RESPONSE RATE, REINFORCEMENT FREQUENCY, AND CONDITIONED SUPPRESSION¹

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In the first of two experiments, periods of noise were terminated with unavoidable shock to 36 rats. The rats' continuously reinforced responding was later completely suppressed during the noise when it was introduced without shock. The rats were then assigned to nine experimental groups. Each group was exposed to different paced variable-interval schedules of reinforcement, which independently controlled response rate and reinforcement frequency. Periods of the noise were periodically superimposed on these schedules, and loss of response suppression was studied. Differences between the groups were assessed statistically. The second experiment used a steady-state design. Six rats were exposed to paced schedules which generated two alternating response rates but gave constant reinforcement frequencies, and six rats to schedules which maintained the same response rates throughout, but in which the reinforcement frequency was alternately high and low. Response suppression was studied during a pre-shock stimulus superimposed on each rat's two behavioral baselines. Both experiments suggest that (1) conditioned suppression is affected by rate of operant responding, high rates being most suppressed, and (2) the frequency of reinforcements obtained also has an effect, most suppression occurring when frequency is low.

The behavioral phenomenon now known as conditioned suppression was first demonstrated by Estes and Skinner (1941). They maintained rats' bar-pressing by a schedule of intermittent food reinforcement, and found that such behavior became less frequent during a period of tone which ended with an unavoidable electric shock.

The severity or amount of conditioned suppression is dependent in some way on the characteristics of the behavior on which the procedure is superimposed, but the exact determinants are not clear. Brady (1955) tentatively suggested that high response rates are less affected by the Estes-Skinner procedure. He exposed animals either to schedules which specified the ratio of responses to reinforcements (FR 6, FR 12, VR 12), or the average time interval between reinforcements (VI 1-min, VI 0.5-min). These schedules generated characteristic patterns of bar-pressing, and Brady studied the disruption of these behavior

patterns during periods of a clicking noise which had previously, but no longer, ended with shock. He found that all the behavior patterns were suppressed completely on the first occasion that noise was superimposed, but that suppression gradually disappeared with further presentations of noise. However, this process did not occur at a uniform rate, for the suppression of ratio behavior was lost faster than the suppression of interval behavior. Since one of the most obvious differences between these types of schedule is the rate of responding which they generate, Brady suggested that this might be the source of the difference in loss of conditioned suppression.

Lyon (1963) suggested that reinforcement frequency acts as a determinant of conditioned suppression, for he found that behavior which produced an average of one reinforcement every minute (VI 1-min) was less suppressed during a pre-shock stimulus than was behavior which was reinforced on a VI 4-min schedule.

Adequate analysis of the crucial variables in these two experiments may be confounded by their failure to control response rate and reinforcement frequency independently. Thus, in Brady's experiment, the high response rates generated by the ratio schedules must have produced higher frequencies of reinforcement

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than was possible with the interval schedules; in Lyon's experiment, the higher frequency of reinforcement was accompanied by higher response rates. It follows, therefore, that either variable might account for both sets of results.

In more recent work, attempts have been made to control response rate and reinforcement frequency independently in order to discover how these variables affect conditioned suppression. Lyon (1965) claimed that response rate is not a determinant when reinforcement frequency is controlled. However, Blackman (1966, 1967a) used a different experimental procedure to control the two variables independently, and found that high response rates were more suppressed than lower response rates when reinforcement frequency was controlled. This non-agreement has led to discussion (Lyon, 1967; Blackman, 1967b), but it is the purpose of this paper to offer more experimental data relevant to the question.

The two present experiments had the same general aims: (1) to investigate further Blackman's earlier claims that response rate affects conditioned suppression when reinforcement frequency is controlled; (2) to discover whether reinforcement frequency affects the degree of conditioned suppression when response rate is controlled. Experiment 1 tackled the problem by means of a transitional-state design. Small groups of subjects were assigned to different experimental conditions, and the speed at which conditioned suppression disappeared (extinguished) was measured. A simple statistical technique was used to assess differences between the experimental groups in this respect. In Exp. 2, two forms of behavior were brought under independent stimulus control with each subject. The degree of conditioned suppression produced by a standardized procedure was measured on both forms of behavior.

EXPERIMENT 1

METHOD

Subjects

Thirty-six naive male albino rats were maintained at 80% of their pre-experiment weights. They were between 120 and 150 days old at the start of the experiment. At the time of each experimental session, they had been deprived of food for approximately 23 hr. Water was available in the living cages, but not in the test chambers.

Apparatus

Three commercially manufactured test chambers were used. Each measured $9\frac{1}{4}$ by $7\frac{1}{8}$ by $11\frac{1}{2}$ in. The floors consisted of 18 stainless steel rods which formed an electrifiable grid. Grason-Stadler E1064 shock generators scrambled the polarities of the rods of the grid as shock was delivered. In one wall of each chamber was a hopper, to which 45-mg pellets of standard rat food could be delivered automatically. Above the hopper, and about 3.25 in. above the grid floor, a stainless steel lever projected 0.5 in. 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, mounted in the same wall, illuminated the chambers during each experimental session. A small loudspeaker was connected to a Grason-Stadler E901B white-noise generator. Each test chamber was in a sound-attenuating and ventilated chest.

The experiment was completely automated by means of relays, timers, and rotary switches. Responses and reinforcements were counted by digital impulse counters and a three-channel print-out counter. Cumulative recorders 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 their 80% weights was almost constant. They were then adapted to the test chambers by being placed in them for two 75-min periods. Each rat was placed in the same chamber at the same time for each daily experimental session. Then, a further ten 75-min sessions were given, during which 1-min periods of white noise were presented every 10 min; as each of these periods of noise ended, an unavoidable shock was delivered through the grid floors. The shock generators were set to deliver 2.0 ma for 0.5 sec. Following these 10 sessions, the rats were placed in the chambers for a further 10 sessions, during which there were no further periods of noise, and no shock. The rats were then magazine-trained by delivering pellets of food at irregular intervals which averaged 1 min. There were two such sessions, each lasting for 75 min. Next, the delivery of a food pellet was contingent upon a bar-press. It was necessary to rein-

force successive approximations to a bar-press for six of the rats, but for the others this shaping procedure was not necessary. Five sessions of this continuous reinforcement schedule were given, each allowing 100 reinforcements. During the last of these sessions, the noise stimulus was presented once for 1 min; no shock followed this period of noise.

Each rat was then assigned at random to one of nine experimental groups, care being taken to ensure that at least one rat from each test chamber was included in every group. Two variables were to be differentiated: response rate and reinforcement frequency. Response rates were intended to be approximately 60 (or more), 30, and 10 per min. Reinforcement frequencies were intended to be about 2.0, 1.0, and 0.67 per min. The nine experimental groups accounted for each possible combination of these variables, as shown in Table 1.

The reinforcement frequencies were governed by appropriate variable-interval (VI) schedules, *i.e.*, VI 0.5-min for Groups 1, 2, and 3, VI 1-min for Groups 4, 5, and 6, and VI 1.5-min for Groups 7, 8, and 9. Reinforcements were made available from a continuously driven tape-timer. Only one potential reinforcement could be stored, so a rat missed any reinforcement which was not produced before the next one was made available. On the other hand, 60 reinforcements per hour could be obtained on a VI 1-min schedule; even if each was not obtained immediately it became available. Such an arrangement has been used before (Blackman, 1967a), when it was found to minimize differences in the number of reinforcements obtained by rats responding at very different rates.

Response rates were manipulated by simple response pacing techniques. Thus, in Groups 1, 4, and 7 reinforcements were produced only by a response which occurred less than 0.3 sec after the previous response. This was to differentially reinforce a high rate of responding and is here termed a DRH contingency. Note that this is not identical to the original use of this term by Ferster and Skinner (1957, pp. 33-34), but since the end result is similar in some respects (Blackman, 1966), the term seems appropriate. In Groups 2, 5, and 8, a reinforcement was produced only by a response which was emitted between 2.0 and 4.0 sec after the preceding response. Such pacing requirements were first defined and discussed by

Ferster and Skinner (1957, p.498). The responses of Groups 3, 6, and 9 were followed by reinforcement only if at least 5.0 sec had elapsed since the immediately preceding response. This was to differentially reinforce a low rate of responding, and is termed a DRL contingency.

The schedules assigned to each group were therefore expressed as follows:—

- Group 1: VI 0.5-min DRH 0.3-sec
- Group 2: VI 0.5-min pacing (1) 2.0 — 4.0 sec
- Group 3: VI 0.5-min DRL 5.0-sec
- Group 4: VI 1-min DRH 0.3-sec
- Group 5: VI 1-min pacing (1) 2.0 — 4.0 sec
- Group 6: VI 1-min DRL 5.0-sec
- Group 7: VI 1.5-min DRH 0.3-sec
- Group 8: VI 1.5-min pacing (1) 2.0 — 4.0 sec
- Group 9: VI 1.5-min DRL 5.0-sec

Having been assigned to the nine experimental groups, the rats were exposed to these schedules for 30 consecutive daily sessions of 75 min. Then the white noise was superimposed for periods of 1 min every 10 min as before, but with no delivery of shock. Counts were taken of the number of operant responses emitted during each period of noise, and these were divided by the number of responses emitted in the immediately preceding minute. This provided a measure of any change in behavior during the periods of noise, and is called a suppression ratio. A ratio of 1.00 would be obtained if the noise produced no measurable change in behavior, *i.e.*, the rate of responding during the noise was the same as the rate just before the noise. A suppression ratio smaller than 1.00 would indicate some degree of conditioned suppression. Complete suppression (*i.e.*, no responding during the noise) would be indicated by a suppression ratio of 0. This calculation is therefore similar to that used by Lyon (1963) but differs from that used by Brady (1955). This procedure was continued for six sessions. Since there were seven periods of noise in each session, the noise was presented for forty two 1-min periods.

RESULTS

All rats stopped responding completely during the 1-min period of noise presented during the fifth session of continuous reinforcement. This demonstrated that complete conditioned

suppression had resulted from the earlier treatment.

Table 1 summarizes the response rates and reinforcement frequencies generated by the schedules of reinforcement. The figures given are the means obtained from the last five sessions of the VI schedules before the periods of noise were reintroduced.

Table 1

Intended response rates and reinforcement frequencies for each group in Exp. 1, together with mean response rates and average deviations obtained, and mean reinforcement frequencies obtained.

Group	Response per Min			Reinforcements per Min	
	In-tended	Ob-tained	Av. Dev.	In-tended	Ob-tained
1	≥60	84.1	±2.26	2.0	1.99
2	30	35.2	±1.46	2.0	1.99
3	10	9.8	±0.83	2.0	1.97
4	≥60	78.7	±2.82	1.0	1.00
5	30	33.8	±1.42	1.0	1.00
6	10	9.4	±0.51	1.0	0.99
7	≥60	77.9	±2.56	0.67	0.67
8	30	35.0	±1.58	0.67	0.67
9	10	9.0	±0.28	0.67	0.66

These figures approximate the desired values outlined in the Method section. However, note that the data given for Group 7 were obtained from three rats only. One of the original subjects of this group was not included in the data analysis, because its behavior was not typical of that generated by the reinforcement schedule to which this group was exposed. With this rat, short bursts of rapid responding were mixed with long pauses; it was discarded from the experiment because such behavior did not satisfy the baseline requirements of the experimental design.

All other subjects in the experiment showed little intra-session variability, and the cumulative records were approximately linear. It was possible to identify stereotyped forms of behavior intervening between the recorded responses in some, but not all, of the rats exposed to the DRL contingency (Groups 3, 6, and 9). Unfortunately, it was not possible to describe the behavior generated by these schedules in any supplementary way (for example, by interresponse-time analyses).

The schedules used in the experiment therefore controlled response rates and reinforce-

ment frequencies independently in the required way. Suitable baselines were therefore provided for a satisfactory analysis of loss of conditioned suppression.

Figure 1A shows a comparison of the loss of conditioned suppression between groups of rats which obtained equal frequencies of reinforcement, but which were responding at different rates. All rats were exposed to six sessions with periods of noise, but group curves are not plotted after all subjects in that group had reached a criterion of two successive suppression ratios of at least 0.95. After this, all group curves varied around 1.00 (i.e., no suppression). There is clear differentiation of the group curves at all reinforcement frequencies, the fastest loss being shown by the animals which responded at the lowest rates, and the slowest by the groups responding at the highest rates.

Figure 1B compares, in the same way, the curves of groups of rats responding at similar rates, but obtaining differing frequencies of reinforcement. Again, there is clear differentiation of the curves. In these cases, the fastest loss of suppression is associated with the highest frequencies of reinforcement, and the slowest with the groups receiving the fewest reinforcements.

Loss of conditioned suppression was compared in a further way. The number of trials needed to reach a criterion was calculated for each rat, this criterion being again two successive suppression ratios of 0.95 or more. These data were subjected to Kruskal-Wallis one-way analyses of variance by ranks (from Siegel, 1956). These tested the null hypothesis that there was no difference between groups receiving equal frequencies of reinforcement but responding at different rates. The null hypothesis was also tested that there was no difference between groups responding at similar rates but obtaining different frequencies of reinforcement. Each null hypothesis was rejected as being below the 0.01 probability level.

Results presented in terms of suppression ratios may be open to objection when comparisons are made between rats responding at different rates (Blackman, 1966, 1967*b*). For this reason, an attempt was made to handle the data of this experiment without reference to normal rates of responding. To do this, a calculation was made for each subject of the number of trials required before the first re-

Fig. 1. Experiment 1: loss of conditioned suppression, comparing groups obtaining the same reinforcement frequencies but responding at different rates (A), and comparing groups responding at similar rates but receiving different frequencies of reinforcement (B). The number attached to each curve denotes the experimental group. Suppression ratios were calculated as described in the text: 0 = complete response suppression, 1.0 = no behavioral disruption during noise.

sponse was emitted during the noise (therefore when the suppression ratio was greater than 0 for the first time). This measure was not as reliable as the criterion used previously; emission of the first response in one period of noise was sometimes followed by complete suppres-

sion during the next period. However, Kruskal-Wallis one-way analyses of variance by ranks were used again in order to assess differences between the groups. The analysis was applied as before. In all cases, the null hypothesis that there is no difference in the number

Table 2

Experiment 1—number of trials before the first response was emitted during a period of noise.

			<i>P of H_o</i>
Group 1 : 4, 6, 9, 12.	Group 2 : 2, 2, 2, 4.	Group 3 : 1, 1, 2, 2.	<0.05
Group 4 : 5, 11, 12, 15.	Group 5 : 2, 3, 3, 4.	Group 6 : 2, 3, 3, 4.	<0.05
Group 7 : 13, 16, 17, (—).	Group 8 : 3, 5, 6, 10.	Group 9 : 1, 4, 4, 5.	<0.05
P of H _o <0.05	<0.05 (corrected for ties)	<0.10	

of trials to the first response between groups responding at different rates but receiving the same frequency of reinforcement may be rejected as being below the 0.05 level of probability. The null hypothesis that there is no difference between groups responding at similar rates but receiving different frequencies of reinforcement may be rejected for rats emitting 60 and 30 responses per minute, but the differences between the groups making 10 responses per minute were not significant. See Table 2.

Finally, Fig. 2 gives sample segments of cumulative records to illustrate the results of the experiment. These are taken from the first and fourth noise periods (first session of extinction), the ninth and fourteenth periods (second session), the nineteenth period (third session), the twenty-fourth period (fourth session), and the final period (sixth session). These records were chosen by taking the suppression ratio nearest to the group mean. The groups are arranged in threes as numbered, subjects receiving equal frequencies of reinforcement being placed together. Comparison may be made of animals which responded at equal rates, but the responses of which were reinforced at different frequencies, by comparing the representative of Group 1 with those of Groups 4 and 7, of Group 2 with those of Groups 5 and 8, and of Group 3 with those of Groups 6 and 9 on each of these trials. The trials were selected to illustrate the differences between the groups in loss of conditioned suppression.

DISCUSSION

The results of this experiment confirm that the loss of conditioned suppression may be related to variables which affect operant responding. They suggest that both response rate and reinforcement frequency may have a detectable effect.

The conclusion that high response rates are

associated with slow loss of suppression is in agreement with an earlier experiment (Blackman, 1966). The evidence provided by analysis of the number of trials to the first response is especially important to this conclusion, revealing that it is not merely an artifact of the measuring devices used. Brady (1955) found that high response rates led to faster loss of suppression in his experiment; the contrary conclusion now reached stresses the importance of controlling reinforcement frequency. It seems probable that Brady's results may be explained by differences in the frequencies of reinforcement produced by his schedules. Thus, the rats which showed the fastest loss of suppression did so because they received the highest frequency of reinforcement, and despite the fact that they were responding at the highest rates.

This is the first experiment to investigate the effects of reinforcement frequency on conditioned suppression in which response rates have been controlled. The finding that high reinforcement frequencies lead to faster loss of suppression is complementary to Lyon's findings (1963), although response rates were not controlled in Lyon's experiment. The analysis of the number of trials necessary before the first response was emitted during a noise-period was less crucial to the investigation of the effects of reinforcement frequency, for response rates were similar. However, the lack of significant difference between groups making 10 responses per minute deserves attention. It may be because the DRL 5.0-sec contingency which applied to these groups exerted a relatively strong control over the subjects' behavior. Such a suggestion is prompted by the earlier observation that many of these rats emitted stereotyped patterns of behavior between the recorded bar-presses. It is conceivable that this might minimize the effects of differences in reinforcement frequency.

Fig. 2. Experiment 1: sample segments of cumulative record to illustrate the results. The pen was deflected downwards during the noise stimulus; reinforcements are not shown. The numbers denote the experimental groups.

EXPERIMENT 2

METHOD

Subjects

Twelve male albino rats, between 120 and 125 days old at the start of the experiment, were maintained at 80% of their pre-experiment weights.

Apparatus

The experimental chambers were two of the three used in Exp. 1. An additional loud-speaker mounted in each of these chambers was connected to an audio-frequency generator and amplifier. Control and recording devices were those used in Exp. 1.

Procedure

The rats were accustomed to the deprivation conditions and to the test chambers. They were then placed in the chamber for ten 75-min sessions during which a 1000-cps tone was presented for 1-min periods every 9 min. As each period of tone ended, an unavoidable shock (0.5 ma/0.5 sec) was delivered. Following these 10 sessions, a further 10 were given during which the rats were simply placed in the test chamber as for the original adaptation sessions. They were then magazine trained, and allowed five sessions of continuous reinforcement, in each of which 100 reinforcements were obtained. The bar-pressing of Rats 2, 3, 9, and 11 needed to be shaped. Fol-

Table 3
Schedules of Reinforcement used in Exp. 2

Rat	Component A	Component B
1.	VI 0.5-min DRH 0.2-sec.	VI 0.5-min pacing (1) 1.5 - 3.0 sec.
2.	VI 0.5-min DRH 0.2-sec.	VI 0.5-min pacing (1) 3.0 - 6.0 sec.
3.	VI 0.5-min DRH 0.2-sec.	VI 0.5-min pacing (1) 5.0 - 10.0 sec.
4.	VI 0.5-min pacing (1) 1.5 - 3.0 sec.	VI 0.5-min pacing (1) 3.0 - 6.0 sec.
5.	VI 0.5-min pacing (1) 1.5 - 3.0 sec.	VI 0.5-min pacing (1) 5.0 - 10.0 sec.
6.	VI 0.5-min pacing (1) 3.0 - 6.0 sec.	VI 0.5-min pacing (1) 5.0 - 10.0 sec.
7.	VI 0.5-min DRH 0.2 sec.	VI 1-min DRH 0.2 sec.
8.	VI 0.5-min pacing (1) 1.5 - 3.0 sec.	VI 1-min pacing (1) 1.5 - 3.0 sec.
9.	VI 0.5-min pacing (1) 3.0 - 6.0 sec.	VI 1-min pacing (1) 3.0 - 6.0 sec.
10.	VI 0.5-min pacing (1) 5.0 - 10.0 sec.	VI 1-min pacing (1) 5.0 - 10.0 sec.
11.	VI 0.5-min pacing (1) 1.5 - 3.0 sec.	VI 1.5-min pacing (1) 1.5 - 3.0 sec.
12.	VI 1-min pacing (1) 3.0 - 6.0 sec.	VI 1.5-min pacing (1) 3.0 - 6.0 sec.

lowing this, one 30-min session was given, in which a VI 0.5-min schedule of reinforcement was in operation. Thereafter, the subjects were exposed to a multiple schedule of reinforcement for daily sessions of 71-min duration. These sessions consisted of four 8-min periods of one schedule (Component A) which alternated with four 8-min periods of another schedule (Component B). Each period was separated from the next by 1-min timeout, during which the houselights were extinguished, and no reinforcement schedule was in operation. The component schedules were specified as shown in Table 3.

Rats 1 to 6 were therefore exposed to the same variable-interval schedule throughout each session, but the pacing requirements specified were designed to produce differences in rates of responding between components. Rats 7 to 12 were exposed to different variable-interval schedules on the two components of the multiple schedule, but the pacing requirements were identical on both.

The pacing schedules are specified in the same terminology used by Ferster and Skinner (1957, p.498); note again that the schedules specified as VI DRH are not in accord with the discussion of DRH contingencies given by these authors (pp. 33-34). Designation of DRH schedules is that used and discussed in Exp. 1.

Finally, it should be noted that in all of these schedules, the tape-timer which governed the variable-interval components was used as in the preceding experiment, that is, it was driven continuously.

The order of presentation of components

was balanced across sessions, ABAB . . . ; BABA Masking white noise acted as the stimulus used to differentiate the two components of the multiple schedule. This noise was present during periods of Component A for Rats 1, 3, 5, 7, 9, and 11, and during Component B for the remaining rats. During the periods of the other component, no noise was present.

For each session, counts were taken of the number of responses made and the number of reinforcements produced by each animal during each component. Interresponse-time analyses were taken for the entire duration of each component during the eightieth session of the multiple schedules for Rats 1 to 6, and during the seventy-ninth session for Rats 7 to 12.

After 80 days of exposure to these multiple schedules of reinforcement, conditioned suppression training was added. The 1000-cps tone used earlier was presented for 1-min periods as before. Each period of tone began 4 min after the beginning of each 8-min period of the schedule. As each tone presentation was terminated, an unavoidable shock was delivered to the subject (0.5 ma/0.5 sec as before). There were therefore eight pairings of the pre-shock stimulus and shock during each experimental session, consisting of four against each component schedule. Suppression ratios were calculated for each period of tone as in Exp. 1.

After 20 sessions at 0.5 ma, the shock intensity was increased to 2.0 ma, and after a further 20 sessions to 4.0 ma. The experiment was terminated after 20 sessions at this last shock intensity.

Table 4

Mean response rates and reinforcement frequencies in Exp. 2, before tone was introduced when the schedules were in operation. Average deviations are also shown for response rates.

Rat	Component A		Component B	
	Responses per Min	Reinforcements per Min	Responses per Min	Reinforcements per Min
1	88.0 $\pm$ 1.0	2.01	37.8 $\pm$ 1.1	2.00
2	95.5 $\pm$ 2.0	2.01	20.4 $\pm$ 0.9	1.99
3	115.6 $\pm$ 1.8	1.99	9.6 $\pm$ 0.1	1.98
4	37.0 $\pm$ 1.2	1.98	20.2 $\pm$ 0.8	1.97
5	41.4 $\pm$ 0.7	1.94	10.3 $\pm$ 0.3	1.94
6	21.5 $\pm$ 0.3	1.94	11.9 $\pm$ 0.1	1.95
7	92.7 $\pm$ 0.9	2.02	90.7 $\pm$ 0.9	1.01
8	41.4 $\pm$ 0.8	1.99	41.6 $\pm$ 0.7	1.01
9	23.1 $\pm$ 0.5	1.96	24.3 $\pm$ 0.9	0.97
10	9.9 $\pm$ 0.4	1.94	10.3 $\pm$ 0.2	1.01
11	38.9 $\pm$ 1.2	2.00	43.5 $\pm$ 0.6	0.66
12	22.5 $\pm$ 0.7	0.99	21.8 $\pm$ 1.1	0.67

RESULTS

The results of this experiment are analyzed *within* individual subjects only.

Table 4 shows the mean response rates and reinforcement frequencies obtained from Sessions 76 to 80 of the multiple schedules. It is clear that the schedules established satisfactory stimulus control of the subjects' behavior. Thus, for Rats 1 to 6, reinforcement frequency differed minimally between components, while response rates approximated the desired values. With Rats 7 to 12, response rates differed little between components, although reinforcement frequencies differed as planned.

The interresponse-time analyses all had a

mode in the first class interval in which a response might be followed by reinforcement. In many cases, a substantial number of interresponse times was also recorded in the class interval immediately preceding the shorter limit of the timing requirements. With Rats 7 to 12, the interresponse-time analyses obtained from the two components did not differ substantially, although in all cases a smaller proportion of responses was recorded in the modal class interval on Component B (the lower reinforcement frequency). To this extent, the interresponse-time distributions were flatter on Component B than on Component A. In addition, Rat 10 showed more very short interresponse times on Component B than on

Table 5

Suppression ratios obtained in Exp. 2. Data are the mean and the average deviation for the last five sessions at each shock setting (*i.e.*, 20 tone-shock presentations on each component). The cells which are indicated by asterisks are examined in more detail in Table 6.

Shock Intensity Component	0.5 ma		2.0 ma		4.0 ma	
	A	B	A	B	A	B
Rat 1	0.04 $\pm$ 0.02	0.60 $\pm$ 0.06*	0	0.09 $\pm$ 0.02*	0	0
2	0.15 $\pm$ 0.01	0.30 $\pm$ 0.04	0	0.11 $\pm$ 0.03*	0	0
3	0.18 $\pm$ 0.01	0.92 $\pm$ 0.06	0.08 $\pm$ 0.01	0.30 $\pm$ 0.04	0	0.14 $\pm$ 0.08*
4	0.24 $\pm$ 0.03	0.58 $\pm$ 0.09	0.03 $\pm$ 0.02	0.25 $\pm$ 0.08*	0	0
5	0.17 $\pm$ 0.03	0.91 $\pm$ 0.06	0	0.25 $\pm$ 0.05*	0	0
6	0.63 $\pm$ 0.07	0.89 $\pm$ 0.07	0.14 $\pm$ 0.02	0.55 $\pm$ 0.07*	0	0.06 $\pm$ 0.05

Table 6

Experiment 2; mean number and average deviation of responses emitted in the 1-min periods before tone and the 1-min periods of tone. These data expand those cells in Table 4 marked with asterisks.

Rat	Shock	Component A		Component B	
		Tone off	Tone on	Tone off	Tone on
1	0.5 ma	89.5 $\pm$ 2.7	4.6 $\pm$ 1.3	36.3 $\pm$ 1.6	21.7 $\pm$ 1.7
1	2.0 ma	88.5 $\pm$ 2.3	0	37.7 $\pm$ 0.9	3.3 $\pm$ 0.8
2	2.0 ma	91.5 $\pm$ 2.5	0	20.2 $\pm$ 0.8	2.3 $\pm$ 0.6
3	4.0 ma	83.1 $\pm$ 10.2	0	9.6 $\pm$ 1.5	1.4 $\pm$ 0.7
4	2.0 ma	36.0 $\pm$ 1.0	1.2 $\pm$ 0.7	17.0 $\pm$ 1.6	4.2 $\pm$ 1.0
5	2.0 ma	41.2 $\pm$ 1.2	0	9.8 $\pm$ 0.6	2.5 $\pm$ 0.5
6	2.0 ma	21.4 $\pm$ 1.1	3.0 $\pm$ 0.4	11.2 $\pm$ 0.9	6.2 $\pm$ 0.7

Component A; this reflects an increased tendency for response "bursting" on that component (Sidman, 1956).

Table 5 shows the mean suppression ratios obtained from Rats 1 to 6, together with their average deviations. These data were obtained from the last 20 presentations of the tone and shock on each component of the multiple schedule. It may be seen that the suppression ratios obtained from Component A were invariably smaller than those obtained from Component B (except when complete conditioned suppression was observed on both components). This denotes greater suppression of the behavior characterized by higher response rates. Once again, of course, it is possible that these differences are merely artifacts of the dif-

ferences in baseline response rates on the two components. Therefore, the data were examined in an attempt to ensure that this was not the case. Occasions were sought when the absolute number of responses emitted during the tone was greater on Component B than on Component A, *despite* the differences in the opposite direction in the baseline response rates. Where such evidence was found, the data are so designated in Table 5. These data are expanded in Table 6 to give a more adequate description of the behavior at these shock settings in terms of absolute number of responses emitted during the tone.

Table 7 shows the mean suppression ratios obtained from Rats 7 to 12, with average deviations. The data are again for the last 20 pair-

Table 7

Suppression ratios obtained in Exp. 2. Data are the mean and the average deviation for the last five sessions at each shock setting (*i.e.*, 20 tone-shock presentations on each component).

Shock Intensity Component	0.5 ma		2.0 ma		4.0 ma	
	A	B	A	B	A	B
Rat 7	0.12 $\pm$ 0.01	0	0	0	0	0
8	0.36 $\pm$ 0.04	0.07 $\pm$ 0.02	0.04 $\pm$ 0.02	0	0	0
9	0.65 $\pm$ 0.02	0.22 $\pm$ 0.05	0.28 $\pm$ 0.04	0.12 $\pm$ 0.04	0	0
10	0.90 $\pm$ 0.04	0.88 $\pm$ 0.06	0.26 $\pm$ 0.07	0.21 $\pm$ 0.07	0	0
11	0.18 $\pm$ 0.03	0	0.09 $\pm$ 0.02	0	0	0
12	0.76 $\pm$ 0.08	0.11 $\pm$ 0.03	0.14 $\pm$ 0.04	0	0	0

Fig. 3. Experiment 2: sample segments of cumulative record to illustrate the results with each rat (1 to 12). On the left of each section are two segments of Component A, on the right two segments of Component B. These are the second and fourth 8-min periods of each component during the last experimental session at the shock setting shown. The pen was deflected downwards during the tone stimulus; reinforcements are not shown.

ings of tone and shock on each component at each shock intensity. The suppression ratios are smaller on Component B than on Component A, except when both are zero, and with the consistent exception of Rat 10. Since the two components of the multiple schedules produced similar response rates with these rats, differences in suppression ratios are reflected by similar differences in absolute numbers of responses made during the tone.

Finally, Fig. 3 shows sample segments of cumulative records to illustrate the results of this experiment. Two segments are shown for each component at the shock setting which produced the clearest differential effects. The segments are the second and fourth 8-min period of each component during the last experimental session at that shock setting.

Finally, it should be noted that the baseline behavior often changed considerably at the highest shock intensity; the behavior became less predictable, and high response rates tended to drop. This was probably because of the high intensity of the shock used; fortunately, it does not contaminate an analysis of the results, for this partial loss of baseline behavior was usually observed when both components were accompanied by complete suppression during the tone stimulus. It was not possible to measure these changes in baseline behavior, except by inspecting the counts used to calculate suppression ratios. These confirm the evidence afforded by visual inspection of the cumulative records, and repeat a similar observation made in an earlier experiment (Blackman, 1968).

DISCUSSION

The results of the conditioned suppression procedure were in the expected direction in all cases, with the exception of Rat 10, which showed no detectable differences between components. Thus, with Rats 1 to 6, which received the same frequency of reinforcement during both components of the schedule, the higher rates of response are subject to the more conditioned suppression, except, of course, when both components are accompanied by complete suppression. This observation is based on suppression ratios, but may be supported by absolute measures of responding during the tone at one or more shock intensities. This applies to all six subjects. These dif-

ferences are not the results of adventitious punishment contingencies in the early stages of conditioned suppression training, since there was no very close proximity between a response and a shock; this was a result of the pairings of the tone and shock stimuli before bar training. It is concluded that response rate affected conditioned suppression with these animals, high rates being the most disrupted by the Estes-Skinner procedure.

With Rats 7, 8, 9, 11, and 12 (but not Rat 10), it is concluded that reinforcement frequency affected conditioned suppression, for these rats showed less conditioned suppression of behavior which received higher frequencies of reinforcement (except when complete conditioned suppression was observed on both components). Clearly, absolute measures of responding during the tone support this conclusion, for the control rates of responding (and therefore the pre-tone counts) are approximately equal on both components of the multiple schedule.

In the case of Rat 10, it is possible that the DRL 5.0-sec requirement exerted a relatively strong control of operant behavior, as argued in the Discussion of Exp. 1. Such strong pacing control may have minimized the effects of changes in frequency of reinforcement.

The results of the response pacing procedures are consistent with previous experiments in which responses after specific interresponse times have been reinforced. (*e.g.*, Skinner, 1938, p. 306; Ferster and Skinner, 1957; Anger, 1956; Malott and Cumming, 1964). They are consistent with the assumption that independent stimulus control had been established over behavior by both components of the multiple schedules.

With Rats 7 to 12, the flatter distributions of interresponse times on Component B (lower reinforcement frequency) may be in agreement with the findings of Malott and Cumming (1964), for they found that flatter distributions resulted from a decrease in the probability of reinforcement following a criterion response. The increased tendency of Rat 10 to short interresponse times on Component B may have been associated with the lower incidence of reinforcements following criterion responses on that component. Unfortunately, no measure was possible of the sequential aspects of responding, but this observation does suggest an experiment which might throw

some light on the significance of the response-bursting phenomenon on DRL schedules.

Finally, it should be noted that the effects of the schedules on Rats 7 to 12 do not appear to be in agreement with an observation by Revusky (1963). He also examined the effects of VI value on behavior generated by response pacing schedules, and concluded that the pacing contingency "did not eliminate the usual effects of . . . frequency of reinforcement (Clark, 1958) on VI rate of response." The reason for this lack of agreement is not clear, but may be due to the considerable procedural differences between Revusky's experiment and this.

GENERAL DISCUSSION

The main conclusion from these experiments is that both response rate and reinforcement frequency may affect conditioned suppression in a controlled experiment.

It has been established that, if response rate is controlled, the severity of conditioned suppression is inversely related to the frequency of reinforcement. This corroborates the conclusion offered by Lyon (1963). The reason for this relationship has not been investigated; it may be because suppression on low-valued variable-interval schedules would "cost" more in terms of reinforcements missed (Stein, Sidman, and Brady, 1958), or because such suppression interrupts more quickly the rate at which reinforcements are obtained (Carlton and Didamo, 1960).

When reinforcement frequency is controlled, it has been shown that conditioned suppression is also affected by the rate of operant responding. However, the severity of suppression increases with higher response rates, which does not agree with the conclusion tentatively suggested by Brady (1955). Nor does this finding agree with Lyon's suggestion (1965) that response rate has no effect. However, although the present conclusions are not in accord with Brady's or Lyon's, there is no contradiction between their results and these (Blackman, 1966).

The differences in suppression ratios with different rates of response are not artifacts of the formula used in their calculation, for they are often supported by similar differences in the absolute number of responses. Possible reasons for the effect of response rate have not

been investigated; there are a number of such possibilities. Possibly the most plausible is that animals responding at high rates necessarily make more responses per reinforcement than animals responding at lower rates for the same frequency of reinforcement. Chung (1965) has suggested, in another context, that this may be important. Thus, behavior with which the ratio of responses to reinforcements is high may be more susceptible to conditioned suppression. It is difficult to conceive of a crucial experiment which could distinguish the effects of response rate *per se* and the ratio of responses to reinforcement, except by allowing the frequency of reinforcement to change. Since this would itself affect the severity of conditioned suppression, it would not be helpful.

Finally, Lyon has suggested (1967) that earlier non-agreement between his work and Blackman's (1966) might be due to comparison of steady-state and transitional-state design. The present experiments suggest that with both research techniques it is possible to detect effects of response rate and reinforcement frequency on conditioned suppression.

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