*RESPONSE PATTERNING ON AN
AVOIDANCE SCHEDULE AS A FUNCTION
OF TIME-CORRELATED STIMULI¹*

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Control of avoidance response patterning by time-correlated stimuli was studied in rhesus monkeys. At several shock-shock = response-shock intervals, the intervals were divided into 8, 4, or 2 time segments by correlating, respectively, 1, 2, or 4 discrete lights of an eight-light display with each successive segment. A further condition examined response patterning when the avoidance interval was not segmented: all eight lights of the display were lit throughout the interval. Reversal of the order in which the lights were lit in sequence was also examined. Generally, increasing the number of lights lit at one time (decreasing the number of signalled time segments) increased response rates and shifted interresponse time distributions to the left. When the lights were lit one at a time, signalling eight discrete time segments of the interval, response rates were consistently low.

Investigators have demonstrated that the introduction of stimuli correlated with response and/or temporal requirements of reinforcement schedules generally modifies the pattern of responding generated by schedules alone. Post-reinforcement pauses lengthen and running rates increase when an added 'clock' is correlated with a fixed-interval schedule (Ferster and Skinner, 1957). Post-reinforcement pauses shorten and fewer rate irregularities appear when an added counter is correlated with a fixed-ratio schedule (Ferster and Skinner, 1957). Stimuli correlated with schedule parameters facilitate free operant avoidance acquisition (Powell and Morris, 1968). The major effect of schedule-correlated stimuli (or "pre-shock" stimulus) on stable avoidance responding is to decrease overall rate (Sidman, 1953; Behrend and Bitterman, 1963; Hyman, 1969). The decrement in overall rate is the result of increased response frequency in the presence of the correlated stimulus and decreased response frequency in its absence (Sidman, 1953; Ulrich, Holz, and Azrin, 1964). The magnitude of rate decrease and change of response patterning depends on the duration of the correlated stimulus in relation to the response-shock (RS) interval (Ulrich, *et al.*, 1964). Extension of the schedule-correlated stimulus to include

the total RS interval has effects similar to stimulus omission (Ulrich, *et al.*, 1964). Response rates, response patterning, and shock frequency in the avoidance situation vary substantially between animals and across species when schedule correlated stimuli are omitted (Thompson and Grabowski, *in press*).

Schedule-correlated stimuli have generally been referred to as added stimuli when used with food-maintained operants (Ferster and Skinner, 1957), while schedule-correlated stimuli in the avoidance situation have acquired the label "warning stimulus" when correlated with impending shock and "safe stimulus" when they follow a response that precludes shock for some finite period. While the terms "safe" and "warning" may have some descriptive value, it is the discriminative or reinforcing function of stimuli that is of interest. The presentation of a single stimulus correlated with impending but unavoidable shock (Ulrich, *et al.*, 1964), or two stimuli that divide the RS interval (Hyman, 1969) clearly indicate the development of stimulus control. However, the use of a one- or two-component stimulus does not permit detailed study of the properties of the stimuli. A previous investigation (Grabowski and Thompson, 1969) demonstrated that when a sequence of stimuli correlated with successive equal segments of the RS interval are presented, response patterning of rhesus monkeys is unlike that found by Ulrich, *et al.*, (1964) with rats using a single "pre-shock" stimulus or by Hyman (1969) with

¹This research was supported in part by grant MH 15349. The research described is derived from the senior author's doctoral dissertation. Reprints may be obtained from J. Grabowski, School of Medicine, University of Southern California, Los Angeles, Calif. 90033.

monkeys using two stimuli dividing the interval. A sequence of stimuli permits a detailed study of the functional properties of each stimulus in the sequence in terms of the cumulative frequency of responding in each stimulus and its correlated segment of the RS interval. The present study sought to delineate further the discriminative and/or reinforcing properties of the stimuli in such a sequence.

METHOD

Subjects

Three male rhesus monkeys, approximately 3 yr old and weighing approximately 5 kg each, served.

Apparatus

The animals were maintained in transparent Lucite primate restraining cockpits in sound-attenuating chambers. Food and water were available on a continuous reinforcement schedule from dispensers operated by chain-pull manipulanda, except during avoidance sessions. During acquisition, the avoidance lever was a T-shaped Lucite bar 12 in. (30.5 cm) across at waist level in front of the animal. After acquisition, this was replaced with a triangular piece of Lucite 1 in. (2.54 cm) per side. Each closure of the avoidance lever micro-switch required 210 g (2.059N) and produced a capacitor discharge through a speaker in the chamber (providing an auditory feedback stimulus), reset the shock-shock-response-shock (SS = RS) timer, reset the stimulus sequence to the first position, and provided input to the recording devices.

Stimuli used in the sequence were mounted on a brown Masonite panel and initially consisted of ten 28-v, 1.1-w translucent white panel lights aligned vertically in front of the animal at face level. To facilitate binary scheduling, the number of lights was subsequently reduced to eight.

Electric shock was delivered through 0.75-in. (0.6-cm) diameter parallel stainless steel bars comprising the seat of the restraining chairs. Shock of 2400 v ac with 0.1-msec 6-mA spikes was generated by a high impedance shock source through 400,000 ohms resistance.

Data were recorded with electromechanical counters and cumulative recorders. Transistor-

ized Massey Dickinson equipment located in an adjacent room was used for scheduling.

Procedure

Each animal was trained to emit the avoidance response through successive approximations. After the avoidance response was acquired a single 1-hr session per day was arranged until approximately 95% of scheduled shocks were being avoided. Then, three 1-hr sessions per day were arranged for the duration of the investigation. The larger lever, which facilitated training but permitted excessive twisting force, was replaced with the smaller lever at this time. Sessions were separated by 1 hr, with 19 hr between the last session of one day and the first session of the subsequent day.

The baseline condition, which was also in effect during acquisition, consisted of presenting the stimulus lights sequentially with offset of each light coincident with onset of the next light. The number of stimulus lights was reduced to eight after Subject 0-2 acquired avoidance responding. The experimental manipulations consisted of presenting the lights in blocks of one light at a time (baseline), two lights, four lights, and eight lights. In each condition, the duration in seconds of each segment of the interval, correlated with each block of lights, equalled $\frac{1}{8}$ (baseline), $\frac{1}{4}$, $\frac{1}{2}$, or $\frac{3}{4}$ of the avoidance interval. During added stimulus manipulations, light duration was a function of the added stimulus condition and avoidance interval length. The condition in which all eight lights were on at once was similar to the basic free operant procedure, since no stimulus changes occurred during the shock-shock = response-shock (SS = RS) interval, except that in this condition as in the other conditions, the lights terminated immediately before the onset of shock.

The basic free operant avoidance paradigm was used in which shocks were presented at regular intervals unless postponed by a response. Each response postponed shock for a finite period and in the present case the shock-shock and response-shock intervals were equal. Avoidance intervals studied were SS = RS = 8, 10, 16, and 32 sec. Added stimulus conditions were changed after development of stable performance, which was defined as $\pm 5\%$ of the mean response total of the third session for three consecutive days.

Fig. 1. Interresponse time distributions of performance by Monkey 0-2 during avoidance acquisition with SS = RS = 10-sec interval and correlated sequential stimuli.

RESULTS

Transitions

The course of acquisition was similar for all animals. Acquisition data for Subject 0-2 with SS = RS = 10 sec (10 lights, one light per 1-sec segment) show the development of response patterning correlated with the stimulus sequence. Three distinguishable, though continuous phases occurred (Figure 1). Early in acquisition (Day 1), animals avoided approximately 60% of the total possible shocks and the mean response rate was seven responses per minute. The mode of the corresponding interresponse time (IRT) distribution was at the shortest IRT, with rapidly decreasing frequencies at longer IRTs. In the second phase, response rate increased to a mean of 12 responses per minute and the per cent of avoided shocks increased to 96%. The resultant IRT frequency distribution is bimodal. One mode appears at the shortest IRT bin and is due to

spaced high-rate sequences. Developing stimulus control is suggested by increased response frequency at long IRTs. Terminal baseline performance consisted of a mean rate of 10 responses per minute and the per cent of shocks avoided increased to 99.8%. The corresponding IRT frequency distribution shows low response frequency during the first half of the avoidance interval followed by a rapid increase to the modal IRT.

Subsequently, when longer SS = RS intervals were introduced, similar transitions occurred in the IRT distributions, except that shock frequency did not increase. Response rate decreased in the baseline stimulus condition when longer SS = RS intervals were instated.

Stimulus Manipulations

(1) SS = RS = 8 sec. All three animals exhibited stable baseline performance with the SS = RS = 8-sec avoidance interval. The effi-

Fig. 2. Interresponse time distributions of stable baseline avoidance performance for Monkeys 0-2, 0-4, and 0-5 with SS = RS = 8-sec interval and correlated sequential stimuli.

ciency of stable performance, in terms of the ratio of responses emitted to responses required, varied, with Subject 0-2 exhibiting the most, and 0-4 the least efficient baseline performance. (Efficiency is defined as the number of responses emitted divided by the number of responses required to avoid those shocks that were successfully avoided). Few high-rate response sequences (bursts) were emitted by any of the animals when stable baseline performance was achieved (high-rate response sequences contribute to the shortest IRT frequency), (see Figure 2).

After stable baseline performance was established at SS = RS = 8 sec (one light on in each 1-sec segment) the size of the stimulus block and the correlated number of segments of the

interval were manipulated. A sequence of decreasing number of segments (increasing block size) and then the baseline condition was scheduled for Subjects 0-2 and 0-5 followed by a sequence of increasing number of segments (decreasing block size). At SS = RS = 8 sec, only a sequence of increasing number of segments was scheduled for 0-4. Descriptions of the experimental conditions and the order in which they occurred are presented in Table 1.

Successive IRT frequency distributions show changes in temporal patterning as a function of decreasing the number of segments in the interval (increasing stimulus block size) for 0-2 and 0-5 (Figure 3). Each increase in the size of the stimulus block increased overall rate, as shown in the cumulative records of 0-2's per-

Table 1

Number of interval segments, stimulus conditions, avoidance interval durations, and number of sessions for each animal.

	<i>Interval Segments</i>	<i>Lights/Block</i>	<i>Sec/Segment</i>	<i>SS = RS</i>	<i>Sessions</i>
<i>0-2</i>					
1. Acquisition	10	1	1	10	33
2. Baseline	8	1	1	8	30
3. Decreasing*	4	2	2	8	15
	2	4	4	8	24
	1	8	8	8	27
4. Baseline	8	1	1	8	30
5. Increasing*	1	8	8	8	18
	2	4	4	8	27
	4	2	2	8	24
6. Baseline	8	1	1	8	18
7. Baseline	8	1	2	16	48
8. Increasing*	1	8	16	16	27
	2	4	8	16	18
	4	2	4	16	21
9. Baseline	8	1	2	16	15
<i>0-4</i>					
1. Acquisition	8	1	1	8	75
2. Baseline	8	1	1	8	
3. Increasing*	1	8	8	8	
	2	4	4	8	
	4	2	2	8	15
4. Baseline	8	1	1	8	18
5. Baseline	8	1	4	32	69
6. Decreasing*	4	2	8	32	24
	2	4	16	32	15
	1	8	32	32	12
7. Baseline	8	1	4	32	15
8. Ext. I	8	1	4	[NO SHOCK]	42
9. Ext. II	8	1	4		48
10. Baseline	8	1	4		33
11. Reversal I	8	1	4		24
12. Reversal II	8	1	4	32	15
13. Baseline	8	1	4	32	
<i>0-5</i>					
1. Acquisition	8	1	1	8	87
2. Baseline	8	1	1	8	
3. Decreasing*	4	2	2	8	
	2	4	4	8	
	1	8	8	8	24
4. Baseline	8	1	1	8	18
5. Increasing*	1	8	8	8	15
	2	4	4	8	33
	4	2	2	8	21
6. Baseline	8	1	1	8	15

*"Increasing" and "Decreasing" refer to the number of segments into which the interval was divided by blocks of lights.

formance (Figure 4). Reinstatement of the baseline condition generated response rates and patterning equivalent to the baseline performance preceding the manipulations.

(2) $SS = RS = 16, 32$ sec. Following transition to stable performance at longer avoidance intervals, stimulus sequences were scheduled with decreasing and increasing block size for

Subjects 0-2 ($SS = RS = 16$ sec) and 0-4 ($SS = RS = 32$ sec), respectively (Figure 5). Subject 0-4's performance in each condition indicated a high degree of stimulus control. In every case, the highest IRT frequency occurred in the IRT interval after onset of the last stimulus before shock, *i.e.*, the last segment of the interval.

Fig. 3. Interresponse time distributions of avoidance performance by Monkeys 0-2 and 0-5 with SS = RS = 8-sec interval under each of the stimulus conditions; (a) eight segments, 1-sec/light, sequential stimuli; (b) four segments, 2-sec/2-light block, sequential stimuli; (c) two segments, 4-sec/4-light block, sequential stimuli; (d) one segment, 8-sec/8-light block, sequential stimuli; (e) eight segments, 1-sec/light, sequential stimuli. Distributions were derived from performance during last 1-hr session under each condition.

(3) *Stimulus reversal.* Stimulus reversal consisted of presenting the stimuli in the reverse order to which the animal had been previously exposed. The stimulus lights were normally presented from the top to the bottom of the panel. Reversing the order involved presenting the bottom stimulus at the beginning of the avoidance interval. Reversal of the order was scheduled for Subject 0-4 with SS = RS = 32 sec. Onset of the stimulus light that previously had immediately followed a response or shock, and was temporally most remote from subsequent shocks, became the light that preceded shock. The stimulus light that had previously preceded shock, and during which response frequency had been highest, was similarly reversed in temporal relation to shock.

Reversing the order of the stimuli produced an immediate increase in overall rate. Responding occurred with highest frequency at the shortest IRT and the configuration of the frequency distribution was reversed (Figure 6). The high overall rates decreased and efficient temporal patterning reappeared rapidly. Rein-

statement of the original stimulus order produced greater initial disruption, as indicated by higher response rates, than the first reversal, but return of stable performance was more rapid than it had been following the initial reversal.

DISCUSSION

Transition periods, including those during acquisition and after changes of temporal parameters and stimulus conditions, were similar. There were (1) initial periods of frequent short IRTs followed by (2) a period of frequent short IRTs and IRTs of the subsequently highest frequency duration, producing bimodal frequency distributions, and then (3) stable performance generating a frequency distribution with a single mode at a long IRT. The apparent exception to this sequence occurred when the condition in which all eight lights were on at once was instated. The absence of stimulus changes during the interval generated high rates. The transition phases

Fig. 4. Selected cumulative records of avoidance performance by Monkey 0-2 with $SS = RS = 8$ -sec interval under each of the stimulus conditions.

appeared but since the highest-frequency IRT during stable performance under this condition was also a relatively short IRT, the changes were less evident. The high rates that followed each new change in stimulus conditions did decrease over extended exposure to the new condition. Sidman (1958) noted that high-rate response sequences that began with onset of the warning stimulus and continued after termination of the warning stimulus decreased in frequency as stable avoidance performance developed. In the present study, there was a progressive decrease in the frequency of high-rate response sequences that followed emission of the response required to reset the avoidance interval and also in response bursts that followed shocks. In acquisition, shocks were invariably followed by periods of high response rate. It is evident that

the effects of time-correlated stimuli and of shock both change through continued exposure to the situation.

The extent of stimulus control in the present situation can be determined only by manipulations of the stimuli. The fact that, regardless of the inefficiency of performance in the baseline condition, changes occurred in IRT distributions and session response totals following each new stimulus condition indicates stimulus control.

The most efficient baseline performance would have appeared as responding only at the longest IRT and hence with onset of the last stimulus light. However, for each animal the modal baseline IRT frequency when $SS = RS = 8$ sec was the seventh rather than the eighth (or last) IRT. These data indicate that with these temporal parameters and stimulus condi-

Fig. 5. Interresponse time distributions of avoidance performance by Monkey 0-2 with SS = RS = 16-sec interval and Monkey 0-4 with SS = RS = 32-sec interval. The order of stimulus conditions for 0-2 was (a) eight segments, 2-sec/light; (b) one segment, 16 sec/8-light block; (c) two segments, 8-sec/4-light block; (d) four segments, 4-sec/2-light block, and (e) eight segments, 2-sec/light. The order of stimulus conditions for 0-5 was (a) eight segments, 4-sec/light; (b) four segments, 8-sec/2-light block; (c) two segments, 16-sec/4-light block; (d) one segment, 32-sec/8-light block, and (e) eight segments, 4 sec/light. Distributions were derived from performance during last 1-hr session under each condition.

tions the last light in the sequence developed negative reinforcing properties and/or was inadequate as a discriminative stimulus. This stimulus light was avoided, perhaps because of previous pairings with shock that resulted from the precise discrimination required to respond in this 1-sec interval. It is possible that in the present case, the animal was unable to respond reliably with sufficient rapidity. Given a short RS interval, patterning of responding may appear that is a function of the schedule's temporal parameters and is unrelated to any temporal discrimination. For example, during the present investigation Subject 0-5 was exposed briefly to SS = RS = 4 sec. With these contingencies, no responses occurred at the shortest or longest IRTs and the highest response frequencies were at the intermediate IRTs. When the SS = RS = 8-sec contingency was reinstated, responding reappeared at the shorter IRT. Therefore, patterning of responses *per se* may occur as a function of factors other than stimulus control or temporal discrimination.

Comparison of 0-4's baseline performance at SS = RS = 8 sec (Figure 2) and at SS = RS = 32 sec (Figure 6) clarifies the relationship between duration of the last stimulus segment, response frequency in the segment, and the discriminative or reinforcing properties of the segment. Response patterning in the base-line condition at SS = RS = 32 sec was such that the highest response frequency was at the longest IRT (*i.e.*, in the last light). At SS = RS = 32 sec, each light in the baseline condition was presented for 4 sec and this apparently provided sufficient opportunity to respond successfully (*i.e.*, avoid shock).

The stimulus manipulation that suggests discriminative properties of the eighth light (longest IRT) was stimulus reversal. Extremely high-rate responding followed this manipulation. During stimulus reversal, each response reset the stimulus sequence to the light that had previously been the strongest discriminative stimulus for responding. This produced another response and reset the stimulus and the cycle repeated. Before reversal, the ani-

Fig. 6. Interresponse time distributions of avoidance performance by Monkey 0-4 with SS = RS = 32 sec and correlated sequential stimuli; in upper series, (a) baseline performance, (b) Session 1 following stimulus reversal, (c) Session 12 following reversal, (d) Session 18 following reversal, (e) Session 24, return to stable performance following reversal; in lower series (a) baseline performance before second reversal (return to original order of stimuli), (b, c, d, e) Sessions 1, 9, 12, and 15 following second stimulus reversal.

mal's highest response frequency was at the longest IRT.

Similar effects of stimulus reversal have been demonstrated using a continuous (rather than discrete-component) added "clock" with food-maintained fixed-interval schedules (Ferster and Skinner, 1957). The immediate performance change generated by reversal in the fixed-interval case appeared in the cumulative records as inversion of fixed-interval scallops, while in the avoidance case, high rate and irregular pausing followed reversal. These differences are attributable to differences in schedule contingencies. However, comparison between different phases of performance following reversal shows transition performance in both cases resembling the acquisition performance with the respective schedules. The cumulative records of fixed-interval performance presented by Ferster and Skinner (1957) show a period of intermediate rate followed by development of schedule control in the form of post-reinforcement pauses. In the present case, the transition appeared as high rate fol-

lowed by the development of a bimodal IRT frequency distribution. Therefore, reversal appears to be similar to initial introduction of the added "clock". These similarities appear despite the different consequences (food *versus* shock) arranged with the two schedules.

Generally, progressive increases in the number of stimuli presented at one time (correlated with decreases in the number of segments of the interval) increased overall rate and the relative frequency of shorter IRTs. There was variability among animals in the extent of these changes. In general, increased response frequency was correlated with onset of the last stimulus block (the last segment of the interval). Instatement of the eight-light block produced varying degrees of disruption. The data were similar to those resulting from investigations involving increasing the duration of a single discriminative ("warning") stimulus (e.g., Ulrich, *et al.*, 1964).

The increased response rate and increased variability of IRTs with increases in the number of lights presented at one time was not

simply a function of changing stimulus conditions. It was also related to duration of the avoidance interval. The performance of Subject 0-4 at $SS = RS = 32$ sec demonstrated this most clearly. As the size of the stimulus block increased, the response rate and variability of the IRT distributions relative to performance in the baseline condition were related to the greater potential variability permitted by the longer avoidance interval.

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Received 15 July 1971.

(Final acceptance 5 July 1972.)