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FIXED-RATIO PERFORMANCE UNDER CONDITIONS OF DELAYED REINFORCEMENT[1]

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Four rats were trained on a schedule in which completion of a fixed number of lever presses initiated a signalled delay period, at the end of which food was delivered. Lever presses made during the delay had no scheduled consequences. Delays of 12, 3, and 0.75 sec were used, and it was found that the latency of the first response after food (the post-reinforcement pause) increased with length of delay. There was, on the other hand, no consistent effect of delay upon rates of responding after the post-reinforcement pause.

The longer the delay between entering a goal box and delivery of food, the more slowly rats run through a straight alley. The relevant data have been reviewed by Logan (1960) and Renner (1964). Studies of delayed reinforcement in the free-operant situation have not been so extensive, but at least in the case of continuous reinforcement (reinforcement of every response) it seems that rates of responding decline with increasing delays of reinforcement both in pigeons (Dews, 1960), and in rats (Azzi, Fix, Keller, and Rocha e Silva, 1964). This occurs whether responses are permitted during the delay (Dews, 1960), or made to reset the delay interval, as in Skinner's (1938) procedure. The effects of having a signal present during the delay were investigated by Azzi *et al.*, (1964), who reported that responding was faster and more stable with this procedure than when the delay was unsignalled. Their finding seems to confirm Dews' (1960) suggestion that onset of the delay stimulus might act as a conditioned reinforcer.

Nearly all the data on delay refer to continuous reinforcement schedules. From the fact that delay affects overall response rate in these circumstances, it may be deduced that one of the effects of delay must be to increase the latency of the first response after reinforcement (the post-reinforcement pause). What the data cannot tell is the effects delay has upon rates of responding after the pause. To find that out, one must turn to intermittent schedules of reinforcement such as the fixed-ratio, in which more than one response is required for each reinforcement. That was the purpose of the present experiment. Rats were trained on a fixed-ratio schedule in which every ninth lever press operated the food magazine after a delay of either 12, 3, or 0.75 sec. The effects of delay upon the post-reinforcement pause and terminal response rate were studied separately. Responses during the delay had no scheduled consequence, and delays were signalled by dimming the houselight in the chamber. Signalled delay was used because the indications are that responding is more stable under these conditions (Azzi *et al*, 1964).

The effects of delay upon fixed-ratio performance have previously been studied by Ferster and Hammer (1965) in rhesus monkeys and baboons. It was found that performance could be maintained with very long delays (up to 24 hr) provided that the ratio requirement was not too great, the amount of food large, and a signal present during the delay. The effects of delay upon post-reinforcement pause and terminal rates were not separated.

METHOD

Subjects

Four female hooded rats from the Medical Research Council were fed for 1 hr a day after testing. The rats were approximately three months old at the start of testing and had not served as subjects in any other experiment.

Apparatus

The experimental chamber, with inside dimensions of 10 by 10 by 15 in. (25.4 by 25.4 by

[1]This research was carried out in the Department of Experimental Psychology at the University of Cambridge, Cambridge, England. Reprints may be obtained from the author at that address.

38 cm) had transparent plastic sides (Plexiglas) and a floor made from stainless steel rods. A lever made from a 1.5 in. (38.1 mm) wide strip of 0.036 in. (0.91 mm) mild steel projected 0.88 in. (22.2 mm) into the chamber at a height of 1.75 in. (44.5 mm) above the floor, and required approximately 16 g (0.157N) force to activate the microswitch. A modified Gerbrands food magazine delivered 0.48-mg sugar pellets manufactured by Boots Pure Drug Co. Ltd., Nottingham. Light was provided by a 2-w houselight mounted 6 in. (15 cm) above the lever, and this could be dimmed to 6.3% of its normal luminance to provide a signal inside the chamber. The chamber was enclosed in a sound resistant chest and cables led to conventional electromechanical scheduling and recording devices in a corridor outside the testing room. White masking noise was broadcast over a loudspeaker inside the testing chamber.

Procedure

The rats first received a pellet for every lever press, and were then gradually shifted in later sessions to a fixed-ratio schedule in which only every ninth lever press was reinforced. In the early stages of fixed-ratio training, each reinforced response operated the magazine immediately. In later sessions, delays were introduced during which the houselight dimmed to 6.3% of its normal luminance. (Morgan and Firsoff, 1970, demonstrated that this illumination change was discriminable by the rat.) At the end of each delay period, the houselight brightened once more and a pellet was delivered simultaneously. Each session lasted until the rat had obtained 40 pellets. In any one session the delay period was not varied. For the first 14 sessions of delay training, the rats encountered a pseudo-random sequence of 5, 10, 3, and 0.75 sec delays, all rats meeting 5 sec as the first delay. This was followed by three blocks of six sessions each, with 12 sec delay in the first block, 3 sec delay in the second, and 0.75 sec during the third.

RESULTS

The post-reinforcement pause was calculated as the interval elapsing between arrival of a pellet and the subsequent lever press. "Work time", which is reciprocally related to terminal response rate, was calculated as the interval elapsing between the end of the post-reinforcement pause and the completion of the ratio. The delay interval itself was obviously not included. On each day, the median post-reinforcement pause and work time was calculated separately for each rat; and the median of these medans inside blocks of sessions was taken as the measure of central tendency inside the blocks.

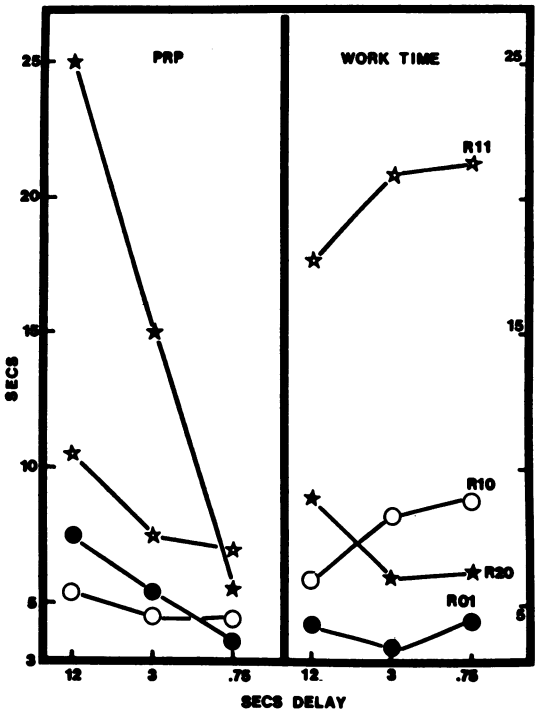

Fig. 1. Post-reinforcement pause (PRP) and time to complete the ratio requirement (work time), at three different delays of reinforcement. Data are plotted separately for the four rats, and symbols in the left half of the figure indicate the same rat as in the right.

During the first 14 sessions, in which delays were presented in pseudo-random order, no delay was held long enough for performance to stabilize. This stage of training established, however, that no systematic drifts in responding were occurring, so it was considered justified to take measurements from the final 18 sessions, in which 12, 3, and 0.75-sec delays were given for six sessions each.

The results for the final 18 sessions are given in Figure 1. The left-hand side of the figure shows that in all rats the post-reinforcement pause increased consistently with delay,

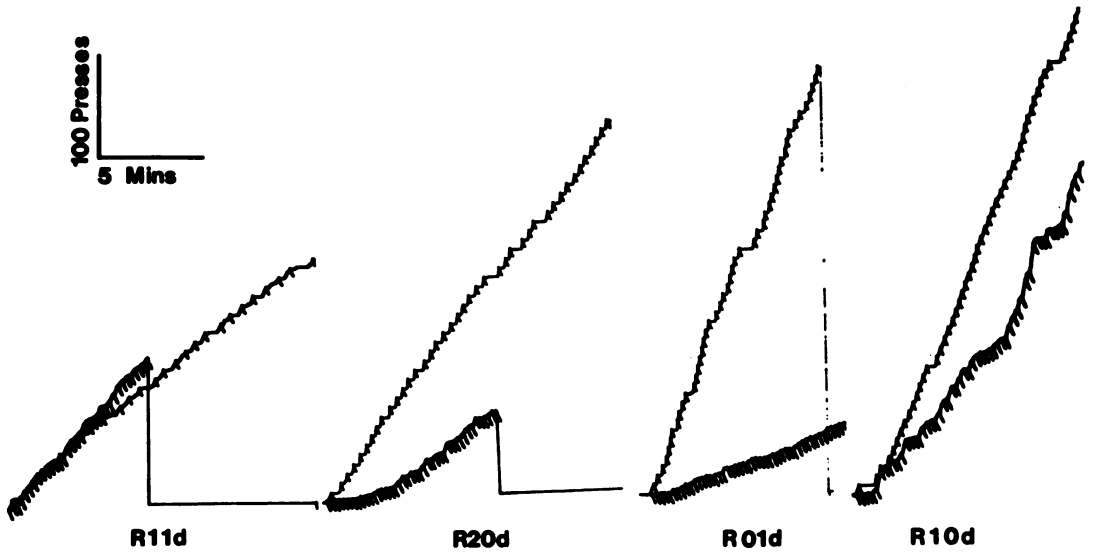

Fig. 2. Cumulative records from a session with 12-sec delay of reinforcement. Responses before and during the delay were recorded separately on two recorders to allow a comparison between the two rates. The "before delay" record may be distinguished by its smaller slashes: these slashes mark completion of a ratio, and hence beginning of a delay. The larger slashes on the "during delay" record mark delivery of a pellet. The chart motor of each recorder ran only when it was recording lever presses.

except that for Rat R10d there was no significant difference between 3 and 0.75-sec delays. In contrast, the right-hand side of the figure shows that there was no consistent effect of delay upon "work time": that is, upon the rate of responding once the rat had started to respond. Thus, Rats R10d and R11d worked more slowly with increasing delay of reinforcement. The other two rats suggested the reverse result, without, however, there being any monotonic relation.

Although lever pressing during the delay period had no consequence, all rats showed such responding, albeit irregularly. A comparison between responding before and after onset of the delay stimulus is shown for a representative 12-sec session in Figure 2. Three of the rats showed clear evidence of a discrimination, responding at a reduced rate during the delay, but R11d actually responded faster during the delay.

DISCUSSION

The data show that delay of reinforcement may be added to the list of variables already known to affect the post-reinforcement pause in fixed-ratio schedules without consistently affecting terminal rate of responding. These variables are: size of ratio (Felton and Lyon, 1966), magnitude of reinforcement (Powell, 1969), level of deprivation (Sidman and Stebbins, 1954), and criterion force on the lever (Notterman and Mintz, 1965). The question of a relation between these similarly acting variables, particularly between size of ratio and delay of reinforcement, has exercised the attention of Neuringer and Schneider (1968) and Killeen (1969). Neuringer and Schneider suggest that changes in ratio size have their effect only because they indirectly affect delay of reinforcement. On similar, but not identical, lines, Killeen has implicated the inter-reinforcement interval as the fundamental variable. Both hypotheses predict that delay of reinforcement would increase the post-reinforcement pause, the result reported here. The present data are also consistent with the possibility that delays acts indirectly by increasing the ratio size, because all rats were observed to respond vigorously throughout the delay period. However, this hypothesis predicts that rates of responding would increase if responses during delay were discouraged by making them reset the delay. Since Dews (1960) found the reverse result, this possibility may safely be rejected, with the result that the hypotheses of Neuringer and Schneider (1968) and Killeen (1969) remain the most plausible alternatives.

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