CONDITIONED SUPPRESSION OR FACILITATION AS A FUNCTION OF THE BEHAVIORAL BASELINE¹

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Rats were exposed to a multiple schedule of reinforcement. During one component, a bar-press was followed by reinforcement only if it occurred between 15 and 20 sec after the previous response. This differential-reinforcement-of-low-rate (DRL) schedule produced a typical slow rate of responding. During the other component, reinforcement followed the first response to be emitted during limited periods of time which occurred at fixed intervals. These fixed-interval schedules with a limited hold produced higher response rates, described as 'interval' or 'ratio-like' behavior. Responding during the DRL component increased in frequency during a tone which ended with an unavoidable shock of low intensity, but decreased during the tone when the shock intensity was raised. The 'interval' and 'ratio-like' responding decreased in frequency during the tone at all shock intensities. Initial acceleration of the DRL responding appeared to be due to adventitious punishment of collateral behavior which was observed between the bar-presses. The more severe conditioned suppression during the fixed-interval components might be the result of the lower probability of reinforcement after any single response.

The behavioral phenomenon known as conditioned suppression was first demonstrated by Estes and Skinner (1941). They maintained bar-pressing by rats by a schedule of food reinforcement. This responding decreased in frequency during a stimulus which ended with an unavoidable shock. This has been confirmed in experiments using different schedules of food or water reinforcement (*e.g.*, Brady, 1955; Lyon, 1964; Lyon and Felton, 1966). However, there are discrepant reports when baseline behavior has been maintained by a schedule which differentially reinforced low rates of responding (DRL). Finocchio (1963) observed that responding accelerated during a pre-shock stimulus, but Leaf and Muller (1964) found no such evidence.

The present experiment was designed to investigate this discrepancy. The effects of a pre-shock stimulus were observed on DRL behavior, as in the experiments by Finocchio and Leaf and Muller. Periods of the DRL schedule alternated with periods of another schedule which produced higher rates of responding. The second schedule was provided so that the effects of the preshock stimulus on DRL re-

sponding could be compared immediately with its effects on a schedule which produced a higher response rate, and one which has consistently been suppressed by the Estes-Skinner procedure.

METHOD

Subjects

Four naive, male, albino rats were maintained at 80% of their free-feeding weights. They were deprived of food for approximately 23 hr before each session. Water was freely available in the living cages but not in the test chamber.

Apparatus

The test chamber was 9¼ by 7½ by 11½ in. The floor consisted of 18 stainless steel rods which formed an electrifiable grid. In one wall was a hopper, to which 45 mg pellets of standard rat food could be delivered automatically. Above the hopper, and about 3¼ in. above the grid floor, a stainless steel lever, 2-in. wide, projected 0.5 in. into the test compartment. The operant response was the depression of the lever by 0.5 in., which required a force of approximately 30 g. Two 10-w lamps were mounted in the same wall, one shielded by red, the other by white glass. Two small loudspeakers were mounted near the pellet dispenser. One was connected to a Grason-

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Stadler E901B white noise generator, the other to an audiofrequency generator and an associated amplifier. A Grason-Stadler E1064 shock generator scrambled polarities of the grid as shock was delivered. The test compartment was in a sound-attenuating and ventilated chest.

The experiment was automated by means of relays, timers, and uniselectors switches. Responses and reinforcements were counted by digital impulse counters and a three-channel printout counter. A cumulative recorder provided a continuous display of bar-pressing behavior.

Procedure

The rats were accustomed to the deprivation conditions until the daily intake of food needed to maintain 80% normal weight was almost constant. They were then adapted to the test chamber for two 1-hr periods involving no experimental contingencies. The rats were then magazine-trained for two 2-hr sessions in which food pellets were delivered at irregular intervals averaging 1 min. Next, the delivery of a food pellet was made contingent upon a bar-press. No shaping procedure was necessary. Two bar-training sessions, each with 100 reinforcements, were given.

A multiple schedule was then introduced. During one component (A), a reinforcement followed any response emitted between 15 sec and 20 sec after the preceding bar-press. Responses which did not meet this timing criterion were not reinforced, and the timers were reset. This component therefore differentially reinforced low rates of responding (DRL). In this experiment, however, reinforcements were available only for 5-sec periods, designated as a limited-hold contingency (LH). The schedule during Component A may therefore be defined as DRL 15-sec LH 5-sec. It was accompanied for Rats 1 to 3 by the red light and masking white noise, and by the white light for Rat 4.

During Component B, the first bar-press was reinforced during limited periods of time, which occurred at fixed intervals (FI). This schedule may be defined as FI LH, in which the fixed interval was timed from the end of the previous fixed interval (see Ferster and Skinner, 1957, p.133). For Rat 1, this schedule was FI 20-sec LH 5-sec; for Rat 2, it was FI 10-sec LH 0.3-sec; for Rats 3 and 4, it was FI

10-sec LH 0.15-sec. (For Rats 2 to 4, these short limited holds were achieved by gradually reducing them from longer time periods; this was done during the first 75 experimental sessions). Component B was accompanied by the white light, with no masking noise, for Rats 1 to 3 and by the red light and masking white noise for Rat 4.

The two components of the multiple schedule alternated for eight 5-min periods in each session. Each period was separated from the next by a 1-min period during which reinforcement was not possible (timeout). During these periods, all lights and auditory stimuli were extinguished. Each session lasted 47 min and each rat was tested at the same time daily. The first 5-min period was alternately Component A and Component B.

After about 100 sessions, Rats 1 to 3 participated in a drug experiment which continued for 45 days (Stretch, Blackman, and Bradley, 1967). After this, they were tested daily for another 15 sessions without drug injections. Rat 4 received no drug treatment.

About 160 days after the experiment began (100 days for Rat 4), a 60 cps tone was introduced for periods of 1 min. The tone was presented 130 sec after the start of the third, fourth, sixth, and seventh 5-min periods of the experimental session. Responses during each 1-min period of tone were counted and the total was divided by the number of responses during the 1 min immediately preceding the tone. This provided a measure of any change in behavior during the tone, and is called a suppression ratio. A suppression ratio of 1.00 would be obtained if the tone produced no measurable effect on behavior, *i.e.*, if the rate of responding during the tone was the same as the rate just before it. A suppression ratio greater than 1.00 would indicate an increase in response rate during the tone, and a ratio smaller than 1.00 would be produced by some degree of response suppression during the tone. Complete suppression (*i.e.*, no responding during the tone) would be indicated by a suppression ratio of 0.

The tone alone was presented for six sessions. After this, Rat 3 was discarded (see Results section).

For Rats 1, 2, and 4, the tone next ended simultaneously with a brief, unavoidable, electric shock. For 20 sessions, the shock was 0.5 ma for 0.2 sec. Following this, 10 consecutive

sessions were given with each of the following shock settings: 1.0 ma/0.2 sec; 1.6 ma/0.2 sec; 2.0 ma/0.2 sec; 3.0 ma/0.2 sec; 3.0 ma/0.5 sec; 4.0 ma/0.5 sec; and 4.0 ma/1.0 sec. Finally, in a number of sessions, the tone was no longer followed by shock.

RESULTS

Figure 1 presents segments of typical cumulative records obtained during the last experimental session before the tone was introduced; the DRL LH schedule produced low stable rates of responding. Such behavior is typical of that under DRL schedules. The cumulative records showed little evidence of the occasional bursts of responding sometimes observed with DRL behavior (*e.g.*, Sidman, 1956). However, other reports support the

present findings (*e.g.* Kelleher, Fry, and Cook, 1959). Table 1 shows the mean response rates and reinforcement frequencies for each rat obtained over the last five sessions before the tone was introduced.

With all four rats, patterns of behavior were characteristic between the bar-presses on Component A. Rat 1 reared to the roof of the chamber, Rats 2 and 3 gnawed the grid floor in a rhythmic fashion, and Rat 4 groomed itself. This finding agrees with Laties, Weiss, Clark, and Reynolds (1965) and may explain the lack of response bursts. Thus, a bar-press, whether followed by reinforcement or not, was the occasion for the beginning of a regular chain of behavior.

Table 1 also shows the mean response rates and reinforcement frequencies obtained on

Fig. 1. Sample segments of cumulative record. These describe the behavioral baseline generated by the multiple schedule. Oblique pips indicate reinforcements. 5 min of DRL (A) are followed by 1-min timeout, and then by 5 min of FI (B). The pen reset at the end of each 5-min period, or after 200 responses.

Table 1

Mean response rates and reinforcement frequencies for each component of the schedule

	RAT	1	2	3	4
COMPONENT A	Responses per min	5.51	4.11	4.19	4.62
	Reinforcements per min	2.35	2.31	2.21	2.45
COMPONENT B	Responses per min	31.55	80.73	125.28	117.12
	Reinforcements per min	3.00	3.15	1.71	1.43

Component B. Rat 1 missed no reinforcements on this component, and its behavior appears typical of that produced by such a fixed-interval schedule. Rats 2, 3, and 4 responded at much higher rates. Many reinforcements were missed because of failure to respond during the very short limited holds. The behavior of Rats 2 to 4 was similar to that produced by conventional variable-ratio schedules (in which the average ratio of responses to reinforcements is specified). This supports the claim made by Schoenfeld, Cumming, and Hearst (1956) that schedules defined by temporal contingencies may produce behavior previously regarded as a function of a ratio requirement.

Responses emitted during the timeout periods were infrequent, revealing that behavior was under the control of the stimuli associated with the two components of the multiple schedule.

Figure 2 shows the mean suppression ratios obtained over the last five sessions at each shock setting. Since the tone was superimposed on each component of the schedule twice in each session, these means were calculated from ten 1-min periods. No data are shown for Rat 3 because the tone alone persistently disrupted Component B behavior. Its suppression ratios for this component varied about 0.05 at this stage of the experiment. Rat 3 was discarded because this unconditioned suppression of responding during the tone might have made it difficult to assess the effects of a conditioning procedure. The DRL LH behavior of Rat 3 was not affected during the tone periods.

Figure 2 shows that the behavior of Rats 1, 2, and 4 was not measurably affected by the tone alone. With the first two shock settings, the low rates of responding maintained by Component A increased during the tone. This is shown by mean suppression ratios greater than 1.00. At these same shock settings, the behavior maintained by Component B was

suppressed during the tone, as is indicated by suppression ratios smaller than 1.00. As the shock intensity was increased, conditioned suppression was observed on both components.

Figure 3 shows representative segments of cumulative records obtained during the tone with selected shock settings. Before shock was introduced, the three rats continued to respond as normal. Responding was more frequent during the tone if it was presented when Component A was in operation, and if the shock was mild (*e.g.*, 0.5 ma/0.2 sec). Visual observation revealed that the chains of behavior, already described as being typical of each animal during Component A, were disrupted or eliminated. The animals appeared to be responding in a more random manner. As the shock became more severe, bar-pressing became less frequent during the tone. The behavioral chains did not reappear during the tone until after shock was discontinued.

During Component B, all three rats showed conditioned suppression at all shock intensities. The bottom records in Fig. 3 (shock setting of 4.0 ma/1.0 sec) show that all responding was eventually suppressed during the tone. Figure 3 also shows that at least one shock setting, Component B responding was completely suppressed during the tone, but Component A bar-pressing was still recorded. This is shown with all three rats in the records illustrating the effects of a 3.0 ma/0.5 sec shock. It suggests that all rats were more affected by a pre-shock stimulus superimposed on Component B than when it was superimposed on Component A. This is also suggested by comparisons of suppression ratios made within subjects in Fig. 2. However, this latter comparison should be interpreted carefully; suppression ratios are a relative measure. With Component A, this measure is crude; the low response counts used as the divisor in calculat-

Fig. 2. Mean suppression ratios obtained throughout the experiment. Component A (DRL) is compared with Component B (FI) at each shock setting. No data are shown for Rat 3, which was discarded (see Results section).

ing suppression ratios could provide only a very coarse interval scale.

Special attention should be paid to the Component B behavior of Rat 1. The schedule was FI 20-sec and no reinforcements were missed before the Estes-Skinner procedure was introduced. The first reinforcement in each Component B period became available 15 sec after that period began. The tone began 130 sec after the start of the 5-min period. So, reinforcements became available 5, 25, and 45 sec after the beginning of the tone. When the shock setting was 0.5 ma/0.2 sec, Rat 1 responded long enough into the period of tone to obtain the first of these reinforcements (*i.e.*, for 25 sec). This was followed by complete suppression until the tone ended and the shock was delivered. When the shock was 1.6 ma/0.2 sec, responding continued only long enough for the first reinforcement to be obtained (*i.e.*, 5 sec). At a shock setting of 3.0 ma/0.5 sec, all responding was suppressed during the tone.

Figure 4 shows the effects of the conditioned suppression procedure on the baseline response rates. The only measures available for this were provided by the counts of responses during the 1-min period immediately before the period of tone. However, these samples appeared typical of the behavior during the entire period when the tone was absent. The data plotted are again the means obtained from the last five sessions at each shock setting. The circled points indicate the intensities at which responding was completely suppressed during the tone. Figure 4 suggests that the rate of responding was not affected by the Estes-Skinner procedure when conditioned suppression during the tone was only partial. When the conditioned suppression became complete, however, the behavioral baselines became suppressed or more variable.

Figure 5 shows the suppression ratios obtained from each rat at the end of the experiment, when shock no longer followed the tone. Each point is the mean suppression ratio of one session. The suppression ratios remained at zero during the first session, but then gradually increased. When the suppression ratios reached 1.00 on both components, testing was discontinued. Each subject responded, in at least one session (Session 2), during the tone in Component A but not during the tone in Component B. With each rat,

Fig. 3. Representative segments of cumulative record. No reinforcements are shown on these records. The pen was deflected down during the period of tone. The number in each section designates the mean suppression ratios obtained at that shock setting (plotted in Fig. 2).

conditioned suppression extinguished faster on Component A than on Component B. Finally, notice that all three rats produced mean suppression ratios greater than 1.00 on Component A before settling at this value. This shows that the extinction process included a transitional stage when responding accelerated during the tone. This is similar to the accelerated responding noticed earlier, when the tone ended with a mild shock.

DISCUSSION

Behavior reinforced with food may accelerate during a stimulus ending with an unavoi-

able shock if the subject has an unextinguished history of avoidance conditioning (e.g., Sidman, 1960). The subjects used by Finocchio (1963) had no such history, yet they showed facilitation of responding in some conditions. The present results indicate that this effect can be reliably replicated. On DRL components, the three rats responded more frequently during the tone if it ended with a mild shock. With the same shock intensity, the response rate of all three rats fell during the same tone when it was superimposed on a schedule generating 'interval' (Rat 1) or 'ratio-like' behavior (Rats 2 and 4). The comparison made possible by the multiple schedule there-

Fig. 4. Effects of the Estes-Skinner procedure on the behavioral baselines. The mean response rates of Rats 1, 2, and 4 are shown for each shock setting. Circled points show that complete suppression of this behavior was observed during the signal which ended with the specified shock.

fore suggests that facilitation may be specific to schedules which differentially reinforce low rates of responding.

Finocchio (1963) found that a more severe shock suppressed DRL responding during his pre-shock stimulus. This too is confirmed by the present results. However, a further observation made by Finocchio has not been investigated directly. He reported that, even with milder shock, DRL responding was suppressed during a pre-shock stimulus shorter than that which had produced acceleration. The reason for this has not been elucidated by the present experiment, but the work of Stein, Sidman, and Brady (1958) indicated that the degree of suppression varies with the relative duration of the pre-shock stimulus. If this is high, little conditioned suppression is observed. Finocchio noticed acceleration of DRL responding during a relatively long pre-shock stimulus. Such a stimulus would be likely to produce less suppression than the longer one in any case. The amount of conditioned suppression is a positive function of shock intensity (Anau and Kamin, 1961; also, Component B behavior in this experiment). In the present experiment, mild shocks, which might have been expected to produce slight conditioned suppression, produced acceleration. It seems that DRL responding will accelerate if the conditions are those which produce mild suppression with other schedules. This suggestion is supported by the transitional acceleration of DRL responding observed during the tone when its effects had almost extinguished. Leaf and Muller's data (1964) were obtained in conditions which favored suppression. Their pre-shock stimulus was relatively short. Their

Fig. 5. Extinction of conditioned suppression. The periods of tone no longer ended with shock. The points plotted are the means of each session, i.e., of two trials on each component.

shock intensity is not specified, but was probably quite high, for responding was considerably disrupted after the shock when it was first introduced (see their Fig. 1, Session 48). This may be why they did not observe acceleration of DRL responding.

The question remains: why does DRL responding accelerate during a pre-shock stimulus? Perhaps it is the timing process generated by these schedules and not the recorded response which is disrupted. Migler and Brady (1964) considered this possibility. They performed an experiment in which two responses were used. On the average, every second response on key B was followed by reinforcement if a minimum specified interval had elapsed since a preceding response on key A. The Estes-Skinner procedure was then introduced. There was a marked decrease in the frequency of A-to-B response sequences during the pre-shock stimulus, but the time between A and B responses did not change appreciably. Migler and Brady concluded that the effect of the Estes-Skinner procedure on timing behavior was related predominantly to its effect on behaviors other than timing itself.

Migler and Brady did not discuss the exact nature of "timing behavior". Their discussion of "other behaviors" generated by DRL schedules includes the following examples: "eating, drinking, response bursting after nonreinforcement, and long pauses between responses". In the present experiment, there appeared to be only a repeating, stereotyped pattern of behavior which intervened between the recorded bar-presses. It might be argued that these stereotyped chains were timing behavior. Such behavior regularly occurred between responses, and might have provided the discriminative stimuli for the bar-presses (see Laties, Weiss, Clark, and Reynolds, 1965). This process would be strengthened, for this behavior was followed by bar-presses which often produced reinforcement. It was also noted that these behavioral chains disappeared during the tone when the shock was mild. This in itself might "explain" the increase in bar-pressing during the tone at this stage of the experiment: in the absence of discriminative cues, the rats responded more randomly and the rate therefore increased.

This still leaves the question: why did the behavior intervening between bar-presses disappear during a pre-shock stimulus, while bar-

pressing was still emitted? This may have been the result of adventitious punishment. In the Estes-Skinner procedure, the shock is delivered to the subject regardless of its behavior at that time. However, with the DRL behavior, there was a high probability that the shock would coincide with a stereotyped chain of behavior, because a very high proportion of the animals' time was spent in this (timing?) activity. It is conceivable that the chains of intervening behavior dropped out because of such a chance punishment contingency, so producing an increase in bar-pressing, as discussed above. The subsequent suppression of bar-pressing would not be difficult to explain. It is exactly analogous to the suppression of any bar-pressing behavior in such conditions. No punishment contingency need be hypothesized for this. This suggestion is highly speculative, but would seem to be open to experimental test.

Holz, Azrin, and Ulrich (1963) reported an experiment in which DRL key-pecking was punished. Shock was delivered immediately after a key-peck, making it impossible for the shock to be associated by chance with any form of chained behavior which might have intervened between the key-pecks. In this experiment, it was the key-pecking behavior which was suppressed; in fact, this behavior actually became more efficient, for short inter-response times were eliminated.

The conditioned suppression of the Component B behavior is less difficult to understand. There are a number of points which must be discussed, however.

The suppression of the interval-behavior of Rat 1 was outlined at length in the Results section. It is reminiscent of conditioned suppression reported by Lyon (1964) with a fixed-ratio schedule. In his experiment, every 150th response was reinforced. The subjects continued to respond during the first part of the pre-shock stimulus if they had already emitted a certain number of responses of the ratio required. The responding would continue until the next reinforcement was obtained. Then the birds would suppress completely until the shock was delivered. If the pre-shock stimulus was introduced after only a few responses on the ratio run, the pigeons showed complete conditioned suppression. The similar effect with a fixed-interval schedule would seem well worth following up. It also seems likely that the critical number of responses on the ratio

run with fixed-ratio schedules would be a function of the intensity of the shock.

The behavior of Rats 2 and 4 on Component B has been described as 'ratio-like'. The cumulative records are very similar to those produced by variable-ratio schedules of reinforcement. However, the conditioned suppression of this behavior is not exactly the same as that reported with variable-ratio schedules by Lyon and Felton (1966). They found clear evidence of a bimodal response rate during the pre-shock stimulus. No such pattern was consistently observed in the present experiment. In fact, the most remarkable feature of the suppression of this behavior was its severity. Complete conditioned suppression was produced by relatively mild shocks.

The patterns of behavior produced by the two components of the multiple schedule were very different and detailed comparison across components should therefore be limited. However, it is worth noting that Rats 1 and 2 obtained more reinforcements on Component B than on Component A. Yet there is evidence that the Component B behavior was the more affected by the Estes-Skinner procedure. Suppression ratios were lower on Component B. A milder shock was needed to produce complete conditioned suppression of this behavior. More trials were needed before complete extinction of suppression was achieved on Component B. This is contrary to predictions that might be made on the basis of earlier work; Lyon (1963) has shown that suppression is more severe when reinforcement frequency is low. It is certainly possible that the more severe conditioned suppression obtained on Component B was a function of the much lower probability that any single response would be followed by reinforcement on that component.

Many previous experiments have reported that shock has a suppressive effect on behavioral baselines maintained by schedules of food or water reinforcement (e.g., Hunt and Brady, 1955; Hake and Azrin, 1965). This is also confirmed in the present experiment. However, it is noticeable that the behavioral baselines remained uninterrupted as long as the shock used in the Estes-Skinner procedure produced only partial conditioned suppression during the tone. When the shock was severe enough to produce complete conditioned suppression, the behavioral baselines

were also liable to become slightly suppressed. Such a finding has not been reported before.

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