Maintenance of response summation under conditions of minimum stimulus intensity

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Four rats were conditioned on a multiple schedule, in which different composite stimuli were associated with extinction and a variable-interval reinforcement schedule. The composite extinction stimulus consisted of light plus tone. The composite stimuli associated with reinforcement were light plus silence and tone plus darkness. After response rate had stabilized, three test intervals were presented to a S in each session. During two of the test intervals the composite stimuli were the same as the stimuli associated with reinforcement. During the third test interval the composite stimulus was darkness plus silence. Response rate was highest during the third test interval, and this rate difference was maintained for 60 sessions.

Pavlov (1927) first described the summation of responses observed when two separately established conditioned stimuli were presented simultaneously. Since then a number of experiments have examined the effects of simultaneous presentation of two discriminative stimuli (S^Ds) on free-operant response rate. In several of these experiments (Miller & Ackley, 1970; Weiss, 1964; Wolf, 1963) no responses were reinforced when the stimulus condition was darkness and silence (S^Δ), while a schedule of reinforcement was in effect during the presentation of either a light S^D or a tone S^D. When light and tone were presented simultaneously, the rats in each of these experiments responded at a higher rate than they did when either S^D was presented alone. A similar phenomenon has been demonstrated using the conditioned suppression procedure. Miller (1969), Reberg & Black (1969), and Van Houten, O'Leary, & Weiss (1970) all used two different preshock stimuli and adjusted shock intensity until each stimulus produced moderate response suppression. When the stimuli were presented simultaneously, response suppression was intensified in each of the experiments.

In those experiments using appetitive reinforcement to demonstrate response summation there was a serious problem of interpretation. The simultaneous presentation of light and tone meant that the summation condition stimulus was also the most intense stimulus the S experienced. Weiss (1969) showed that the summation effect was not caused by stimulus intensity simply by making the summation stimulus the least intense of the stimuli the S experienced. No responses were reinforced during S^Δ, which was light plus tone. A schedule of reinforcement was in effect during both a light-silence S^D and a tone-darkness S^D. After the discrimination had been well learned, Weiss measured the number of responses a S made during a single extinction session. The stimuli presented during the extinction session included S^Ds, S^Δ, and a summation stimulus which consisted of darkness and silence. There were more responses emitted to the darkness-and-silence stimulus than to either of the S^Ds. However, this evidence only demonstrated that summation under conditions of minimum stimulus intensity could occur during extinction. It was not clear that a similar summation effect could be demonstrated when responses by a S during S^D presentations were still being reinforced. This experiment was intended to demonstrate response summation under conditions of minimum stimulus intensity while the discrimination was maintained.

SUBJECTS

Four male hooded rats, approximately 120 days old at the beginning of the experiment, served as Ss. Each S was allowed free access to water for 15 min following an experimental session but was deprived of water at all other times. Food was continuously available in a S's home cage.

APPARATUS

The experiment was carried out in a standard Lehigh Valley experimental chamber with interior dimensions of 7.5 x 12 x 8 in. The minipulandum was a lever with an operating pressure of 20 g, located 1.5 in. above the floor and 2.0 in. from the left side of the chamber. Reinforcement was provided by a 0.06-cc liquid dipper, located at the base of the front wall midway between the sides. There were two pilot lights on the front wall of the chamber. Both lights were 3.5 in. above the floor. One light was 1.5 in. from the left side of the chamber, and the other light was 1.5 in. from the right side of the chamber. Light intensity was measured 2 in. above the floor, 3 in. from the front wall, and 1.5 in. from the left side of the chamber, with the meter facing the front wall. Illumination when both pilot lights were turned on was 8.4 fc, measured with the light meter facing the front wall. The auditory stimulus was a 714-Hz tone which was 4 dB above a background noise level of 63 dB.

Electromechanical control and recording equipment was located in an adjacent room. White noise was always present in the experimental room to mask extraneous sounds.

PROCEDURE

Each of the four Ss was shaped to press the bar during the first session. They then received four consecutive sessions in which they were allowed to earn 100 reinforcements per session on a continuous reinforcement (CRF) schedule. The light was always on and the tone was always off during the first two CRF sessions. During the next two CRF sessions the light was always off and the tone was always on.

The discrimination procedure was introduced during the fifth session. One S^D was light plus silence, the other was tone plus darkness. The schedule of reinforcement during S^D intervals was increased gradually from VI 30 sec to VI 1 min over 14 sessions. The duration of the S^D intervals remained constant at 3 min throughout the experiment.

Responses were never reinforced in the presence of S^Δ, which consisted of tone plus light. The S^Δ stimulus, it should be noted, was the most intense stimulus a S experienced during the experiment. S^Δ intervals lasted a minimum of 3 min and 20 sec. After 3 min of extinction, the S had to wait 20 sec without responding before the S^D would recur. Any response during the 20-sec interval reset the timer and forced the S to wait another 20 sec without responding. Session duration was fixed at 1 h beginning with the fifth session.

After 30 sessions of discrimination training, during which the schedule of reinforcement in the presence of S^D remained VI 1 min, the testing phase of the experiment was begun. The testing procedure involved the presentation of three 1-min test intervals during a session. No reinforcements were ever delivered during a test interval and each test interval was preceded and followed by an S^Δ presentation. In addition, there were always at least two S^D presentations between any two test intervals, and the first test interval was

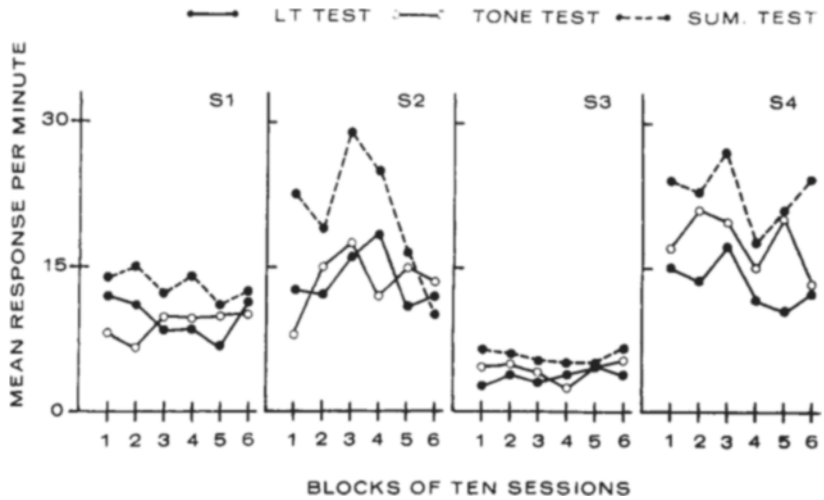

Fig. 1. Mean response rates over blocks of 10 sessions during each of the three test intervals. Stimulus conditions during the first test were light plus silence; stimulus conditions during the tone test were tone plus darkness; stimulus conditions during the summation test were darkness plus silence.

not presented until each S^D had been presented at least once. This procedure was adopted so that S^D and S^Δ would retain control of the behavior while the testing procedure was in progress. In two of the test intervals, the stimuli were identical to the S^Ds; that is, in one test interval the stimulus was light plus silence, while in another of the test intervals the stimulus was tone plus darkness. In the third test interval, which was the summation test, the compound stimulus was darkness plus silence. Each S was run for 60 sessions after the introduction of the test interval procedure. The order of the two S^Ds was changed every third day, as was the order of the test intervals.

RESULTS AND DISCUSSION

Figure 1 shows the mean response rate in each of the test intervals in 10-session blocks for the 60 sessions in which the test procedure was used. Response rate in the summation test interval with light and tone off was higher than response rate in either of the other two test intervals for all four Ss. The summation effect seemed to diminish over trials, but in the last block of 10 sessions only S 2 had a lower rate in the summation condition than in either of the other test intervals. There were no consistent differences between response rate in the other two test intervals for three of the four Ss. The exception was S 4, which had a slightly higher rate in the light-silence condition than in the darkness-tone condition. Response summation thus seems to be a function of increased discriminability between S^D and S^Δ. If there is a stimulus intensity effect, it would probably serve to affect the magnitude of response summation rather than to produce the phenomenon.

The persistence of response summation over 60 sessions was significant because the Ss were not reinforced for responding during the darkness-silence stimulus. Darkness-silence therefore might have been expected to function as an S^Δ and to have inhibited responding after repeated presentations. If this analysis is correct, the magnitude of response summation we observed must have been the result of competing excitatory and inhibitory tendencies. A pure measurement of response summation, if such a thing were possible, would presumably reveal an even bigger effect.

Since the Ss in Weiss's (1969) study were exposed to darkness-silence only during extinction, a similar implicit discrimination may have affected his results. However, Weiss found a much greater summation effect than we were able to demonstrate. He reported that the total number of summation responses during extinction exceeded the sum of the total number of responses to each of the S^Ds; we found summation response rate to be higher than response rate in either S^D but far below the sum of the S^D response rates. Procedural differences probably accounted for most of the difference between the magnitude of the summation effect in the two studies. However, Weiss also reported substantially greater differences between S^D and S^Δ rates for his Ss than we observed in our Ss. This suggests the possibility that magnitude of summation is related to accuracy of discrimination.

Since the test interval procedure had been used so that S^D and S^Δ would retain control over the behavior, the data were examined to see if this goal had been met. The stability of the discrimination over the test sessions was fairly good. Table 1 shows that during the last five pretest sessions the S who showed the poorest discrimination, S 1, had a mean response rate during the S^D presentations which was at least three times as high as response rate during S^Δ. However, the test procedure disrupted the discrimination to some extent. During the first 10 test sessions, all the Ss except S 4 showed some reduction in S^D response rate. In addition, response rate during the test intervals in which the stimulus conditions were identical to the S^Ds was higher than the response rate during the actual S^D presentations. This difference may have been caused by the difference between the duration of the 1-min test intervals and the duration of the 3-min S^D presentations. Although the data were not recorded consistently, periodic examination of the response rate within S^D intervals always showed that response rate was highest in the first minute.

Data from the last block of 10 test sessions are also shown in Table 1. Response rate during S^D presentations either remained approximately the same as during the first 10 test trials or increased slightly. However, the mean response rate of most of the Ss was still below the mean response rate in S^D during the pretest sessions. The one exception was S 4, which had a higher mean response rate in the tone-plus-darkness S^D during the last block of test sessions than during the five pretest sessions. Response rate during S^Δ changed during the test sessions but the rate changes were not in the same direction for all Ss.

Table 1
Mean Response (Response/Minute) Rate in Different Blocks of Sessions During the Discriminative Stimuli and the Extinction Stimulus

Block of Sessions	S	Light Plus Tone (Extinction)	Light Plus Silence (VI)	Tone Plus Darkness (VI)
Last	S 1	2.14	7.14	7.50
Five	S 2	2.80	11.94	12.54
Pretest	S 3	0.96	4.32	4.62
Sessions	S 4	5.58	15.48	14.28
First	S 1	2.21	4.56	6.78
10	S 2	2.36	9.60	10.38
Test	S 3	1.41	2.94	3.66
Sessions	S 4	4.86	14.28	14.58
Last	S 1	2.74	5.88	6.84
10	S 2	2.56	9.12	11.64
Test	S 3	1.17	3.66	3.48
Sessions	S 4	3.48	14.46	17.52

There is one aspect of the Ss' performance which is apparent in their mean S^D rate and which does not appear so clearly in the test interval response rates. Mean response rates were usually slightly higher in the light-plus-silence S^D than in the tone-plus-darkness S^D. The only exceptions to this statement were S 4's mean response rate during the last five pretest sessions and S 3's mean response rate during the last 10 test sessions. These data suggest that some type of stimulus dominance may be affecting the results of the experiment. However, it is not clear how such stimulus parameters would affect response summation.

These data do confirm Weiss's (1969) results in showing that response summation occurs even when the summation stimulus is less intense than either of the S^Ds. They also show that the response summation effect can be maintained for prolonged periods and can be demonstrated using a response rate measure taken during the conditioning session rather than during extinction.

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Incubation of a passive avoidance response after frontal lesions in the rat*

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Rats with lesions of prefrontal cortex were compared with sham operates and cortical controls on a one-trial stepdown passive-avoidance task. At training-test intervals of 5 sec, 10 sec, or 24 h, one-trial learning effects were observed. All groups showed an incubation effect, i.e., stepdown latencies increased after longer retest intervals. There were no differences between animals with prefrontal lesions and the sham controls, suggesting that frontals have normal short-term timing behavior.

Lesions of prefrontal cortex result in severely impaired performance on delayed response and delayed alternation tasks in monkeys (see Pribram, Ahumada, Hartog, & Ross, 1964) and in rats (Bourke, 1954). One interpretation of this deficit is that frontally damaged animals suffer from a loss of recent or immediate memory (Jacobsen, 1935). Consolidation theorists (Glickman, 1961; McGaugh, 1966; Pinel & Cooper, 1966) have suggested that in one-trial passive-avoidance learning situations, incubation of the learned experience occurs during a time interval usually associated with immediate or short-term memory; they report a positive correlation between memory strength and training-test interval. The present study tests the effects of prefrontal lesions in rats upon immediate memory for footshock (FS) in a passive-avoidance situation. If the prefrontal cortex is important in incubation of the memory trace for the FS, removal of that cortical area should result in no change from the preshock stepdown latency when the retention interval falls within a short-term incubation period.

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SUBJECTS

The Ss were 54 hooded rats of the Long-Evans strain. They ranged in age from 3 to 5 months at the start of the study. All Ss were divided randomly into three groups of 18. The rats in the experimental (F) group received one-stage bilateral lesions of the prefrontal cortex (Fig. 1). Those in the cortical control (P) group had an equivalent amount of posterior (parietal) cortex bilaterally removed (Fig. 1). A group of sham operates (N) served as normal controls.

APPARATUS

The stepdown apparatus was identical to that described by Riddell & Herman (1968). It consisted of a 2 x 2 ft electric FS grid enclosed by four walls, 18 in. high. A 6 x 6 in. stepdown platform was placed in one corner of the apparatus, and a clear 18-in. Plexiglas guillotine door enclosed the platform. A simple string harness was used to facilitate the replacement of S onto the platform.

PROCEDURE

During the habituation phase of the experiment, each S was given one stepdown trial a day without FS for 5 days. A trial began with E placing S on the center of the raised platform. Stepdown latency (SDL), i.e., the time required for S to place both front feet on the grid floor, was then measured. When all four feet were on the grid, the guillotine door was lowered to prevent S's return to the platform. The S was allowed to remain on the grid floor for 5 sec before being returned

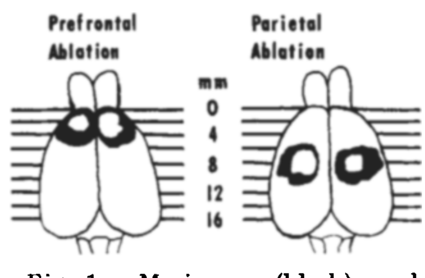

Fig. 1. Maximum (black) and minimum (central white) extents of cortical lesions.