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PERIODIC SHOCK WITH ADDED CLOCK[1]

DEREK P. HENDRY, MATTHEW YARCZOWER,[2] AND RICHARD C. SWITALSKI

UNIVERSITY OF ILLINOIS, CHICAGO CIRCLE AND UNIVERSITY OF MARYLAND

Rats were shocked every 6 min while responding was maintained on a variable-interval schedule of reinforcement. With some rats, shocks were interspersed with a sequence of three different stimulus conditions (S3→S2→S1), or clock cues, each lasting 2 min. For other rats, a single stimulus condition prevailed between shocks at the beginning of the experiment and clock cues were introduced later. Response rate decreased from S3 to S1. Response rate in S3, S2, and S1 was inversely related to shock intensity. When clock cues were added, response rate increased in all 2-min intershock periods. During clock cues, an index of curvature, indicating the degree of negative acceleration of response rate, was greatest for S1 and least for S3, and was directly related to shock intensity. The response-facilitating effect of shock and its relation to a possible discriminative function of shock and to behavioral contrast is discussed.

Responding maintained by a fixed-interval (FI) schedule of reinforcement typically is positively accelerated between reinforcements. The addition of a sequence of cues temporally related to the occurrence of reinforcement accentuates the positive acceleration, whether the cues change continuously (Ferster and Skinner, 1957, p. 266 ff; *cf, e.g.*, Fig. 311, p. 268) or discretely (Segal, 1962; Weiss and Laties, 1964). The procedure of adding a sequence of cues temporally related to reinforcement has been called "added clock" (Ferster and Skinner, 1957), and the cues themselves have been called "clock cues" (Hendry and Dillow, 1966). The accentuation of positive acceleration is probably at least partly due to the fact the early cues are associated with nonreinforcement. The original FI schedule is thus converted into a multiple FI EXT (extinction) schedule, and the rate during the EXT components decreases. This account is consistent with the effect of introducing a single, brief clock cue during an FI schedule: response rate is depressed virtually to zero during the clock cue, except when the clock cue is relatively close to reinforcement (Farmer and Schoenfeld, 1966).

It may be fruitful to extend the concept of clock cue to refer to stimuli temporally related to the occurrence of a negative reinforcer or aversive stimulus. The present study was designed to provide data on the effects of a sequence of cues between periodically administered electric shock.

METHOD

Subjects

Five male hooded rats, about four months old at the beginning of the experiment, were maintained at about 75% of their free-feeding weights throughout the experiment.

Procedure

All rats were trained with food reinforcement (45-mg Noyes pellets) to press a bar in a standard small-animal metal chamber with a grid floor (Sidman, 1953). There followed seven 1-hr sessions of a variable-interval schedule of reinforcement with mean interreinforcement interval of 1 min (VI 1-min). The VI 1-min was obtained by having a mechanical timer send a signal every 3.75 sec to an electronic probability device (Hendry, 1965) which allowed the signal, with a probability of 0.0625, to make available a reinforcement. In all sessions after the first seven, while the VI 1-min schedule remained in effect, a 0.5-

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[2]Now at Bryn Mawr College, Bryn Mawr, Pennsylvania.

sec unavoidable shock (Grason-Stadler Model 1064 GS shock generator) was presented every 6 min. The experimental procedures varied further in the shock intensity used and whether or not clock cues, as shown in Fig. 1, were presented. The procedures are summarized in Table 1.

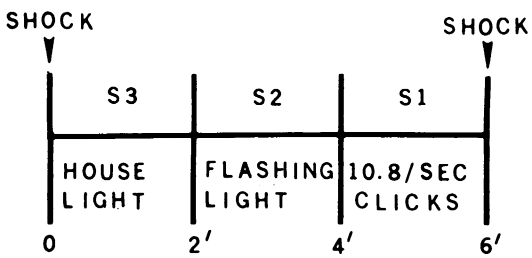

Fig. 1. The intershock sequence of cues. The flashing light was located directly above the bar.

Table 1

Experimental procedures, showing for each shock intensity the number of sessions and the stimuli (clock cues or houselight) presented.

Subjects	*Shock (ma)*	*No. of Sessions*	*Stimuli Presented*
B1, B2, B3	0.0	7	Houselight
	0.5	35	Clock cues[a]
	1.0	40	Clock cues[a]
	2.0	20	Clock cues[a]
A1, A2	0.0	7	Houselight
	0.5	25	Houselight
	1.0	20	Houselight
	1.0	20	Clock cues[a]
	2.0	15	Clock cues[a]

[a]"Clock cues" are the recurrent sequence of cues shown in Fig. 1.

RESULTS

Response rate gradually increased over the 20 to 30 sessions after the periodic shocks were introduced. This increase may be seen in Fig. 2, which shows the response rates of B1, B2, and B3 during each of the 2-min clock cues in all sessions that included clock cues. It is clear from Fig. 2 that the response rate in the period between shocks was not uniform, but varied systematically, with the highest rates generally during S3 (after shock) and the lowest rates during S1 (before shock). The rates during S2 were between the rates during S1 and S3, except in the case of rat B1 at lower shock intensities, when the rate during S2 was approximately equal to the rate during S3.

Figure 3 shows the performance of rats A1 and A2 except for the initial seven sessions without shock. The clock cues were added after Session 45. The procedure in the first two panels of Fig. 3 may be compared with that shown in the first two panels of Fig. 2; the only difference was that B rats had the added clock cues and A rats did not. The effect of adding clock cues is shown in the third panel of Fig. 3. From the ninth to the thirteenth block of sessions, response rate increased in all components for both A1 and A2.

Figure 4 shows typical cumulative records of final performance at each stage of the procedure for rats A1 and A2. The order of presentation of conditions is preserved in Fig. 4, reading from the top down. Figure 4 shows the order of magnitude of variation in response rate from one intershock interval to another, at a given shock intensity, during a given 2-min intershock period, with and without clock cues. The differences in final response rates as a function of cue (S1, S2, and S3), 2-min cue period when cues were absent, and shock intensity, shown in Fig. 3, were barely consistent enough to be seen at the level of individual within-session performance illustrated in Fig. 4, but differences as a function of shock intensity were consistent enough to be detected even in the small segment of performance shown in Fig. 4. In the segments shown, a higher intensity of shock is associated with a lower response rate, when cases with and without clock cues are considered separately.

The effect of intensity of shock (with clock cues) on overall response rate of each rat is shown in Fig. 5. The higher the intensity of periodic shock, the lower the rate at which each rat bar-pressed for food.

The effect of shock intensity on response rate during each 2-min cue is shown in Fig. 6. The inverse relation between response rate and shock intensity (Fig. 5) is preserved during each clock cue. Thus, the stronger the shock, the lower the response rate during S1, S2, and S3.

The present results show that performance was affected in an orderly fashion by shock intensity and according to the position of the clock cue relative to shock, but no quantita-

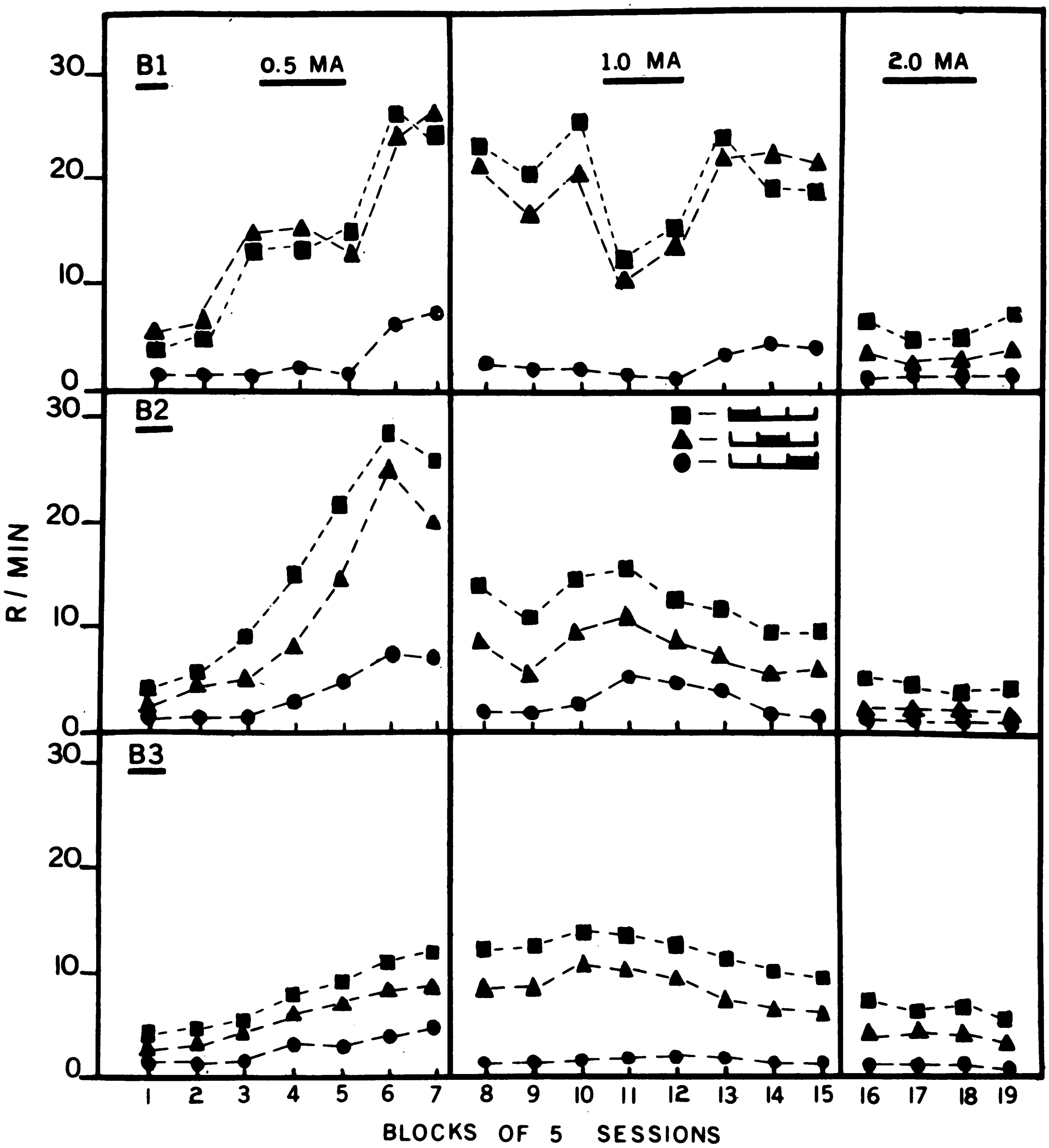

Fig. 2. Response rate during S1, S2, and S3 for rats B1, B2, B3 throughout the experiment (with initial no-shock sessions omitted). The performance was maintained by VI 1-min for food; shocks were delivered every 6 min. S1, S2, and S3 were as shown in Fig. 1. The key in the central panel indicates that rates in the first, second, and third 2-min periods after shock are plotted as squares, triangles, and circles respectively.

tive data have been presented on the pattern of response rate during S1, S2, and S3. The existence of a well-defined pattern is suggested in the cumulative records of Fig. 4, which show that response rate during at least some presentations of a 2-min cue was negatively accelerated. To obtain a quantitative measure of deceleration within a 2-min period, the number of responses in the first third (40 sec) of each period was expressed as a ratio of the total number of responses emitted in the 2-min period. This measure is referred to as an "index of curvature". For a uniform rate of responding, the ratio would be 0.33; negatively accelerated responding would yield ratios above 0.33 and positively accelerated responding would yield ratios below 0.33. The indices of curvature of each rat as a function

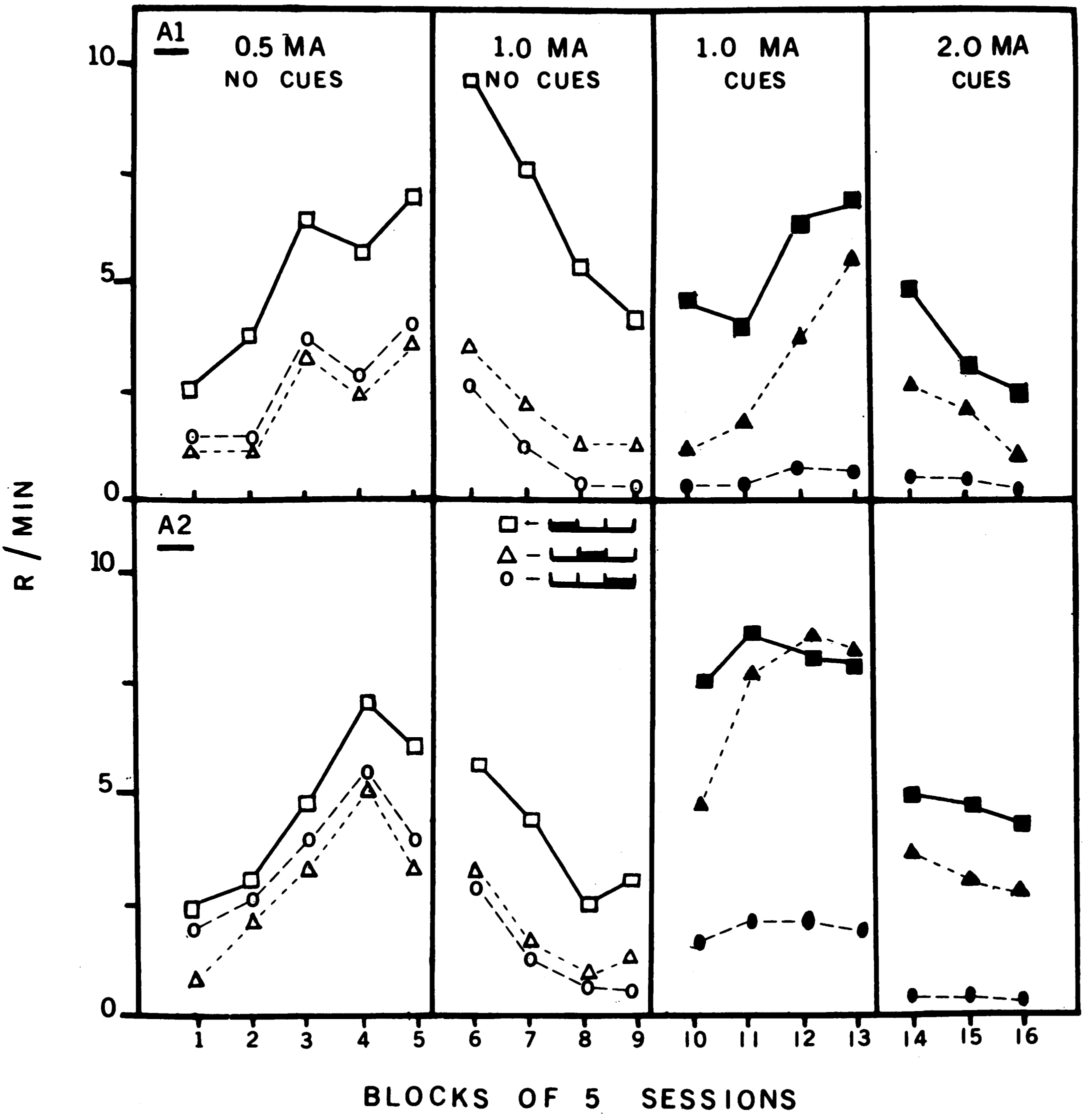

Fig. 3. Response rate during specific 2-min intershock periods for rats A1 and A2 throughout the experiment (with initial no-shock sessions omitted). Performance was maintained by VI 1-min for food; shocks were delivered every 6 min. Clock cues (S1, S2, S3) were not presented for the first nine blocks of sessions, and were presented for the remaining sessions.

of cues (S1, S2, or S3) and shock intensity are given in Fig. 7, for A1 and A2 when no clock cues were presented.

An analysis of variance of indices of curvature over the last five sessions of each condition for the B rats showed a significant effect of shock intensity ($F = 29.31$, $df = 2, 54$, $p < 0.01$) and stimulus period ($F = 76.82$, $df = 2, 54$, $p < 0.01$). The meaning of these effects is clarified by Fig. 7. The sharpest negative acceleration of responding occurred in S1, with much less extreme curvature occurring in S2 and perhaps even less in S3. (The results for A1 and A2 show a more regular decrease in curvature from S1 to S3.) On the average, the higher the shock intensity, the sharper the negative acceleration. With the combined effects of cue and intensity, extreme negative acceleration is obtained. Thus, with a 2.0-ma shock virtually all responses during S1 are emitted in the first 40 sec, giving an index of curvature of close to 1.00.

The importance of the added clock cues in the development of negative acceleration of

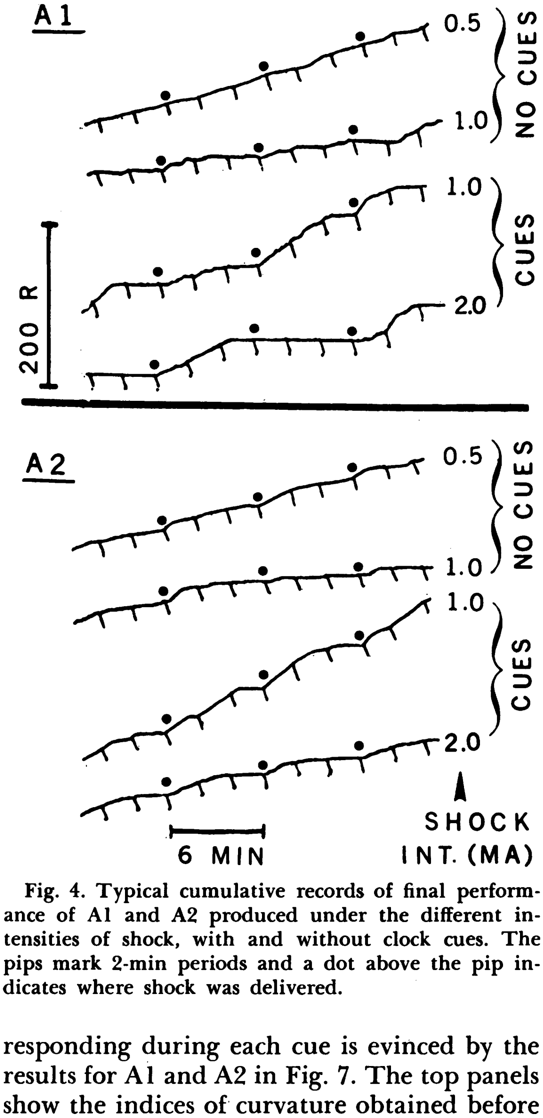

Fig. 4. Typical cumulative records of final performance of A1 and A2 produced under the different intensities of shock, with and without clock cues. The pips mark 2-min periods and a dot above the pip indicates where shock was delivered.

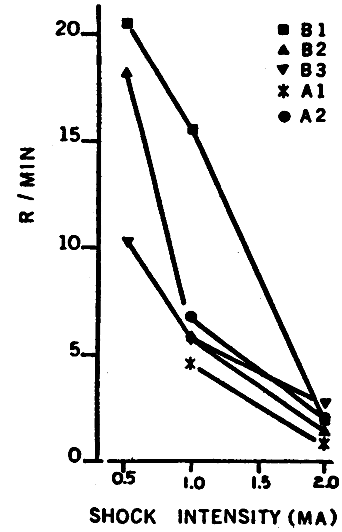

Fig. 5. Mean response rate of each rat as a function of shock intensity, with added clock cues. Data are from the final five sessions at each intensity of shock.

responding during each cue is evinced by the results for A1 and A2 in Fig. 7. The top panels show the indices of curvature obtained before the clock cues were added; these results show no evidence of an effect of shock intensity or of the intershock periods corresponding to S1, S2, and S3. In contrast, these two variables were effective when clock cues were added (lower panels), confirming the results obtained with B1, B2, and B3.

DISCUSSION

The main results of the present study are that with periodic shock separated by a temporal sequence of cues ($S3 \rightarrow S2 \rightarrow S1$) response rate decreases, while negative acceleration increases, from S3 through S1; both these effects are larger with a higher intensity of shock (Fig. 6 and 7). As a consequence, the stronger the shock the lower the overall response rate (Fig. 5). Without cues, the response rate is lower and negatively accelerated between shocks (Fig. 3).

Since no redetermination of effects was made, the effects attributed here to shock intensity and presence of clock cues might be attributed to time. This interpretation may safely be dismissed because: (a) the transition from 0.5 ma to 1.0 ma without cues reversed the direction of change in response rates (Fig. 3); (b) the addition of cues again reversed the direction of change in response rate (Fig. 3); (c) the increase in shock intensity from 0.5 ma to 1.0 ma with cues immediately reduced response rate during S1 (Fig. 2); (d) the increase in shock intensity from 1.0 ma to 2.0 ma with cues immediately reduced response rate during S1, S2, and S3 (Fig. 2 and 3).

A fixed-interval shock schedule superimposed on a variable-interval reinforcement schedule was used with pigeons by Azrin (1956). He found that this procedure led to a response rate that was negatively accelerated between shocks. Present results therefore confirm, with rats, Azrin's finding. In addition, the present results include a quantitative expression of the degree of curvature and details of temporal changes in response rate at two intensities of shock.

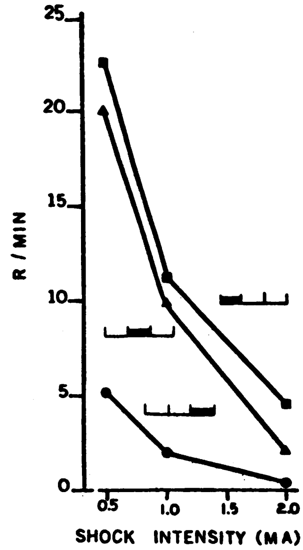

Fig. 6. Mean response rate as a function of clock cue (S1, S2, or S3) and shock intensity. Data are from the final five sessions at each intensity of shock. The data for 0.5 ma are from B1, B2, and B3 only, since no data were obtained from A1 and A2 with clock cues and shock intensity of 0.5 ma. Other data points are the means for all five rats.

The study by Segal (1962) of the effect of a clock added to a fixed-interval reinforcement was procedurally similar to the present experiment. In Segal's experiment, the successive quarters of FI schedules were identified by different cues (clock cues). Relative to response rates in the absence of clock cues, the rates during the first three quarters were greatly reduced, while the rate in the final quarter was not. The effects of interreinforcement clock cues, shown by Segal, and also in a similar experiment by Weiss and Laties (1964), are in some senses opposite to the effects of intershock clock cues. Thus, while response rates during early interreinforcement clock cues are relatively low, response rate during early intershock clock cues are relatively high. Segal concluded that the early interreinforcement clock cues acquired negative discriminative properties. The present results contain evidence of a kind similar to Segal's, namely, rate changes when clock cues are introduced. Specifically, A1 and A2 developed a marked increase in rate after 1.0-ma shock when cues were added. Therefore, it seems formally justifiable to draw the parallel conclusion that the early intershock clock cues acquired positive discriminative properties.

In the present experiment, the highest response rates (after shock was introduced) occurred immediately after shock was delivered. Response rate increases after delivery of shock in a wide variety of situations. Perhaps the best-known case occurs in avoidance behavior (Sidman, 1958*a*). This may be related to the fact that only long pauses in responding are punished. However, with simple negative reinforcement too, a relatively high rate occurs after the aversive stimulus (Keller, 1941). When shock is contingent on every *n*th response, relatively high rates of responding may occur immediately after shock (Hendry and Van Toller, 1964), though the appearance of high rates is not invariable and probably depends also on the schedule of reinforcement (Azrin, Holz, and Hake, 1963). A slightly higher rate for a brief period after shock may also occur with the conditioned emotional response (CER) procedure. Although this was pointed out in the original report on conditioned suppression (Estes and Skinner, 1941), and examples can be seen in many published records, the phenomenon has not been the subject of systematic research. In the case of the CER, the event that initiates an increased response rate could be the end of the preaversive stimulus, rather than the delivery of shock. In discriminative avoidance conditioning, an increased response rate follows termination of the warning stimulus even when no shock is delivered (Sidman, 1958*a*).

The effect on response rate of a stimulus that precedes an aversive event is not at all simple or easy to state precisely. Although suppression of positively reinforced responses by a stimulus that precedes shock is a well-known phenomenon, it is by no means an invariable finding. For example, under some conditions, conditioned suppression virtually disappears after extended exposure, giving way to a slight acceleration during the first part of the preaversive stimulus (Hendry and Van Toller, 1965; Millenson and Hendry, 1967). An increased response rate during a preaversive stimulus is also produced with low intensities of shock and a differential-reinforcement-of-low-rate (DRL) schedule of positive reinforcement (Blackman, 1968). A further complexity is provided by the case of extinction or timeout from moderate frequencies of positive reinforcement, an aversive condition (*e.g.*, Thomas, 1965). It has consistently been found that a pre-timeout stimulus produces an ac-

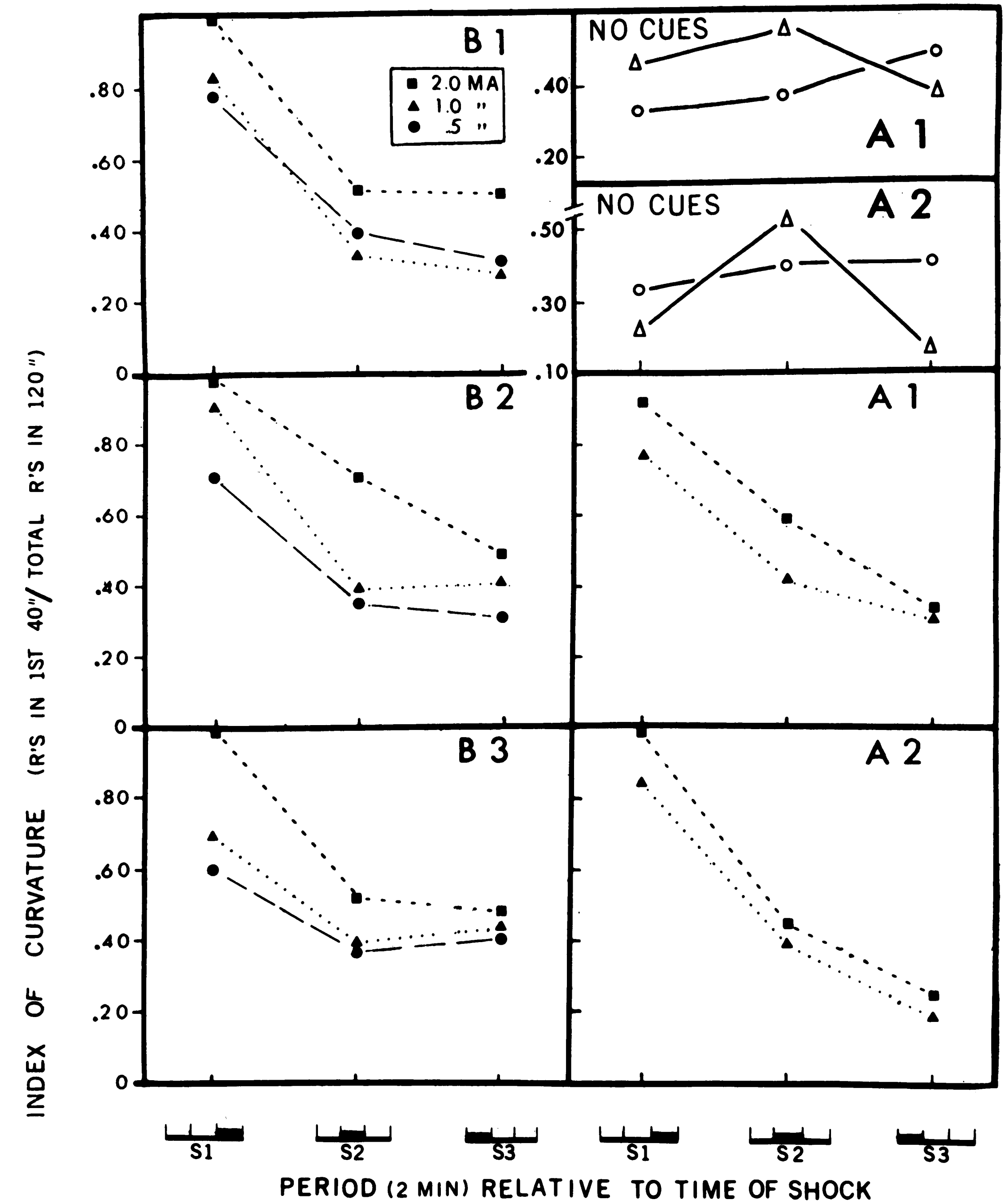

Fig. 7. Indices of curvature of all rats as a function of clock cue (S1, S2, or S3) and shock intensity. Control data for A1 and A2 without clock cues are shown at the top right. All data are from the final five sessions of each condition.

celerated, not reduced, response rate (Ferster, 1958; Herrnstein, 1955; Leitenberg, 1967; Pliskoff, 1963). Avoidance is another case in which a preaversive stimulus produces an increased rate; the rate of a free operant with a history as an avoidance response accelerates in the presence of a stimulus that precedes unavoidable shock (Herrnstein and Sidman, 1958; Sidman 1958*b*; Sidman, Herrnstein, and Conrad, 1957).

A period of low-frequency reinforcement is likely to be followed by a relatively high rate of responding maintained by higher frequencies of reinforcement (*e.g.*, Reynolds, 1961). This effect is known as behavioral contrast. When positively reinforced responses are suppressed by punishment or during a preaversive stimulus, one consequence may be a lowering of the frequency of reinforcement during response suppression, leading to a higher-than-normal response rate when punishment or the preaversive stimulus is terminated. The increased response rate is sometimes referred to as the "punishment contrast" effect (Azrin and Holz, 1966). The fact that the highest response rates in the present study occurred during S3 may be identified as an instance of punishment contrast. The frequency of reinforcement during S1, S2, and S3 was not measured, but because of the very low response rate in S1, the reinforcement frequency in S1 was probably very low also. Therefore, the relatively high rate in S3 might have been a behavioral contrast phenomenon mediated through differences in frequency of positive reinforcement.

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