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REDUCTION OF SHOCK DURATION AS NEGATIVE REINFORCEMENT IN FREE-OPERANT AVOIDANCE

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Rats were trained on a free-operant procedure in which shock duration was controlled by responses within a limited range of interresponse times. Shocks of 1.6-mA intensity occurred randomly with average density of 10 shocks per minute. As long as interresponse times were 15 seconds or less, any shocks received were at the briefer of two durations (.3 second). Whenever interresponse times exceeded 15 seconds, any shocks received were at the longer duration (1.0 second). For six of eight animals, avoidance responding developed quickly and reached levels of better than 90%. Four yoked animals stopped responding within the first few sessions. Shock duration reduction without change in shock probability or intensity was sufficient for the acquisition and maintenance of avoidance responding.

Key words: avoidance, shock duration reduction, negative reinforcement, rats

The contribution of the duration of a shock to its aversiveness is well established. In fact, it appears to be as powerful an attribute of shock as intensity. Thus, Church, Raymond, and Beauchamp (1967) reported that the suppressive effect of punishment was linearly related to the logarithm of the product of intensity and duration. Boroczi, Storms, and Broen (1964) and Storms, Boroczi, and Broen (1965) kept intensity constant and showed that the suppressive effect of punishment was directly related to shock duration whereas rate of recovery from punishment was inversely related to duration. Leander (1973), using the free-operant avoidance procedure developed by Sidman (1953), found that response rates were a positive linear function and shock rates a negative linear function of the logarithm of the intensity-duration product. Under his conditions, a .3 product (1 mA, .3 sec) constituted a threshold value for avoidance conditioning. In other investigations, Sidman avoidance has been acquired and maintained with considerably smaller values of this product. Riess and Farrar (1972) were successful with 1.3 mA shocks of .15 or .2 sec duration. After initial training with .15 sec, 2.5 mA shocks, Riess (1970) had no difficulty in maintaining avoidance responding with .5 mA shocks of .2 or .3 sec duration. Keehn (1963) found that intrasession response rates in Sidman avoidance were a function of shock duration, but two of three animals responded at rates of 6 to 10 responses per min even when shocks were as brief as .05 sec. Unfortunately, he failed to report shock intensity.

Presumably, a reduction in shock duration will function as negative reinforcement to maintain escape and avoidance behavior. Of course, shock escape, by its very nature, produces a reduction in shock duration. However, the change in duration is entirely confounded with the resulting reduction to zero of shock intensity. An evaluation of shock duration reduction as negative reinforcement requires a procedure which can separate its influence from the effects of changes in other salient characteristics of shock. The free-operant avoidance procedure developed by Bersh and Alloy (1978) to investigate shock intensity reduction as negative reinforcement was used in the present study to demonstrate the efficacy of shock duration reduction per se in the acquisition and maintenance of avoidance behavior. This procedure exposes an animal to response-independent shock occurrence, but permits the animal to terminate or avoid a more aversive condition in favor of a less (though still) aversive condition by emitting responses which meet an interresponse time

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(IRT) requirement. In the present experiment, only the duration of shock was subject to response control.

METHOD

Subjects

Twelve naive male Holtzman rats, 70 to 80 days old and weighing 250 to 300 g on arrival at the laboratory, were housed individually. Throughout the experiment, the animals had continual access to food and water in their home cages.

Apparatus

The experimental chamber (Lehigh Valley Electronics, 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, 24.0 cm wide and 36.8 cm high. A stainless-steel lever (Lehigh Valley Electronics, Model 1352), requiring a force of approximately 10 g (.1 *N*) to depress and measuring 2.7 cm wide and .9 cm in thickness, protruded 2.5 cm through the front wall. The center of the lever was located 3.0 cm above the grid floor, 3.5 cm from the right sidewall. Stainless-steel grid bars, .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 1.6-mA intensity measured at the grids were delivered through a shock scrambler (Lehigh Valley Electronics, Model 1311SS) in series with a 150-KΩ resistor. Shock duration was either .3 sec or 1.0 sec. White masking noise of 70 dB, delivered through a large speaker to the experimental room, was constantly present throughout each experimental session. Programming and recording equipment was located in an adjacent room.

Procedure

Shocks occurred at random intervals throughout the session, with an average density of approximately 10 shocks per min. The range of intershock intervals was 1.6 to 25.6 sec. At the start of the session, shocks were of 1.0-sec duration (long-duration shocks). The period of long-duration shocks continued until the animal made a pair of responses with an IRT of 15 sec or less. This introduced a 15-sec period during which shocks of .3-sec duration (brief-duration shocks) might occur. Each subsequent response which occurred 15 sec or less after the previous response reset a timer and extended the period of exposure to brief-duration shocks. Thus, as long as the IRT did not exceed 15 sec, the period of brief-duration shocks continued. Whenever 15 sec elapsed without a response, a period of long-duration shocks began and continued until the animal again made a pair of responses with an IRT no greater than 15 sec. Shock density (i.e., the number of shock occurrences per unit time) was completely independent of duration as well as of responding. Several features of the procedure should be emphasized: (a) each animal received all shocks, approximately 1,000 per session, and only the shock duration was affected by the animal's behavior. (b) failure to meet the IRT requirement did not inevitably result in exposure to long-duration shocks. Since intershock intervals might be as great as 25.6 sec, an animal might emit a pair of responses which met the IRT requirement before the next scheduled shock had occurred, thus terminating the period without the occurrence of a long-duration shock. Similarly, a period of brief-duration shocks need not involve the actual occurrence of a brief shock, inasmuch as the IRT limit might be exceeded before the next scheduled shock had occurred. Obviously, however, continued failure to meet the IRT requirement increased the frequency of long-duration shocks received, whereas continued responding within the IRT limit increased the frequency of brief-duration shocks received.

Animals were trained 5 days a week in sessions lasting 100 min. Of the 8 animals exposed to the avoidance contingencies described above, 6 acquired the response and were observed for a minimum of 13 sessions and for as long as 40 sessions. When training was terminated, these animals were consistently avoiding at least 85% of the long-duration shocks, and the session-to-session variation over the last 5 sessions was less than 10% of the 5-day mean. The remaining 2 animals did not acquire the lever-press response and training was terminated for them after 27 sessions.

Each of four additional animals (Rats 2Y, 3Y, 4Y, and 5Y) was yoked to an animal that acquired the response (Rats 2C, 3C, 4C, and 5C, respectively). Whenever an avoidance animal was shocked, its yoked partner received a shock identical in intensity and duration. The yoked rats also had a lever in their ex-

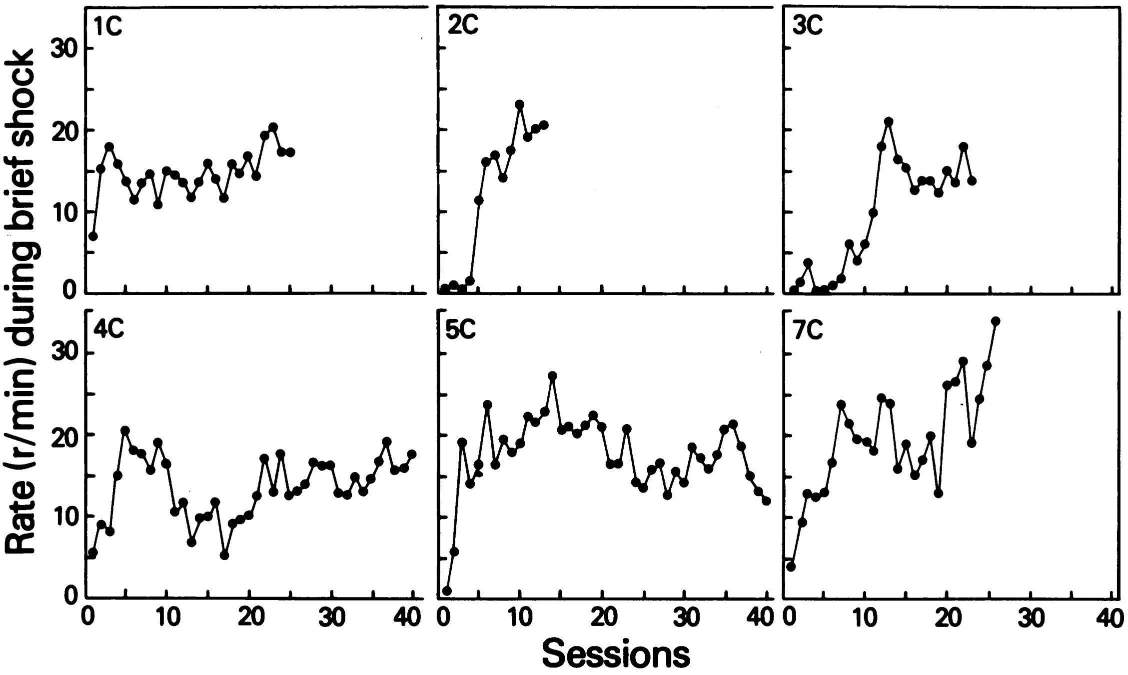

Fig. 1. Responses per min during periods of brief-duration (.3 sec) shock. Each point is the rate for the last hour of a 100-min session.

perimental chambers, but responding on this lever had no effect.

RESULTS

Performances of the rats that acquired the response are presented in Figures 1 and 2 and in Table 1. Data are based upon the last hour of each 100-min session to reduce the influence of warm-up; warm-up effects will be examined in later figures. Figure 1 shows response rates during periods of brief-duration (.3 sec) shocks. Though quite variable, these rates increased sharply within the first five sessions for all animals except Rat 3C, for which the increase occurred after the tenth session.

Table 1

Number of responses per long (1.0 sec) shock. Values are based on the last hour of the session to minimize the influence of warm-up.

Subject	*First Session*	*Mean and range: last 5 sessions*
1C	.22	1.18 .91-1.39
2C	.06	1.06 .68-1.28
3C	.04	1.01 .50-1.58
4C	.22	1.20 1.02-1.35
5C	.14	1.41 1.00-1.69
7C	.16	0.85 .48-1.36

The effect of training upon responding during periods of long-duration (1.0 sec) shocks is summarized in Table 1 in the form of the number of responses per shock for the first session and the mean number of responses per shock for the last five sessions. The level of such responding increased substantially for all animals, and in view of the fact that mean shock density remained constant, indicated more rapid termination of periods of long-duration shocks. Table 1 shows that the value for the first session did not overlap with the values for the last five sessions. Since a minimum of two responses was required to terminate periods of long-duration shocks, it is evident that the animals often received more than one long-duration shock before pressing twice with an IRT no greater than 15 sec. Rat 7C was especially slow to respond appropriately during periods of long shocks; Rat 5C tended to terminate such periods quickly. All rats showed warm-up effects in their termination of periods of long shocks.

Figure 2 provides additional evidence for

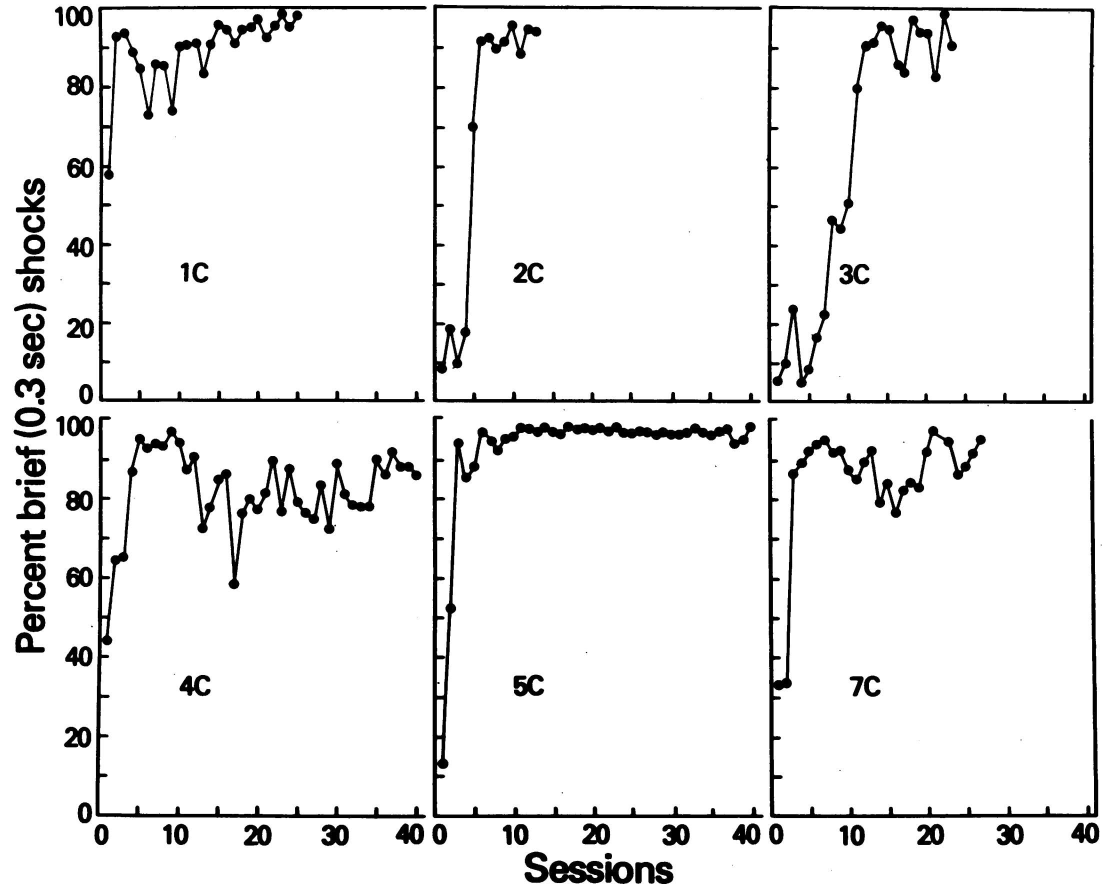

Fig. 2. Number of brief-duration (.3 sec) shocks as a percentage of the total number of shocks received. Each point is the percentage for the last hour of a 100-min session.

the effectiveness of the avoidance training procedure. Each point represents the percentage which brief-duration shocks constituted of total shocks received during the last hour of a session. Since animals received all scheduled shocks, this percentage is also the percentage of potential long-duration shocks avoided and serves as an index of avoidance performance. The marked improvement in avoidance performance early in training roughly parallels the increase in response rates. Avoidance performance was quite stable especially during the latter part of training, and only two animals showed more than 5% variation from the mean of the last five sessions (Rat 3C, 9.6%; Rat 7C, 5.6%). By the end of training, all six animals were avoiding long-duration shocks efficiently. Mean avoidance for the last five sessions exceeded 90% for all animals except Rat 4C (88.2%) and was better than 95% for Rats 1C and 5C.

Performances during the course of training sessions are presented in Figures 3 and 4, which show means for each 10-min period during the last five sessions. Four of the six animals (1C, 2C, 4C, 7C) showed clear warm-up effects in terms of response rate (Figure 3), with especially marked and prolonged increases occurring for Rats 2C, 4C, and 7C. For these four animals, the daily session trends were similar to the trends based on the means. The rate increase for Rat 3C was quite small, and the rate for Rat 5C declined after a small initial rise. Rat 3C showed considerable variability from session to session as well as a tendency for the rate to fluctuate frequently within a session. On the other hand, the trend for Rat 5C was repeated during each of the last four sessions.

Numbers of shocks avoided typically reflect warm-up effects in a more consistent fashion than response rates (Hineline, 1978a, b). Thus,

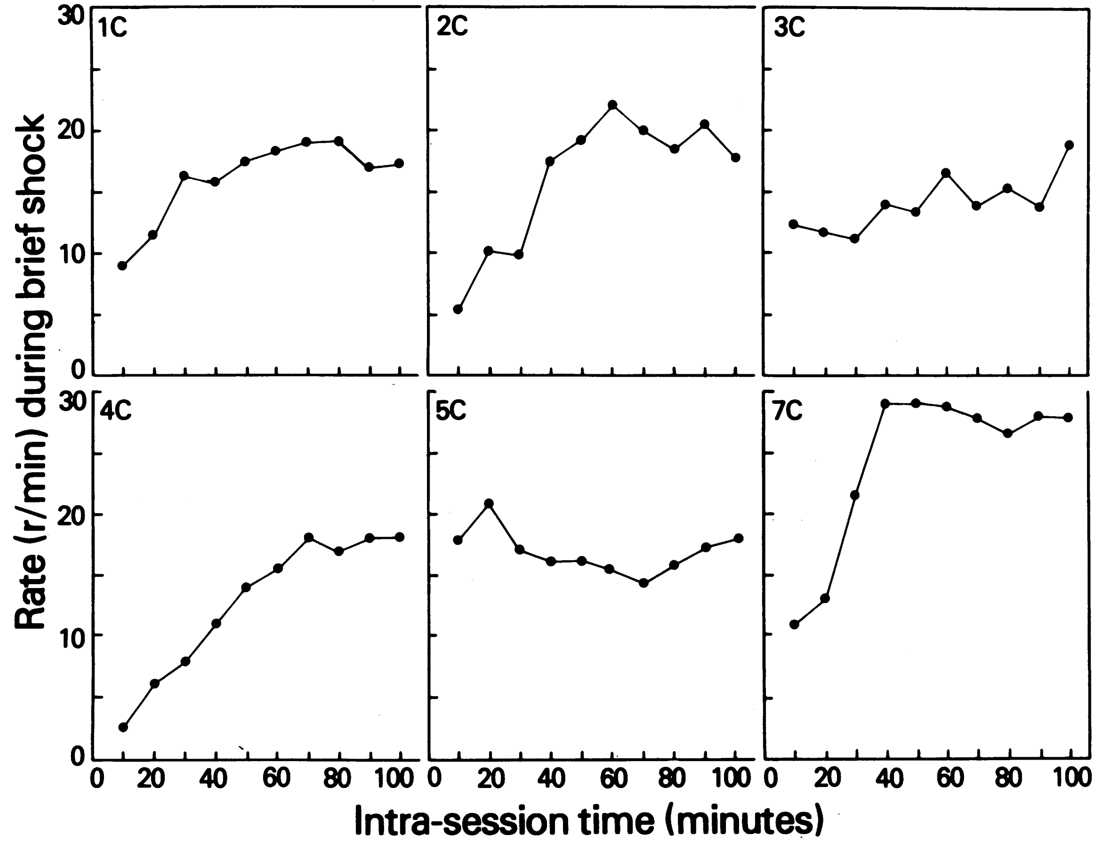

Fig. 3. Responses per min during periods of brief-duration (.3 sec) shock for successive 10-min intervals of the session. Each point is a mean based on the rates for the last five sessions for each animal.

as measured by brief shocks as a percentage of total shocks during each 10-min period (Figure 4), all animals showed some warm-up, with marked within-session improvement evident for Rats 1C, 2C, 4C, and 7C. Trends for each of the last five sessions were similar to the trends based on the means for all animals except Rat 3C. In the case of Rat 4C, warm-up was especially prolonged, so that its avoidance performance is somewhat underestimated by the use of the last hour as a base.

As noted previously, two animals failed to acquire the response. These animals, run for 27 sessions, made few responses during early sessions (less that 1 per min) and were soon observed to have adopted a crouching posture facing the door of the experimental chamber, from which they were removed at the end of a session. Performances of the yoked animals were similar. In all cases, they essentially stopped responding within the first five sessions. Table 2 presents response rates for Session 1 and mean response rates for the last five sessions for each yoked rat and its avoidance partner.

Table 2

Response rates (R/min) during periods of brief (.3 sec) shock for avoidance (C) rats and their yoked (Y) partners. Values are based on the entire sessions, since intrasession data were not recorded for yoked animals.

Subject	*First session*	*Mean and range: Last 5 sessions*
2C	1.4	16.4 13.9-17.6
2Y	.7	.02 .00-.05
3C	.4	14.3 11.8-17.6
3Y	.7	.0
4C	5.5	13.0 11.6-14.7
4Y	.1	.0
5C	.7	16.8 13.3-19.5
5Y	.6	.0

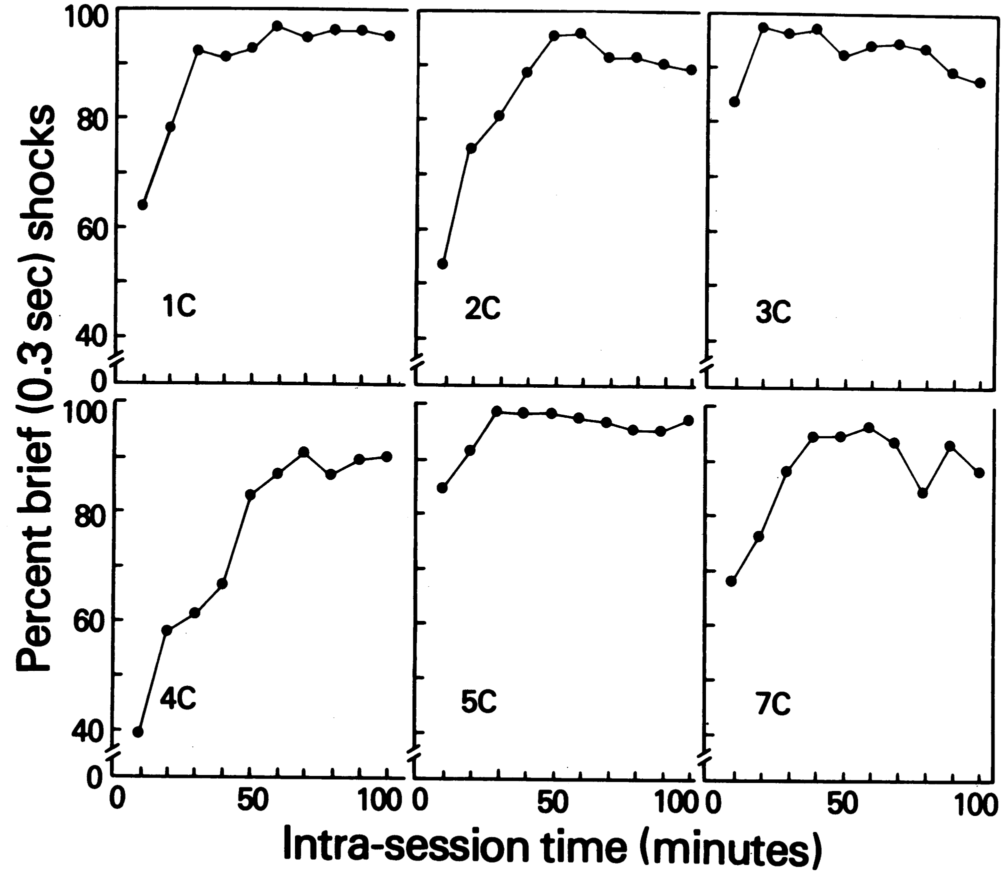

Fig. 4. Number of brief-duration (.3 sec) shocks as a percentage of the total number of shocks received during successive 10-min intervals of the session. Each point is a mean based on the percentages for the last five sessions for each animal.

Interresponse-time distributions were obtained for each animal on a daily basis. However, distributions for early sessions are not available for Rats 4C and 5C because of recorder malfunction. Interresponse times were recorded in 11 separate intervals. Each of the first 10 intervals covered 1.5 sec; the 11th interval included all IRT's greater than 15 sec. Table 3 provides data on the proportion of all IRT's falling within the first interval (1.5 sec) and within the first three intervals (4.5 sec) for the first session and averaged for the last five sessions. In the case of Rats 2C, 3C, and 7C, the proportion of short IRT's increased considerably during training, with no overlap between the first session value and those for the last five sessions. For all animals, IRT distributions had the same form as those for animals in the previous experiment on shock intensity reduction (Bersh & Alloy, 1978). That is, the peak of the distribution was in the shortest interval (0 to 1.5 sec) with a rather steep and progressive decline for later intervals.

DISCUSSION

Reduction of shock duration by itself is clearly an effective form of negative reinforcement for avoidance conditioning. Avoidance behavior was acquired and maintained in six of eight animals on the basis of a reduction in the duration of 1.6 mA shocks from 1.0 sec to .3 sec, despite the absence of a contingency between responding and shock occurrence, intensity, or other shock characteristics. In fact, avoidance responding was as efficient as that manifested by animals trained by a comparable procedure with shock intensity reduction as negative reinforcement (Bersh & Alloy, 1978). Further indication of the potency of shock-duration reduction as negative reinforcement is provided by the rapidity with which avoid-

Table 3

Mean proportion of responses with interresponse times ≤ indicated values.

	First session		*Mean and range: Last 5 sessions*	
Subject	*1.5 sec*	*4.5 sec*	*1.5 sec*	*4.5 sec*
1C	.49	.70	.53 .46-.62	.75 .69-.82
2C	.42	.55	.62 .51-.90	.79 .70-.95
3C	.33	.42	.66 .54-.78	.87 .81-.94
7C	.46	.61	.72 .66-.76	.84 .82-.86

ance conditioning developed in six animals. All but Rat 3C attained an avoidance level of 70% or better within five sessions, and four animals attained levels of close to 90% within 10 sessions. These results support the general finding that duration approximates intensity in its contribution to shock aversiveness (e.g., Church et al., 1967; Leander, 1973).

Although data were not collected to show that the brief-duration shocks were, in fact, aversive, we have observed Sidman avoidance in our laboratory with shocks of 1.0 mA at a duration of .3 sec. Thus, an intensity-duration product of .3 can maintain avoidance responding; by comparison, this product was .48 (1.6 mA, .3 sec duration) for the brief-duration shocks of the present experiment (cf. Leander, 1973). In addition, there are reports from other laboratories of successful avoidance conditioning with shocks of lower intensity and briefer duration than those of the present study (e.g., Leander, 1973; Riess, 1970; Riess & Farrar, 1972). The high shock density of the present experiment (an average of one shock per 6 sec) may also have contributed to the aversiveness of periods during which briefer shocks occurred.

The two animals that did not respond to reduce the duration of the shocks manifested the immobile posture typically observed in rats that do not avoid under conventional procedures. It is tempting to attribute the failure in the present experiment to inadequate exposure to the rather subtle contingencies of the procedure. Animals were required not only to discriminate between shocks solely on the basis of duration, but to discriminate the fact that shock duration was controlled by interresponse time rather than by the occurrence of any single response. Some evidence that the latter form of discrimination developed for successful avoiders is provided by Table 3, which shows a substantial rise in the proportion of short IRT's for three of the four animals for which complete IRT records were available. The failure of Rat 1C to show any differentiation of IRT's may be due to the special rapidity with which it acquired the necessary avoidance behavior. The percentage of long-duration shocks avoided by Rat 1C increased from 18.2% for the first 30 min of Session 1 to 78.8% for the last 30 min. During the first few sessions, the two nonavoiding animals responded less than once per min and by the third or fourth sessions had essentially stopped responding entirely. By contrast, all but one of the animals that acquired the response pressed the lever at a rate of at least five responses per min within the first two sessions. Nevertheless, the fact that Rat 3C responded less than once per min during five of the first seven sessions, but eventually avoided an average of more than 90% of the longer shocks, demonstrates that infrequent exposure to the contingencies of the present procedure during early training need not lead to failure of acquisition. It also is possible that shaping or an initial requirement of a single response to terminate periods of long shock would have resulted in conditioning for the two non-avoiding rats.

Since the animals received all scheduled shocks with only the duration contingent on behavior, avoidance responding may have been subject to at least partial control by the brief shocks. This might help to account for the persistence of responding later in the session when long-duration shocks occurred infrequently. For most of the avoiding animals the density of long shocks during the last hour of a session was consistently less than one per min. For the most efficient animals (e.g., Rat 5C), the density of long-duration shock was often one per 5 or 10 min. These findings suggest that any control exerted by the brief shocks was primarily discriminative rather than elicitative (cf. Bersh & Alloy, 1978). Certainly a simple elicitation interpretation is ruled out by the performance of the four yoked animals. They made fewer than one lever press per min during the first session and almost entirely stopped pressing within the first five sessions. As Table 2 reveals, cessation of responding occurred for yoked rats despite the fact that in three of four cases their initial response rates were equivalent to those of their avoidance partners. It is possible to argue that the shocks initially elicited a range of behavior, but that the avoidance contingency led to a focusing of shock elicitation effects on the avoidance response, thus contributing to avoidance performance. However, discriminative control inevitably has such a selective or focusing effect upon behavior and is, of course, explicitly related to reinforcement contingencies. There is no reason to assume, therefore, that elicitation was involved. Furthermore, even the long shocks failed to elicit bursts of responding as indicated by the data on responses per long shock (Table 1). It should be pointed out that evidence was presented in the earlier study (Bersh & Alloy, 1978) to show that discriminative control by shocks cannot by itself account for the maintenance of avoidance responding with the type of conditioning procedure used here. In that study, the IRT limit within which animals could terminate high-intensity (1.6 mA) shock periods or prolong low-intensity (.75 mA) shock periods was progressively reduced. This led to increasingly high response rates during low-intensity shock periods, even though the number of such shocks decreased.

The present data, like those of the earlier study (Bersh & Alloy, 1978), appear to create difficulty for a safety-signal interpretation of avoidance conditioning (Dinsmoor, 1977). Dinsmoor has noted that, since stimuli produced by the avoidance response are negatively correlated with shock or are less closely followed by shock than any other stimuli, they provide positive reinforcement to maintain the avoidance response. He has suggested a safety-signal interpretation of Sidman avoidance as an alternative to the conditioned aversive temporal sitmulus approach of Anger (1963). Dinsmoor has also argued that a safety-signal interpretation provides a viable two-process account of avoidance acquisition and maintenance with the free operant procedure developed by Herrnstein and Hineline (1966). In the present experiment, shock duration was contingent not on any single response, but on successive responses with particular temporal relationships. Since only those responses which met an IRT requirement (15 sec) were reinforced, any response might be followed either by a brief-duration shock or by a long-duration shock. Furthermore, once a period of long-duration shocks was in effect, it continued until two responses occurred with an IRT of 15 sec or less. A safety-signal interpretation would have to maintain that responses occurring within 15 sec of a previous response provided safety signals whereas those occurring with a greater delay did not. The basis for such a discrimination is problematic.

Several forms of negative reinforcement have previously been identified as sufficient for avoidance conditioning. They are shock frequency reduction (Herrnstein & Hineline, 1966), delay of shock onset (Hineline, 1970), and shock intensity reduction (Bersh & Alloy, 1978; Powell & Peck, 1969). Shock duration reduction may be added to the list on the basis of the present results. Changes in qualitative characteristics of aversive stimuli like shock may also provide sufficient negative reinforcement for avoidance conditioning. Such changes might include response-contingent shifts from DC to AC shock, from interrupted to continuous shock, or even changes in the time distribution of shocks with no frequency reduction or delay in shock-train onset. The avoidance procedure of the present experiment appears to provide a fairly sensitive technique for evaluating such potential forms of negative reinforcement, without contamination by forms of negative reinforcement already demonstrated as sufficient for avoidance conditioning.

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