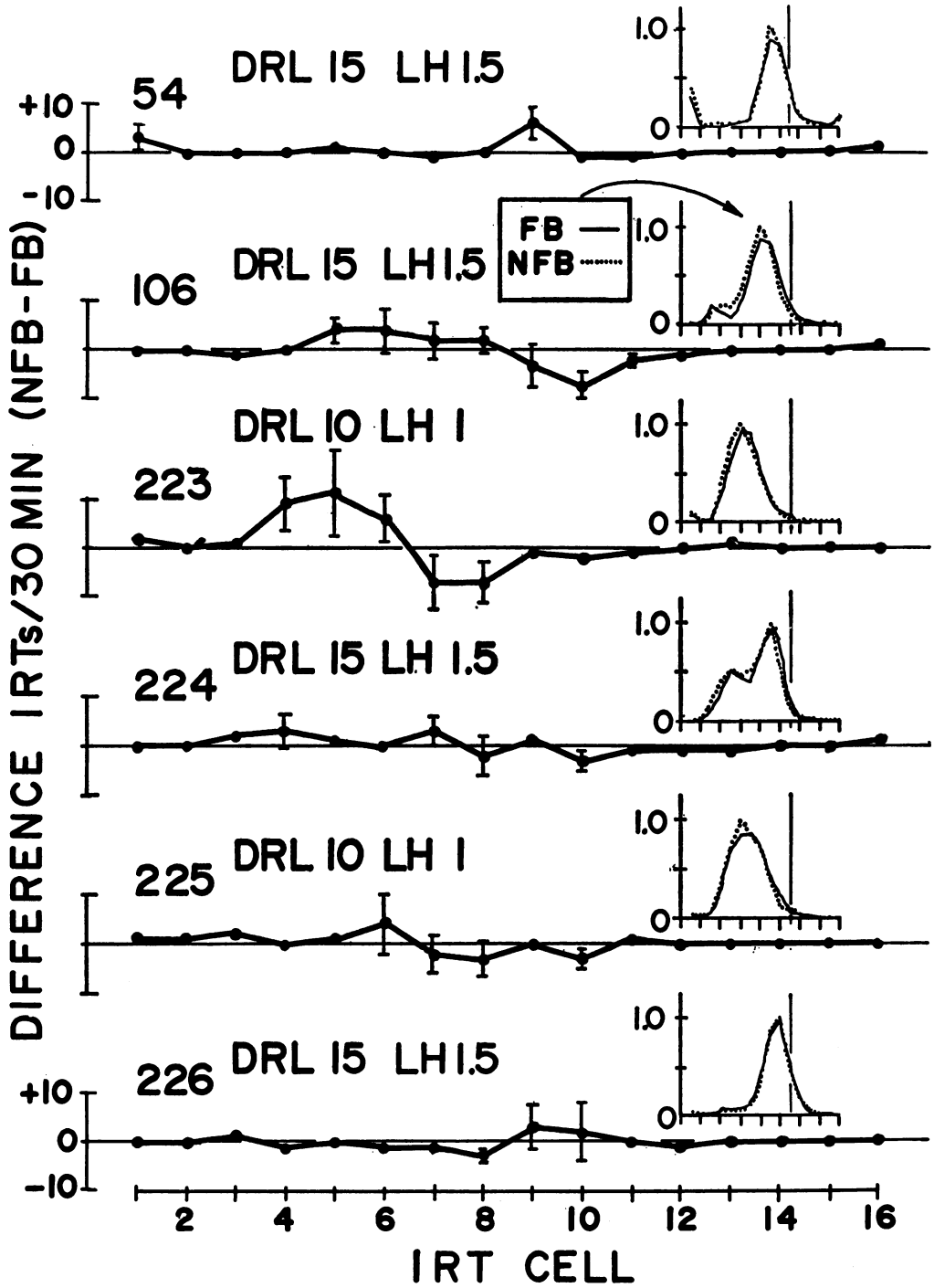

Fig. 6. Difference interresponse-time distributions for the six pigeons. The difference (NFB − FB) between the number of IRTs falling in each of 16 cells in the feedback and no-feedback components was computed for each of the last 14 days of the experiment. Each plotted point in the difference curve is the mean of these 14 differences. Vertical bars are 95% confidence intervals. IRTs falling in cell 11 were reinforced. The small, relative-frequency IRT distributions on the right are 14-day averages with and without feedback over the same period.

parent than under the cyclic procedure of the previous experiment, even for the two birds (54 and 106) that showed clear evidence of control by the feedback stimuli in that experiment.

Another comparison was afforded by the extinction sessions given to Birds 54 and 226. In the absence of cues provided by reinforcement, control by feedback might be expected to become more apparent. Such was not the case. Little breakdown in performance occurred during the extinction condition for either bird (*i.e.*, the form of IRT distribution closely resembled distributions obtained during training) and there were no significant differences between feedback and no-feedback components in this respect.

It remains possible that prolongation of the extinction condition, computation of more comprehensive average IRT distributions, or a number of other manipulations, both experimental and computational, would have shown an effect of the feedback stimuli. On the other hand, the results of this experiment strongly suggest that any effect is, at best, of small magnitude under these conditions.

GENERAL DISCUSSION

The present results indicate that feedback stimuli can assist pigeons to maintain a cyclic, temporal tracking performance and can sustain this behavior in the absence of reinforcement. The exact mode of action of the stimuli is unclear, however, although the results of the cyclic tracking procedure, together with the negligible effect of the stimuli in the stationary tracking experiment, suggest that they did not act in a simple negative feedback fashion, interresponse time by interresponse time.

One implication of these results is that the limitations on DRL performance alluded to earlier probably cannot be attributed to lack of informative feedback. A second implication concerns the relationship between "information" and the capacities of the organism. The information contained in a set of instructions is of little help to a hearer who does not speak the language; on the other hand the fact that instructions of some kind are being given may be of some help, although the detailed content is unavailable. In other words, a given situation may contain information on several levels and only those for which the organism possesses the appropriate decoding system can come to control behavior. In the cyclic tracking situation with feedback, the stimuli contained two kinds of information: (a) Information corresponding to the scheduled contingencies concerning the relation between the just-emitted IRT and the tracking requirement. This information was associated with each stimulus occurrence. (b) Information contained in the pattern of feedback stimuli over time: because the pigeons adapted much better to the shorter (DRL 8 and 10) tracking requirements than to the longer (DRL 20 and 30) components, both the frequency of reinforcement and the relative frequency of the red ("too long") feedback stimulus increased during the shorter components. The effectiveness of the feedback stimuli in the cyclic situation, their relative ineffectiveness in the simple DRL LH situation, and the results of the various transfer and probe tests all suggest that the latter property of the stimuli was the effective one in this situation. The mechanism of action both of this relative frequency variable and of the other cues in the cyclic situation (beginning of session, reinforcement, and reinforcement frequency) remains obscure, however. A general implication of the results is that perhaps pigeons either cannot come under the control of a feedback "knowledge of results" relation of this sort, cannot rapidly and systematically shift the mode of their IRT distribution under discriminative control, or both.

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