JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR VOLUME 5, NUMBER 1 JANUARY, 1962

EXTEROCEPTIVE CONTROL OF FIXED-INTERVAL RESPONDING

EVALYN F. SEGAL[1]

WALTER REED ARMY INSTITUTE OF RESEARCH AND
LABORATORY OF PSYCHOPHARMACOLOGY, UNIVERSITY OF MARYLAND[2]

Two pigeons were exposed to several fixed-interval schedules of food reinforcement. In some cases, exteroceptive stimuli associated with the passage of time were present. Such visual "clock" stimuli were found to gain almost complete control over the behavior, although at the longest fixed interval studied, the superposition of a new temporal discrimination upon the visual discrimination was observed. Where clock stimuli were made contingent upon the birds' behavior, a new form of responding was generated. This behavior was discussed in terms of positive and negative response-tendencies resulting from several stimulus factors: Some of these functioned as S^{Δ}'s and secondary negative reinforcers; some functioned as S^D's and secondary positive reinforcers; and some were ambiguous with respect to reinforcement conditions. A "pure temporal" discrimination was superimposed upon these factors, but its exact nature was indeterminate from the present data.

Ferster and Skinner (1957) have investigated the effects of an external "clock" on the performance of pigeons responding under fixed-interval schedules of reinforcement. In their experiments, the visual stimulus used as a "clock" changed continuously over the fixed interval, and reset to a zero value immediately after reinforcement. In most cases, the performance resembled normal fixed-interval responding, with a pause after reinforcement followed by a gradual increase in rate until a terminal rate was reached some time before the end of the interval. The external stimulus' control over the performance was demonstrated in various ways, such as "reversing" the clock and extinguishing the behavior in the presence of an automatically recycling clock.

The present study extends these findings by the use of a "clock" with four discrete, visual stimuli of equal temporal value. They occurred in fixed order on all occasions, and the set of four made up the length of a single fixed interval. Thus, a discontinuous clock with four discrete and equal steps was substituted for the continuous clocks of Ferster and Skinner. A degree of external control of fixed-interval responding was observed exceeding that of the previous studies in certain respects.

METHOD

Two adult, male, homing pigeons, maintained at 80% of free-feeding weight, were used. Both birds had previously been subjects in a study of fixed-ratio behavior that had terminated several months before the present experiment began. In the interim, the animals were maintained on a free-feeding regimen.

A single Foringer pigeon apparatus was used. A small speaker in the experimental chamber continuously fed in white masking noise, and a larger speaker in the experimental room delivered additional masking noise. The apparatus was lightproof, and the houselight inside the pigeon chamber was not used. The experimental room was dimly illuminated, however; and in certain phases of the experiment, a window in the roof of the apparatus was uncovered, allowing a small amount of room light to illuminate the interior of the pigeon chamber.

Reinforcement consisted of 5-sec access to the grain magazine located several inches below the pecking key, and was associated with temporary illumination of the magazine. Every experimental session lasted for 50 rein-

---

[1] During the conduct of this research, the author held a Postdoctoral Research Fellowship from the National Institute of Neurological Diseases and Blindness, under the sponsorship of Dr. J. V. Brady. Thanks are due to the Laboratory of Psychopharmacology of the University of Maryland for provision of research facilities under Grant No. MY-1604 from the National Institute of Mental Health.

[2] Present address: San Diego State College.

forcements. Where necessary to maintain constant weights, additional grain was given in the home cages at the end of the session.

Response-independent Light Condition

Four colored 6-V lamps located behind the pecking disc illuminated it to provide the exteroceptive stimuli. The lights always appeared in the following order within each fixed interval: green, orange, blue, and red. Each light appeared for exactly one-fourth of the fixed interval, except that the final light, the red, remained on until a reinforced response occurred following "timing out" of the interval. The red light also remained on during the 5-sec reinforcement period; then, all lights went out for a fraction of a second while the programming apparatus reset. The first light, the green, then reappeared, signalling the beginning of a new fixed interval. Each light followed the preceding one without interruption (except at reset, as noted), and no sounds audible in the experimental room were associated with changes in key color. This procedure, in which the appearance of the colored lights on the key was automatically programmed and independent of the birds' behavior, will be called the *response-independent light conditions.* As a baseline control, sessions were also run in the presence of a single response-independent light, the red light.

Response-dependent Light Condition

In some stages of the experiment, the colored lights were not independent of the birds' behavior. In this condition, pecking at the disc illuminated it momentarily, and the disc remained dark when not being pecked. The *color* of the light flash produced by a key peck was, as before, dependent only upon whether it was the first, second, third, or fourth quarter of the fixed interval, and not upon the bird's behavior; but the *appearance* of the colored flash of light did depend upon the bird's pecking the key. The duration of the light flash corresponded to the release time of the keying relay operated by key pecks. In stages of the experiment when this *response-dependent light condition* was used, the animals had to peck "to find out what time it was." The similarity to the "observing responses" of Wyckoff (1952) and Kelleher (1958) is apparent. As a baseline control, some sessions were run with only one light (red); but in this case, the light remained response-dependent.

Because the experimental apparatus was lightproof and the only light inside the apparatus was that from the illuminated pecking disc, long periods of total darkness sometimes occurred in the response-dependent light conditions, especially when it was first introduced. Pigeons are known to roost in total darkness; and, in fact, when first introduced to this procedure, the birds of this study did not respond at all. Therefore, the window in the roof of the chamber was uncovered, permitting very dim illumination of the interior of the chamber with room light. The window remained uncovered through all succeeding sessions with the response-dependent light condition.

Table

Sequence of Experimental Conditions

Sessions	*Length of FI*	*No. of Lights*	*Duration of Each Light*	*Control of Light*
13	12 sec	4	3 sec	R-indep.*
20	12 sec	1	12 sec	"
31	1 min	1	1 min	"
19	1 min	4	15 sec	"
16	1 min	4	15 sec	R-dep.**
25	1 min	1	1 min	"
15	5 min	1	5 min	"
18	5 min	4	75 sec	"
12	5 min	4	75 sec	R-indep.
7	5 min	1	5 min	"

* Independent

** Dependent

Table 1 gives the sequence of experimental conditions. Each stage of the experiment was continued until the percentage distribution of responses over the four quarters of the fixed interval had not changed by more than one or two percentage points over at least four or five sessions, and often more. The birds' previous experience on ratio schedules may have contaminated early data of the present experiment; but use of a stringent criterion of stability, and analysis only of stable performance data, should have reduced contamination from ratio-generated behavior to a minimum.

RESULTS

Figure 1 summarizes the experiment in the form of percentage of total responses in each one-fourth of the fixed interval under each experimental procedure. (There were

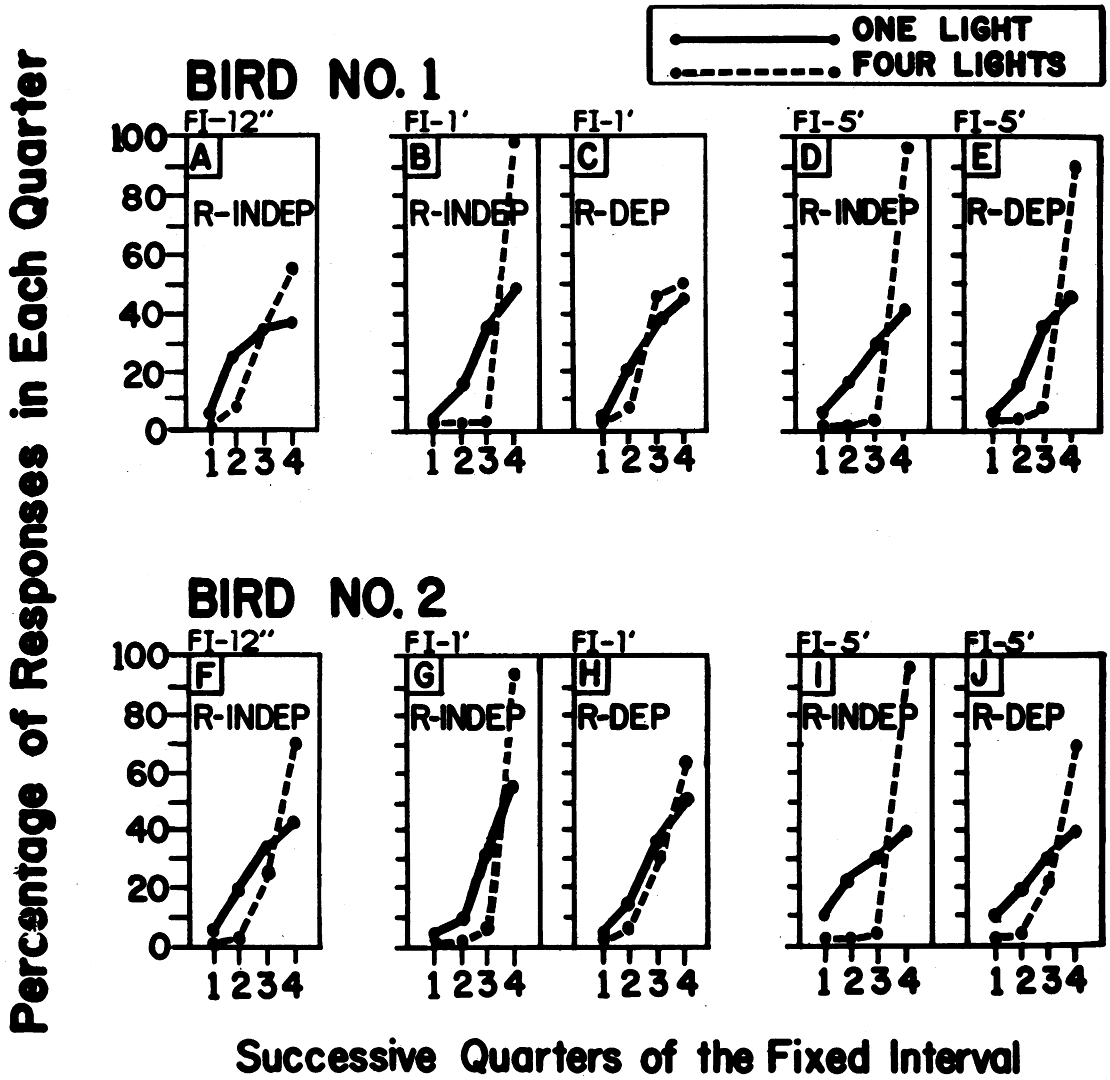

Fig. 1. Average percentage of total responses in each quarter of the fixed interval.

no response-dependent light conditions at FI 12 sec.) Every datum point is the mean of the final four to ten sessions of an experimental procedure, and in every case represents behavior that was stable within the limits specified above.

One-light Sessions, Considered Alone

The heavy unbroken lines of Fig. 1 show the distributions of responses in the baseline, one-light sessions. These distributions are similar to one another, and each is almost linear. As Fig. 2 shows, the *absolute* number of responses emitted per interval differed considerably as a function of each of the independent variables (subject, interval length, and manner of control over appearance of the key lights); however, the way responses are *distributed* within a normal fixed interval appears to be constant, at least within the limits explored in this experiment. Of particular interest is the finding that the manner of control over light appearance did not affect the percentage distribution of responses, where key illumination was unrelated to the passage of time, as in the baseline, one-light sessions.

Figure 2 gives the mean absolute number of responses per quarter of the fixed interval in each stage of the experiment. The means were computed from the same data plotted in Fig. 1 as percentages. In the baseline, one-light fixed-interval conditions, the absolute

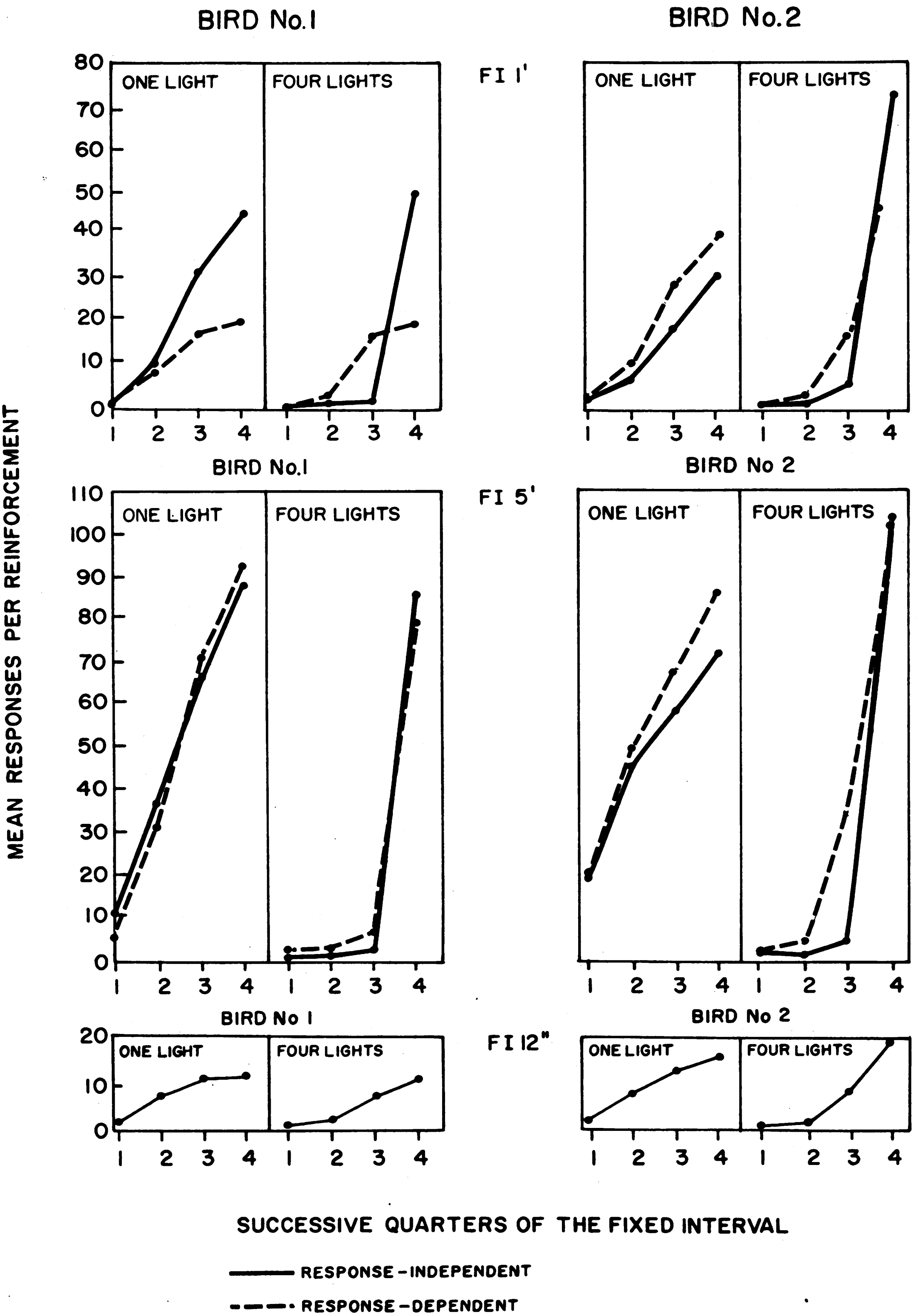

Fig. 2. Average absolute number of responses in each quarter of the fixed interval.

number of responses emitted differed between birds and was influenced by the length of the interval and the manner of key-light production. The greatest discrepancy in number of responses between response-dependent and response-independent light conditions occurred at FI 1 min. In FI 5 min the discrepancy diminished considerably.

As in the percentage distributions, the increase in absolute amount of responding from quarter to quarter of the baseline (one-light) fixed intervals was approximately linear.

Four-light Sessions, Considered Alone

The broken lines of Fig. 1 show the distributions of responses in the four-light sessions. Again, these distributions were similar over the three independent variables (subjects, interval length, and manner of key-light production) in that all curves show some positive acceleration. However, the *degree* of positive acceleration differs considerably as a function of the independent variables. Little, if any, responding occurred in the first three quarters at FI 1-min and FI 5-min response-independent lights. A greater proportion of responding occurred in the first three quarters at FI 12 sec, and also at FI 1 min and FI 5 min, where responding was a necessary condition of clock-light appearance. The differential effect of making light appearance response-dependent or response-independent is especially marked in FI 1 min. In the FI 5-min distributions, the differences between response-dependent and response-independent procedures were much reduced, especially for Bird No. 1. At first, this suggests that at longer fixed intervals the early portions of the interval are more easily discriminated from the later portions, even in the absence of an independent external clock. However, such an inference is not borne out by the one-light distributions. Here, too, if longer fixed intervals make temporal discrimination easier, the proportion of responding in the first three quarters of the interval should be less at FI 5 min than at FI 1 min; but this was not the case. The explanation of the greater resemblance between response-dependent and response-independent distributions at FI 5 min than at FI 1 min is probably complex. It may involve a decrease in the secondary-reinforcing value of response-produced lights correlated with the first three quarters of the longer interval and differential opportunities for "superstitious" reinforcement of early-quarter responding by key-color changes. Bird No. 2's higher over-all response rate explains the larger proportion of responses in the third quarter of the response-dependent (FI 5 min) distribution of Bird No. 2 than of Bird No. 1. At the higher rate, a response was more likely to be emitted just as the light changed, indicating the beginning of the fourth quarter. Thus, with Bird No. 2, light-producing responses in the third quarter were more likely to be adventitiously reinforced by the appearance of the fourth light. Such adventitious secondary reinforcement may have maintained this bird's third-quarter responding at a higher level.

Comparison of One-light and Four-light Procedures

Notwithstanding differences between the response-independent and response-dependent distributions, the influence of the *number* of lights is evident in all the graphs. Fewer responses occurred early in the interval, and more late in the interval, in the presence of four time-correlated exteroceptive stimuli. In most instances, so little responding occurred in the first three quarters in the four-light sessions that the first three lights may be considered to have acquired S^{Δ} properties.

All plots of Fig. 1 indicate little responding in the first quarter of the fixed interval, regardless of number of lights. The occurrence of reinforcement, then, independently of any other stimuli, acted as an effective S^{Δ}, the effect wearing off with time since reinforcement. Thus, the decline in proportion of responding in the second and third quarters in the presence of the four discrete lights is a more critical demonstration of the effect exerted by the clock lights than is the low proportion of responses in the first quarter.

Figures 3, 4, and 5 contain sample performances. Figure 3 shows cumulative-response records for Bird No. 1 at the shorter fixed intervals. (In the figures which follow, the other bird's performance was similar, unless otherwise noted.) Curves A and B present the final session under FI 12 sec, four response-independent lights. Curves C, D, E, and F present the first session under FI 1 min, four response-independent lights; and Curves G, H, and I present the final session under the same conditions. In Curve F the manner of recording was changed so that downward deflections of the pen now represented not only food reinforcements but also the passage of each quarter of the interval. This manner of recording was continued for the remainder of the experiment.

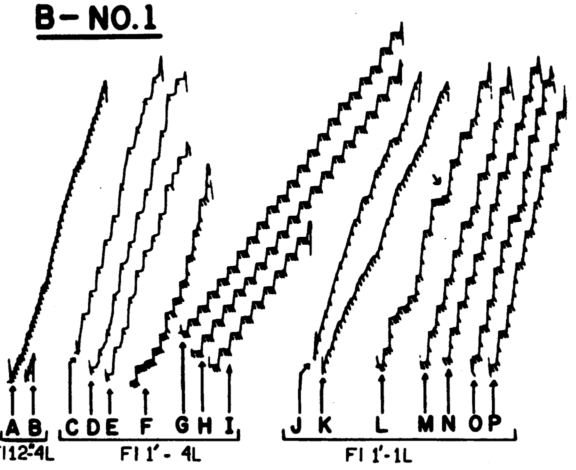

Fig. 3. Bird No. 1's cumulative-response record for FI 12 sec, four response-independent lights (Curves A and B); FI 1 min, four response-independent lights (Curves C through I); FI 1 min, one response-independent light (Curves J through P).

Curves G, H, and I attest to the considerable degree of control exerted over responding by the four key-colors. The step-wise character of these curves results from the total cessation of responding in the first three lights, and the abrupt resumption of responding, at terminal rate, as soon as the fourth light appeared. The gradual attainment of terminal rate characteristic of normal fixed-interval records was absent. Occasionally, Bird No. 2 exhibited a somewhat more gradual assumption of terminal rate (but never so gradual as in normal fixed interval), beginning in the third quarter of the interval. Bird No. 2's over-all rate was higher here, as in all phases of the experiment.

Curves J and K present a portion of the first session under FI 1 min, one response-independent light. The high response rates occur partly because the single color illuminating the key throughout the interval was red, the color correlated with the *final* quarter of the interval in the just-preceding stage of the experiment.

Curves L, M, N, O, and P present the final session of FI 1 min, one response-independent light. Normal fixed-interval performance was not present in the first sessions of this procedure, but it had appeared by the final sessions.

The upper half of Fig. 4 shows Bird No. 2's behavior under FI 5 min, one response-independent light. This procedure followed FI 5 min, four response-independent lights. Curve A presents the first 10 reinforcements of the first session under the new procedure, and Curve D presents the last 10 reinforcements of the final session of this procedure. Curve A demonstrates the considerable control exerted by the red light following "clock training," and its gradual replacement by normal fixed-interval control. Curve D shows a terminal baseline performance under fixed interval.

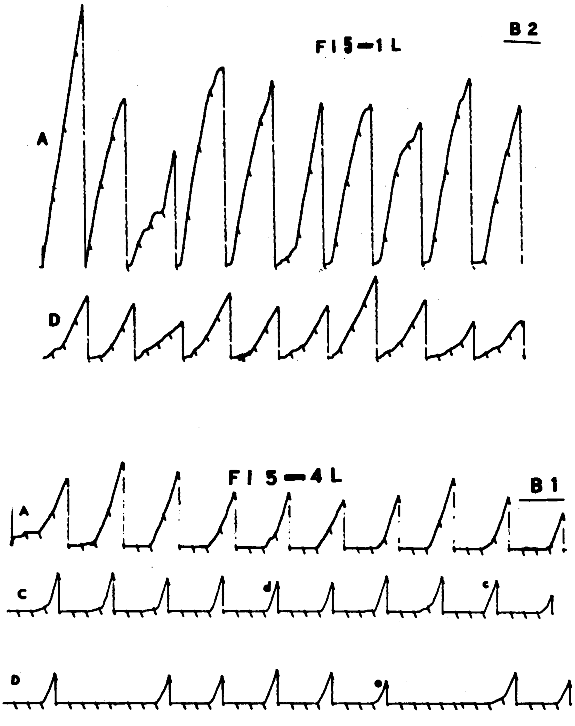

Fig. 4. Performance under FI 5 min, response-independent lights. The upper half shows Bird No. 2's performance for one light. The lower half shows Bird No. 1's performance for four lights. (See text for further explanation.)

The lower half of Fig. 4 presents the performance of Bird No. 1 under FI 5 min, four response-independent lights. This procedure followed FI 5 min, four response-dependent lights. Curve A gives the first 10 reinforcements of the first session; and Curves C and D, the first and last 10 reinforcements of the final session. Since the four clock lights had already achieved discriminative control over the pattern of responding under the preceding condition, little change was seen between initial and final exposure to the new procedure. An instance of the abrupt assumption of terminal rate in the fourth quarter appears at *c*, whereas instances of more gradual attainment of terminal rate appear at *d* and *e*. Examples of gradual assumption of terminal rate in the *third* key-light are in the first three fixed intervals of Curve C. This was more common early in a session than late. Bird No. 2's performance differed only in that *abrupt* assumption of terminal rate was never seen; rather, terminal rate was always achieved gradually, and always beginning in the fourth quarter.

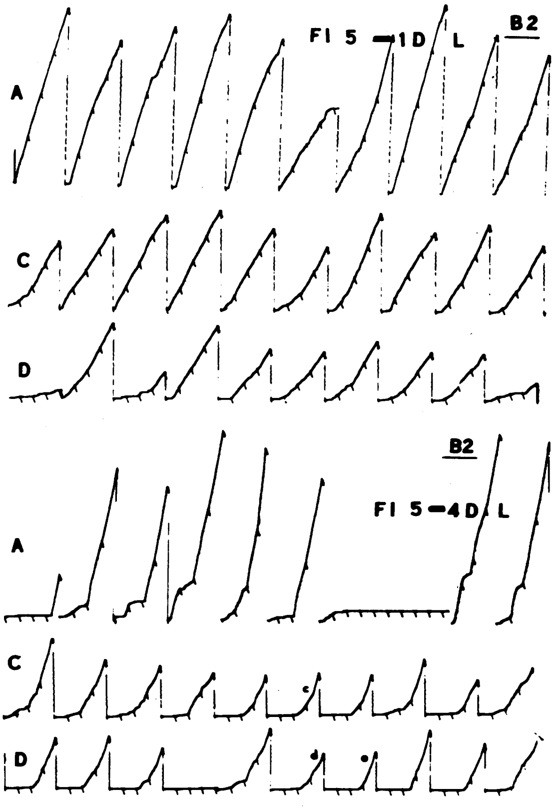

Fig. 5. Bird No. 2's performance for FI 5 min, response-dependent lights. The upper half shows the one-light condition. The lower half shows the four-light condition. (See text for further explanation.)

Figure 5 shows Bird No. 2's behavior in the response-dependent light conditions. The upper half of Fig. 5 shows cumulative responses under FI 5 min, one response-dependent light. This procedure followed FI 1 min, one response-dependent light. Curve A is for the first 10 reinforcements of the first session of the procedure, and Curves C and D are for the first and last 10 reinforcements of the final session.

Comparison of the upper halves of Fig. 4 and 5 reveals little difference in the performance under FI 5 min, one key-light, as a function of whether the key light was response-contingent or response-independent.

The lower half of Fig. 5 shows cumulative responses under FI 5 min, four response-dependent lights. This procedure followed the one in the upper half of the figure. Although gradual recovery of some degree of visual control of the performance occurred, comparison with the lower half of Fig. 4 reveals that responding in the response-dependent condition was never so sharply under the discriminative control of the key lights as was responding in the response-independent condition. However, the degree of discriminative control must be further analyzed: Only by responding occasionally in the early quarters of the fixed interval could the bird produce for itself the discriminative stimuli for *not* responding. The darkened key was an ambiguous stimulus, in whose presence pecking was sometimes secondarily reinforced by the appearance of a "favorable" key-color (one associated with a late quarter of the interval), and sometimes secondarily punished by the appearance of an "unfavorable" key-color (one associated with an early quarter).

Figure 6 is a final demonstration of the discriminative control of the key lights. This session followed the final session of FI 5 min, four response-dependent lights. Each interval represents an occasion where a single (response-independent) key-color illuminated the key for the entire 5 min of the interval. The session began with the key illuminated by the fourth light. The next interval also occurred in the presence of the fourth color. The next two intervals occurred in the presence of the third color, and so on. The numeral near each interval denotes the ordinal number of the color that appeared on the key.

Each color generated a different number of responses at a different rate. The number of responses emitted in the fourth color was considerably different from that emitted in the third color; the difference in number of responses emitted between the third and second colors was smaller, and that between the second and first colors was smaller still. This result suggests a method for scaling the discriminative or secondary-reinforcing value of stimuli more and more remote from primary reinforcement.

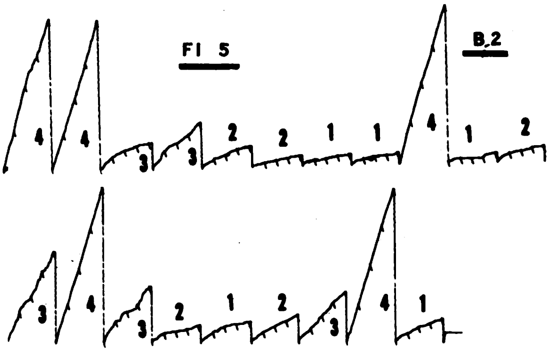

Fig. 6. Bird No. 2's performance in a "test session" in which the various key lights appeared, response-independent, for the entire length of a fixed interval. The numeral near each interval refers to the ordinal number of the key color appearing on the key, relative to the clock-light sequence on which the bird was previously trained.

By the close of this session, the differential control of the key colors was already beginning to give way to simple temporal discrimination of the fixed interval.

DISCUSSION AND CONCLUSIONS

The principal results of the experiment were the following. First, the average quarterly percentage distribution of responding within the fixed interval under ordinary, baseline conditions was constant and linear over interval lengths, between subjects, and irrespective of the manner of key-light production. This was true in spite of variations in average absolute number of responses per quarter of the interval, as well as variations in rate, amount of responding, and pattern of responding from interval to interval of a session. Quarterly percentage distribution appears to be an orderly variable, and highly resistant to change under ordinary fixed-interval conditions. For these reasons, it may be preferable to absolute amount of responding for many analytic purposes. Moreover, if the linearity of quarterly percentage distribution were found to hold at other values of fixed interval, and if linearity were found even under finer temporal analysis (*e.g.*, tenths of an interval), it might shed light on the nature of temporal discrimination itself.

Reference to "temporal discrimination" is not, of course, an explanation of fixed-interval behavior, for the explicit variables mediating temporal discrimination have not been specified. Some of the factors contributing to temporal discrimination have been described by Ferster and Skinner (1957), who point to the important stimulus contribution of the animal's own ongoing behavior. In the studies on visual "clocks" and "counters," they were able to "externalize" the response-produced stimuli, by correlating an exteroceptive stimulus with changes in the bird's rate of responding. Their results suggest that where exteroceptive stimuli, proprioceptive stimuli, and perhaps further interoceptive "timing" factors all operate in the same direction, the exteroceptive stimuli become prepotent. Thus, the behavior of their subjects was shown to accommodate to experimenter-produced aberrations in the visual clock or counter, even though such changes were inappropriate to the schedule of reinforcement. Under such conditions, however, the behavior eventually returned to a form suitable to the schedule of reinforcement.

The prepotence of exteroceptive factors is also exemplified in the second main result of the present study. Following sufficient exposure to four discrete clock-lights correlated with the four quarters of the interval, responding virtually ceased in the early lights, even though the same interoceptive "timing cues" must be supposed to have been present as in the one-light case. No differential response-produced timing cues were generated by the birds, since their responding followed strictly the color and appearance of the key lights. The abrupt assumption of terminal rate in the fourth light in FI 1 min is evidence for this. The more gradual attainment of terminal rate in the fourth light in FI 5 min, however, implies the superposition of a new temporal discrimination upon the simple visual discrimination: The birds' behavior suggests a crude discrimination of whether is was early or late in the fourth quarter. The visual discrimination was by far the stronger, since responding began almost immediately in the fourth light, proceeded from a higher initial rate, and attained terminal rate sooner than in simple

FI 1 min, where the length of the total fixed interval was comparable to the length of the final quarter of FI 5 min. The present data do not precisely specify the stimulus variables mediating the new temporal discrimination.

The third principal result of the experiment was that where occurrence of the clock lights was made contingent upon responding, the behavior generated was intermediate between ordinary, baseline fixed-interval and highly discriminated clock-controlled performance. It was intermediate both with respect to absolute number of responses and percentage of responses per quarter of the fixed interval. The result may be interpreted as follows. Responding in the presence of the darkened key was always reinforced eventually according to the fixed-interval schedule of food reinforcement. Sometimes, responding in the presence of the darkened key produced an "early light," which had two effects: (1) It was an S^{Δ} for further responding; and (2) it secondarily punished the just-completed responses. On the other hand, responding in the presence of the darkened key sometimes produced a "late light," which had two effects: (1) It was an S^{D} for further responding: and (2) it secondarily reinforced the just-completed response. The resultant performance, then, was the algebraic sum of several sources of strength—some positive, some negative, some exteroceptive, some proprioceptive, and some interoceptive (pure "timing" cues).

REFERENCES

Ferster, C. B., and Skinner, B. F. *Schedules of reinforcement.* New York: Appleton-Century Crofts, 1957.

Kelleher, R. T. Stimulus-producing responses and attention in the chimpanzee. *J. exp. Anal. Behav.*, 1958, **1**, 87-102.

Wyckoff, L. B., Jr. The role of observing responses in discrimination behavior. *Psychol. Rev.*, 1952, **59**, 437-442.

Received February 20, 1961