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REDUCTION OF SHOCK FREQUENCY AS REINFORCEMENT FOR AVOIDANCE BEHAVIOR

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An avoidance technique was used in which rats had two levers available, with independent shock schedules associated with each. Behavioral patterns in initial conditioning and in the maintenance of the responses with various response-shock intervals led to the suggestion that reduction of shock density be considered an important variable in avoidance behavior.

In previous publications (*e.g.*, Sidman, 1953), I have used a response-competition framework (Schoenfeld, 1950) within which to encompass the conditioning and maintenance of avoidance behavior: The animal is punished after the shortest delays for any responses by which it does not avoid shock. Because of the relative rapidity with which it is followed by shock, the animal's nonavoidance behavior can not compete successfully with the avoidance response.

The formulation has proved embarrassingly unamenable to direct test, inasmuch as unobserved behavior carries the explanatory burden. A thorough discussion of the problem must, of necessity, be undertaken elsewhere; but a few lines of evidence point to a directly observable factor which may serve to integrate findings from a number of avoidance experiments. This factor is shock frequency, or synonymously, shock density.

An observation that makes one uncomfortable about the response–competition formulation is the rapidity with which some subjects learn the avoidance response. Black and Morse (1961) have published a curve indicating that one of their dogs acquired stable and efficient avoidance behavior after receiving fewer than 20 shocks; the shock-shock interval was 4 sec and the response-shock interval, 30 sec. Ader and Tatum (1961) have demonstrated that human subjects can learn an avoidance response equally rapidly, even with shock-shock and response-shock intervals of 20 sec; and in my own laboratory I have observed similar instances with rats. (See also Verhave, 1959.) It is, at the least, questionable to assume that so few shocks can suppress the subject's nonavoidance behavior to a level where the avoidance response becomes prepotent. An assumption more consonant with direct observation and with the rapidity of conditioning would be that the avoidance response reduces shock density by interrupting the sequence of shocks.

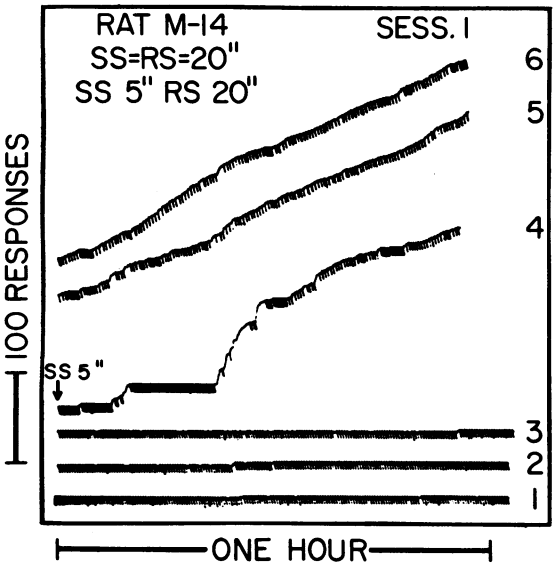

Fig. 1. Cumulative-response record of the first session of avoidance conditioning. The numbers indicate successive segments of the record, which has been collapsed for more condensed reproduction. The oblique markers indicate shocks. At the arrow, the shock-shock interval was changed from 20 to 5 sec.

A second observation, which is among the items of laboratory lore I have accumulated during a decade of investigation into avoid-

[1]The writer gratefully acknowledges the invaluable assistance of Marie McArthur in the conduct of these experiments.

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ance behavior, and which has received more formal confirmation by Black and Morse (1961), is that animals will learn an avoidance response most quickly if the shock-shock interval is relatively brief, *e.g.*, 5 sec or less. Figure 1 illustrates a commonly observed phenomenon which suggests that the effectiveness of short shock-shock intervals derives from the greater shock density they impose on the subject. This animal's lever-pressing behavior failed to condition during more than 3 hr of exposure to shock-shock and response-shock intervals of 20 sec. When the shock-shock interval was reduced to 5 sec, however, the animal started to press the lever after receiving only a relatively small number of shocks. It would seem highly coincidental if the reduced shock-shock interval were effective so quickly because it happened to provide exactly the number of additional shocks needed to suppress all competing nonavoidance behavior; the frequent replication of the effect makes such an eventuality improbable.

A second feature of Fig. 1 is also relevant. The animal's prevailing pattern of behavior in the later part of the session was to press the lever one or more times immediately after a shock, thereby terminating the 5-sec shock-shock interval, and then to wait out the 20-sec response-shock interval. An observable consequence of this response pattern was a decrease in shock density from one shock every 5 sec to one every 20-25 sec. This was approximately the same density that prevailed during the first 3 hr, when the animal failed to maintain a substantial rate of lever pressing. The major difference is the amount of change in shock density the animal produced when it pressed the lever.

Dinsmoor (1962) has reported a procedure in which rats could press a lever and terminate a series of irregularly spaced shocks. Termination of the shock series was programed according to a variable-interval schedule. Dinsmoor found that when the average time between shocks was short relative to the period in which shocks were discontinued (the "safe" period), the animals rarely pressed the lever during the safe period. But as he lengthened the average interval between shocks, the animals tended to respond at more nearly equal rates both during the shock series and after its termination. One way a change in shock density can make contact with the animal's behavior is via the lapse of a longer time interval than usual without shock. When the shocks are spaced further and further apart, such an interval will extend longer into the safe period, and the animal can be expected to continue responding for a greater portion of the safe period before slowing its rate. It should also be noted that Dinsmoor's animals pressed the lever less frequently during the shock series when the average intervals between shocks were longer.

A preliminary theoretical development by Anger (personal communication) strongly suggests consideration of shock density as a variable relevant to avoidance behavior. Anger points out that when the response-shock interval is shorter than the shock-shock interval, the subject may actually increase the shock density by responding at certain rates. On the assumption that the subject distributes its avoidance responses randomly in time, Anger shows that shock density will pass through a maximum at certain values of response rate when the response-shock interval is less than one-half of the shock-shock interval. An examination of existing data (Sidman, 1953) indicates that the abrupt maxima in the functional relations between rate of avoidance responding and response-shock interval fall remarkably close to the point at which the response-shock interval is one-half of the shock-shock interval; the animals stop responding when they can produce more shocks by responding than by not responding.

The experiments to be reported here will illustrate further the role of changes in shock density in the control of avoidance behavior.

METHOD

Subjects and Apparatus

Data from at least one conditioning session were obtained from 10 male albino rats. The attrition rate among the animals was high, probably because of an interaction between the rather demanding experimental procedure and several air-conditioning breakdowns in the laboratory.

The experimental space was a Foringer sliding-drawer test chamber. A sound-resistant outer shell enclosed an inner working space for the animal, 9.875 by 10.5 by 11.75 in. high above a grid floor. The grid rods ran parallel to the narrow end of the chamber and were

0.25-in. stainless steel rods, spaced 0.75-in. apart, measured from center to center. Two modified telegraph-key levers projected through the narrow end of the chamber, 3.375 in. from the grid floor and separated from each other by 4 in. The levers, the sides of the box, and each rod in the floor were insulated from one another; and each was independently wired into a shock scrambling unit which randomly reversed the polarity of each element when shocks were delivered to the animal. Each shock to the animal was 0.3 sec and 1.5-3.0 ma in intensity.

A system of relay and timer circuits located in an adjoining room programed and recorded automatically; and white noise helped to mask extraneous sounds.

Basic Procedure

Although experimental sessions usually lasted 6 hr, some of the early sessions were 3 hr. At least 1 day intervened between experimental sessions.

Seven of the ten animals had no preliminary training before being placed on a concurrent two-response avoidance schedule. A shock was delivered to the animal whenever either of two independent recycling timers reached the end of its timing cycle. If the animal pressed Lever A, however, it reset Timer A back to the beginning of its timing cycle. Similarly, by pressing Lever B, the animal could reset Timer B. Both timers were set at 20 sec, and each one therefore controlled a shock-shock and response-shock interval of 20 sec. The contingencies on each lever were independent. If the animal pressed only Lever A, it would postpone the shock that Timer A would otherwise have delivered; but Timer B would be unaffected and would continue to deliver a shock to the animal every 20 sec. Similarly, if the animal pressed only Lever B, Timer A would continue to deliver shocks. The animal could avoid all shocks only by alternating sufficiently often between the two levers.

Because of a slight variability in the action of the timers, they were out of phase with each other even if the animal did not press either lever; whenever the animal did press one of the levers, it automatically altered the phase relation between the two timers. Therefore, although each individual timer programed a fixed shock-shock and response-shock interval, the combination of two timers operating concurrently but out of phase made both intervals variable.

With some subjects, the training procedures were varied; these variations will be described below.

RESULTS AND DISCUSSION

Conditioning

Of the seven animals placed directly on the concurrent avoidance schedule, two died before the end of their second session without showing any reliable signs of conditioning. An additional three animals failed to survive beyond a third session, but the records of their lever-pressing behavior are of interest. A typical example appears in Fig. 2. In this record, all shocks, regardless of which timer delivered them, are recorded on both curves. During its first session, Rat CO-41 pressed Lever B 551 times, but pressed Lever A only 36 times; a

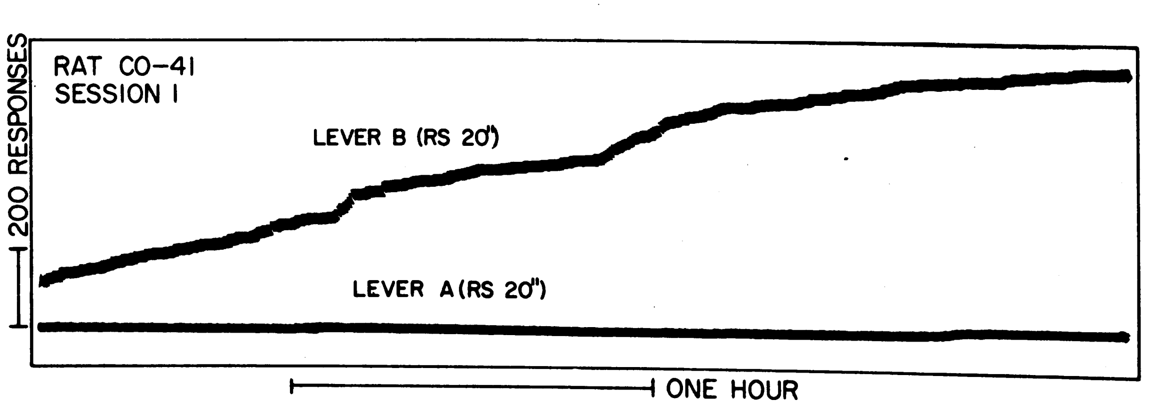

Fig. 2. Cumulative records of the first session of an animal on the concurrent avoidance procedure. All shocks are recorded on both curves, and the oblique shock markers are often so close together that they appear as a solid block in the reproduction.

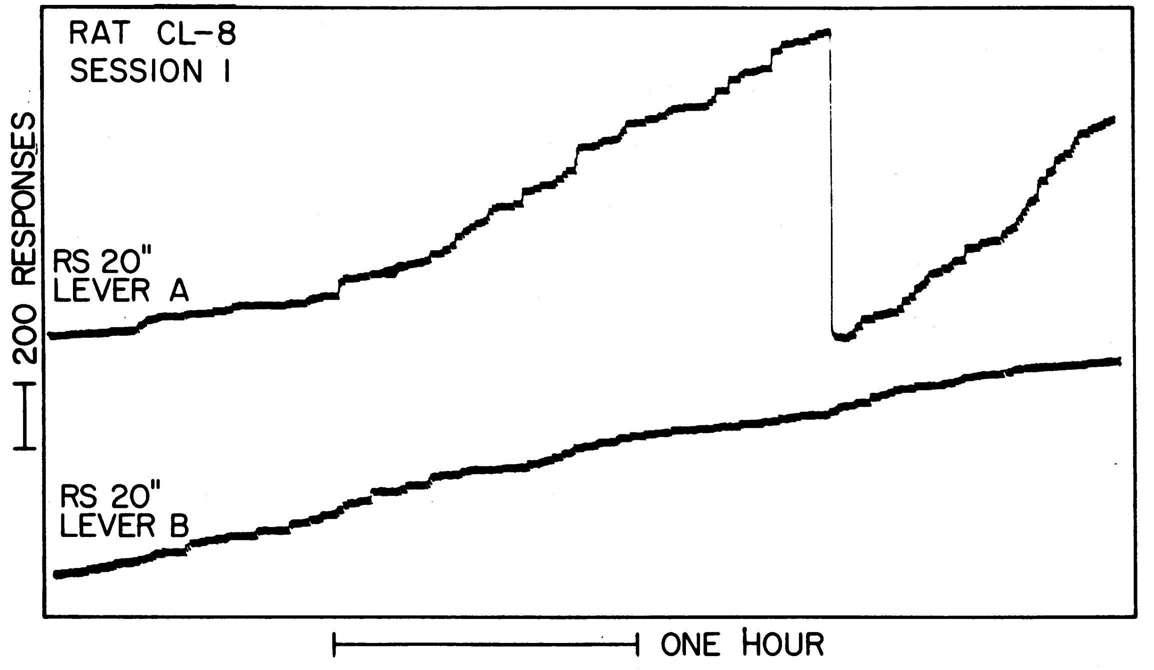

Fig. 3. Cumulative records of the first session of an animal on the concurrent avoidance procedure.

total of 527 shocks was delivered from Timer A and 434 from Timer B.

By pressing Lever B almost exclusively, the animal did not give its B-responses the advantage of a longer delay of punishment than other behavior, since Timer A continued to deliver a shock nearly every 20 sec. Nonetheless, Rat CO-41 developed a respectable rate of responding on Lever B. What it accomplished by this behavior was a decrease in the over-all shock density. If the animal did not press either lever, it would have received a shock every 10 sec, on the average; if it had pressed one of the levers often enough, it would have reduced the shock density to one every 20 sec. Rat CO-41 tended toward the latter type of adjustment to the situation.

An instance of more effective conditioning appears in Fig. 3. Again, all shocks are recorded on each curve. Rat CL-8 pressed Lever A 1633 times and Lever B 576 times; it received 443 shocks from Timer A and 532 from Timer B. Independent measurements of the frequency with which the animal switched from one lever to the other indicated that the probability of switching was very low—0.09 for Lever A and 0.17 for Lever B. The animal was much more likely to press one lever several times in succession than to press one lever and then switch to the other. Again, therefore, the subject did not greatly increase the competitive advantage of its A-response with respect to the delay of punishment. Yet, it did succeed in decreasing the density of shocks.

When the animal confines most of its responses to one lever, the more frequently it presses the briefer will be the average time interval between response and shock; the higher the response rate, the shorter the delay of punishment. Nevertheless, the animals often developed high rates of lever pressing, and such a high rate begins to emerge in the last segment of the record for Lever A in Fig. 3. High response rates despite frequent shocks were especially common at the start of the experimental sessions. Figure 4 contains an example. Rat CG-20 survived several sessions of the experimental procedure and consistently pressed Lever A approximately 15 times per min at the start of each session, while at the same time showing a pronounced "warmup" on the other lever.

Because of the great difficulty many of the animals experienced when they were exposed to the concurrent schedule at the start of the experiment, Rat CR-12 was brought to the basic procedure more gradually. At first, only one timer was operative, and the animal could reset the timer and postpone the shock by pressing either lever. After six sessions, the animal was well conditioned but was responding exclusively on Lever B. Then, on one day the animal was allowed to avoid shock only by pressing Lever A; the next day, by pressing Lever B; the following day, by pressing Lever A; and so on. Rat CR-12 quickly adjusted to this daily alternation, often pressing both levers for a brief period at the start of each session and then confining its responses exclusively to the effective lever for the remainder of the session. After 2 hr of the 10th session of this procedure, the concurrent schedule was introduced, with both timers operative. Figure 5 is a record of the animal's behavior immediately before and after the changeover. Unlike the previous figures, shocks from Timer A are recorded only on the curve for Lever A; and those from Timer B, only on the curve for Lever B.

During the first 2 hr, Rat CR-12 pressed only Lever B, which was the effective lever. This behavior demonstrates that the mere presence of two levers in the chamber does not cause the animal to press them both. Its first responses on Lever A came after only three shocks from Timer A; thereafter, it gradually increased the rate at which it pressed Lever A. Shortly after the introduction of shocks from Timer A, the animal's response rate on Lever B dropped; but it quickly recovered and was maintained in spite of a relatively high frequency of shocks from Timer A.

Rat CL-8, whose record for the first session was shown in Fig. 3, had two sessions of the concurrent schedule and was then permitted to avoid shock by pressing either lever; only one timer was operative. After six sessions, it was confining its responses almost exclusively to Lever B, and the procedure was then changed so that the animal could avoid shock only if it pressed Lever A. During the next three sessions, Rat CL-8 responded more frequently on the effective lever; but when it was again given two sessions in which it could reset the timer and avoid shock by pressing either lever, it returned to Lever B and rarely pressed Lever A.

The concurrent procedure was then reintroduced. Although the animal did respond on Lever A for a few sessions, this behavior eventually all but disappeared; and after eight sessions of the concurrent schedule, Rat CL-8 produced the record shown in Fig. 6A. Shocks from both timers appear on each curve. During this session, the animal received 1072 shocks from Timer A, but only 27 shocks from Timer B. Because it so rarely pressed Lever A, the animal received a shock nearly every 20 sec, but it maintained a rate of approximately 30 responses per min on Lever B. Although this pattern of behavior was not the most efficient that was possible, the animal did reduce the shock density to nearly half of

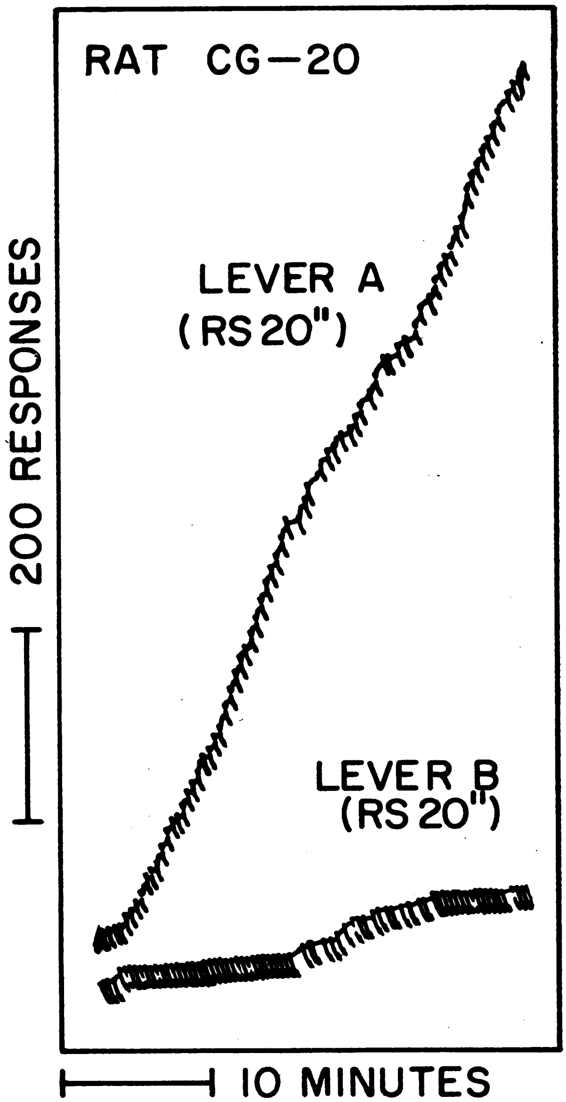

Fig. 4. An illustration of a high response rate on Lever A at the beginning of a session, along with a simultaneous "warmup" on Lever B.

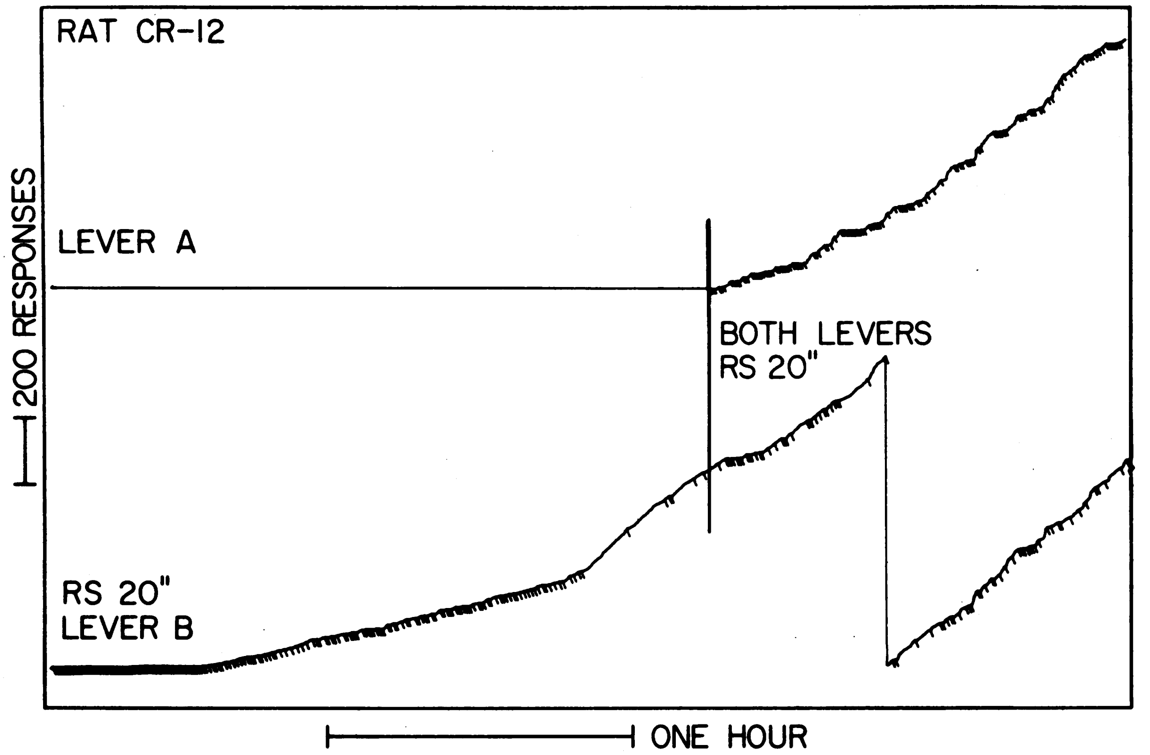

Fig. 5. In the left segments of the records, only Timer B was operating and Lever B was effective in avoiding shock. In the right segments, the concurrent schedule was in effect.

what it would have been if it did not respond at all.

Schedule Changes

Following the session shown in Fig. 6A, the shock-shock and response-shock intervals programed on Timer B were increased to 40 sec. Timer A, which remained unchanged, still delivered a shock whenever the animal did not press Lever A for 20 sec, but Timer B delivered its shock only when the animal failed to press Lever B for 40 sec. In the first session after the schedule change, the animal did not alter its pattern of behavior; its record was almost identical to that shown in Fig. 6A. During the next session, however, there was a radical behavioral change, as Fig. 6B shows. The animal's response rate on Lever B declined; but even though the response-shock interval on Lever A had not been altered, the animal pressed Lever A much more frequently than it ever had before.

Rat CL-8 did not survive the session shown in Fig. 6B, probably because of a breakdown of the air-conditioning and ventilating systems. The low response rates near the end of the session reflect the animal's weakened physical condition. A more thorough investigation of the effects of schedule changes was therefore carried out with another animal, and a detailed description follows.

In the initial sessions, only one timer was in operation, and Rat CJ-22 could avoid shock by pressing either lever. The animal conditioned rapidly, and the concurrent schedule was introduced in the fifth session. After 15 sessions of the concurrent schedule, the animal characteristically maintained a relatively high response rate on Lever A, but pressed Lever B much less frequently. Figure 7A illustrates the performance.

When the shock-shock and response-shock intervals on Lever A were increased from 20 to 40 sec, Rat CJ-22 replicated the major features of Rat CL-8's performance. (See Fig. 6B.) The rate at which it pressed Lever A decreased, but it pressed Lever B considerably more often than before. The performance

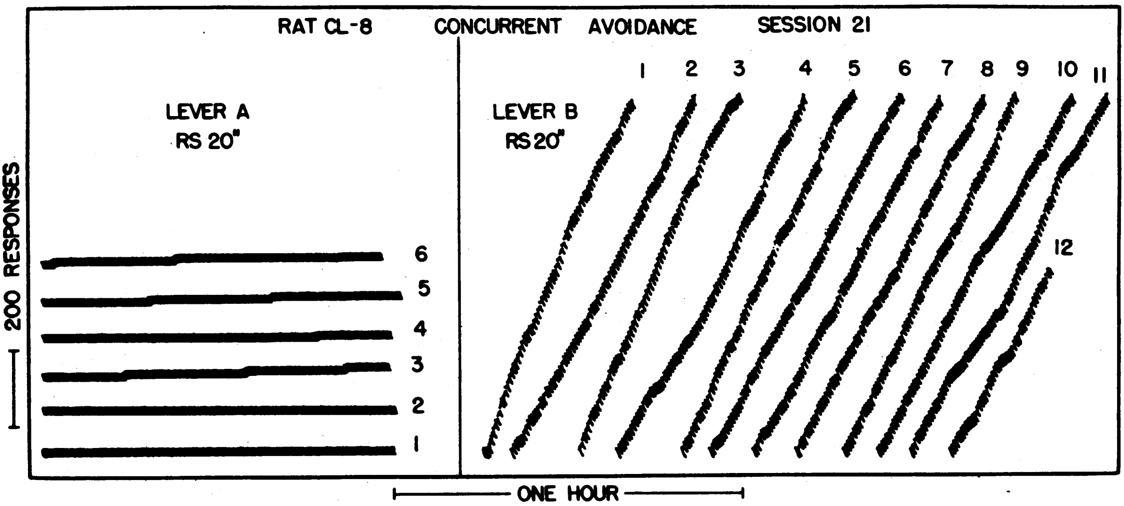

Fig. 6A. Performance of an animal on both levers in the concurrent avoidance schedule. The response-shock interval on each lever was 20 sec.

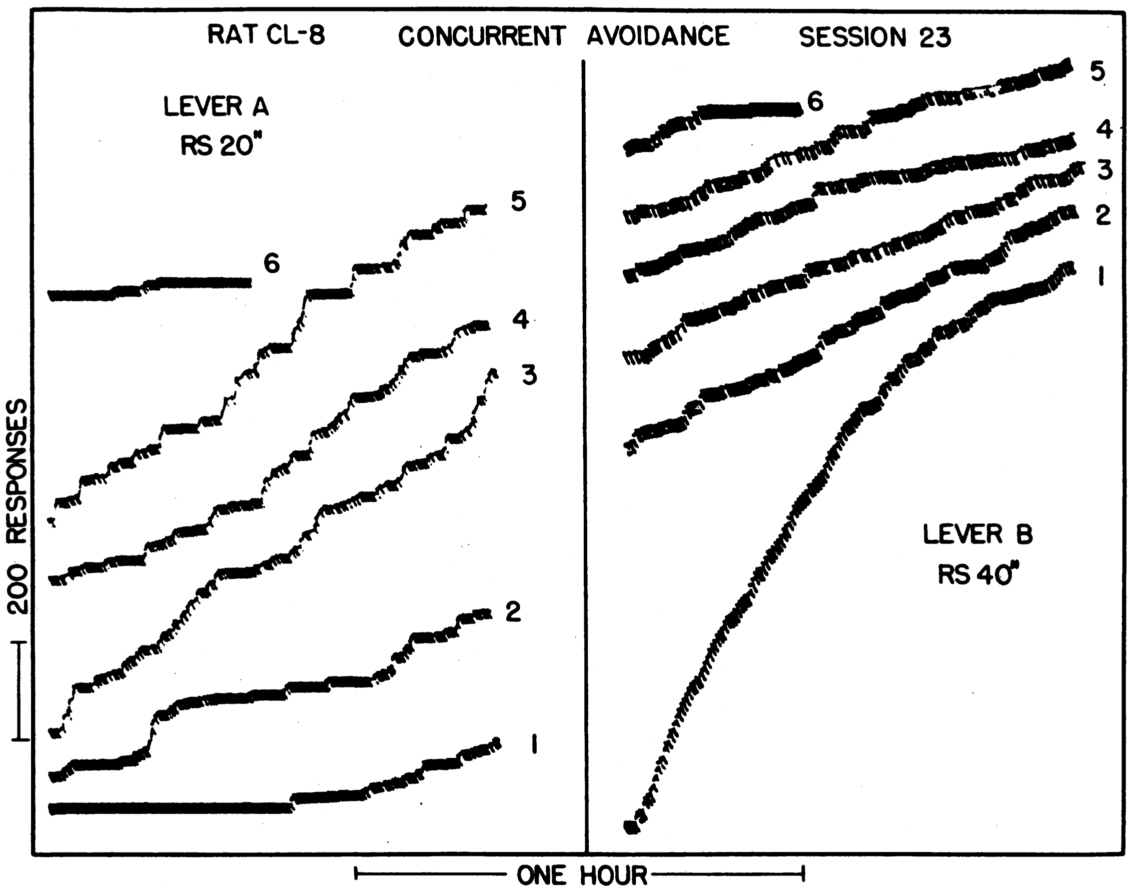

Fig. 6B. A cumulative record illustrating the animal's increased rate on Lever A after the response-shock interval on Lever B was lengthened to 40 sec.

after 10 sessions appears in Fig. 7B. (In Fig. 7B and 7C, shocks from Timer A are recorded only on the curves for Lever A; and those from Timer B, only on the curves for Lever B.) To determine whether the effects were reversible, Timer A was again set at 20 sec, with Timer B remaining unchanged. Figure 7C shows the performance after 10 sessions; the animal returned to its original pattern of a high response rate on Lever A and a low rate on Lever B. The cause of the low rates at the end of the session is unknown, and they were not observed in any other session.

When the response-shock interval on the preferred lever was lengthened, the animals increased the rate at which they pressed the other lever, associated with the shorter response-shock interval. In a previous two-lever experiment, the opposite was observed: The animals more frequently pressed the lever associated with the longer response-shock interval (Sidman, 1954a). In that experiment, however, the two response-shock intervals were not independently programed. When the animal pressed one lever, the timer controlled by the other lever was turned off. By selecting the longer response-shock interval, the animal also achieved the maximum reduction of shock density.

Rat CJ-22 was exposed to a number of combinations of response-shock intervals on the two levers. The sequence of procedures can be followed session by session in Fig. 8. The upper frame of Fig. 8 shows the rates at which the animal pressed each lever. The center frame shows the number of shocks delivered to the animal by each timer. The lower frame shows the probabilities that the animal would switch from one lever to the other; *i.e.*, of all the times the animal pressed Lever A, how often did it respond next on Lever B (AB/A), and, similarly, what proportion of the animal's responses on Lever B were followed by responses on Lever A (BA/B)?

The first three schedule combinations illustrate in detail the data discussed above, in which the response-shock interval on Lever A was changed from 20 to 40 and back again to 20 sec. It was once more returned to 40 sec in Sessions 41-50, and the previous results were replicated.

In considering the factors which control the animal's rate of responding on Lever A, we may again examine shock density, this time as it is affected not only by the programed intervals but also by the animal's behavior. When both intervals were 20 sec, unknown variables led the animal to reduce shock density mainly by pressing Lever A. The over-all shock density ("base-line density") was therefore governed largely by Lever B. With a 40-sec response-shock interval on Timer A, the animal increased its rate of response on Lever B because this became the most effective way of reducing shock density. The increased rate of pressing Lever B acted in concert with the lengthened response-shock interval on Lever A to reduce the base-line density, and the animal's rate of pressing Lever A declined. A similar change in the base-line density was accomplished in Sessions 51-61 by changing the response-shock interval on Lever B to 40 sec. Therefore, the animal did not recover the high rate of pressing Lever A that it had maintained when both intervals were 20 sec, even though Lever A was simultaneously returned to a 20-sec response-shock interval.

By setting both intervals at 40 sec in the next phase of the experiment, the base-line density was reduced still more, and the animal's response rate declined on both levers. But when the response-shock interval on Lever A was increased to 60 sec in Sessions 72-81, the results were anomalous. The animal maintained its low rate on Lever B and pressed Lever A at a higher rate. In the succeeding sessions, with both intervals at 60 sec, the changes were in the expected direction but were not large. With longer response-shock intervals, a greater difference between the two intervals is probably required if the earlier data are to be replicated in their entirety. Also, the already low shock density may have prevented the difference between the 60- and 40-sec intervals from making effective contact with the animal's behavior. In Sessions 91-100, therefore, the 20-sec interval was restored on both levers, and higher response rates and shock densities were re-established.

In Sessions 101-110 the response-shock interval on Lever A was again increased to 60 sec, this time keeping the interval on Lever B at 20 sec. The animal's response rate on Lever A dropped precipitously, along with an increase on its rate on Lever B. These changes were reversed in the following sessions by again equalizing the two intervals at 20 sec. In the final phase of the experiment, the

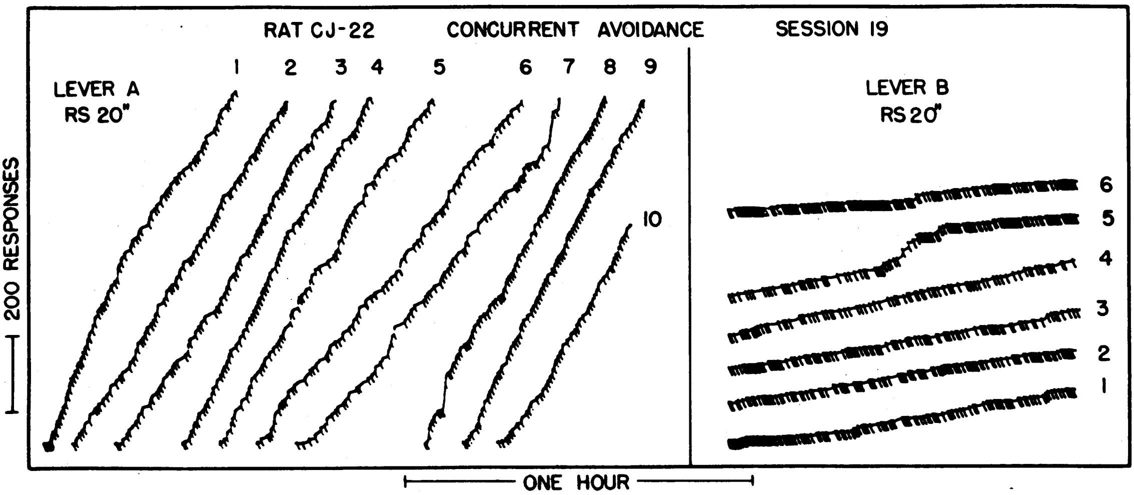

Fig. 7A. Performance of an animal on both levers in the concurrent avoidance schedule. The response-shock interval on each lever was 20 sec.

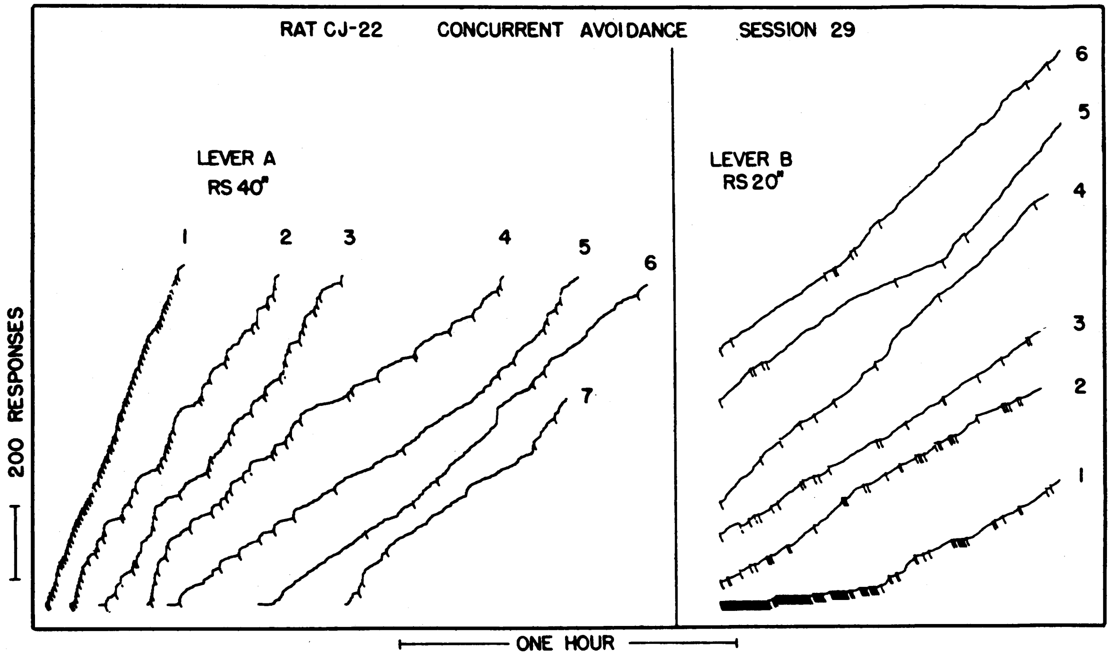

Fig. 7B. A cumulative record illustrating the animal's increased rate on Lever B after the response-shock interval on Lever A was lengthened to 40 sec.

interval on Lever A was again raised to 60 sec while the interval on Lever B was simultaneously increased to 40 sec. Perhaps because the change was made this time from a base line of greater shock density, the rate on Lever A dropped, instead of increasing as it did in Session 72-81. Although the rate on Lever B did not actually increase, the fact that it did not drop from its previous level probably reflects its larger role in determining shock density.

Increases in shock density were generally correlated with lowered response rates, if the response-shock interval was kept constant, or with shorter response-shock intervals. The probability of switching was inversely related to the animal's rate of response.

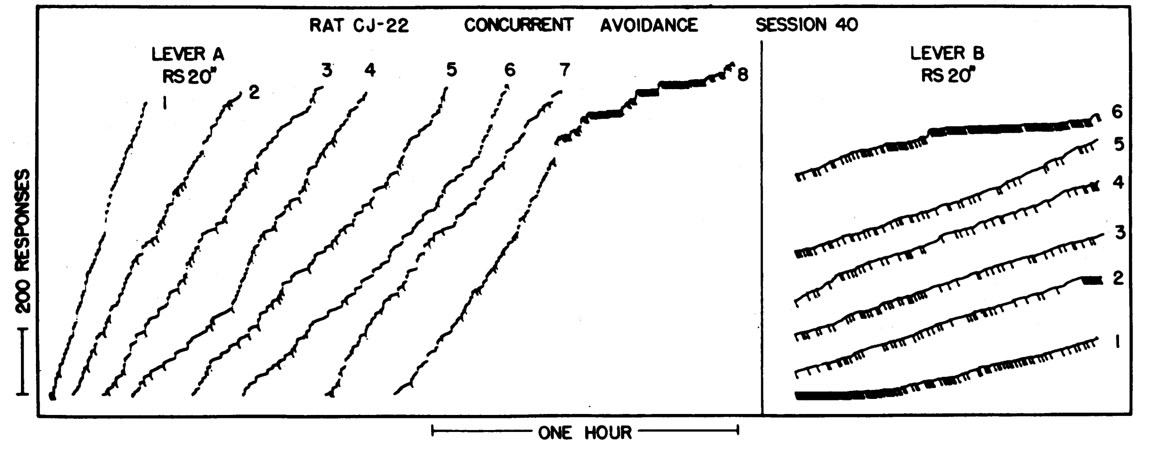

Fig. 7C. Recovery of the animal's performance after the response-shock interval on Lever A was returned to 20 sec.

Temporal Spacing of Responses

Inter-response times of responses on each lever were recorded independently, in class intervals equal to one-tenth of the response-shock interval. The inter-response times were

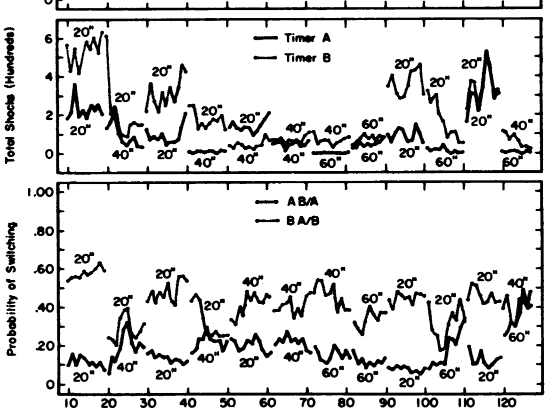

Fig. 8. Total responses per session on each lever, total shocks delivered per session by each timer, and the probability of switching from one lever to the other in each session. The response-shock intervals on each timer and its associated lever are indicated above and below each block of sessions.

converted into response probabilities by dividing the number of times the animal responded in each class interval by the number of times the animal waited long enough to have an opportunity to respond in that interval. Probabilities were not caculated when the number of opportunities fell below twenty. The probability functions for the final session of each schedule combination are presented in Fig. 9; replications have been omitted because they did not differ essentially from the curves shown in Fig. 9. It should be noted that when the animal pressed one lever, it did not interfere with the recorded inter-response intervals of the other lever.

The high response probabilities in the first class interval reflect rapid bursts of responses (Sidman, 1954b). Except for these bursts, the likelihood is low that the animal will press either lever after a short pause. As more time elapses since the animal last pressed the lever, however, the probability of a response rises gradually to its maximum value. This probability function, which may be characterized as a temporal discrimination, is often observed in avoidance experiments in which the subject has only one lever to press. Here we see the same function for both levers in a two-lever situation. Does this mean that the animal can keep two "clocks" running concurrently?

A possible alternative conception would be that the two responses become linked together in a chain. According to the lower frame of Fig. 8, the animal did not often switch from one lever to the other; but these data may be

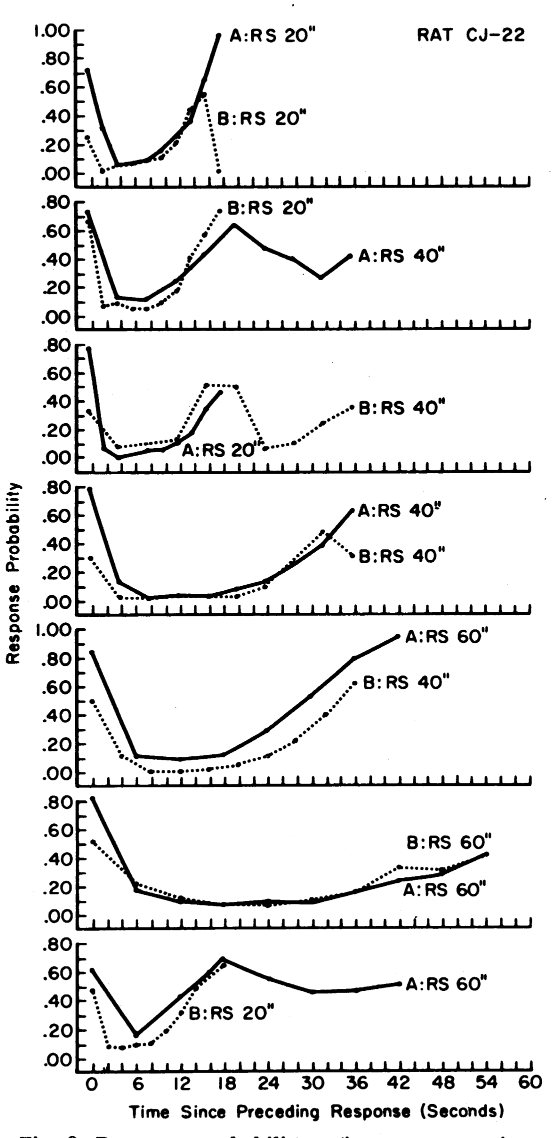

Fig. 9. Response probabilities (inter-response times per opportunity) as a function of the length of time the animal has paused. The response-shock intervals and the levers are identified beside each curve.

unduly weighted by the large number of responses involved in bursts. If a response chain did develop, it would be expected to be largely under the control of the shorter response-shock interval, since most of the shocks were always delivered by the timer set at the shorter interval. This would indeed explain the early peak in the probability functions for the response with the longer response-shock interval, *e.g.*, the second and third set of curves from the top in Fig. 9.

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