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THE DISCRIMINATIVE CONTROL OF FREE-OPERANT AVOIDANCE DESPITE EXPOSURE TO SHOCK DURING THE STIMULUS CORRELATED WITH NONREINFORCEMENT[1]

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Four rats were trained in darkness on a free-operant avoidance procedure in which shocks occurred randomly, but lever presses could reduce their frequency. Discrimination training followed, during which responses in light continued to reduce shock frequency, but responses in darkness had no effect. During each cycle, the light period was 4 min, while darkness lasted only until a 20-sec interval had elapsed without a response. This no-response requirement was increased to 40 sec for three animals and eventually to 60 sec for two of them. Discriminative control developed, despite a greater shock density in the dark, with response rate and number of responses per shock maintained or increasing during light and decreasing to very low values in darkness. Two animals were later exposed to a procedure in which shock density was unaffected by responding either in light or darkness. A 60-sec no-response requirement was continued in the dark. Discriminative control persisted through 42 sessions for one animal and required 45 sessions to approach extinction for the other animal. The role of the light as a potential conditioned reinforcer of other behavior in the dark was implicated in the development and persistence of discriminative control. These data support shock-frequency reduction as reinforcement for avoidance behavior.

Experiments on the discriminative control of free-operant avoidance have typically employed a procedure in which the avoidance schedule remains in effect during one stimulus condition (S^D), and all shocks are eliminated during a second stimulus condition (S^Δ). This differs from procedures used in the appetitive case. That is, elimination of shocks does not constitute an extinction procedure. Rather, as Davenport, Coger, and Spector (1970) and, more recently, Smith and Hineline (1973) have argued, elimination of shocks is a drive-reduction operation, analogous to satiation in the appetitive case. A more appropriate avoidance discrimination procedure would instead continue the presentation of shocks during S^Δ, but eliminate the avoidance schedule. Thus, S^Δ in the avoidance situation, as in appetitive discriminations, would constitute the stimulus correlated with the absence of reinforcement, not with the absence of the drive operation. The present experiment investigated the discriminative control of free-operant avoidance in rats with a procedure of the latter type.

A previous attempt by Appel (1960) to achieve discriminative control of avoidance responding in rats with shocks present during the S^Δ was unsuccessful. After training on a Sidman-type avoidance procedure, rats were exposed to the usual avoidance schedule in the presence of one stimulus, but in its absence, shocks occurred at fixed intervals independently of responding. None of the four animals gave any evidence of discriminative control. Furthermore, three of four animals first trained to discriminate by a procedure that eliminated all shocks during S^Δ, failed to maintain the discrimination when shocks were introduced during S^Δ. On the other hand, Hake (1968) was able to train seven of eight squirrel monkeys to discriminate with a multiple schedule that alternated periodic unavoidable shocks in the presence of one stimulus with a Sidman-type avoidance schedule in the presence of another. Discriminative control became evident, however, only after many sessions (a mean of 20), each lasting from 3 to 6 hr.

The possible interference by shocks during S^Δ with the development of discriminative control of avoidance responding is in line with a substantial body of data indicating that avoidance responding tends to be very

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persistent when shocks continue during an extinction phase (*e.g.*, Kelleher, Riddle, and Cook, 1963; Morse and Kelleher, 1970; Powell, 1972; Sidman, Herrnstein, and Conrad, 1957). There are at least three ways in which shocks during S^{Δ} may interfere with the acquisition of discriminative control:

1. The shocks may elicit responding, or behavior such as biting, which adds to the recorded response total. Hake and Campbell (1972), Hutchinson, Renfrew, and Young (1971), Pear, Moody, and Persinger (1972), Powell (1972), and Smith (1973) have all emphasized the possible role of shock elicitation in the persistence of responding during avoidance extinction. Extensive observations of the influence of shock-elicited aggression on escape and avoidance behavior were also reported by Azrin, Hutchinson, and Hake (1967).

2. Brief shocks may support adventitious escape conditioning (Keehn and Chaudrey, 1964; Migler, 1963).

3. The shocks may function as discriminative stimuli (Sidman, 1966) since, during acquisition, responses in their presence or shortly thereafter may be followed by timeout from shock, and this state of affairs may continue during the S^D periods of discrimination training. Related to this is the general reduction in discriminability between the stimulus complexes denoted as S^D and S^{Δ} by virtue of the presence during both periods of the highly salient shock stimuli. These stimuli may even "overshadow" (Kamin, 1969; Pavlov, 1927) nonshock stimuli experimentally presented as S^D and S^{Δ}.

In the present study, a shock-frequency reduction schedule of the type introduced by Herrnstein and Hineline (1966) was used for avoidance conditioning and during the S^D periods of discrimination training. The Herrnstein-Hineline procedure schedules shocks at random intervals according to two probability values. The higher probability is in effect as long as an animal fails to respond. A response lowers the shock probability. The next scheduled shock on the low-probability schedule returns control to the high-probability schedule. Because of the random distribution of shocks on both schedules, a response may be followed by shock immediately or after a brief interval. Unlike a Sidman-type procedure, the animal cannot avoid shocks entirely. In general, however, shock frequency is inversely related to response rate. With this procedure, elimination of shock-frequency reduction (*i.e.*, removal of the avoidance contingency) during S^{Δ} markedly increases shock density, and no other changes occur. Thus, the time distribution of shock is random both in S^D and S^{Δ}, but shock density is unaffected by responses in S^{Δ}. To enhance the possibility of achieving discriminative control, a potentially more efficient discrimination training procedure than that used by Appel was employed. The S^D interval was fixed in duration, but the duration of S^{Δ} was dependent on fulfillment of a no-response requirement.

The efficacy of shock-frequency reduction as a reinforcer for avoidance behavior has been questioned by Bolles (1970). He pointed out that the large number of shocks required with the Herrnstein-Hineline procedure before the avoidance response appears in strength contrasts sharply with the very rapid acquisition of avoidance behavior observed in other situations. Yet, shock-frequency reduction even without delay of shock onset has been shown to be a sufficient condition for avoidance acquisition and maintenance (Lambert, Bersh, Hineline, and Smith, 1973). The development of discriminative control of avoidance behavior on the basis of the presence *versus* the absence of shock-frequency reduction would provide further support for the possible role played by such reinforcement in avoidance conditioning.

METHOD

Subjects

Four male Sprague-Dawley rats (designated 3, 4-A, 4-B, and 6), which weighed 250 to 300 g at the start of the experiment, were housed individually and given free access to food and water in their home cages.

Apparatus

The experimental chamber (Lehigh Valley Model 11414) consisted of Plexiglas sidewalls and ceiling, stainless-steel front and rear walls, and a grid floor. The internal dimensions were 30.2 cm long, 24 cm wide, and 36.8 cm high. A stainless-steel lever (LVE Model 1352) requiring a force of approximately 10 g (0.1 N) to depress and measuring 2.7 cm wide and 0.9 cm in thickness, protruded 2.5 cm through the front wall. The lever center was located 3 cm above the grid floor 3.5 cm from the rightmost sidewall. Stainless-steel grid bars 0.5 cm in diameter mounted perpendicular to the sidewalls and spaced 1.8 cm apart (center to center) provided the shock delivery surface. Shocks of 0.5-sec duration and 0.8-mA intensity measured at the grids were delivered to the grid floor through LVE shock scrambler Model 1311SS in series with a 150 K ohm resistor. The overhead houselight was a 7.5-W Tung-Sol lamp in a Dialco amber lens. A punched-tape reader and standard switching relay circuitry supplied programming and controlled stimulus and shock presentation.

Procedure

As indicated in the introduction, the random-shock procedure developed by Herrnstein and Hineline (1966) was used for avoidance conditioning. Two channels of punched paper tape controlled presentation of shocks. Shocks were scheduled randomly in time by both channels but occurred with a higher probability on one of them. As long as an animal failed to respond, shocks occurred with a probability of approximately 0.35 per 2 sec, or about one shock per 6 sec. A response switched control to a second channel on which shocks occurred with a probability of approximately 0.10 per 2 sec, or about one shock per 20 sec. The probability ratio was, therefore, about 3.5 to 1. Additional responses on the low-probability schedule had no effect, and the first shock on that schedule returned control to the high-probability channel. With such a procedure, a shock may follow a response immediately or within a short interval. Up to a point, however, the higher the animal's response rate, the lower the shock rate. Daily sessions lasted 100 min. An animal could receive more than 1000 shocks, therefore, if it failed to respond at all.

Each animal was given one operant-level session without shocks, followed by at least 32 avoidance-conditioning sessions, during which the test chamber was dark. For discrimination training, the illumination provided by the houselight served as the S^D; its absence was the S^Δ. Since the animals had been conditioned in the dark, this was a conservative procedure that might be expected to increase the difficulty of achieving discriminative control. During S^D, the usual shock-frequency reduction procedure was in effect. During S^Δ, on the other hand, the high-probability channel was always in control of shock, *i.e.*, irrespective of responding. Thus, shock probability during S^Δ was a constant 0.35 per 2 sec, but during S^D was reduced from 0.35 per 2 sec to 0.10 per 2 sec by responses made when the high-probability channel was in control. S^D periods lasted 4 min. The duration of an S^Δ, however, depended on the animal's behavior. At the beginning of discrimination training, a 20-sec no-response requirement was established for S^Δ. That is, S^Δ continued until 20 sec elapsed without a response, at which time the next S^D began. Thus, S^Δ duration could be as brief as 20 sec, or could last the entire session if an animal continued to respond at intervals shorter than 20 sec. For three rats (3, 6, 4-A), the no-response requirement was lengthened to 40 sec when discriminative control of responding was evident under the 20-sec requirement. The requirement was finally extended to 60 sec for Rats 3 and 6. Rat 4-B died as the result of an accident while still in the 20-sec phase. The no-response requirement in S^Δ was used to increase the effectiveness of discrimination training by inserting a delay between the last S^Δ response and the occurrence of the S^D. In the course of discrimination training, the latter becomes a potential conditioned reinforcer. Increases in the duration of the no-response requirement were designed to ensure that discriminative control would be maintained with longer S^Δ periods.

Rats 3 and 6, the two animals exposed to the 60-sec no-response requirement, later received, respectively, 45 and 42 sessions of discrimination extinction. The 60-sec no-response requirement was continued for S^Δ, but responses in S^D no longer changed shock probability, so that in S^D as in S^Δ the probability remained fixed at 0.35 per 2 sec.

RESULTS

Figure 1 presents daily response rates for each animal for all phases of training. Rates for two of the animals (4-B and 4-A) were fairly stable by the end of the acquisition phase, while rates for the other two, though substantial, showed little evidence of stability after 33 days of avoidance conditioning. The start of discrimination training produced a sharp rate increase in the presence of S^Δ. This

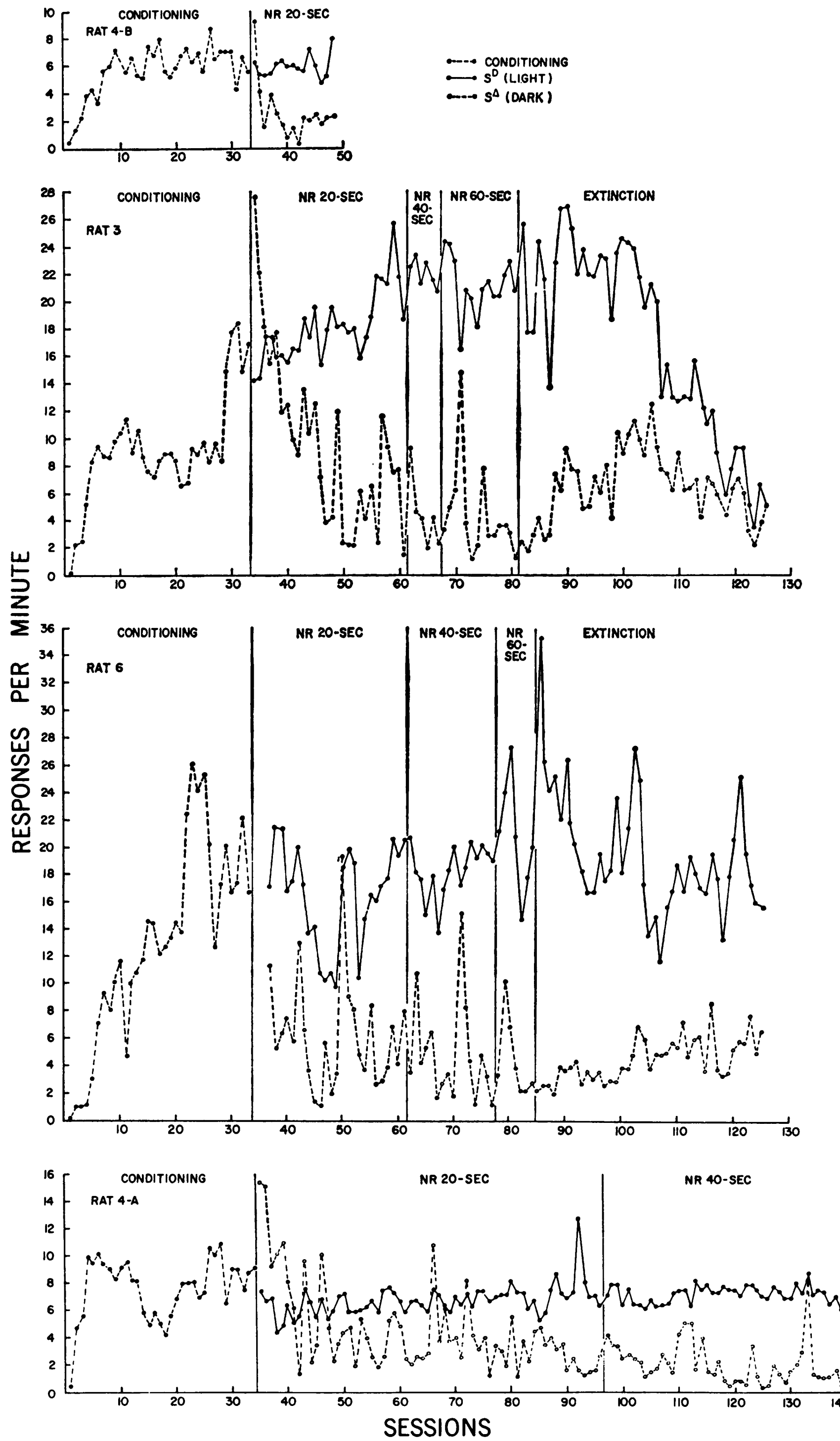

Fig. 1. Response rate per session for the avoidance conditioning, discrimination, and extinction of discrimination phases of the experiment. During the discrimination phases, rates are presented separately for S^D and S^Δ periods. NR followed by time in seconds indicates the interval of no-response required during S^Δ for the next presentation of the S^D.

correlates with a substantial increase in shock density during S^{Δ}. The S^{Δ} rate dropped to a level below the S^{D} rate within 3, 4, and 8 sessions for Rats 4-B, 3, and 4-A respectively. Except for occasional lapses, particularly in the case of Rat 4-A, the S^{Δ} rate remained consistently below the S^{D} rate throughout discrimination training. Data for the first three days of discrimination training are missing for Rat 6 because of recorder malfunction, but by the fourth day its S^{Δ} rate was already lower than the S^{D} rate. Especially noteworthy is the rapid decrease in S^{Δ} rate for Rat 4-B. From an initial rate of 9.2 responses per minute, its rate dropped to fewer than two responses per minute by Day 5 and thereafter fluctuated around one response per minute. For all animals, on the other hand, the S^{D} rate tended to be maintained (4-B, 6, 4-A) or to increase with discrimination training (Rat 3).

Rats 3 and 6 were exposed to approximately six weeks of daily sessions, during which shock probability remained fixed at the high value and was unaffected by responding either during S^{D} or S^{Δ} (extinction of discrimination). For Rat 3, the S^{D} rate was well maintained for the first 25 extinction sessions and then showed a progressive drop to about one-fourth the rate prevailing at the outset of extinction. After six days of extinction, the S^{Δ} rate increased to double or triple its initial value and then declined along with the decrease in S^{D} rate. Only after about 40 extinction sessions did the S^{D} and S^{Δ} rates become roughly equal. For Rat 6, the S^{D} rate reached a peak of about 35 responses per minute on the first day of extinction, well above any rate recorded during the previous 84 days of avoidance conditioning and discrimination training. The rate then returned rapidly to a level comparable to that prevailing during discrimination training, where it remained for the rest of the extinction phase. For this rat, the S^{Δ} rate showed no tendency to rise during the first several weeks of extinction and then increased slowly to a moderately higher level. However, six weeks of extinction failed to bring about even approximate equalization of the S^{D} and S^{Δ} rates.

With continuing exposure, shocks assume increasing control over responding on the Herrnstein-Hineline procedure (Herrnstein and Hineline, 1966). They reported that, as conditioning proceeds, an increasing proportion of responses occur during or immediately after shocks. Accordingly, a second measure of performance is provided by a responses-per-shock ratio (R/Sh). This ratio is graphed for the discrimination phases of the experiment in Figure 2. In general, the curves of this graph parallel the response-rate curves, but show considerably less variability. Stability of the ratio was especially evident for S^{Δ} responding during extinction by Rat 6 and for both S^{D} and S^{Δ} responding during the 40-sec no-response phase by Rat 4-A. In addition, transitions to longer no-response requirements had little or no effect upon the R/Sh ratios for S^{Δ} responding, whereas such transitions appeared to produce temporary increases in S^{Δ} response rate. The most significant departures from the rate data occurred for S^{D} during extinction. Thus, the R/Sh ratio during S^{D} decreased for both Rats 3 and 6 at the very outset of extinction, with the decline for Rat 3 a steep one. These changes contrast with the sharp initial increase in response rate for Rat 6 and the smaller one for Rat 3, shown in Figure 1. To some extent, the drop in R/Sh ratio may be artifactual. Extinction involved a large increase in shock density during S^{D}. Smaller average time intervals between shock reduced the opportunity for separate responding to each shock. In fact, the higher density increased the frequency of occurrence of shocks in rapid succession, so that a series of shocks may have been functionally equivalent to a single shock of longer duration. Such a potential ceiling effect does not, of course, account for the much lower R/Sh ratios found for S^{Δ} responding. Moreover, despite the fact that shock density during the extinction phase was equal in S^{D} and S^{Δ}, the R/Sh ratios for Rat 3 were clearly separate until the end of the extinction phase, and the gap between the S^{D} and S^{Δ} ratios for Rat 6 remained sizeable throughout the six weeks of extinction.

Each S^{Δ} period ended, of course, with a no-response interval equal to the no-response requirement then in effect. It can be seen from Figures 1 and 2, however, that inclusion of this irreducible no-response time in the determination of S^{Δ} rate and responses per shock ratios did not materially restrict these measures. As noted, S^{Δ} rate at the outset of discrimination training greatly *exceeded* the S^{D} rate, while R/Sh values were approximately equal for S^{D} and S^{Δ}. In addition, a considera-

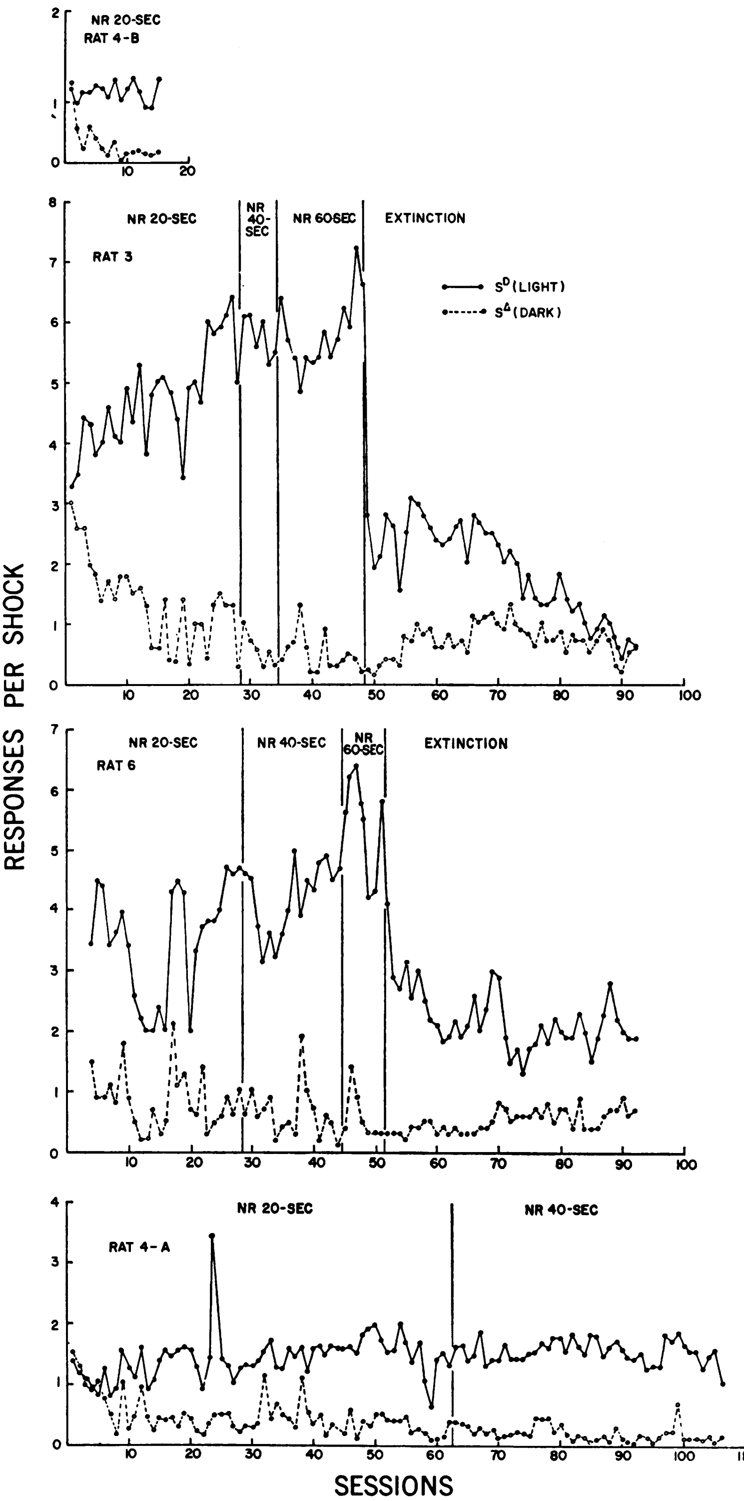

Fig. 2. Number of responses per shock for the avoidance discrimination and extinction of discrimination phases of the experiment, computed separately for S^D and S^Δ periods. NR followed by time in seconds indicates the interval of no-response required during S^Δ for the next presentation of the S^D.

ble range of variation in S^{Δ} rate was observed during later phases of discrimination training, especially for Rats 3 and 6. For example, Rat 3 manifested rates as low as one per minute and as high as 15 per minute during the NR 60-sec phase. Accordingly, the systematic decrease in S^{Δ} rate and R/Sh with discrimination training, and the *rise* in these measures during the extinction of discrimination phase, are not attributable to the fact that the time base for their calculation incorporated the no-response interval.

Further evidence for the control acquired by the S^{Δ} over responding is provided by Figure 3. This figure presents the mean time in seconds by which S^{Δ} duration exceeded the no-response requirement. Excess, rather than absolute, duration is graphed to make the data comparable for different values of the no-response requirement. Except for Rat 6, whose data for the first three discrimination sessions are missing, the excess duration decreased, to near-zero value for Rats 3 and 4-A. Though somewhat irregular, the curve for Rat 6 also showed a preponderance of near-zero values. A temporary rise in the excess duration accompanied transitions to longer no-response requirements, but the curves again approached the zero level. A near-zero mean excess duration demonstrates a strong tendency on the part of the animals to stop responding at the onset of S^{Δ} or very shortly thereafter. Exposure to the extinction of discrimination procedure led to an increase in the mean excess duration. The curves parallel the changes in S^{Δ} rate, quite closely in the case of Rat 3. The final sharp rise in the mean excess duration for Rat 6, when combined with the levelling of its S^{Δ} rate curve, indicates a tendency for that animal to increase the spacing of its S^{Δ} responses during extinction.

DISCUSSION

The data indicate that discriminative control of free-operant avoidance responding may develop in rats when shocks continue during an S^{Δ} in which the avoidance schedule is eliminated. In the present experiment, avoidance conditioning was carried out in a dark experimental chamber. Despite the use of darkness as the S^{Δ} in subsequent discrimination training, and despite the increase in shock density during S^{Δ} (often to double or triple the S^{D} value), discriminative control was observed. The development of such discriminative control was probably facilitated by a training procedure that required the animal to withhold the response during S^{Δ} for a prespecified interval before the S^{D} was again presented. As discrimination training continued, the S^{D} presumably became a conditioned reinforcer and strengthened the tendency to withhold the response in S^{Δ}, or, at a minimum, its presentation involved a delay of reinforcement for the last S^{Δ} response equal to the duration of the no-response requirement. In either case, the acquisition of discriminative control would be aided relative to a procedure, such as that used by Appel (1960), that incorporates a fixed-duration S^{Δ}.

It has frequently been reported that responding produced by free-operant avoidance procedures may be highly resistant to elimination of the avoidance schedule when shocks continue on a response-independent basis (*e.g.*, Powell, 1972). The present results suggest that, beyond simple response perseveration, discriminative control of free-operant avoidance responding also tends to persist when extinction (*i.e.*, elimination of the avoidance schedule in S^{D}) is attempted with response-independent shocks present during both S^{D} and S^{Δ}. Forty-five sessions were required to produce near-complete extinction for one animal. For a second animal, approximately the same amount of exposure to the extinction procedure produced little narrowing of the gap between S^{D} and S^{Δ} rate or responses/shock. Since the no-response requirement for S^{Δ} was continued during the extinction phase, the persistence of discriminative control may again reflect reinforcement of nonresponding or of competing responses by the S^{D}. As noted earlier, the S^{D} might be expected to acquire conditioned reinforcement properties during discrimination training. If this is the case, the durability of discriminative control in turn suggests the long-lasting character of such conditioned reinforcement properties.

Contrary to Bolles' (1970) assertion, the potency of shock-frequency reduction as a reinforcer for avoidance behavior proved to be great. Discriminative control developed rapidly despite a higher density of shocks during S^{Δ} than during S^{D} and persisted in the face of an extinction procedure that eliminated

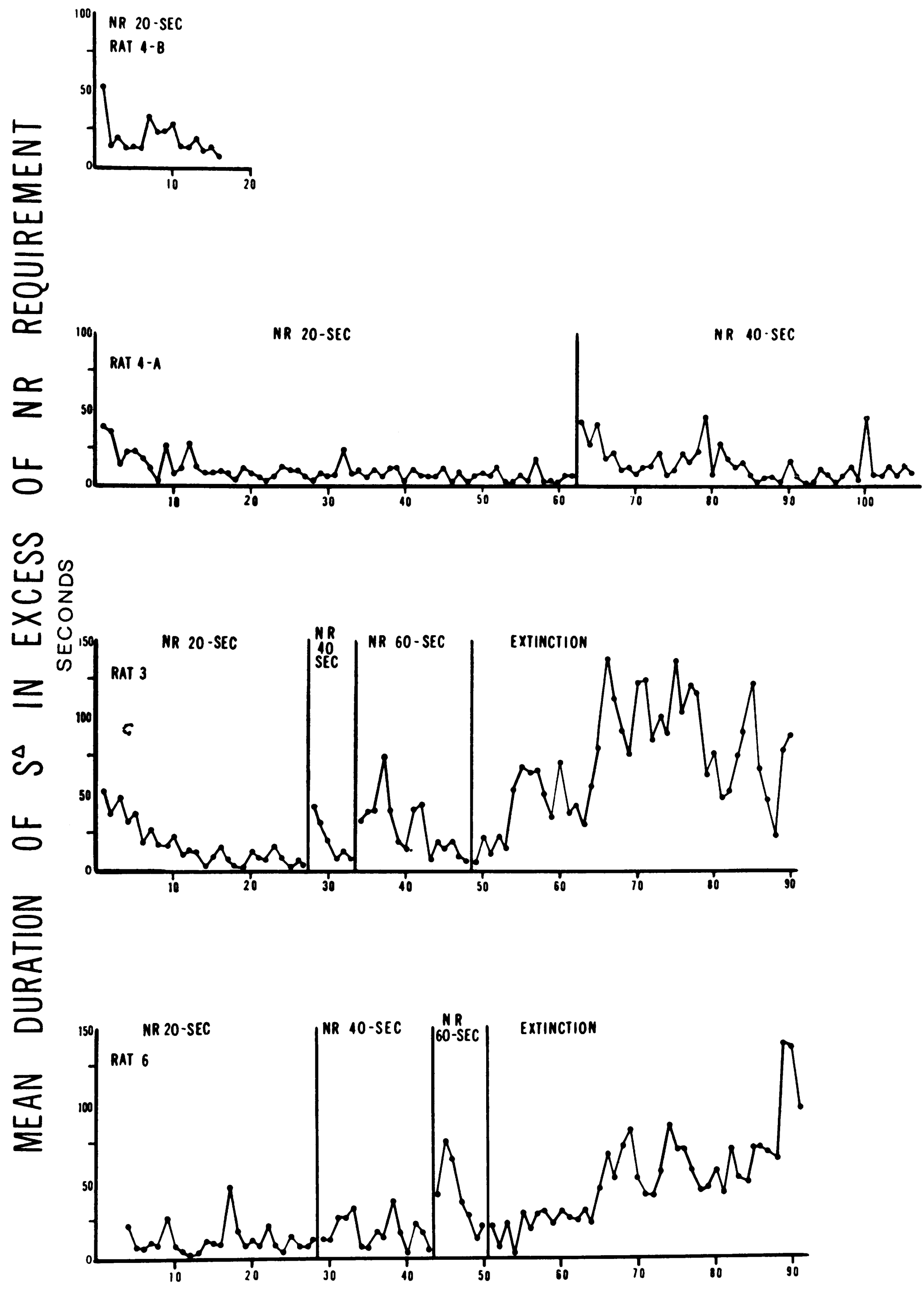

Fig. 3. Mean S$^{\Delta}$ duration in excess of the no-response requirement for the avoidance discrimination and extinction of discrimination phases of the experiment. NR followed by time in seconds indicates the interval of no-response required during S$^{\Delta}$ for the next presentation of the S^{D}.

the avoidance schedule and equated shock density in S^D and S^Δ. This conclusion holds even if such results are attributable to the conditioned reinforcement of competing behavior in S^Δ by the subsequent occurrence of S^D. Presumably, any conditioned reinforcement properties acquired by the S^D stem from the contingency of shock-frequency reduction upon lever-press responding in its presence.

The present results also have implications for the issue of shock-elicited responding. Pear *et al.* (1972) and Powell (1972), among others, assigned a major role to shock elicitation in the persistence of responding when response-independent shocks are present during avoidance extinction. In the present experiment, however, responding to shocks came under a high degree of discriminative control. In the advanced stages of discrimination training, few lever depressions, whatever their topographic basis (*e.g.*, biting), were induced by shocks during S^Δ. Thus, responses-per-shock ratios were consistently 0.2 or below for three of the animals. For one of them (Rat 4-A) maintained on the discrimination procedure longer than the others, ratios were frequently below 0.1 toward the end of training. This hardly resembles an unconditioned respondent, and it is difficult to see in what sense the term "shock elicitation" applies. In fact, it was observed that animals failed to respond to shocks during S^Δ even while "poised to press" the lever. Rats 3 and 6 often made a flurry of responses immediately upon light onset and before any shocks had occurred in the presence of the light. They then resumed the typical pattern of responding during or immediately after shocks in the presence of the light. If this control by S^Δ over shock-elicited responding is the product of the occurrence of the S^D after a no-response requirement has been met during S^Δ, then the conditioned reinforcement of other responses may be added to punishment (Ulrich *et al.*, 1969) as a technique for suppressing shock-elicited responding.

Perhaps also a discriminative, rather than an eliciting, function of shocks should be given greater emphasis in free-operant avoidance conditioning and extinction. Certainly the present findings are consistent with a discriminative status for shock. A compound of light and shock, rather than light itself, was the S^D during the discrimination phase. Similarly, shock plus the absence of light served as a compound S^Δ. In view of the control exerted by shocks over responding during the avoidance conditioning phase, and in view of their highly salient character, the absence of light may tentatively be considered to have acquired conditioned inhibitory properties. Indeed, the effect of the absence of light appears to meet the requirements of the summation test as described by Rescorla (1969), as well as those suggested by Hearst, Besley, and Farthing (1970) in their definition of a conditioned inhibitor. It remains to be seen, of course, whether an S^Δ resulting from the type of discriminative training procedure used here can inhibit responses to shocks of higher intensity than the 0.8-mA shocks of the present experiment.

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