PERCENTAGE REINFORCEMENT OF FIXED-RATIO AND VARIABLE-INTERVAL PERFORMANCES¹

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Twenty to seventy per cent of the reinforcements scheduled for pigeons' fixed-ratio 80 performances were replaced by a 4-sec timeout. Pauses after reinforced ratios were unchanged at 80% reinforcement, but were lengthened at lower reinforcement percentages. Pauses after nonreinforced ratios were shorter than post-reinforcement pauses. When 50% of the reinforcements arranged by a variable-interval 60-sec schedule were replaced by a 4-sec timeout, pauses after reinforcement omission increased. Both frustrative nonreward and reinforcement aftereffects notions can explain the fixed-ratio results; neither easily explains the variable-interval data.

When scheduled reinforcements are replaced by timeout the modified procedure is called a percentage reinforcement schedule. Ferster and Skinner (1957) trained pigeons on intermediate valued fixed-ratio schedules, where each food reinforcer was followed by a timeout. Then they withheld 15 to 50% of the scheduled reinforcements. This procedure produced an increase in the mean duration and variability of pausing after ratio runs. Zimmerman (1960) reported similar increases in duration and variability of pausing under percentage reinforcement with rats that were required to depress a lever in a discrete trials procedure. Furthermore, pause durations were not differentiable on the basis of whether they followed reinforcement or reinforcement omission. While the outcomes of these two experiments are consistent, the group of experiments discussed below shows a different effect of percentage reinforcement on various schedules of reinforcement.

Staddon and Innis (1966) showed that the effect of percentage reinforcement on fixed-interval schedules is an increase in response rate after reinforcement omission compared with the rate after reinforcement; a shortened pause after reinforcement omission relative to post-reinforcement pause length was also found. Staddon and Innis (1969) manipulated the duration of timeout replacing omitted reinforcements, showing that the effect of reinforcement omission diminished as timeout duration increased. In addition, they reported that the obtained increases in response rate after reinforcement omission was accounted for

almost completely by the shortened pause after nonreinforcement. Davenport and Thompson (1965) showed that percentage reinforcement of fixed-ratio performances produces a shortened pause after reinforcement omission. Similarly reinforcement omission results in shortened pauses after nonreinforcement on a schedule (DRL) that differentially reinforces long interresponse times (Davenport, Flaherty, and Dyrud, 1966). Davenport *et al.* also demonstrated that the difference between DRL pause lengths after reinforcement and omitted reinforcement decreased as the timeout duration substituted for reinforcement increased.

The present paper reports an investigation of the effects on fixed-ratio performances of various reinforcement percentages and the interaction between reinforcement omission and timeout duration. In addition, evidence from percentage reinforcement of variable-interval performance is presented, suggesting that the omission effect is schedule-dependent.

METHOD

Subjects

Four adult male White Carneaux pigeons were maintained at 75% of their free-feeding

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weights. All birds had extensive histories with various reinforcement schedules. Birds P172 and P182 were used in the fixed-ratio procedure; P302 and P304 were used in the variable-interval procedure.

Apparatus

The experimental chamber used in the fixed-ratio procedure measured 10 by 12 by 12 in. (25 by 30 by 35 cm). A 1 in. (2 cm) diameter response key transilluminated with white light was centered in the intelligence panel 8 in. (20 cm) above the floor. A 7-w white lamp placed behind a white Plexiglas window in the upper right corner provided ambient illumination. Each peck activated a feedback relay situated behind the intelligence panel. The reinforcer was 3.5-sec access to the feeder filled with mixed grain and located 2.5 in. (6 cm) above the floor centered under the response key. The experiment was controlled by electromechanical circuitry located in a different room than the one housing the ventilated experimental chamber. The chamber used in the variable-interval procedure had ambient illumination provided by a 7.5-w white lamp located above a white Plexiglas ceiling; in other aspects it closely resembled the first chamber. Pause durations in the fixed-ratio procedure were measured by switching the output of a Foringer 1699 M1 ten-per-second pulse stream generator into a Sodeco printing counter (LVE 1530). Pause durations in the variable-interval procedure were timed by the same pulse generator and printed by a BRS POC-012 printing counter.

Procedure

Fixed ratio. Experimental sessions were run daily, each continuing until 30 ratios were completed. Since both P172 and P182 had histories of pecking a response key, the experiment was begun with an FR 30 response requirement. This value was increased daily by 10 responses until a final value of FR 80 was reached. During this preliminary training, the terminal response of each ratio turned off the houselight and keylight for 4 sec; the initial 3.5 sec of this period consisted of feeder presentation. The final 0.5 sec was timeout, during which the chamber was dark and responses had no scheduled effect. The birds were run under these baseline conditions (100% reinforcement) until the daily mean pause dura-

tion had stabilized for five consecutive sessions before any manipulation was made.

The first manipulation involved varying the percentage of scheduled reinforcements delivered; the percentages used were 30, 50, 60, and 80%, but the order of presentation differed for the two birds. Reinforced ratios were followed by the same sequence of events that occurred during preliminary training. Nonreinforced ratios, which were chosen randomly with the restriction that the first and thirtieth ratios were always reinforced, were followed by a 4-sec timeout. Responses occurring during reinforcement and timeout were counted but had no scheduled consequence. The dependent measure was the pause duration for each ratio. This value was measured from the onset of houselight and keylight after each timeout. Each percentage reinforcement condition lasted five sessions. The baseline condition was reinstated between successive experimental conditions and performance was allowed to stabilize.

Before the second manipulation, 10 baseline sessions were given; during these sessions the final response of each ratio turned off the houselight and keylight for 16 sec. The first 3.5 sec consisted of feeder presentation and the final 12.5 sec was timeout. Sixty per cent reinforcement was then introduced, during which reinforced ratios produced a 3.5-sec feeder presentation followed by 12.5-sec timeout. Nonreinforced ratios produced a 16-sec timeout. In other aspects the procedure was identical to that described above.

Variable interval. Pigeons P302 and P304 were placed directly on a VI 30-sec schedule generated from the progression given by Catania and Reynolds (1968) with $N = 48$ and $t = 30$ sec. After eight sessions, the schedule was changed to VI 60-sec with $N = 60$, $t = 60$ sec. As in the fixed-ratio procedure, the keylight and houselight were illuminated during all intervals; the first response after an interval elapsed turned off the house and keylights for 4 sec. The first 3.5 sec of this 4 sec consisted of feeder presentation. The final 0.5 sec was timeout. Each preliminary training session terminated after 30 reinforcements. After 10 sessions on VI 60-sec, response rate and pause duration after reinforcement had stabilized. Reinforcement percentage was then reduced to 50% for 10 additional sessions. Intervals terminating with nonreinforced responses

were chosen as in the fixed-ratio procedure; the final response in these intervals produced a 4-sec timeout. Reinforced intervals were terminated by a reinforcement cycle of 3.5-sec feeder presentation followed by 0.5-sec timeout. Pause duration and response rate were measured separately for each interval.

RESULTS

Fixed Ratio

All data from the first ratio of each session were excluded from the following analysis because this ratio was begun under conditions different from those existing at the beginning of the other ratios. For each baseline (100% reinforcement) condition the mean pause duration was computed for the final five sessions individually. In addition, the overall mean was computed for the combined data from these sessions. Under all percentage reinforcement conditions the means were computed on a session-by-session basis. The performance maintained during 100% reinforcement conditions was qualitatively similar to that de-

scribed by Ferster and Skinner (1957). During all repetitions of the baseline condition, overall mean pause duration for P182 stabilized within ± 2 sec of the value obtained during the initial 100% reinforcement condition. This was true for P172 in three of five baseline conditions; the two baseline conditions in which the overall mean did not return to initial value were after 50% reinforcement and after the second exposure to 60% reinforcement. The daily means from the last five sessions of each baseline condition generally fell within ± 3.5 sec of their respective overall means. At the same time, response rates varied by less than ± 0.5 responses per second across sessions.

The overall mean pause lengths from prior 100% reinforcement conditions and the individual session means after reinforcement and reinforcement omission are plotted in Fig. 1 for all reinforcement percentages. The first panel for each bird shows large differences in pausing after obtained and omitted reinforcements. Pause duration after nonreinforcement fell below both the baseline value and

Fig. 1. Mean fixed-ratio pause after reinforcement (filled circles) and reinforcement omission (open circles) over the five sessions of each reinforcement percentage. The unconnected point (B) is the overall mean pause for the five sessions preceding the introduction of the reinforcement percentage indicated in each panel.

the value after reinforcement. These shorter pauses were not produced by responding through the timeout substituted for reinforcement because such responses rarely occurred. During successive exposures to reduced reinforcement percentages, pause durations after nonreinforcement for P182 remained shorter than both the baseline value and the post-reinforcement value. Pauses after reinforcement omission for P172 decreased in a similar fashion during the first three exposures to reduced reinforcement percentages. However, in the final two panels, pause length after nonreinforcement increased until it exceeded the mean value after reinforcement at 30% reinforcement.

A second feature of the data of Fig. 1 is a gradual increase in pause length after reinforcement relative to the baseline value during most percentage reinforcement conditions. Figure 1 shows that the increase tends to occur at all reinforcement percentages with the exception of 80%.

The effect of increasing timeout duration at 60% reinforcement is shown in Fig. 2. When timeout duration was 16 sec, pause lengths after reinforcement gradually increased to values exceeding the previous baseline condition, a result similar to that obtained at 60% reinforcement when timeout duration was 4 sec. Pause durations after nonreinforcement for P182 were generally of the same length as those following reinforcement; pauses after nonreinforcement for P172 remained shorter than those following reinforcement.

Variable Interval

Pause duration during the first interval of each session was again excluded from the analysis. Baseline pause duration shown in Fig. 3 is the overall mean pause duration across the final five sessions of 100% reinforcement. For the 10 sessions of 50% reinforcement, mean pause lengths were computed separately for intervals following reinforcement and reinforcement omission. These values are also shown in Fig. 3. Mean pause length following reinforcement was essentially unchanged relative to the baseline pause length for both birds. Unlike the results from the fixed-ratio procedure, after omitted reinforcement, pausing increased relative to the values obtained at 100% reinforcement and after reinforcement at 50%.

Fig. 2. Mean fixed-ratio pause after reinforcement (filled circles) and reinforcement omission (open circles) when timeout duration was 16 sec. The unconnected point (B) is the overall mean value for the five preceding sessions at 100% reinforcement.

DISCUSSION

The fixed-ratio procedure in the present experiment resulted in two outcomes. First, pause durations after reinforced ratios showed a gradual increase relative to the baseline value at all reinforcement percentages with the exception of 80%. The nature of the percentage reinforcement schedule used was such

Fig. 3. Mean variable-interval pause after reinforcement (filled circles) and reinforcement omission (open circles) over the 10 sessions of 50% reinforcement. The unconnected point (B) is the overall mean value for the five preceding sessions at 100% reinforcement.

that the probability of a nonreinforced ratio was higher after a reinforced ratio than after a nonreinforced ratio; this sequential dependency was even greater after two ratios had been reinforced in succession. If the subjects were discriminating these differences in probability over the percentage reinforcement sessions, this could account both for the increase in pause length following reinforced ratios as well as the finding that the increase tended to emerge gradually. The fact that an increase in post-reinforcement pause duration was not obtained at 80% reinforcement may reflect the possibility that too few nonreinforced ratios occurred at 80% for the discrimination to be acquired.

The second outcome, that nonreinforcement generally resulted in shorter pauses compared with those after reinforcement in the same percentage reinforcement schedule or in a 100% schedule, has been called the "omission" effect or the "frustration" effect. Similar findings have been reported for fixed-interval schedules (Staddon and Innis, 1966; Staddon and Innis, 1969), DRL schedules (Davenport *et al.*, 1966) and fixed-ratio schedules (Davenport and Thompson, 1965). Staddon and Innis (1969) pointed out the similarities between these types of free operant experiments and frustrative nonreward procedures (see Amsel, 1958), suggesting that a single mechanism encompassing different response classes and procedures is responsible for the similarity of omission/frustration effects obtained in both the free operant and runway experiments.

Amsel attributes the frustration effect to the elicitation of unconditioned "frustration" by nonreward. Frustration was introduced as a motivational construct contributing to drive, such that when an animal that has been trained to respond under continuous (100%) reinforcement is faced with nonreinforcement of the previously learned response it performs the response more vigorously because of increased drive. While the explanatory scope of the frustration effect was originally limited to the double runway procedure, it has since been extended to the free operant situation by Scull, Davies, and Amsel (1970) and others (Davenport and Thompson, 1965; Davenport *et al.*, 1966).

Staddon and Innis (1966, 1969), on the other hand, proposed a nonmotivational explana-

tion of the omission effect in terms of the discriminative control exerted by reinforcement. According to this account, the stimulus conditions existing immediately after reinforcement in fixed-ratio and fixed-interval schedules exert inhibitory aftereffects, producing a low post-reinforcement response probability. The origin of these inhibitory aftereffects was not specified. However, when some other event (*e.g.*, timeout) replaces reinforcement, these inhibitory aftereffects still occur, through stimulus generalization, but to a smaller degree, resulting in a much shortened pause after nonreinforcement. Staddon (1970) reported data from a procedure in which pigeons' responses were reinforced according to a mixed VI VI schedule involving reinforcement for not responding during one of the components (DRO). He obtained negatively accelerated cumulative response curves as a function of post-reinforcement time. When timeout was presented instead of reinforcement during the VI DRO component, response rate in the next interval was depressed. The explanation offered was again in terms of the discriminative properties of reinforcement. It was suggested that this procedure resulted in post-reinforcement aftereffects that were excitatory rather than inhibitory; when timeout was presented in lieu of reinforcement the excitatory aftereffects were weaker because of generalization decrement, thereby producing a lower response rate.

The frustration notion and the aftereffects hypothesis are equally capable of interpreting the present fixed-ratio results because each predicts shorter pauses after nonreinforcement than after reinforcement. Interpretation of the variable-interval result is clearly more complex. It is not beyond question that the interval schedule employed in the present experiment could have resulted in excitatory aftereffects following reinforcement, in which case nonreinforcement would result in response depression (longer pauses). To the extent that such effects developed, the results from this procedure would be consistent with Staddon's hypothesis.

Frustration theory initially seems incapable of interpreting the variable-interval data because enhanced responding is the usual result of nonreinforcement. However, before explicitly rejecting such an explanation it should be noted that a requirement for the elicitation

of unconditioned frustration by nonreward is that the stimulus conditions prevailing at the time of nonreward must be discriminated by the subject as those that normally accompany reinforcement. In fixed-ratio schedules, features of the response (e.g., rate, proprioceptive cues, etc.), as well as the occurrence of reinforcement, may become discriminative with respect to availability of the next reinforcement. In a schedule such as the present variable-interval schedule, response properties and the occurrence of reinforcement are deliberately prevented from becoming discriminative about impending reinforcement. It seems possible then that reinforcement omission in variable-interval schedules might not be discriminated sufficiently to result in frustration. Even if one accepts this interpretation, the finding that pauses after nonreinforced intervals were longer than those following reinforcement still requires explanation. If time-out was not discriminated as an instance of reinforcement omission, frustration theory would suggest that reinforcement omission would have no effect on response strength. Thus, it is clear that nonreward in the operant context can have effects in addition to those easily characterized by the frustrative nonreward notion.

In summary, it is difficult to choose between the frustrative nonreward and reinforcement aftereffects accounts of reinforcement omission effects in the context of reinforcement schedules. This difficulty exists because the aftereffects notion requires that reinforcement in variable-interval schedules like the present one exert excitatory aftereffects. There is no way of determining whether this precondition was met. On the other hand, the frustrative non-

reward notion makes no provision for response depression resulting from nonreward, an outcome obtained in the present experiment and one previously reported by Staddon (1970), using a different procedure.

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