**EFFECTS OF CYCLE LENGTH ON
PERFORMANCE ON A TEMPORALLY DEFINED
AVOIDANCE SCHEDULE¹**

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Three rats were trained on a temporally defined avoidance schedule logically similar to a fixed-interval, limited-hold positive reinforcement schedule. This avoidance schedule was composed of time periods during which responses had no scheduled consequences alternating with time periods during which a response precluded shock. As with fixed-interval length and response rate on positive reinforcement schedules, an inverse relationship was obtained between the length of the no-consequence interval and response rate during the no-consequence interval. An inverse relationship was also obtained between the length of the no-consequence interval and the per cent of shocks avoided. A rate increase within the no-consequence interval, similar to that typically produced by fixed-interval positive reinforcement procedures, was displayed by one of the rats where the no-consequence interval was at intermediate values and frequency of shock was relatively high. The introduction of a discriminative stimulus correlated with the avoidance interval produced typical discriminated avoidance behavior as well as alterations in temporal patterning of responses during the no-consequence interval in the two rats exposed to this procedure. These alterations in temporal patterning disappeared when the discriminative stimulus was removed. The results were consonant with those reported in the literature involving food reinforcement and fixed-interval, limited-hold schedules.

Several investigators have been concerned with temporally defined schedules of reinforcement of the type outlined by Schoenfeld, Cumming, and Hearst (1956). Such schedules are composed of time periods during which the organism's responses have no scheduled consequences (t^A) and time periods during which responses may produce or preclude events (t^D). Typically, the total experimental session is composed of alternating t^A and t^D periods, a cycle being defined as a t^A period followed by a t^D period. In the case of positive reinforcement, such temporally defined schedules are identical to fixed-interval limited-hold schedules. The latter schedules are also composed of a fixed time period during which responding has no consequence (the fixed interval) followed by a fixed time period during which the first response produces a positive reinforcing stimulus (the limited-hold interval) Ferster and Skinner, (1957).

Hearst (1958) and Clark (1959) described experiments in which a positive reinforcer, grain, was presented following the first response in t^D and the ratio $T = [t^D / t^A + t^D]$ (i.e., the proportion of the cycle during which reinforcement was possible) was varied from 1.00 to 0.00, cycle length ($t^A + t^D$) being held constant. Response rate was found to be inversely related to T up to a point where T became so small as to approximate an extinction schedule, and rate declined. Other studies (Hurwitz and Millenson, 1961; Sidman, 1962) involved a similar temporally defined schedule with shock-avoidance as the scheduled consequence of t^D responding. Under this procedure, the first response in t^D precludes an electric shock that would otherwise occur at the end of the t^D period. Hurwitz and Millenson (1961) varied T , where the cycle length was held constant at 30 sec. As in studies using positive reinforcers, the rate of response was found to be inversely related to T up to a point where T became so small as to approximate an extinction schedule, and rate declined.

Sidman (1962), using $t^A + t^D$ equal to 15 sec, found that when the temporal order of the t^D and t^A was varied, a temporal patterning of responses similar to the "scallop" observed un-

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der fixed-interval positive reinforcement schedules developed. That is, a positive acceleration in rate occurred as the cycle progressed in time. The greatest degree of such temporal patterning of response occurred when many shocks were received. It is possible that the frequent and regularly occurring shocks acted as temporal "anchor points", as suggested by Anger (1963). Such conditions appear optimal for the development of "timing" behavior.

The logical similarity between the temporally defined avoidance schedule and the fixed-interval, limited-hold positive reinforcement schedule, and the fact that both schedules may lead to a distinctive, positively accelerated temporal patterning of response, suggested that other functional similarities might be found. Thus, in the present experiment, the relationship between t^A length and response rate was investigated on the assumption that lengthening t^A was functionally equivalent to lengthening the fixed interval. An inverse function between t^A and response rate was predicted, similar to that reported by Wilson (1954), Catania and Reynolds (1968), Cumming and Schoenfeld (1958), and Farmer (1963) for response rate changes under a fixed-interval positive reinforcement schedule. Specifically, in the present study, t^A was varied and t^D was held constant in contrast to the procedure adopted by Hurwitz and Millenson (1961) and Sidman (1962), where cycle length ($t^A + t^D$) was constant and t^D varied.

At one stage of the experiment, a discriminative stimulus was correlated with t^D , thus converting a non-discriminated schedule to a discriminated avoidance procedure. Of special interest was the effect of this change in procedure upon the temporal distribution of responses within the t^A period.

METHOD

Subjects

Three rats were used: Rat 1AM was a mature, male albino rat (Sprague-Dawley strain) previously used in a maze experiment, Rats 3HF and 6HF were experimentally naive hooded females bred in the Departmental animal colony and were approximately 100 days old at the beginning of the experiment. The subjects were individually housed in the Departmental animal colony and had free access

to water and laboratory chow. The colony room was maintained on an electrically timed light-dark cycle. The light-up times were from 7 A.M. to 7 P.M.

Apparatus

Experimental sessions were conducted in an operant conditioning chamber measuring 9 by 9 by 8 in. (22.5 by 22.5 by 20 cm) and equipped with a grid floor, two G.E. #1819, 28-v house-lights, and a response lever. A force of 0.098 N was required for the lever to operate its microswitch. The electric shock was 0.8 mA 170 v dc provided by a constant current shock source and was delivered to the grid floor of the chamber through a scrambler. The conditioning chamber was located in a sound-attenuating housing, which was in turn located in a man-sized sound-attenuating cubicle. Ventilating fans provided masking noise, and scheduling and recording circuitry were located outside this cubicle.

Procedure

Each session was begun in t^A , during which the rat's lever presses had no scheduled consequences. This was followed by a 5-sec t^D period. At the end of t^D , a 2.5-sec t^S time period occurred, thus completing one cycle. If no lever press occurred during t^D , shock was delivered to the grid during t^S . In the presence of shock during t^S , a lever response terminated the shock but did not influence the duration of t^S . If a lever response occurred in t^D , no shock was delivered during the next t^S , but the 2.5-sec period elapsed before t^A was begun again.

All subjects were initially exposed to the temporally defined avoidance schedule with t^A equal to 1 sec, t^D equal to 5 sec, and t^S equal to 2.5 sec. Rats 1AM and 3HF received a 1-sec stimulus (houselights extinguished) after the first avoidance response in t^D and after the first escape response in t^S . Rat 6HF received this stimulus after the first avoidance response in t^D , but not after escape responses during t^S . Subsequent removal and reinstatement of these stimuli with all three rats produced no change in their behavior, although the stimuli had been intended to serve as temporal "anchor points" on cycles when shock was avoided. Session durations varied in length from 150 to 600 min, depending on the value of t^A and number of cycles per session.

After the subjects' rate of lever responding had stabilized under the initial conditioning schedule, t^A was gradually increased from 1 sec to 8 min for Rats 1AM and 3HF, and from 1 sec to 6 min for Rat 6HF. The periods t^D and t^S were kept constant at 5 and 2.5 sec, respectively, throughout the experiment. Response rate was computed for both t^D and t^S time periods, while the t^A period was divided into eight successive intervals. Rate measures were computed for responding within each of these intervals, thus permitting the detection of any response-rate changes within the t^A period.

At $t^A = 3$ min for Rat 1AM and at $t^A = 8$ min for Rat 3HF, response rates during t^A were allowed to stabilize and a buzzer was then introduced which operated simultaneously with the t^D timer. (Sound level inside the operant conditioning chamber without the buzzer was 75 db; during operation of the buzzer, sound level rose to 85 db). This experimental operation was performed in an attempt to influence the distribution of responses within t^A .

The subjects were exposed to numerous intermediate values of t^A in addition to those discussed below. Data for the discussed t^A values were obtained in the last session of each experimental condition after visual inspection of cumulative recordings and numerical data indicated that behavior had stabilized. Subjects were exposed to the reported t^A values for a minimum of 80 cycles ($t^A = 3$ min) and a maximum of 10,500 cycles ($t^A = 0.5$ min).

RESULTS

The effect of a gradual increase in the duration of t^A may be seen in Fig. 1, where t^A response rates (top), per cent avoidance (middle) calculated as [(no. shocks avoided/no. cycles) $\times 100$], and the Index of Curvature (bottom) (Fry, Kelleher, and Cook, 1960) are plotted. Values of the Index of Curvature falling around zero indicate little or no positive acceleration ("scallop") in the response distributions, whereas values of the Index greater than zero indicate increasing degrees of positive acceleration. The maximum value of the Index of Curvature is determined by the number of categories in the distribution, and the eight categories used in this experiment produced a maximum value of 0.875. The points

plotted in Fig. 1 are measures obtained from the last session under each t^A value.

As can be seen in Fig. 1, there was an inverse relationship between t^A length and response rate, as well as between t^A length and per cent avoidance; *i.e.*, as t^A increased, response rate and per cent avoidance decreased.

An attempt was made to recover the response rates, per cent avoidance, and Index of Curvature observed at shorter t^A durations. Thus, Rat 1AM was exposed a second time to $t^A = 0.5$ min and Rat 3HF was exposed a

Fig. 1. Response rate, per cent avoidance, and Index of Curvature for Subjects 1AM, 3HF, and 6HF as a function of t^A duration. Unconnected data points refer to the results of replications.

second time to $t^A = 1$ min and $t^A = 4$ min. Measures obtained in the last session of each reexposure appear in Fig. 1 as unconnected open points. (The significance of the unconnected solid points is explained below)

The response distributions presented in Fig. 2 were obtained for each rat in the last session of each experimental condition. It will be noted that, in the absence of the t^D -correlated buzzer, the distributions for Rats 3HF and 6HF fell around a value of 12.5% and approximated a horizontal line. Such distributions indicate a constant rate of response throughout t^A as do the curvature measures for rats 3HF and 6HF in Fig. 1 (bottom). On the other hand, in the absence of the t^D -correlated buzzer, the distributions for Rat 1AM deviated noticeably from the value of 12.5% and from the horizontal (Fig. 2). This indicates an increase in rate as t^A progressed from subinterval 1 through subinterval 8, as does the Index of Curvature for Rat 1AM in Fig. 1 (bottom). It should be noted further that Rat 1AM consistently received the greatest number of shocks per session (Fig. 1, middle) and that this rat ceased to display the marked temporal patterning when t^A reached the value of 6 min. The absence of this patterning at $t^A = 6$ min can be seen in both the percentage distribution (Fig. 2) and the Index of Curvature (Fig. 1, bottom) for Rat 1AM, the percentage distribution being approximately horizontal and the Index of Curvature decreasing to a value of approximately zero. When exposed a second time to $t^A = 0.5$ min, Rat 1AM resumed this scalloped pattern, as indicated by the percentage distribution (Fig. 2) and Index of Curvature (Fig. 1, bottom, unconnected point). Finally, Fig. 1 (bottom) indicates that a nonmonotonic relationship existed between t^A length and Rat 1AM's Index of Curvature, whereas the Index of Curvature for Rats 3HF and 6HF assumed similar values for all t^A lengths.

The introduction of a buzzer during t^D resulted in typical discriminated avoidance behavior (Hurwitz, 1964) for Rats 1AM and 3HF. Response rate during t^A declined to virtually zero, whereas response rate during t^D was somewhat higher than t^D rates obtained on the unsignalled temporally defined avoidance schedule. While the discriminated avoidance procedure was in effect, responses were evenly distributed throughout t^A , except for

the marked concentration of responding in subinterval 1 of t^A (Fig. 2). This concentration in subinterval 1 was due to post-shock response bursts which, on the few occasions when shocks were received, began in t^S and carried over into subinterval 1. This factor was responsible for the great variability of the distribution for Rat 1AM and it contributed further to the inflation of the percentages in t^A subinterval 1 for Rats 1AM and 3HF.

Measures obtained in sessions following reinstatement of the unsignalled t^D are presented in Fig. 1 as solid unconnected points. As can be seen in Fig. 1 (bottom) and in Fig. 2, the Curvature measures and percentage distributions of t^A responding returned to values similar to those observed before the buzzer was introduced; *i.e.*, Rat 1AM once again displayed a marked temporal patterning, and Rat 3HF again distributed responses evenly throughout t^A . Thus, although marked alterations in overall t^A rate and patterning occurred while the discriminated avoidance procedure was in effect, exposure to this schedule produced no residual alteration in the temporal patterning of t^A responding once the unsignalled, temporally defined avoidance schedule was reinstated.

DISCUSSION

The present experiment was suggested by the logical similarity of the temporally defined avoidance schedule to the fixed-interval, limited-hold positive reinforcement schedule, and by the apparent behavioral similarity ("scalloping") produced by the two procedures (Sidman, 1962). The present results suggest an additional behavioral similarity of the two schedules in that the inverse relationship observed between t^A length and t^A response rate is similar to that obtained between fixed-interval length and response rate in positive reinforcement procedures (Wilson, 1954; Catania and Reynolds, 1968).

With regard to the occurrence of "scalloping", the analogy of the fixed-interval limited-hold positive reinforcement schedule to the temporally defined avoidance schedule seems appropriate only when the latter schedule induces a high shock frequency at short inter-shock intervals (short t^A lengths). Sidman (1962), using a very short cycle ($t^A + t^D = 15$ sec) with albino rats, reported such temporal

Fig. 2. Response distributions for Subjects 1AM, 3HF, and 6HF during the t^Δ periods.

patterning only in the presence of high shock rates. Similarly, in the present experiment, this temporal patterning appeared only in albino Rat 1AM, given short-to-moderate inter-shock intervals (t^A lengths) and high shock rates (low per cent avoidance; Figure 1, middle).

Hooded Rats 3HF and 6HF, although exposed to the same short-to-moderate inter-shock intervals, apparently had sufficiently low shock rates (high per cent avoidance; Fig. 1, middle) to prevent the development of positively accelerated response rates within t^A . This is to be expected because a low shock rate implies that few temporal "anchor points" would be delivered so that little opportunity would be provided for the development and maintenance of "timing" behavior. It should be noted that temporal patterning failed to develop in spite of the fact that a 1-sec stimulus (houselights extinguished) accompanied the first response in t^D . This fact further illustrates the irrelevance of this visual stimulus, whose removal from, and reinstatement in the procedure produced no behavioral effect.

In summary, it is suggested that Rat 1AM developed positively accelerated temporal patterning at short-to-moderate t^A lengths because of a relatively high shock frequency. It is further suggested that Rats 3HF and 6HF did not display such temporal patterning at the same short inter-shock intervals (short t^A lengths) due to their low shock frequencies and to the apparent behavioral irrelevance of the visual stimulus produced by the first avoidance response in t^D . For Rat 3HF, even though exposure to a discriminated avoidance procedure produced marked pausing throughout t^A , no residual effect on the patterning of t^A responses was observed once the non-discriminated avoidance schedule was reinstated.

REFERENCES

- Anger, D. The role of temporal discriminations in the reinforcement of Sidman avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 477-506.
- Catania, A. C. and Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 327-383.
- Clark, R. Some time-correlated reinforcement schedules and their effects on behavior. *Journal of the Experimental Analysis of Behavior*, 1959, 2, 1-22.
- Cumming, W. W. and Schoenfeld, W. N. Behavior under extended exposure to a hi-value fixed interval reinforcement method. *Journal of the Experimental Analysis of Behavior*, 1958, 1, 245-263.
- Farmer, J. Properties of behavior under random interval reinforcement schedules. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 607-616.
- Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.
- Fry, W., Kelleher, R. T., and Cook, L. A mathematical index of performance on fixed-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1960, 3, 193-199.
- Hearst, E. The behavioral effects of some temporally defined schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1958, 1, 45-55.
- Hurwitz, H. M. B. and Millenson, J. R. Maintenance of avoidance behavior under temporally defined contingencies. *Science*, 1961, 133, 284-285.
- Hurwitz, H. M. B. Method for discriminative avoidance training. *Science*, 1964, 145, 1070-1071.
- Schoenfeld, W. N., Cumming, W. W., and Hearst, E. On the classification of reinforcement schedules. *Proceedings of the National Academy of Science*, 1956, 42, 563-570.
- Sidman, M. Classical avoidance without a warning stimulus. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 97-104.
- Wilson, M. P. Periodic reinforcement interval and number of periodic reinforcements as parameters of response strength. *Journal of Comparative and Physiological Psychology*, 1954, 47, 51-56.

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