TWO PARAMETERS OF A TEMPORALLY DEFINED SCHEDULE OF NEGATIVE REINFORCEMENT

NORMAN A. SIDLEY¹

COLUMBIA UNIVERSITY²

Temporal schedules of negative reinforcement were derived in a manner analogous to those for positive reinforcement, and two parametric studies were carried out with two of the three defining variables. With some limiting values of the defining variables, escape schedules result and data obtained at these values were similar to those obtained in escape studies. At other values of the defining variables avoidance behavior was generated.

A temporal classification of reinforcement schedules which sought to integrate the effects of many diverse schedule specifications into one conceptual framework has been proposed by Schoenfeld, Cumming, and Hearst (1956). With one exception, Hurwitz and Millenson (1960), all of the work within this temporal framework has been concerned with schedules of positive reinforcement. Hurwitz and Millenson have demonstrated that avoidance behavior similar to that obtained by Sidman (1953) may also be obtained within a similar temporal framework. The present experiments, utilizing negative reinforcement, were an attempt to broaden the temporal classification of reinforcement schedules to possibly integrate the effects of both escape and avoidance schedules into a single framework.

In the schedule proposed here, the experimental session is divided into temporal intervals called cycles. Each cycle is composed of a time period t^D_A , during which an aversive stimulus is scheduled to occur continuously, and a time period t^A_A , during which the stimulus is not scheduled. If a response by the organism coincides with t^D_A , it terminates the stimulus. An additional variable, TO (for Time Out), is defined as a response-produced period of time during which aversive stimuli, scheduled to occur, are withheld. In addition,

during TO any "extra" responses have no effect upon the schedule or TO . A diagram of the relations between schedule and behavior which could occur is presented in Fig. 1.

It is possible within the present system to define a schedule which is identical with many "free-operant" escape procedures (*e.g.*, Keller, 1941; Sheffield and Temmer, 1950; Kaplan, 1952; Barry and Harrison, 1957; and Dinsmoor, Hughes, and Matsuoka, 1958). Thus, when t^D_A is any arbitrary length and t^A_A is set equal to zero, the aversive stimulus is scheduled to occur throughout the experimental session and can be terminated only by the organism's response. Varying TO in this situation is identical with varying the "inter-trial interval" in the usual escape procedure. This procedure was, in fact, employed in the present study, with TO being varied over a range which included some of the values of Dinsmoor, *et al.*, but which also was extended to determine the limits of functions obtained in that experiment.

Avoidance behavior could emerge under the schedule defined above when t^D_A is short,

Fig. 1. A schematic representation of the possible relations between schedule and behavior. (For details see text.)

¹This research was supported by the National Science Foundation through grants G8671 and G18633. The author wishes to express his thanks for the patience and assistance of Professors W. N. Schoenfeld and W. W. Cumming.

²Present address: Minneapolis-Honeywell Regulator Co., MPG Research, 2600 Ridgeway Rd., Minneapolis 40, Minnesota.

say 0.5 sec, and $t\Delta_A$ is longer, say 5.0 sec, and $TO = 10.0$ sec; it is then possible for the organism to respond in a manner which would result in many TO s and few, if any, aversive stimulus presentations.

In addition to the possibility of finding both escape and avoidance behavior along some dimension of a single continuum such as $t\Delta_A$ or TO , and of extending certain escape functions, it is also possible with the outlined procedure to investigate systematically the effects of schedules similar to those used by Hefferline, Keenan and Harford (1959) which contain both escape and avoidance contingencies at the same time. The present study is a parametric investigation of two of the three temporal variables defined above.

METHOD

Subjects

Experiments I and II employed nine Wistar strain, naive male albino rats, 120-130 days old when the experiments began. Each animal was maintained in an individual living cage in constant light, and allowed continuous access to Purina lab chow and water before and after every experimental session.

Apparatus

The test chamber, produced by Scientific Prototype as their model A-100 rat chamber, contained a grid floor composed of sixteen $\frac{1}{4}$ in. steel rods. The grid and front and back walls were electrified with a Grason Stadler Shock Generator model E1064GS which provided a 1 milliamp 60 cycle AC shock. The shock pattern across the grids was modified every 0.3 sec to prevent differential reinforcement for standing on any particular pair. The test chamber was placed in a sound- and light-attenuating shell. A 15CFM blower mounted on the wall of the shell provided both an air supply and a low-level masking noise. An illumination level of 88.5 millilamberts in the test chamber was provided by a tungsten lamp center-mounted 4 in. above the response lever.

A Scientific Prototype model PLS-100 response lever was mechanically and electrically connected to the front wall of the test chamber 2 in. above the grid floor. A depression of the lever with a force of 11 g or more closed a microswitch which activated relays, timers,

and counters located in a separate room, used to program and record the experiment.

In addition to counters and a cumulative recorder, a Grason Stadler Multiple Class Time Analyzer E3950A recorded the distribution of "extra" responses and the distribution of Inter-Response Times (IRT).

Experiment I

TO and $t\Delta_A$ were systematically manipulated in Exp. I. TO took the values 10.0, 5.0, 2.0, and 1.0 sec; $t\Delta_A$ was varied in value from 0.0, 1.5, 4.5, 9.5, to 19.5 sec. The parameter t^D_A was held constant at 0.5 sec. Each of the temporal values was calibrated before and after each day's experimentation using a pre-calibrated oscilloscope. Each subject was exposed to all of the 20 possible combinations of TO and $t\Delta_A$ by fixing TO and allowing $t\Delta_A$ to take on each of the five values in succession, and then fixing a new TO and repeating each $t\Delta_A$ value. With few exceptions, both TO and $t\Delta_A$ were presented in the order

Table 1

Order of presentation for the schedule values used for Rats 0-4^a in Experiment I

Session	Schedule		Session Length (Minutes)
	TO (Seconds)	$t^D_A + t^A_A$ (Seconds)	
1- 7	10	0.5	40 (+ 10) ^b
8- 14	10	2.0	40 (+ 10)
15- 21	10	5.0	40 (+ 10)
22- 28	10	10.0	40 (+ 10)
29- 35	10	20.0	40 (+ 10)
36- 42	10	10.0	40
43- 49	10	2.0	40
50- 56	5	2.0	40
57- 63	5	5.0	40
64- 70	5	10.0	40
71- 77	5	20.0	40
78- 84	5	0.5	40
85- 91	2	0.5	5
92- 98	2	2.0	10
99-105	2	5.0	40
106-112	2	10.0	40
113-119	2	20.0	40
120-126	1	0.5	5
127-133	1	2.0	10
134-140	1	5.0	40
141-147	1	10.0	40
148-154	1	20.0	40

^aRat 2 was also exposed to $TO = 0.5$, $t^D_A + t^A_A = 0.5$ sec for sessions 155-161, each session being 5 min long.

^bThese sessions were run an additional 10 min due to the presence of a "warm-up" effect (see text).

mentioned above. A complete record of the sequence of exposure of each animal to all of the experimental conditions is presented in Table 1.

The subjects were exposed to each schedule value (a combination of TO and $t\Delta_A$) for seven, 40-min sessions, one session at approximately the same time of day for seven consecutive days. Two exceptions to this procedure were: (1) When TO was 1.0 and 2.0 sec, and $t\Delta_A$ was zero, experimental sessions were 5 min long, and when TO was 1.0 and 2.0 sec and $t\Delta_A$ was 1.5 sec, experimental sessions were 10 min. This was done to protect the animals from possible adverse effects of prolonged exposure to shock. (2) For the first five schedule values a "warm-up" effect was detected in the animals' performance during the first 5 or 10 min of each session as compared with the remaining time. Accordingly, these sessions were run 10 min longer than the rest, and the data from the last 40 min only are reported. For all other schedule values, data are reported for the entire session.

Experiment II

Two animals were exposed to the following schedule values, each schedule being in effect for seven, 40-min sessions: $TO = 10.0$, $t\Delta_A = 0$, 1.5, 4.5, 9.5, 19.5, 29.5, and 59.5 sec, and $TO = 5.0$, $t\Delta_A = 1.5$ sec, and $TO = 20.0$, $t\Delta_A = 29.5$ sec, with the parameter t^p_A being held constant at 0.5 sec. Two more animals were exposed to five schedule values: $TO = 10.0$, $t\Delta_A = 19.5$, 9.5, 4.5, 1.5, and 0.0 in that order. Again t^p_A was held constant at 0.5 sec. One of these latter two animals was exposed to each schedule value for three, 94-min sessions, approximately the same total length of exposure as the animals in Exp. I, but covering a shorter span of days. The other was exposed to each schedule value for seven, 240-min sessions on consecutive days.

RESULTS AND DISCUSSION

Experiment I

Figure 2 shows the rate of responding as a function of $t\Delta_A + 0.5$ sec, ($t\Delta_A + t^p_A$), for all animals in Exp. I. Product-moment correlations between 22 (20 schedule values and two redetermination points) means and their re-

spective variances for rates of responding for Rats 0-4, respectively, are: +0.737, +0.293, +0.590, +0.771, and +0.486. All of these values, except that for Rat 1, are significant at the 0.05 level. Relationships of this kind have previously been observed in the operant conditioning literature (e.g., Clark, 1959).

It can be seen from Fig. 2 that, as $t\Delta_A$ increases, response rate generally decreases. Inversions are evident in the rate functions for Rat 0 at $TO = 1.0$ and for Rat 1 at $TO = 2.0$. Holding $t\Delta_A$ constant at some value above zero, there does not appear to be any systematic change in rate with a change in TO as long as TO remains shorter than $t\Delta_A$ (e.g., at $t\Delta_A = 19.5$ there is no change in rate with a change in TO from 10.0 to 1.0 sec). The fact that these changes in TO have little effect on the rate of responding might indicate that TO is not "making contact" with the behavior. That is to say, when TO is shorter than $t\Delta_A$, the animals may not be affected by further reduction in TO either because an extremely good temporal discrimination has been formed, in which a response occurs within 1 sec of a scheduled shock, or because responding is characterized by a "burst" following each shock with subsequent pause until the next shock presentation. As will be seen below, the ratio of responses to shocks, TO s per shock, and the temporal distribution of responses indicate that the second explanation is more likely correct.

The initial point ($t\Delta_A = 0.0$) in the functions for each rat in Fig. 2 corresponds to the rate of responding under an escape schedule as usually defined. It can be seen that, holding $t\Delta_A = 0.0$ and varying TO , with the exception of Rats 2 and 3, a decrease in TO produces an increase in the rate of responding until a maximum is obtained after which further decreases in TO produce decreases in the rate of responding. This finding agrees with that of Dinsmoor, *et al.*, at TO values corresponding to the "inter-trial interval" lengths used in that study. In an effort to determine the location of a possible maximum in the rate function for Rat 2, when $t\Delta_A = 0.0$, this animal was exposed to $TO = 0.5$ sec following exposure to the last schedule value to which all of the animals were exposed. At this value, Rat 2 emitted 42.6 responses per min, a reduction of 11.1 responses per min from that prevailing at $TO = 1.0$ sec.

Fig. 2. Rate of responding as a function of $t_A + 0.5 (t_A + t_D)$ with TO as a parameter for all animals in Experiment I.

Recordings were made of the distribution of responses during successive tenths of the TO interval for those animals which emitted at least 100 responses on the sixth or seventh day of exposure to $t_A = 0.0$ (the escape schedule). Figure 3 presents the relative frequency distributions of these "extra" responses. Most of the "extra" responses occur during the first few tenths of the TO interval. The gradual flattening of the distributions may have been artifactually produced by choosing the class interval proportional to the value of TO . It may be the case that most of the "extra" responses always occur during the first few tenths of a second following shock.

If this were true, one would expect a steeper function to appear as the absolute size of the class interval was increased. Due to the manner in which data were collected in the present experiment it is not possible to determine if this was the case; however, in this connection, Dinsmoor, *et al.* (1958), present similar distributions for "inter-trial interval" lengths of 20.0 and 30.0 sec which show approximately 20 per cent of the "extra" responses occurring in the second 5 sec of the interval.

Figure 4 presents the ratio of responses to shocks for each of the animals on all but three of the schedules used in the present experi-

 Fig. 3. Relative frequency of "extra" responses in successive tenths of TO .

ment. (A recording apparatus failure was responsible for the omission of the responses-to-shock ratio for schedules in which $TO = 10.0$ while $t_{\Delta} = 4.5, 9.5$, and 19.5 sec.) With the exception of Rat 0, there seems to be no consistent relationship between responses-per-shock and either TO or t_{Δ} . Combining the responses-per-shock data with the responses-per-minute data, it can be seen that the rate of responding is directly proportional to the shock frequency, the constant of proportionality being the responses-per-shock ratio. Consequently, manipulations of TO or t_{Δ} only affect the rate of responding when the pattern of responding is such that these manipulations will produce a change in the number of shocks the animal is exposed to in a fixed period of time. Similarly, Sidman (1953) found that when the R-S interval was long, decreases in the S-S interval had little effect on the rate of responding, presumably because the pattern of responding prevented these short intervals from occurring.

 Fig. 4. Responses-to-shock ratios as a function of $t_A + 0.5$, with TO as a parameter.

Fig. 5. IRT distributions for Rat 3 at some schedule values. Open circles are redetermined distributions. Class intervals are 1 sec. Unless otherwise specified, the 20th interval contains all IRTs equal to or greater than 20 sec.

The differences between the patterns of responding of the animals in the present experiment and those frequently seen in avoidance schedules are more pronounced than the similarities, and are especially prominent in the inter-response time distributions. Figures 5 and 6 present the IRT distributions for Rats 3 and 1, respectively. Since in the present system shocks are scheduled independently of the organism's behavior, a shock will always precede the second response of a pair of responses separated by more than the interval $TO + t_{\Delta}$. In addition, if the animal is responding with a "burst" of responses following a shock and then pausing until the next shock presentation, a modal IRT would occur near the value of t_{Δ} when TO is shorter than t_{Δ} , and would occur near $TO + t_{\Delta}$ when TO is longer than t_{Δ} . Most of the IRT distributions in the present experiment, unlike those on avoidance schedules as usually defined, indicate a preponderance of IRTs longer than $TO + t_{\Delta}$ or modal IRTs con-

Table 2

TOs-per-shock ratios as a function of cycle length and Time Out for each animal in Experiment I. Data presented are the means of the last three days at each schedule value.

Time Out	Cycle Length	Rat 0 Mean	Rat 1 Mean	Rat 2 Mean	Rat 3 Mean	Rat 4 Mean
10	0.5	1.00	1.00	1.00	1.00	1.00
10	2.0	0.73	0.77	0.63	0.80	0.90
5	0.5	0.66	1.00	1.00	1.00	1.00
5	2.0	0.57	0.83	1.03	0.90	0.97
5	5.0	0.43	0.73	1.00	0.90	1.13
5	10.0	0.37	0.47	1.00	0.77	1.57
5	20.0	0.17	0.87	1.06	0.87	2.33
2	0.5	0.90	0.93	1.00	1.00	1.00
2	2.0	0.00	0.03	1.00	0.53	0.93
2	5.0	0.07	0.10	1.03	0.80	1.00
2	10.0	0.17	0.23	1.10	0.93	1.30
2	20.0	0.07	0.73	1.03	0.53	1.33
1	0.5	0.63	1.00	1.00	1.00	1.00
1	2.0	0.06	0.33	0.87	0.27	0.37
1	5.0	0.06	0.40	1.23	0.73	0.97
1	10.0	0.10	0.57	1.20	0.47	1.13
1	20.0	0.57	0.53	1.00	0.80	1.03

Fig. 6. IRT distributions for Rat 1 at some schedule values. Open circles are redetermined distributions. Class intervals are one second. Unless otherwise specified, the 20th interval contains all IRTs equal to or greater than 20 sec.

sistent with the pattern of responding mentioned above.

Finally, Table 2 presenting the ratio of TO s to shocks indicates that the animals only occasionally produced more than 1 TO per shock. Combined with the previous data, then, it may be concluded that the present animals did not change their response pattern under schedules in which $t\Delta_A$ is unequal to zero, and avoidance was possible, as compared with the pattern that they had earlier shown under schedules in which $t\Delta_A = 0.0$ where only escape was possible.

An inverse relation was found between the rate of responding and the duration of a response. Product-moment correlations based on 63 pairs of rates and redeterminations (19 schedule values plus two redetermination points on each of the last three days at each point) for Rats 0-4 were: -0.186 , -0.293 , -0.475 , -0.615 , and -0.601 , respectively. All but the correlation for Rat 0 are significant at the 0.05 level. Obviously, the mean duration of a response

places an upper limit on the rate of responding. This does not necessarily mean that the observed correlations are artifactual since for those rats which show significant correlations, the rate of responding is not generally very close to the upper limit set by the duration of a response.

Figure 7 presents the means of the duration of a response for all animals on all but one schedule value. (A recording apparatus failure was responsible for the omission of the duration value at $TO = 10.0$, $t\Delta_A = 1.5$.) With the exception of Rat 2, there is a general tendency for the mean duration of a response to increase with longer values of $t\Delta_A$. That this increase is not due simply to continued training, as reported by Dinsmoor, *et al.*, for their data, is seen by the redetermination values as well as a return to short durations when a short value of $t\Delta_A$ is repeated. Hefferline (1950) has suggested that the return of the aversive stimulus following the release of the bar may suppress "bar-releas-

Fig. 7. Mean duration of a response in seconds as a function of $t_A + 0.5$ sec, with TO as a parameter. Open circles are redetermined points.

ing". It is clear that the present data are not to be accounted for solely in this way in view of the persistence of this behavior despite the fact that Rats 0, 3, and 4 were very frequently shocked while "holding" (*i.e.*, the mean duration of a response was longer than the inter-shock time). Dinsmoor, Matsuoka, and Winograd (1958) have suggested that at least one function of this "holding" response may be "preparation" for the escape response.

Several factors may have contributed to the persistence of escape behavior. (1) Sidman (personal communication) has suggested that it is difficult to condition non-cued avoidance behavior following a history of escape training. In Exp. I all of the animals were first exposed to $TO = 10.0$, $t_A = 0.0$, an escape schedule. (2) The majority of experiments which report the acquisition of avoidance behavior have employed longer session lengths than those employed in Exp. I. Thus, it may be that avoidance behavior would develop with continued exposure to one schedule value. (3) The range of temporal variables investigated in Exp. I may have been too

restricted to encompass avoidance behavior. (4) The length of t_D was held constant at 0.5 sec throughout Exp. I. This shock duration is longer than those typically employed in avoidance schedules. While no parametric investigation of this variable has been undertaken in this study, it may be that shock duration plays an important role in the acquisition of avoidance behavior. (5) Responses which occurred during TO had no effect on the length of that TO . It may be that avoidance behavior would develop if responses during TO prolonged that TO in the same way that responses during an R-S interval prolong that interval in Sidman's procedure. The first three of these factors, order of presentation of t_A , session length, and the range of t_A were examined in Exp. II.

Experiment II

Rats 8R and 9R were exposed to five schedule values, $TO = 10.0$ sec in combination with $t_A = 19.5, 9.5, 4.5, 1.5$, and 0.0 , in that order, opposite to the order of presentation in Exp. I; t_D was held constant at 0.5 sec. For these

Fig. 8. Rate of responding, response duration, and responses-to-shock ratios as a function of $t_A + 0.5$ sec. Bracketed points are redetermined values.

animals the escape schedule was presented last and, in addition, for Rat 9R the length of exposure to each schedule value was increased by a factor of six (*i.e.*, seven, 240-min sessions at each value) over that used in the previous experiment. Rat 8R was exposed to each schedule value for three, 94-min sessions, the same total duration of exposure as the animals in Exp. I over a shorter span of days.

Figure 8 presents the mean rate of responding, duration of response, and the ratio of responses to shocks, for Rats 8R and 9R. No consistent differences appear between the functions for Rats 8R and 9R and those for the animals in the previous experiment. It may be concluded that, within the limits of the present experiment, neither the order of presentation nor the length of exposure to the schedule values is critical to the functions obtained.

In order to determine the effect of an extended range of t_A on the possible acquisition of avoidance behavior, Rats 6c and 7c

Fig. 9. Rate of responding, response duration, and responses-to-shock ratios as a function of $t_A + 0.5$ sec. Bracketed points are redetermined values. Half filled circles represent $TO = 5$, open circles represent $TO = 20$.

Fig. 10. TO 's-per-shock ratios as a function of $t_A + 0.5$ sec. Bracketed points are redetermined values.

were exposed to two additional values of t_A , 29.5 and 59.5 sec, together with those used in Exp. I. TO was generally held constant at 10.0 sec but was varied twice for Rats 6c and 7c, changing its value to 5.0 sec when $t_A = 1.5$ sec and from 10.0 to 20.0 and back to 10.0 when $t_A = 29.5$.

Figure 9 presents the mean rate of responding, response duration, and responses-to-shock ratios for each schedule value. Figure 10 presents the ratio of TO s to shocks for Rats 6c and 7c. For all measures of behavior, with the exception of the responses-to-shock ratio, the results for Rats 6c and 7c resemble those of the animals in Exp. I up to a t_A value of 19.5 sec. The responses-to-shock ratios for Rats 6c and 7c are larger than those obtained in Exp. I for the same schedule values. At $t_A = 19.5$ and longer the responses-to-shock ratio and TO s-per-shock ratio increase to values which, together with the IRT distributions for one of these animals presented below, indicate a pattern of responding unlike that seen for the animals in Exp. I.

Figure 11 presents the IRT distributions for Rat 6c at each schedule value. These IRT distributions resemble those typically obtained from avoidance schedules. At t_A values of 19.5, 29.5, and 59.5 sec between 80 and 90 per cent of all IRTs are shorter than the time scheduled between two shocks, and there is little or no indication of "bursts" of responses (*i.e.*, a preponderance of very short IRTs). These IRT distributions approach rectangularity which would indicate that the probability of a response increases linearly in time, approaching a high value in less than the scheduled inter-shock time. These distribu-

Fig. 11. IRT distributions for Rat 6c at some schedule values. Class intervals are 1 sec. Unless otherwise specified, the 20th interval contains all IRTs equal to or greater than 20 sec.

tions are similar to those obtained by Sidman (1954) which, he suggests, indicate a well-developed time discrimination.

On the basis of the increases in responses-to-shock ratios, TO -per-shock ratios, and the IRT distributions, it may be concluded that it is possible, using values of t_A much longer than TO , to obtain behavior within the present system which is similar to that obtained from the usual non-cued avoidance schedules (e.g., Sidman, 1953; 1954; and 1958).

REFERENCES

- Barry, J. J. and Harrison, J. M. Relation between stimulus intensity and strength of escape responding. *Psychol. Rep.*, 1957, **3**, 3-8.
- Clark, R. Some time-correlated reinforcement schedules and their effects on behavior. *J. exp. Anal. Behav.*, 1959, **2**, 1-22.
- Dinsmoor, J. A., Hughes, L. H., and Matsuoka, Y. Escape-from-shock training in a free responding situation. *Amer. J. Psychol.*, 1958, **71**, 325-337.
- Dinsmoor, J., Matsuoka, Y., and Winograd, E. Barholding as a preparatory response in escape-from-shock training. *J. comp. physiol. Psychol.*, 1958, **51**, 637-639.
- Hefferline, R. F. An experimental study of avoidance. *Genet. Psychol. Monogr.*, 1950, **42**, 231-334.
- Hefferline, R. F., Keenan, B., and Harford, R. A. Escape and avoidance conditioning in human subjects without their observation of the response. *Science*, 1959, **130**, 1338-1339.
- Hurwitz, H. M. B. and Millenson, J. R. Maintenance of avoidance behavior under temporally defined contingencies. *Science*, 1961, **133**, 284-285.
- Kaplan, M. The effects of noxious stimulus intensity and duration during intermittent reinforcement of escape behavior. *J. comp. physiol. Psychol.*, 1952, **45**, 538-549.
- Keller, F. S. Light aversion in the white rat. *Psychol. Rec.*, 1941, **4**, 235-250.
- Schoenfeld, W. N., Cumming, W. W., and Hearst, E. On the classification of reinforcement schedules. *Proc. Nat. Acad. Sci.*, 1956, **42**, 563-570.
- Sheffield, F. D. and Temmer, H. W. Relative resistance to extinction of escape training and avoidance training. *J. exp. Psychol.*, 1950, **40**, 287-298.
- Sidman, M. Two temporal parameters of the maintenance of avoidance behavior by the white rat. *J. comp. physiol. Psychol.*, 1953, **46**, 253-261.
- Sidman, M. The temporal distribution of avoidance responses. *J. comp. physiol. Psychol.*, 1954, **47**, 399-402.
- Sidman, M. Some notes on "bursts" in free-operant avoidance experiments. *J. exp. Anal. Behav.*, 1958, **1**, 167-172.

Received May 21, 1962