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DELAYED REINFORCEMENT VERSUS *REINFORCEMENT AFTER A FIXED INTERVAL*[1]

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When interreinforcement intervals were equated, pigeons demonstrated little or no preference between reinforcement after a delay interval and reinforcement presented on a fixed-interval schedule. The small preferences sometimes found for the fixed interval (a) were considerably smaller than when the delay and fixed intervals differed in duration, and (b) were caused by the absence of light during the delay. These results suggest that the effects of delayed reinforcement on prior responding can be reproduced by imposing a temporally equal fixed-interval schedule in place of the delay; and, therefore, that the time between a response and reinforcement controls the probability of that response, whether other responses intervene or not.

Reinforcement is delayed by interposing an interval between a response and the reinforcement for that response. The delay is found to weaken responding: rates of responding are lower than when reinforcement immediately follows a response, pauses are longer, new responses and discriminations take more time to learn, and a delayed reinforcement is less likely to be chosen than an immediate one (Skinner, 1938, p. 139 ff; Perin, 1943; Perkins, 1947; Grice, 1948; Chung, 1965; Smith, 1967). Such results cause most experimenters to treat the effects produced by schedules of delayed reinforcement as different from those produced by schedules of immediate reinforcement. However, the work of Ferster and his associates suggests that when the temporal parameters of these schedules are equated, the effects produced with delayed reinforcements are replicated with immediate ones. For example, Ferster (1953) showed that pigeons' rates of responding prior to a 1-min delay period were comparable to their rates prior to reinforcement presented on a 1-min fixed-interval schedule; furthermore, superstitious responses—perhaps analogous to responses during the fixed-interval schedule—were observed during the interval of delay. Similarly, Ferster and Hammer (1965) demonstrated that the behavior of monkeys prior to a 24-hr delay of reinforcement interval was approximately the same as that prior to a 24-hr fixed-interval schedule. Technically, these experiments employed chain schedules, with responses in the initial link of the chain leading to a fixed-interval terminal link in one case and a delay-of-reinforcement link in the other. The two terminal links differed in the following ways: responses were emitted throughout the fixed interval and the final response was immediately followed by reinforcement; during the delay interval, effective responses could not be emitted and a response-independent reinforcement (*i.e.*, one presented without regard to the animal's behavior) occurred at the end of the delay. The two schedules were identical with respect to other parameters, most important of which was reinforcement frequency.

The present work extended Ferster's experiments by permitting pigeons to choose between delayed reinforcement and reinforcement on a temporally equal fixed-interval schedule. If, when other parameters are equated, delayed and immediate reinforcers have the same effects on responding, subjects should choose equally between these two alternatives. On the other hand, if delaying a reinforcer has special effects on behavior, a lesser preference for the delay would be predicted.

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METHOD

Subjects

Ten male White Carneaux pigeons, all with previous experience in a variety of experiments, were fed enough after each experimental session to maintain them at approximately 85% of their free-feeding body weights. Only five of these (Subjects 280, 281, 282, 31, and 34) were used in Exp. I.

Apparatus

A standard operant conditioning chamber consisted of two Plexiglas Gerbrands response keys and a Gerbrands food hopper below the keys. The keys could be transilluminated by 7-w white or 7-w red bulbs, and the hopper was illuminated by a 7-w white bulb whenever grain was presented. Except in Exp. III, to be discussed below, these lights provided the only illumination in the chamber (*i.e.*, there was no houselight). Reinforcement consisted of 3-sec access to mixed grain from the hopper. Pecks of at least 15 g force on a lighted key were recorded and produced feedback clicks from a dc relay mounted behind the front panel. The experiment was automatically controlled by relays, stepping switches, counters, and timers.

EXPERIMENT I
EQUAL DELAY AND FIXED INTERVALS

Procedure

In the preliminary condition, pecks on the two response keys were reinforced according to two independent variable-interval (VI) 90-sec schedules, one VI scheduling reinforcement on the left key and the other on the right. The interreinforcement intervals, identical on the two schedules, were 120, 14, 23, 148, 44, 70, 11, 162, 80, 96, and 222 sec. The VIs were presented concurrently so that subjects could freely respond on either key and thereby choose between the two schedules. The only restriction was that a switch from one key to the other prevented reinforcement for 1.5-sec. (This restriction is called a changeover delay, or COD, and was scheduled in the same way as in Herrnstein, 1961.) When the numbers of responses became stable and approximately equal on the two keys, the procedure was changed to a concurrent chain (Herrnstein, 1964). Figure 1 is a schematic diagram of this procedure. The same 90-sec VIs and 1.5-sec COD as used above were presented in the concurrent initial links of two chain schedules. Responses during the initial link on one key now resulted in the occasional presentation (as determined by the respective VI) of a terminal link composed of a fixed-interval (FI) schedule of reinforcement. Responses during the initial link on the other key resulted in the occasional presentation of a delay-of-reinforcement terminal link. Whereas the initial links were presented concurrently, the terminal links were presented exclusive of one another, *i.e.*, the subject was confronted with either a fixed-interval schedule or a delay of reinforcement. During the initial links, both keys were lighted by white bulbs. During the fixed-interval terminal link, the light transilluminating the "fixed-interval key" was changed from white to red, and the other key, the "delay key," became dark and inoperative. The first peck on the fixed-interval key after the fixed interval terminated produced immediate access to grain. During the delay-of-reinforcement terminal link, the chamber was totally dark (blackout) and both keys were inactivated. The delay was terminated by the response-independent presentation of grain. After either a delayed reinforce-

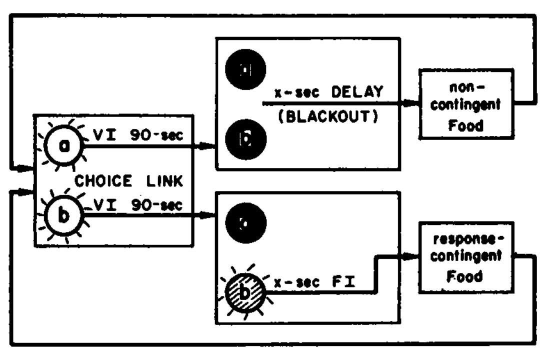

Fig. 1. Diagram of one cycle of the experimental procedure. Each box represents a possible condition in the chamber. A white circle indicates that the key is operative and lighted by a white bulb, a striped circle indicates that the key is operative and lighted by a red bulb, and a black circle indicates that the key is dark and inoperative. Responding in the choice link (left) leads either to a delay (upper-middle) which is followed by response-independent reinforcement (upper-right) or to a fixed interval (lower-middle) which is followed by response-produced reinforcement (lower-right). After reinforcement in either condition, the choice link is again presented.

ment or reinforcement on the fixed-interval schedule, the initial links were again presented. Thus, subjects could freely respond on two keys during the initial links and thereby choose to enter either a delay-of-reinforcement or a fixed-interval terminal link. The basic differences between the delay and fixed-interval periods were: (1) the chamber was totally dark during the delay, whereas the fixed-interval key was red during the fixed interval; therefore, (2) as was expected, few or no pecks were emitted in the darkened chamber during the delay, whereas many responses were emitted on the lighted fixed-interval key during the fixed-interval; and (3) reinforcement was presented without regard to the subject's behavior at the end of the delay period, whereas a response produced reinforcement at the end of the fixed interval.

The duration of the delay always equalled the duration of the fixed interval in this experiment; both will be referred to as the "time to reinforcement". This time was varied in the following order: 8, 2, 30, 60, 18, and 45 sec. Subjects could first choose between an 8-sec delay-of-reinforcement and an 8-sec fixed-interval schedule, then between a 2-sec delay and 2-sec fixed interval, *etc.* A total of 35 to 50 sessions was given at each time-to-reinforcement value, with the functions of the keys being interchanged after a minimum of 15 sessions; thus, a minimum of 15 sessions was given with the delay on the left and a minimum of 15 with the delay on the right. Each session was terminated after the fortieth reinforcement.

Preference was determined from the number of responses emitted on each key during the concurrently presented initial links. The number of initial-link responses emitted on the fixed-interval key was divided by the total number of initial-link responses on both keys. This datum, FI choices divided by total choices, will be referred to as the "per cent choice of the fixed-interval schedule". According to this per cent choice measure, 50% indicates that an equal number of responses were emitted on the two keys during the initial links, 67% indicates that the FI key was chosen twice for each choice response on the delay key, 75% indicates three to one, *etc.* Also to be discussed are (a) the overall rate of responding during the initial links, defined as the total number of initial-link responses on both keys divided by the total time spent in these links; and (b) the rate of responding during the fixed-interval terminal link, defined as the number of responses emitted during the fixed-interval divided by the time spent in the interval. Arithmetic average performances over 14 sessions—the last seven sessions when the delay was on the left plus the last seven when the delay was on the right—were used for all data to be discussed in all of the following experiments.

RESULTS

Figure 2 shows the per cent choices of the fixed-interval key as a function of time to reinforcement. Most points lie close to, but above, the 50% line, indicating a small preference for the FI condition. This preference was approximately constant as time to reinforcement varied. The average of all points is 55%, shown by the dashed line, or an average preference for FI over delay of about 1.2 to 1. Note that these preferences did not greatly influence the relative number of reinforcements obtained from the two conditions. At the 30-sec time-to-reinforcement value, where the difference was greatest, 52.6% of the reinforcements were from the FI condition and 47.4% were from the delay.

The approximate invariance of the choices might indicate that time to reinforcement had no effect in the present experiment. That this was not the case is seen in Fig. 3, where overall rates of responding in the initial links are shown to decrease as time to reinforcement in the terminal links increased. Similarly, Fig. 4 shows that the rates of responding within the terminal fixed-interval component decreased as the duration of the fixed interval increased. Thus, although preferences did not vary, the rates at which choices were emitted and the response rates within the fixed interval decreased as time to reinforcement increased.

EXPERIMENT II
UNEQUAL DELAY AND FIXED INTERVALS

This experiment compared the magnitude of the 55% choice value in Exp. I with preferences for the shorter of two times to reinforcement. Subjects were therefore permitted to choose between unequal delay and fixed intervals.

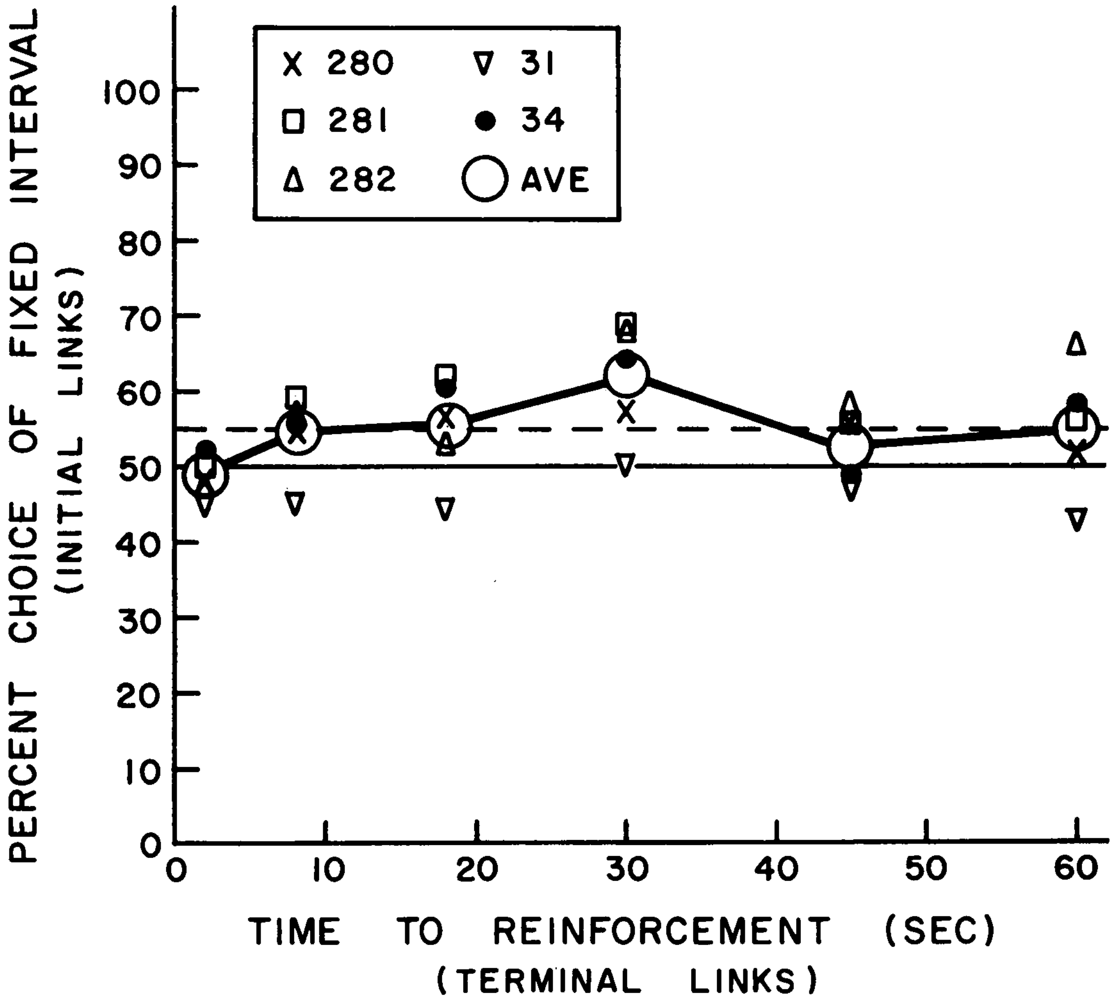

Fig. 2. Per cent choice of the fixed-interval key (initial-link responses on the fixed-interval key divided by the total number of initial link responses on both fixed-interval and delay keys) as a function of the times to reinforcement during the fixed-interval and delay-of-reinforcement terminal links. The fixed and delay intervals were equal.

Procedure

A concurrent-chain schedule was again used. As in Exp. I, the initial concurrent links were identical VI 90-sec schedules with COD 1.5-sec, and the terminal links consisted of a fixed-interval schedule on one key and a delay-of-reinforcement schedule on the other. The only difference between this experiment and Exp. I is that now the durations of the delay and fixed intervals differed. The same subjects used in Exp. I, now referred to as Group I, first chose between a 10-sec fixed-interval and a 2-sec delay, and then between a 10-sec fixed-interval and 20-sec delay. Each of these comparisons was presented for a minimum of 35 sessions, with the fixed interval on the left for at least 15 sessions and then on the right for another 15 sessions. A second group of pigeons, Subjects 1, 5, 11, 26, and 45, received the same experience as Group I, except that the 10-sec condition was a delay of reinforcement while the fixed interval was 2 sec in one case and 20 sec in the other. Thus, while the time-to-reinforcement values were identical for the two groups, the schedule conditions were reversed, *i.e.*, the fixed interval was 10 sec for Group I whereas the delay was 10 sec for Group II. Two groups were used in order to factor out the effects of the type of sched-

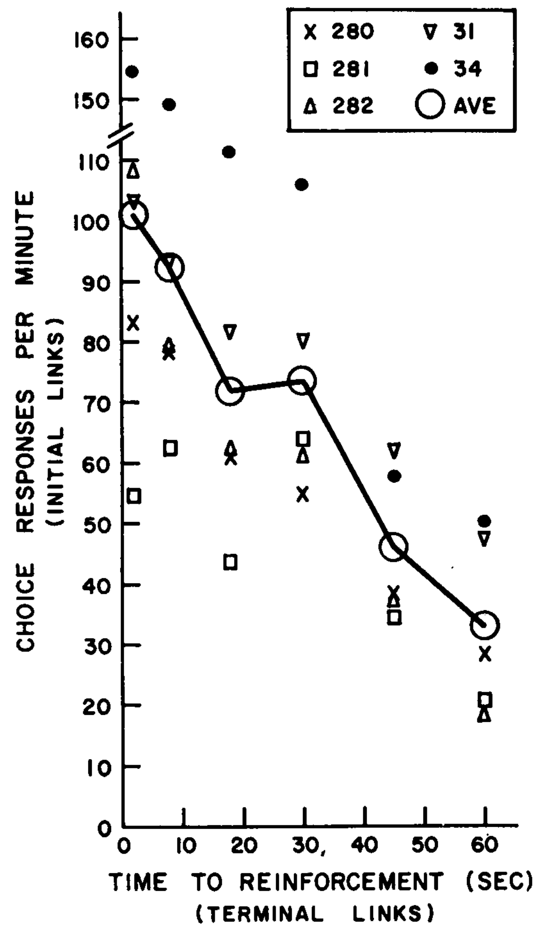

Fig. 3. Choice responses per minute (total initial-link responses on both keys divided by the total time in the initial link) as a function of the times to reinforcement during the terminal links. The durations of the fixed- and delay-interval terminal links were equal.

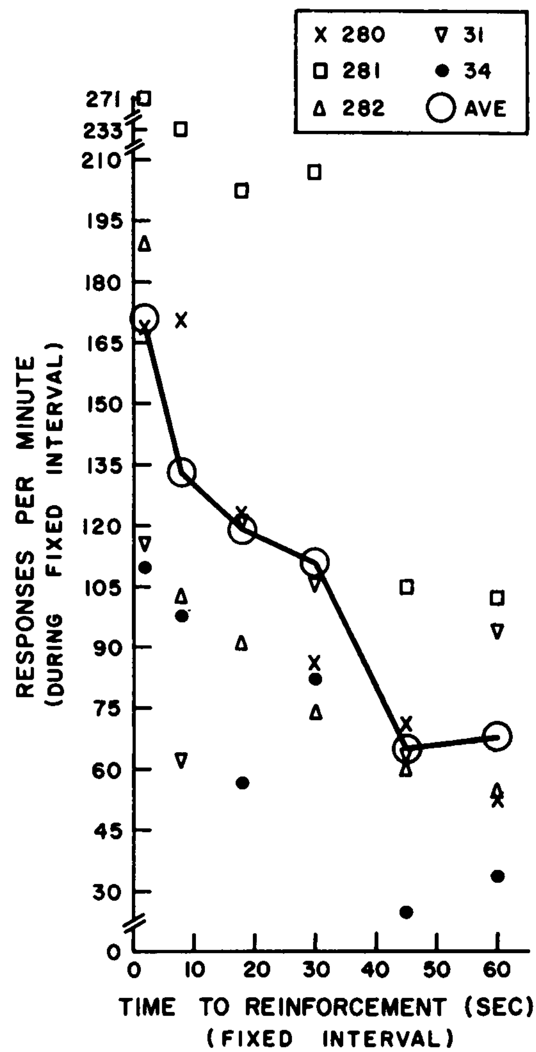

Fig. 4. Rate of responding during the fixed-interval terminal link as a function of the duration of the fixed interval.

ule (delay *versus* FI) from the effects of the times of reinforcement. The schedule effects can be seen by comparing Group I and Group II performances; the effects of time to reinforcement can be seen by comparing choices during the 10-sec *versus* 2-sec condition with choices during the 10-sec *versus* 20-sec condition.

Results

Figure 5 shows the percentage of initial-link choice responses on the "10-sec key", *i.e.*, the key on which the terminal link was either a 10-sec fixed interval (Group I) or 10-sec delay (Group II). The average Group I performances are shown by the open bars and the average Group II performances by the striped bars. Consider first the effects of changing the comparison time to reinforcement from 2 sec to 20 sec. This change caused the average Group I choices of the 10-sec key to increase from 31% to 72%; Group II choices similarly increased from 25% to 67%. Consider next the effects of the type of schedule. Note again that any difference between the two groups' choices must be attributed to the difference in schedule conditions. The Group I choices of the 10-sec condition were, on the average, six and five percentage points higher than the Group II choices. Thus, whereas an

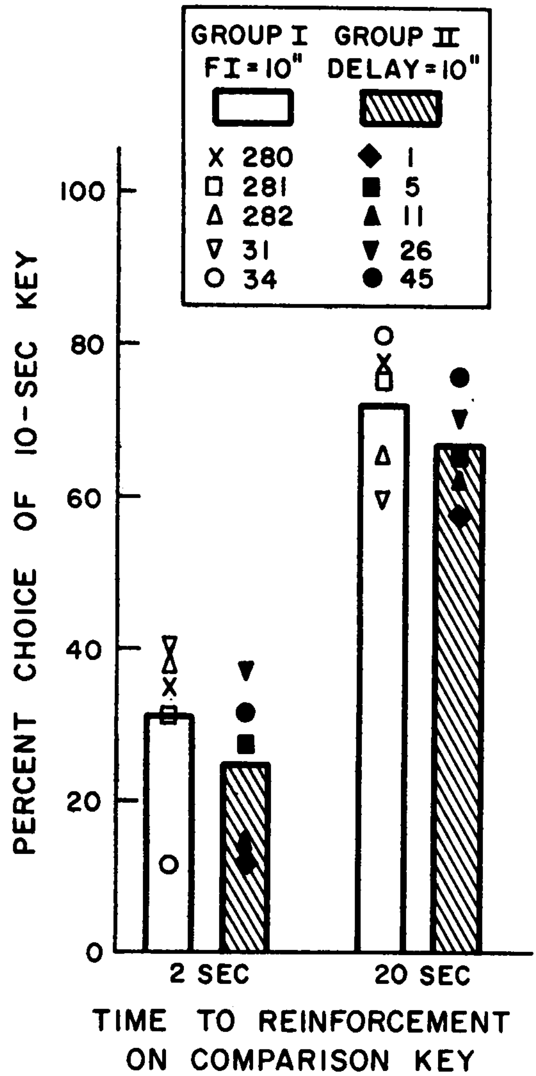

Fig. 5. Per cent choices of the 10-sec fixed-interval condition when the delay condition was 2 sec and 20 sec, respectively (Group I, open bars), and of the 10-sec delay of reinforcement condition when the fixed-interval was 2 sec and 20 sec (Group II, striped bars). The between-group differences show the effects of the different schedule conditions (FI *versus* delay), whereas the within-group changes show the effects of the increase in time to reinforcement.

increase in time to reinforcement caused per cent choices to increase by approximately 42 points, the difference between FI and delay schedules caused per cent choices to differ by only six points. These results are consistent with the small preferences for FI over delay found in Exp. I and, furthermore, suggest that those preferences were indeed relatively small.

EXPERIMENT III CONTROLLING FOR THE BLACKOUT

Attempts were next made to determine whether the blackouts *per se* were responsible for the small preferences for FI over delay obtained in Exp. I and II. The blackout was removed from the delay condition in Exp. IIIA and added to the fixed interval in Exp. IIIB.

Procedure

Experiment IIIA: a 7-w yellow houselight was added to the experimental chamber, and was lighted throughout the session; thus, there were no blackouts. Subjects 280, 281, 282, 31, and 34 chose between a 20-sec fixed-interval terminal link and a 20-sec delay of reinforcement. During the delay, while both keys were dark and inoperative, the chamber remained lighted by the houselight. Except for the absence of blackout, this procedure was identical to that in Exp. I. If the blackout caused the slightly lower preference for delay in Exp. I and II, the subjects would now be expected to respond equally in the initial links of the chains; on the other hand, if the preferences were due to some other characteristic of the delay operation (*e.g.*, the response-independent presentation of grain), the same 55% choice value would be predicted. Subjects received at least 30 sessions' experience under this condition, with the position of the delay and fixed-interval conditions being interchanged after approximately 15 sessions.

Experiment IIIB: Subjects 1, 5, 11, 26, and 45 chose between a 20-sec delay of reinforcement and a 20-sec "delay-plus-FR 1" (delay plus one response) terminal link. The delays in both conditions were identical to those in Exp. I, *i.e.*, the chamber was completely dark (blackout). The delay consisted of a 20-sec period of blackout at the end of which response-independent reinforcement occurred. The delay-plus-FR 1 condition also contained a 20-sec period of blackout; however, at the end of this blackout the "delay-plus-FR 1 key" was transilluminated by a yellow 7-w bulb and a single peck on this lighted key produced immediate reinforcement. Except for the delay-plus-FR 1 contingency, the present procedure was identical to that used in Exp. I. If the blackout stimulus alone caused the obtained preferences, subjects would now be expected to respond equally in the initial links. On the other hand, if another attribute of delayed reinforcement caused the previous results, the subjects should now prefer the immediate reinforcement in the delay-plus-FR 1 condition. Subjects received approximately 30 sessions under this condition, with the positions of the keys being interchanged after approximately 15 sessions.

RESULTS

The basic data were the percentages of initial-link responses emitted on the fixed-interval key in Exp. IIIA (or per cent choices of the fixed interval) and the percentages of initial-link responses to the delay-plus-FR 1 key in Exp. IIIB. The per cent choices of the FI key in Exp. IIIA were 56, 42, 48, 49, and 56 for the subjects in the order given in the procedure above. The average of these is 50%, indicating indifference between the two alternatives. Some subjects responded on the darkened and inoperative key during the delay (since the houselight was on) whereas other subjects responded little or not at all. There was no correlation between this responding and per cent choice. The per cent choices of the delay-plus-FR 1 key for subjects in Exp. IIIB, in the order given above, were 57, 47, 50, 55, and 47, respectively, for an average of 51%. Once again, this average indicates an approximate indifference between the two alternatives. In neither Exp. IIIA, where blackouts were absent in both delay-of-reinforcement and fixed-interval conditions, nor in Exp. IIIB, where blackouts were present in both conditions, were the Exp. I preferences (55%) obtained. These results therefore suggest that the lower preferences for delayed reinforcement in Exp. I and II were caused by the blackout stimulus *per se*.

DISCUSSION

Hull (1952, p. 126 ff) distinguished between two basic types of delay-of-reinforcement experiments: in the first, response chains are required during the "delay" interval and the last response in the chain is immediately followed by reinforcement, *e.g.*, as in a multiple unit maze; in the second, no specific response is required during the delay and response-independent reinforcement occurs at the end of the delay, *e.g.*, as in an operant chamber where the operandum is removed during the delay interval. Most studies on delayed reinforcement use the second type of situation: the operandum is inactivated or removed, the chamber is darkened, or responding during the delay is punished (Perin, 1943; Ferster, 1953; Dews, 1960; Chung, 1965). Studies of Hull's first type of "delay" are now found under the rubric of "schedules of reinforcement" and, more specifically, under "chain schedules". The basic question raised in the present work is whether these two situations, now to be referred to as delay of reinforcement and chain schedules of reinforcement, can be integrated within a single framework. To put the question another way, are the behavioral effects of a delayed reinforcement due to attributes unique to delay (*e.g.*, an interval of "no responding" between response and response-independent reinforcement) or to attributes common to all chain schedules (*e.g.*, the interval between initiation of the chain's terminal link and reinforcement)?

To answer this question, pigeons were permitted to choose between a schedule of delayed reinforcement and a temporally equal fixed-interval schedule. It was found that an average of 55% of the choice responses were emitted on the "fixed-interval key", indicating a 1.2 to 1 preference for fixed interval rather than delay. While this preference might suggest that attributes unique to delayed reinforcement affect responding, the preference was both approximately constant over a range of intervals (Exp. I) and relatively small (Exp. II), suggesting that some factor other than the delay might have been responsible. That factor was shown to be the blackouts present during the delay interval: removing (Exp. IIIA) or controlling for (Exp. IIIB) the blackouts caused the subjects to choose equally between the delay and fixed-interval alternatives. (Note that whereas some studies similarly suggest that blackouts are aversive, *e.g.*, Ferster, 1958, other studies demonstrate the opposite effect, *e.g.*, Neuringer and Chung, 1967). Thus, it is concluded that pigeons demonstrate relatively little or no preference in their choices between a delayed reinforcement and a temporally equal fixed-interval schedule of reinforcement.

This conclusion does not imply that the interval between a response and reinforcement is an unimportant variable. To the contrary, Fig. 3 and 4 show that as this interval increases, response rates decrease, and Fig. 5 shows that subjects prefer the shorter of two times to reinforcement. The present results, together with those of Ferster (1953) and Ferster and Hammer (1965), do imply, however, that the main effects of a delay interval on behavior are due to the interval rather than to attributes unique to the delay operation; in other words, whether or not further responding occurs during the interval, and whether or not a response is immediately followed by reinforcement at the end of the interval, make little or no difference in subjects' preferences.

Other studies similarly suggest that interreinforcement responses exert relatively little influence over behavior, whereas interreinforcement intervals exert a relatively great control. For example, Anger (1956) and Herrnstein (1964) showed that responding by rats in a single operandum situation and pigeons in a choice situation, respectively, was better correlated with reinforcements per unit time than with reinforcements per response. Dews (1962, 1965, 1966*a*, 1966*b*) argued that pigeons' rates of responding under fixed-interval schedules were controlled by the time between reinforcements and did not depend upon the responses emitted during this time. Autor (1960) and Killeen (1968) demonstrated that the choices of pigeons varied with reinforcement rates whether or not responses were required for reinforcement (see, however, Fantino, 1968 for different results). And Neuringer and Schneider (1968) found that the response latencies of pigeons increased linearly with interreinforcement time but were completely unrelated to the number of interreinforcement responses. These studies, together with the present findings, suggest the following hypothesis: the probability (or rate, or latency) of a response is controlled by the interval between that response and reinforcement (a) independently of the number of other responses intervening in the interval, and (b) independently of whether such intervening responses are required or prohibited. (Note that a single response, the one that produces reinforcement, is required under the fixed-interval schedule, whereas effective responses are prohibited under the delay schedule.) More research is of course necessary to substantiate this hypothesis. For example, it must be determined whether the effects of delay of reinforcement intervals on the learning of new responses and discriminations might also be explained by the intervals rather than by attributes unique to the delay.

The series of experiments by Dews (1962, 1965, 1966*a*, 1966*b*) has suggested that the scalloped patterns of responding found under fixed-interval schedules are caused not by hypothetical response chains but by the passage of time. The present work suggests a similar alternative to the notion that "superstitious chains of responses" must be invoked to explain the control exerted by delayed reinforcers. As indicated in the Introduction, Ferster (1953), as well as other experimenters (Blough, 1959; Hearst, 1962) have reported superstitious responses during the delay period. However, the animal often is not observed during the delay (*e.g.*, Chung and Herrnstein, 1967), and, when observed, superstitious chains are sometimes not found (Mabry, 1965; Smith, 1967). Thus, the more general, as well as more parsimonious, hypothesis is the present one, *i.e.*, that the time between a response and reinforcement controls the probability of that response, whether other responses intervene or not.

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