*TWO TEMPORAL PARAMETERS
OF FREE OPERANT DISCRIMINATED
AVOIDANCE IN THE RHESUS MONKEY¹*

ARNOLD HYMAN

COLLEGE OF PHYSICIANS AND SURGEONS OF COLUMBIA UNIVERSITY

Four monkeys were exposed to free operant discriminated avoidance (discriminated Sidman avoidance) in a parametric study of safe stimulus and warning stimulus duration. The safe stimulus was assigned values of 2, 5, 10, 20, and 40 sec, the warning stimulus values of 2, 5, and 20 sec. Rate of responding was a decreasing negatively accelerated function of safe stimulus duration, with a small effect attributable to warning stimulus duration. Control of response rate by safe stimulus duration was due to the predominance of responding in the presence of the warning stimulus. Responding during the safe stimulus was independent of the temporal parameters except at schedules combining short safe and short warning stimulus durations. Latencies of responses in the warning stimulus were analyzed, and mean latency was found to be a direct function of warning stimulus duration, with only one exception, resulting from the order in which the warning stimulus values were presented. Shock rate was not systematically related to either of the manipulated parameters.

When a pre-shock warning stimulus (S_1) is added to the Sidman avoidance paradigm, the response-shock (RS_2) interval is fractionated into two temporal parameters, the response-warning stimulus (RS_1) interval, and the warning stimulus-shock (S_1S_2) interval. For convenience of expression, these intervals will be termed the safe stimulus and the warning stimulus, respectively. Responding during the safe stimulus postpones onset of the warning stimulus for a period specified by the RS_1 interval. A response during the warning stimulus terminates the stimulus and avoids shock. If no response occurs in the warning stimulus during the period specified by the S_1S_2 interval, the stimulus is terminated coincidentally with a brief shock.

That the warning stimulus comes to control

responding in free operant discriminated avoidance has been reported several times (Behrend and Bitterman, 1963; Graf and Bitterman, 1963; Keehn, 1959; Sidman, 1955; Sidman and Boren, 1957; Sidman, Mason, Brady, and Thach, 1962; Thompson, Birch, and Hyman, 1964; Ulrich, Holz, and Azrin, 1964). Most of the work cited used a safe stimulus duration of 15 or 20 sec and a warning stimulus duration of 4 or 5 sec. Only two studies were parametric (Thompson *et al.*, 1964; Ulrich *et al.*, 1964), and their procedures differed. In the study by Ulrich *et al.* the subjects were rats, the shock-shock interval was 5 sec, and the warning stimulus remained on into the shock-shock interval until terminated by a response. The safe stimulus duration was varied while holding the response-shock interval constant at 20 sec. The warning stimulus duration thereby varied inversely with the duration of the safe stimulus.

Thompson *et al.* employed rhesus monkeys and a shock-shock interval equal to the response-shock interval. The warning stimulus was terminated by a response or by a single shock, whichever came first. Safe stimulus duration was varied independently of warning stimulus duration, and thereby the response-shock interval was not constant. However, shock rates were extremely low (0.013 to 0.20 per hr) so that the response-shock interval made little contact with behavior.

¹This paper is based on a dissertation submitted to the University of Cincinnati in partial fulfillment of the requirements for the Ph.D. degree. The research was carried out in the College of Physicians and Surgeons of Columbia University and was supported by United States Public Health Service Research Grant MH 07152, National Institute of Mental Health (Robert L. Thompson, principal investigator). The author expresses his appreciation to Robert L. Thompson for guidance and criticism during all phases of the research and revision of the manuscript. Appreciation is also due R. J. Senter for his guidance and criticism. Reprints may be obtained from the author, Neurosurgical Research, Jewish Hospital and Medical Center of Brooklyn, 555 Prospect Place, Brooklyn, N.Y. 11238.

The present study extended the work by Thompson *et al.* (1964). With monkeys as subjects, the durations of safe and warning stimuli were varied independently over a wider range of values than reported previously. The effect of this procedure upon response rate, temporal distribution of responses, latency of responses in the warning stimulus, and shock rate is presented.

METHOD

Subjects

Four experimentally naive male monkeys (*Macaca mulatta*) were each chronically restrained in a Foringer Primate Chair. Body weights ranged from 2.5 to 4.0 kg at the outset of the experiment to 3.5 to 5.0 kg at the conclusion.

Apparatus

During experimental sessions the subjects' feet were fastened to shoe-type electrodes of the type and in the manner described by Weiss and Laties (1962). The subject's chair was locked in place in a sound-attenuated cubicle. A manipulandum (Lehigh Valley Electronics model 1380) of the microswitch lever type projected from a small box positioned at just less than arm's length from the monkey, and was operated by a force of 23 g. (This arrangement restricted the topography of lever-pressing and reduced "playing with" the lever.) A white masking noise of approximately 80 db was continuously present; sound level was increased to approximately 90 db by onset of the warning stimulus, a 15-per-sec clicking noise generated by a circuit described by Malis and Curran (1960) and presented through a separate loudspeaker.

Shock of approximately 4.0 mA, 60 Hz, and 0.4-sec duration was delivered through the shoe electrodes from a constant current source (Foringer Model 1154). The subject's resistance was measured at the beginning of each of the sessions and at irregular intervals during sessions to monitor the quality of contact between the electrode surface and the feet.

Scheduling and recording were done automatically with remote relay circuitry. The start of a session was signalled by turning on a fluorescent houselight 5 min after the monkey was positioned in the cubicle.

Procedure

Acclimation. During the first seven days of restraint in the chair, subjects were exposed daily to electrode placement and removal, and to being lifted in and out of the cubicle.

Operant level. In the first regular session, each subject was exposed to all experimental variables except shock. The subject could terminate or postpone the warning stimulus. This step, and later observation of extinction demonstrated that the clicking noise itself was not aversive.

Pavlovian pretraining. In Session 2, the lever was absent and each subject received 25 pairings of the warning stimulus and shock. The warning stimulus duration was 5 sec and the intertrial interval was 20 sec. This procedure was intended to establish the warning signal as a conditioned aversive stimulus and to make the subsequent course of avoidance training more uniform (Zielinski and Soltysik, 1964).

Avoidance training. In the third session the lever was present and all contingencies for free operant discriminated avoidance were in effect. The safe stimulus duration was 20 sec, the warning stimulus duration 5 sec, the response-shock interval, therefore, 25 sec, and the shock-shock interval 25 sec. Successive approximations to lever-pressing were differentially reinforced by termination or postponement of the warning stimulus.

The study proper. Each monkey was exposed to three series of five safe stimulus durations, each series being defined by a constant warning stimulus duration. Within each series, safe stimulus values of 2, 5, 10, 20, and 40 sec were randomly assigned, except at the beginning of the study when all of the subjects were assigned the identical schedule (see *avoidance training* above). Monkeys Rh-41 and Rh-44 were assigned the warning stimulus values in the order 5, 20, 2 sec, and Monkeys Rh-42 and Rh-47 in the order 5, 2, 20 sec. At the end of each series one of the safe stimulus durations was repeated in order to evaluate recoverability of data points.

Experimental time was allotted to the schedules in the following manner: within a series at constant warning stimulus duration, when only the safe stimulus duration was changed, each subject was exposed to each schedule for at least eight consecutive 2-hr sessions, of

which the last six (the criterion sessions) furnished the data used in the final analysis. The criterion sessions were presumed to sample steady state behavior. Whenever the warning stimulus duration was changed, a transition period was considered to be in effect at least until the first session in which the animal received a shock under the new warning stimulus duration. The occurrence of the shock indicated that the animal had experienced the entire length of the new warning stimulus duration. The next session was then considered the first criterion session unless a trend was evident in the data.

RESULTS

Response Rate

Rate of responding is shown for the four subjects as a function of warning stimulus duration with the safe stimulus duration as the parameter in Fig. 1. The duration of the warning stimulus exerted an appreciable effect principally at the shorter durations of the safe stimulus. The effect was greatest with the 2-sec safe stimulus. In general, the overall re-

sponse rate either decreased or remained unchanged as the duration of the warning stimulus increased. Only Monkey Rh-47 showed some statistically reliable exceptions. At safe stimulus durations of 2, 5, and 20 sec, response rate at the 20-sec warning stimulus duration was greater than at the 5-sec warning stimulus duration. This result may be attributed to the order in which durations of the warning stimulus were scheduled (see below).

The effect of safe stimulus duration upon response rate at each warning stimulus duration can be obtained for individual subjects from Fig. 1. Mean data based on all four subjects are presented in Fig. 2. For all subjects, response rate was a decreasing monotonic negatively accelerated function of safe stimulus duration. The functions were initially steeper at the 2-sec warning stimulus duration and decreased in steepness as the duration of the warning stimulus increased. At safe stimulus durations from 10 sec to 40 sec (the longest duration studied), warning stimulus duration had no further effect upon the group mean rate. At a given warning stimulus duration and for all subjects, response rates for each session at each value of the safe stimulus showed no overlap with the rates for individual sessions at other safe stimulus values.

Data from the second (recovery) determination of various combinations of safe and warn-

Fig. 1. Rate of avoidance responding as a function of warning stimulus duration for four monkeys. The parameter is duration of the safe stimulus (response-warning stimulus interval). Each point represents the mean of six criterion sessions.

Fig. 2. Rate of avoidance responding as a function of safe stimulus duration (response-warning stimulus interval). The parameter is warning stimulus duration. Each point combines data from six criterion sessions for each of four rhesus monkeys. At the 10-, 20-, and 40-sec safe stimulus durations, the data points are displaced horizontally to avoid overlap. The heavy line was used where the three curves were virtually superimposed.

ing stimulus durations have not been entered in Fig. 1 and 2. These data showed no irreversible effects upon the overall response rate due to exposure to any of the safe stimulus durations.

All of the reported findings relating response rate to the two temporal parameters of safe stimulus duration and warning stimulus duration were supported by analyses of variance and Duncan's Multiple Range Test, given in full detail elsewhere (Hyman, 1966).

The present procedure permitted examination of the relationship between response rate and the response-shock interval. Recalling that the response-shock interval is the sum of the durations of the safe stimulus (response-warning stimulus or RS₁ interval) and the warning stimulus (warning stimulus-shock or S₁S₂ in-

terval), it is apparent from Fig. 1 that equal response-shock intervals did not result in equal response rates. For example, consider Monkey Rh-47 at safe and warning stimulus durations of 5 and 20 sec respectively, and at 20 and 5 sec respectively. The corresponding response rates were approximately 10 and 3 responses per minute, although the response-shock intervals were equal. On the other hand, for the relatively long values of the safe stimulus, the duration of the safe stimulus alone determined response rate. As noted above, at shorter safe stimulus durations there was an interaction with warning stimulus duration.

Temporal Distribution of Responses

Figure 3 presents representative distributions of interresponse times for one subject.

Fig. 3. Distributions of interresponse times for the last criterion session at selected safe and warning stimulus durations. The dark bars indicate responses during the warning stimulus, the open bars responding during the safe stimulus. In the lower left and lower center distributions, the safe stimulus duration is divided into 5-sec class intervals, while the warning stimulus duration appears in 1-sec class intervals. All other class intervals are 1 sec.

The distributions are arranged so that for each vertical pair, the response-shock intervals are equal. From such comparisons it is clear that the gross temporal distribution of responding was determined principally by the duration of the safe stimulus. For all values of safe and warning stimulus duration, responses were concentrated in the warning stimulus.

Responding during the safe stimulus was relatively infrequent. For example, over the range of safe stimulus durations studied, the mean percentage of responses which occurred in the 5-sec warning stimulus varied from 79% to 90% in Rh-41, 77% to 86% in Rh-42, 55% to 76% in Rh-44, and 88% to 97% in Rh-47. These figures are comparable to those reported for rats (Sidman, 1955). More detailed analysis (Hyman, 1966) indicated that responding during the safe stimulus appeared unrelated to either safe or warning stimulus duration. Exceptions occurred at combinations of short (2- or 5-sec) safe stimulus and short (2-sec) warning stimulus durations where

there was generated more frequent responding during the safe stimulus by Monkeys Rh-41 and Rh-42. The percentage of responding during the warning stimulus fell to approximately 48% and 60% for Rh-41 and Rh-42, respectively. The effect is seen in the increased steepness of the curves in Fig. 1 at safe stimulus durations of 2 and 5 sec for Rh-41 and 2 sec for Rh-42.

Latency of Responses in the Warning Stimulus

Mean latency is shown as a function of warning stimulus duration with safe stimulus duration as the parameter in Fig. 4. The curves were drawn on separate axes for clarity since there was considerable overlapping of data points. For Monkey Rh-41, data points for the 20-sec warning stimulus at safe stimulus durations of 10 sec and 40 sec are probably artificially low due to an apparatus problem.

For Monkeys Rh-41 and Rh-44, which were studied at warning stimulus durations in the

Fig. 4. Latency of avoidance responding in the presence of the warning stimulus as a function of warning stimulus duration for four monkeys. Each point represents the mean of six criterion sessions. The parameter is safe stimulus duration.

order 5, 20, and 2 sec, latency was a monotonic increasing function of warning stimulus duration for all but the longest (40-sec) duration of the safe stimulus. For Monkeys Rh-42 and Rh-47, studied at warning stimulus durations in the order 5, 2, and 20 sec, latency in the 20-sec warning stimulus was more nearly equal to or *less than* that in the 5-sec warning stimulus.

These and other experiments point to an order effect in the measurement of latency of responding in the warning stimulus. Once responding was established at the 2-sec warning stimulus duration, latencies obtained subsequently at the 20-sec warning stimulus were consistently less than those obtained if the measurements at 20 sec were obtained first. Latencies in the 20-sec warning stimulus were not recoverable when exposure to shorter warning stimuli intervened.

An effect of safe stimulus duration on latency in the warning stimulus can be assessed from inspection of Fig. 4. Latency in the 20-sec warning stimulus was a generally decreasing function of safe stimulus duration for Rh-41 and Rh-44. The effect was apparently overshadowed by the order effect in Rh-42 and Rh-47. Latency in the shorter (2- and 5-sec) warning stimuli appeared unrelated to safe stimulus duration. All of the latency effects were ascertained by the use of analyses of variance and range tests (Hyman, 1966).

Shock Rate

Shock rate was low and not systematically related to the safe stimulus or warning stimulus duration. The modal number of shocks received per session was zero. Mean shock rate, calculated for the six criterion sessions at each schedule, ranged from 0.02 to 0.25 shocks per hour.

DISCUSSION

Rate of responding was a decreasing, negatively accelerated function of safe stimulus duration (response-warning stimulus interval) as a consequence of the occurrence of responses predominantly in the presence of the warning stimulus. Responding during the safe stimulus contributed only slightly to overall response rate. The function relating response rate and safe stimulus duration is similar in shape to that reported by Clark and Hull

(1966) for rate as a function of equal response-shock and shock-shock intervals in free operant nondiscriminated avoidance.

Rate was also affected by warning signal duration, due to latency changes associated with changes in warning signal duration. In free operant discriminated avoidance, latency and response rate are inversely related, since longer latencies produce longer interresponse times. However, the effect of warning stimulus duration on rate was confined to the shorter safe signal durations, particularly to the 2-sec duration (Fig. 1) because latency changes were proportionally larger relative to safe stimulus duration at short safe stimulus durations, and because absolute changes in latency were small throughout the study. Furthermore, as previously stated, latencies under the 20-sec warning stimulus, for Monkeys Rh-42 and Rh-47, were shortened as a result of the order in which warning stimulus durations were scheduled.

Designation of the warning stimulus solely as a secondary negative reinforcer or conditioned aversive stimulus is giving way to assigning multiple functions to the stimulus (Sidman, 1957; Sidman and Boren, 1957; Ulrich *et al.*, 1964). The present results support interpretation of the warning stimulus as discriminative. Aversive properties of the stimulus were not unequivocally demonstrated. If the warning stimulus had been a conditioned aversive stimulus, substantial responding in the safe stimulus should have been observed. This did not seem to be the case. Even when responses did occur in the safe stimulus, thus postponing or avoiding the warning stimulus, it was not possible to conclude that the warning stimulus had secondary aversive properties, because avoidance of the warning stimulus was not independent of shock avoidance.

Those cases in Fig. 4 in which latency varied directly with warning stimulus duration are consonant with the results of studies of discrete trial discriminated avoidance conditioning (*e.g.*, Brush, Brush, and Solomon, 1955). Reversals on this relationship seen with Monkey Rh-47 and, to a lesser extent, with Rh-42, arose presumably because the animals were studied at the 2-sec warning stimulus before the 20-sec warning stimulus. Transition to the 2-sec warning stimulus condition, whether from the 5-sec or 20-sec warning stimulus, re-

sulted in comparatively more shocks before asymptotic performance was reached, than did transition to the other durations. Thus, it may be supposed that onset of the 2-sec warning stimulus controlled stronger conditional aversive temporal stimuli (Anger, 1963), and the persistence of very short latencies after the warning stimulus duration was increased to 20 sec suggested that the procedure did not permit enough exposure to the longer warning stimulus duration to weaken aversive control by stimulus onset.

An unexpected finding concerning latency was its modification by safe stimulus duration. For Monkeys Rh-41 and Rh-44 at the 20-sec warning stimulus duration, there existed an inverse relationship between latency and safe stimulus duration (Fig. 4). It is possible that the high response rates induced by short durations of the safe stimulus were accompanied by aversive consequences such as muscle fatigue. The reinforcement gained by responding at a lower rate (longer latency) would then offset the aversive stimulation which resulted when the animal permitted the warning stimulus to remain on for a longer period of time. This modification of latency was not seen in Monkeys Rh-42 and Rh-47 due probably to the order effect which led to shortened latencies. Apparently, the contingencies which shaped short latencies in these two animals were predominant over the contingencies which might have led to longer latencies.

Shock rate did not appear to be a function of either of the parameters investigated. This finding is contrary to that of Sidman (1953), Sidman *et al.* (1962, Exp. I), and Clark and Hull (1966) who reported that shock rate was a function of the response-shock interval. However, these studies employed nondiscriminated avoidance, and the difference in the type of schedule is probably responsible for the discrepant results. It has been demonstrated that the addition of a warning stimulus to a nondiscriminated free operant avoidance schedule lowers shock rate (Sidman, 1955; Sidman *et al.*, 1962, Exp. II; Ulrich *et al.*, 1964). The data from rhesus monkeys (Sidman *et al.*, 1962) showed the greatest reduction in shock rate and suggest a phylogenetic superiority of primates in avoidance situations of the type studied. Since response rates of the rhesus monkeys in the present study and in

that of Sidman *et al.* were of the same order of magnitude as those of rats at comparable safe stimulus and warning stimulus durations (*e.g.*, Sidman, 1955; Stretch and Skinner, 1967; Ulrich *et al.*, 1964), the low shock rates of primate subjects are the more noteworthy.

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.
- Behrend, Erika and Bitterman, M. E. Sidman avoidance in the fish. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 47-52.
- Brush, F. R., Brush, Elinor S., and Solomon, R. L. Traumatic avoidance learning: the effects of CS-US interval with a delayed-conditioning procedure. *Journal of Comparative and Physiological Psychology*, 1955, 48, 285-293.
- Clark, F. C. and Hull, L. D. Free operant avoidance as a function of the response-shock = shock-shock interval. *Journal of the Experimental Analysis of Behavior*, 1966, 9, 641-647.
- Graf, V. and Bitterman, M. E. General activity as instrumental: application to avoidance training. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 301-305.
- Hyman, A. *Two temporal parameters of free operant discriminated avoidance behavior in the rhesus monkey*. Unpublished doctoral dissertation, University of Cincinnati, 1966.
- Keehn, J. D. The effect of a warning signal on unrestricted avoidance behavior. *British Journal of Psychology*, 1959, 50, 125-135.
- Malis, J. L. and Curran, C. S. A reliable low-cost generator for audio stimuli. *Journal of the Experimental Analysis of Behavior*, 1960, 3, 200.
- Sidman, M. Two temporal parameters of the maintenance of avoidance behavior in the white rat. *Journal of Comparative and Physiological Psychology*, 1953, 46, 253-261.
- Sidman, M. Some properties of the warning stimulus in avoidance behavior. *Journal of Comparative and Physiological Psychology*, 1955, 48, 444-450.
- Sidman, M. Conditioned reinforcing and aversive stimuli in an avoidance situation. *Transactions of the New York Academy of Sciences*, 1957, Ser. II, 19, 534-544.
- Sidman, M. and Boren, J. J. A comparison of two types of warning stimulus in an avoidance situation. *Journal of Comparative and Physiological Psychology*, 1957, 50, 282-287.
- Sidman, M., Mason, J. W., Brady, J. V., and Thach, J. Quantitative relations between avoidance behavior and pituitary-adrenal cortical activity. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 353-362.
- Stretch, R. and Skinner, N. Methylphenidate and stimulus control of avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 485-493.
- Thompson, R. L., Birch, J. D., and Hyman, A. Temporal and shock intensity parameters of free operant

- discriminated avoidance behavior. *American Psychologist*, 1964, 19, 520 (abstract).
- Ulrich, R. E., Holz, W. C., and Azrin, N. H. Stimulus control of avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 129-133.
- Weiss, B. and Laties, V. G. A foot electrode for monkeys. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 535-536.
- Zielinski, K. and Soltysik, S. The effect of pretraining on the acquisition and extinction of avoidance reflex. *Acta Biologiae Experimentalis*, 1964, 24, 73-78.

Received 7 August 1967.