Can a rat count?

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A 2 × 2 factorial experiment was conducted in a licking-suppression situation to test if a rat could count the number of shocks given in a 5-min session under signaled and unsignaled shock conditions. Groups F received three .7-sec grid shocks per session throughout 80 sessions, whereas Groups V received, on any day, one, two, three, four, or five shocks, with a mean of three shocks. The rats' counting ability was assessed in terms of the post-third-shock acceleration of licking. The results of this measure were compared between Groups F and Groups V on test days in which both groups received three shocks with the identical shock sequence. There was no evidence that rats could count under either signaled or unsignaled shock conditions. The basal rate of licking was less in groups run under the unsignaled shock condition than under the signaled shock condition. The effect of fixed/variable shock frequency upon basal rate of licking was not significant. The results are discussed with reference to the optimal shock density view of Davis and Memmott (1982).

Rats in an aversive situation are known to use various cues as predictors of danger and safety. Predictors may be such salient cues as tones and lights, as well as relatively subtle ones such as temporal cues and frequency cues. In a conditioned suppression situation, the rat's baseline behavior is suppressed in the presence of cues that predict danger, and the behavior recovers in the absence of dangerous cues or in the presence of safe cues. When, in an aversive situation, such cues are absent or when rats are unable to use these cues even when such cues are physically present, the baseline behavior is "chronically" suppressed.

In their recent paper, Imada and Nageishi (1982) gave considerable evidence supporting the view that rats can use external cues and temporal cues. As to the rat's ability to use frequency cues, however, the results were rather inconclusive. The present paper, then, addressed the problem of the rat's ability to use a frequency cue as a predictor of safety.

Davis and Memmott (1982) recently made an excellent, extensive review of counting behavior in animals and concluded that successful demonstrations of learning to count in animals were most likely to occur under relatively extreme experimental conditions in which alternative predictors of food or safety were unavailable. Experimental studies on counting behavior in rats by Davis and his collaborators formally started with the study by Davis, Memmott, and Hurwitz (1975). They found that when three unsignaled shocks were invariably given superimposed

upon a 30-min session of barpressing, rats came to behave as though they had learned, "If three shocks, then no more shocks." More specifically, barpressing was accelerated after the third shock. The percentage of the total responses emitted between the offset of the third shock and the end of the session divided by the percentage of the total session time contained within this period was calculated, and Davis et al. (1975) regarded this ratio over unity as evidence for the rat's ability to count. Actually, this method of analysis was directly borrowed from Seligman and Meyer (1970), who, using this ratio, also reported that rats could count three shocks within a 50-min session. Later, however, Davis, Shattuck, and Wright (1981) correctly came to realize the inadequacy of using the above ratio in assessing the counting ability of rats in a conditioned suppression situation. They found that baseline responding was most suppressed early in the session and recovered gradually as the session progressed. This, of course, would lead to a high ratio, which, in turn, could lead to the faulty conclusion that rats can count, even if they actually cannot. This fact of uneven distribution of baseline responding was also pointed out by Imada and Nageishi (1982, p. 579). Then, in the most recent experiment on counting behavior in rats, Davis and Memmott (1983) used a more conservative within-subject method to assess the counting ability in rats and confirmed again that rats could count three unsignaled shocks, but not three signaled shocks, superimposed upon barpressing.

The purpose of the present experiment was to investigate the counting behavior of rats in a licking conditioned suppression situation, using both signaled and unsignaled shocks. The design was a 2×2 factorial one, and counting ability was assessed with reference to the independent control group for both

signaled and unsignaled shock conditions. Special care was taken not to allow the confounding of the temporal cues with the frequency cue, because shocks always occurred over time.

METHOD

Subjects

Forty experimentally naive male albino rats of the Sprague-Dawley strain were used as the subjects (8 subjects died during the experiment). When taming by handling began, the age and the mean body weight of the remaining 32 rats were approximately 70 days and 305.9 g (range = 244-367 g), respectively.

Apparatus

The apparatus consisted of four identical drinking boxes that had long been used in this laboratory for conditioned suppression experiments (e.g., Imada & Okamura, 1975; Nageishi & Imada, 1974; Yoshida, Kai, & Imada, 1969). Each drinking box had a grid floor and was 20 cm long, 10 cm wide, and 15 cm high (inside dimensions). In the lower part of the wall, at one narrow end of the box, was a hole (12 mm in diameter) through which the rat could gain access to a drinking tube. When a rat made contact with the drinking tube, a low-current circuit between the tube and the grid floor of the box was completed, which activated a contact relay located in the adjoining room. Four such boxes, each having a transparent ceiling, were placed on a table in such a way that each of the boxes was separated from the adjacent two by an equal distance and the drinking-hole wall of each faced outward from the center of the table. A fan was attached directly below the center of the table to produce a masking noise of approximately 65 dB(c). The apparatus was illuminated during the experiment by indirect lighting, which shed light of 1.5 lx into each box.

The signal was a 5-sec tone of 1000 Hz, 84 dB(c), delivered from a speaker fixed 200 cm directly above the center of the table. The shock was of .7-sec duration and was delivered from an ac shock source to the grid floor through a 250-kΩ current-limiting resistor in series with the rat. The shock intensity, as measured between a pair of bars of the grid floor, was 120 V for the first 10 days, 140 V for Days 11 to 35, and 180 V thereafter. Estimated current flows, assuming the resistance of rats as 100 kΩ and with the impedance of the voltmeter taken into account, were .43, .50, and .64 mA in the order described above.

Procedure

All rats were tamed by handling for 5 min/day for 5 days. Beginning with the 2nd day of handling, all rats were placed on a 50-min/day watering schedule that was maintained throughout the experiment or for the following 100 days. The subjects were then trained in the drinking boxes for 5 min daily to drink tap water there. After the daily training, the rats were returned to the home cages and given an opportunity to drink water there for another 50 min. This training of drinking was continued for 16 days. The mean number of licks on the last day of this licking training was 1,532 for the 32 rats that survived throughout the experiment.

Then the subjects were divided into four groups of equal size, matched in body weight and for the number of licks in the drinking box. Then the four groups underwent 80 days of shock treatment superimposed upon, but independent of, drinking behavior.

The experiment was a 2 × 2 factorial one, in which one factor was the presence or absence of a signal presented before each shock and the other was the fixed or variable number of shocks given within a session. The groups were designated as Group Sig-F (signaled-fixed), Group Sig-V (signaled-variable), Group Unsig-F (unsignaled-fixed), and Group Unsig-V (unsignaled-variable). In the signaled-shock groups, a 5-sec tone, which terminated simultaneously with the onset of a .7-sec shock, was always presented. In the unsignaled shock groups, no such signal was given at any time. In groups in which a fixed number of shocks were given

(hereafter called Groups F), three shocks were constantly given per session, whereas in groups in which a variable number of shocks were given (hereafter called Groups V), the number of shocks per session varied from day to day within a range of one to five, with a mean of three. More specifically, on any day, the subjects in Groups V received one, two, three, four, or five shocks per session, in random order within blocks of five sessions.

For Groups F, five different three-shock sequences were used. The temporal locations of the third shock of these sequences were 100, 180, 200, 225, and 290 sec, as measured from the beginning of the 300-sec session. For Groups V, the temporal location of the last shock of each session was matched with that for Groups F.[1] For both Groups F and Groups V, the minimum and the maximum intershock intervals were 20 and 155 sec, respectively, for the first 40 days, and 10 and 165 sec, respectively, for the last 40 days.

In each block of five sessions, there was one session in which three shocks were given exactly at the same temporal locations in both Groups V and Groups F. This was called the test day. Since there were five different three-shock sequences for Groups F, it took 5 test days, or five blocks, for Groups V to undergo all these sequences. The test days were Days 5, 9, 12, 17, 22, 30, 34, 37, 42, 47, 55, 59, 62, 67, 72, and 80.

RESULTS

Of the 40 rats originally used as subjects, three rats of Group Unsig-F died on Days 8, 39, and 49 of the shock phase, two of Group Unsig-V died on Days 18 and 48, and three of Group Sig-V died on Days 3, 38, and 54. In the analyses that follow, only the licking data for the 32 rats that survived to the end of the experiment were considered.

Post-Third-Shock Acceleration in Licking?

Figure 1 represents the mean post-third-shock licking ratios of the four groups for the last 4 test days.
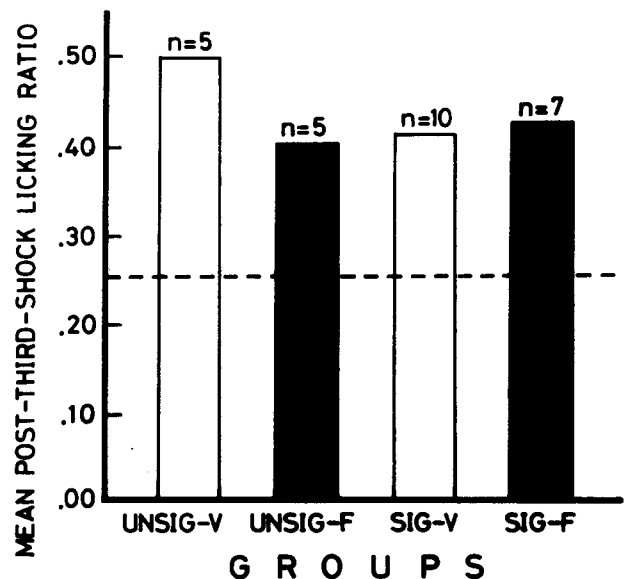

Figure 1. The means of the post-third-shock lick ratio for the four groups during the last 4 test days. The number of subjects used for the calculation of means is shown above each bar.

For each rat, the combined total number of licks following the third shocks of the last four test sessions was divided by the combined total number of licks in all sessions on these days. Since the calculation of these values is meaningful only when a rat has shown a reliable amount of licking, four rats (two rats each from Group Unsig-F and Group Unsig-V) were eliminated from the analysis because they showed no licking during these 4 test days. One rat from Group Unsig-F that showed only 183 licks on only 1 of the test days was also omitted as being an exceptional case, for the same reason.[2] The mean post-third-shock licking ratios were calculated for the remaining rats and are shown for the four groups separately in Figure 1. The mean proportion of time following the third shocks of the total session time of the last four test sessions was .254 and is shown by the horizontal line in Figure 1. The fact that all the bars extend above this horizontal line indicates that all groups licked proportionally more after the third shock than before it. The fact of importance in Figure 1 is that, in each condition, the dark bar is not higher than the corresponding white bar. The results of the t tests conducted for the signaled and unsignaled shock conditions separately between Groups V and Groups F indicate that the differences were nonsignificant in both conditions [t(8) = 1.00 and t(15) = .21, respectively].

Figure 2 represents the mean proportions of licks shown by each group after the first, second, and third shocks during the last 4 test days. Had rats licked with a constant rate throughout the session, the curves should have fitted the diagonal line of Figure 2. In all four groups, there is an abrupt change in the lick rate following the second shock.

Basal Rate of Licking

Figure 3 summarizes the means of the basal rate of licking for the last 4 test days, this time including all 32 rats that had survived. In calculating the basal rates, the numbers of licks during three 5-sec periods immediately preceding each of the three shocks were subtracted from the total number of licks of the session. As shown in Figure 3, the mean basal rates were higher in the signaled shock groups than in the unsignaled shock groups. The results of the 2 × 2 analysis of variance corrected for the unproportional marginal numbers revealed that the main effect of the signal tended to be significant [F(1,28) = 3.99, p < .10]. The main effect of the variability of number of shocks was not significant (F = 1). The interaction effect of the above two terms was also nonsignificant [F < 1].

DISCUSSION

The present experiment did not demonstrate counting behavior in the rat, either under the signaled shock condition, which was consistent with Davis & Memmott (1983), and Davis et al. (1975), or under the unsignaled shock condition, which contradicted the above two studies. It should be noted that the present result was obtained by using independent control groups, by which the effect of the frequency cues was assessed without being confounded with a possible effect of temporal cues. The total number of sessions given is also considered appropriate for detecting the counting ability, if any, of rats, because Seligman and Meyer (1970) obtained a positive effect with a total of 70 sessions.

The present negative results are consistent with those of Imada, Sugioka, Ohki, Ninohira, & Yamazaki (1978), who failed to show double-alternation patterning of licking suppression in rats under the double-alternation schedule of shock intensity, suggesting that rats cannot count even to two.

With regard to the disagreement between the present result and Davis's view, he emphasized the importance of the optimum trial density. Davis and Memmott (1982) wrote: "However, our success may be tied to having chosen an optimal number of events as well as a suitable temporal framework" (p. 565). Davis seemed to regard "three shocks per 30 min session" as being the ideal shock density (see Davis & Memmott, 1983). Davis (Note 1) suggested possible unconditional disruptive effects that 3 shocks in 5 min may have upon the organization of memories (30 min was considered more conducive to organization). This being so, however, one has to assume that this unconditional disruptive effect of
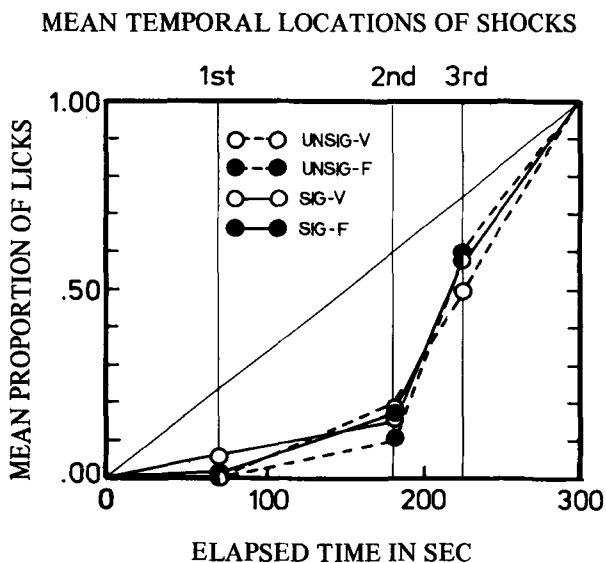
MEAN TEMPORAL LOCATIONS OF SHOCKS

Figure 2. Mean proportion of licks shown by the four groups by the time of the first, second, and third shocks. The data are for the last 4 test days and for the same subjects used for the analyses in Figure 1.
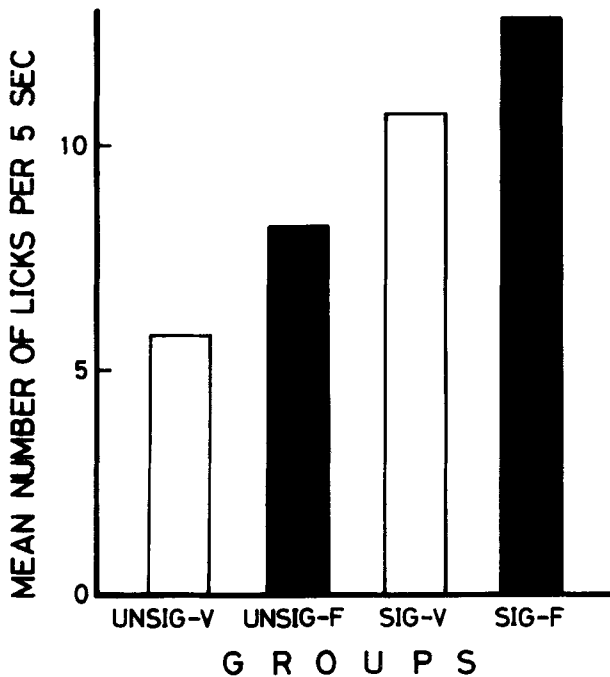
Figure 3. The mean basal rates of licking for the four groups during the last 4 test days.

3 shocks in 5 min should more than offset the advantage of counting to 3 within 5 min, and not within 30 min. One also has to give a clear theoretical explanation of why 3 shocks in 30 min is optimal and 6 shocks in 45 min is not (Davis et al., 1981). An experiment in which rats are required to count the number of appetitive events, such as food pellets, is also awaited. In this case, one does not need to bother with the problem of session length.[3]

One remarkable fact in the present experiment is that, as shown in Figure 2, rats withheld licking until they had been shocked once or twice: It appears that shocks have the effect of reducing freezing. This fact was noticed by Davis et al. (1981) in a bar-press-suppression situation. One should guard against mistakenly regarding these post-second-shock and post-third-shock accelerations of licking as evidence of counting ability in rats.

In the present experiment, the well-confirmed fact that the baseline responding of licking was suppressed to a greater extent in the unsignaled shock condition than in the signaled shock condition was again supported. The fact that the main effect of signals did not reach a conventional level of significance in the last 4 test days is not surprising. This effect usually appears very early in training (see Figure 2 of Imada & Okamura, 1975). The effect, however, seems to become smaller thereafter, due presumably to a relatively long shock-free period after each shock and/or to adaptation to shock. In the present experiment, when the same 2 × 2 analysis of variance was performed for the last 8 test days, the main effect of signal did reach a conventional level of significance [$F(1,28) = 4.34$, p < .05].

As for the effect of fixed/variable number of shocks per session upon basal rates of responding, the main effect was not significant. However, as shown in Figure 3, the basal rates were graphically lower in Groups V than in Groups F, a fact consistent with the results of Seligman and Meyer (1970). Their HU group, in which 1-5 unpredictable high shocks per session were given, showed greater suppression of the basal rate of barpressing and developed more ulcers than did the HU-3 group, to which three unpredictable high shocks were invariably given. Two considerations are in order here. In Seligman and Meyer's study, apart from the possible confounding effect of temporal cues described before[1], it is a logical possibility that "rats cannot count, but they can react differentially to situations involving uncertainty (1-5 shocks) and certainty (3 shocks) by showing a different overall level of response in a suppression experiment" (Imada & Nageishi, 1982, pp. 579-580). The second point is that the lower (although not significantly lower) basal rates in Groups V than in Groups F, shown in Figure 3, need further consideration. If the shock sequences employed on days immediately preceding test days happened to be those involving four or five shocks, the relatively low rates of Groups V could be attributed to the overnight disrupting effects of these shock sequences upon the licking rates on test days. Of the last 8 test days, 6 were preceded by sequences involving four or five shocks. In the remaining two (Days 59 and 62), the immediately preceding sequences involved one and two shocks. The mean basal rates of these 2 test days were 4.92, 8.41, 9.72, and 10.73, in the order from left to right for the groups shown in Figure 3. The general picture of these rates is the same as that shown in Figure 3.

To recapitulate, whatever the reason, there was no evidence in the present experiment that a rat can count. It seems that we are still at the stage in which further empirical data are needed in this specific area of study.

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NOTES

1. Had shocks been given more toward the end of a session in Groups V than in Groups F, the rat's licking toward the end of the session would be more likely to be less in Groups V than in Groups F. This possible confounding effect of temporal cues had to be carefully eliminated in order to make adequate comparisons of the post-third-shock ratios between Groups F and Groups V on matched or test days, as described in the next paragraph of the text. Although Seligman and Meyer (1970) also did the same between-subject comparison in assessing counting ability in rats, it is not clear if they did this kind of between-group matching in the temporal location of the last shock for *all* the sessions. If they did not, the post-third-shock ratios of Groups V (HU group in their experiment) on test days would have been less than those of Groups F (their HU-3 group), which may have led to the over-estimation of counting ability in rats.

2. Inclusion of this rat distorts the data in a conservative direction, that is, in the direction that further heightens the bar for Group Unsig-V.

3. Recently, Fernandes and Church (1982) reported evidence that rats could learn to press one of the two levers for food, and, in doing so, to discriminate correctly two bursts of white noise from four bursts. However, it seems that the explanation of this phenomenon does not necessarily require "organization of memories," which Davis assumes in explaining counting behavior. Incidentally, in the Fernandes and Church (1982) study, the conditioned stimulus was either of 1.2- or 3.2-sec duration and contained either 2 or 4 bursts of noise, each lasting for .2 sec. The confounding effect of temporal cues was also controlled.