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RELATIVE DURATIONS OF CONDITIONED STIMULUS AND INTERTRIAL INTERVAL IN CONDITIONED SUPPRESSION

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The effects of the relative durations of the conditional stimulus and the intertrial interval on bar pressing during a conditioned-suppression procedure were examined as a function of two additional variables—type of operant baseline schedule and rate of shock presentation. In Experiment 1, response suppression was compared across components of a multiple fixed-ratio, random-ratio, fixed-interval, random-interval schedule, at relative conditioned-stimulus/intertrial-interval durations of 1/1, 1/4, and 1/9. In Experiment 2, relative conditioned-stimulus/intertrial-interval duration (1/5, 3/3, or 5/1) was manipulated across groups, while shock frequency (2, 6, or 10 shocks/hr) was manipulated within groups. In both experiments, suppression during the signal was virtually complete at all relative durations. Responding was also suppressed during the intertrial interval, but that suppression varied as a function of experimental manipulations. In Experiment 1, intertrial-interval response rates were higher when relative signal duration was 1/9 than when it was 1/1, although both relative signal duration and shock frequency, which covaried, could have contributed to the difference. In Experiment 2, the patterning of response rates between successive shocks was affected by relative duration, absolute rates during the intertrial interval varied as a function of shock frequency, and differences between suppression during the signal and suppression during the intertrial interval were affected by both relative duration and shock frequency. The data support an analysis based upon relationships between shock-correlated and intertrial-interval stimuli and, as assessed by the relative-delay-to-reinforcement metric, are comparable to results that have been reported from experiments using similar manipulations under the autoshaping paradigm.

Key words: relative CS duration, conditioned suppression, intertrial responding, schedule type, shock frequency, associative control, lever press, rats

In contrast to earlier contiguity models of Pavlovian conditioning that emphasized temporal proximity between conditional and unconditional stimulus (CS and US) events (e.g., Pavlov, 1927), more recent accounts have focused on relative delays to reinforcement (Brown, Hemmes, Coleman, Hassin, & Goldhammer, 1982; Gibbon & Balsam, 1981; Gibbon, Berryman, & Thompson, 1974; Jenkins, Barnes, & Barrera, 1981; Stein, Sidman, & Brady, 1958). For instance, in a conditioned emotional response (CER) procedure, Stein et al. varied CS and intertrial-interval (ITI) durations unsystematically from 0.5 to 50 min, and superimposed CS-shock pairings over a baseline of rats' lever pressing on a variable-interval schedule of food reinforcement. The authors reported that the absolute duration of neither the CS nor the ITI exerted substantial control over suppression during the CS. Instead, suppression ratios (response rate during the CS divided by rate during the ITI) varied directly with relative CS duration. Similarly, Gibbon and Balsam appealed to the finding that speed of acquisition in pigeon autoshaping is controlled by the ratio of US–US to CS–US intervals.

The orientation toward a more molar temporal analysis has been accompanied by a broader view of stimulus control, in which the earlier prominence of the CS has yielded to the notion that the conditional response is under joint control of both CS and extra-CS cues.

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For example, several authors have proposed that behavioral control by the CS is modulated by the role of static background, or context, cues (Gibbon & Balsam, 1981; Rescorla & Wagner, 1972). Alternatively, the modulation function has been assigned to all cues presented between successive US occurrences, including ITI cues (Brown et al., 1982).

Indirect evidence for the role of context has been provided, in autoshaping procedures with pigeons, by demonstrations that responding during the CS may be modified by manipulations that involve context cues alone (e.g., Balsam, 1984; Tomie, 1981). More direct evidence for control by extra-CS cues may be sought in CER procedures with rats, where the target behavior, usually lever pressing maintained by operant reinforcement, is available for study in both the presence and absence of the CS. Several reports have indicated that under some circumstances, CER procedures may, indeed, affect behavior occurring outside the CS period (Davis & McIntire, 1969; Hunt & Brady, 1955; Marlin, 1983). Hurwitz and Davis (1983) have recently addressed this issue directly, showing an inverse relationship between rate of shock delivery (manipulation of which produced concomitant variation in relative CS duration) and response rates during the ITI, although no effects were seen during the CS owing to total suppression at all shock-density values.

These results indicate that response rates during the ITI may be sensitive to the same variables that influence CS responding, and are therefore worthy of direct study. The purpose of the present study was to investigate responding during both the CS and the ITI as a function of relative CS duration. An issue concerning the effect of this variable is its confounding with other temporal parameters (see Balsam, 1984). In particular, in CER studies the US–US interval has been permitted to vary with relative CS duration in studies of ITI (Hurwitz & Davis, 1983) as well as in studies of CS (e.g., Carlton & Didamo, 1960; Stein et al., 1958) responding. Experiment 1 of the present study was designed, in part, to replicate the effect of relative CS duration upon responding during the ITI. Relative CS durations were manipulated in a manner similar to that of Stein et al. in order to evaluate their interpretation of the relative duration effect—a reinforcers-lost hypothesis. In Experiment 2, both relative CS duration and inter-US interval were manipulated independently in order to evaluate their separate contributions to behavioral control.

A second issue in CER studies concerns the widespread use of suppression ratios to assess conditioned behavioral effects. The use of that metric is based upon the assumption that the locus of behavioral effects is restricted to CS events. Because that assumption seems untenable and because of other objections to it (Frankel, 1975; Hurwitz & Davis, 1983; Millenson & de Villiers, 1972), results of the present study were analyzed in terms of absolute response rates in both CS and ITI periods.

EXPERIMENT 1

In the initial demonstration of relative CS duration effects, Stein et al. (1958) reported that conditioned suppression was inversely related to the number of reinforcers that would be lost as a result of suppression. The longer the CS duration, relative to the ITI, the larger the percentage of a session's reinforcers set up, and therefore lost through suppression, during the signal. The direct relationship (in Zeiler & Buchman's 1979 terminology) between relative CS duration and potential reinforcer loss should constrain the level of suppression to a response rate just sufficient to obtain most reinforcers. An implication of this analysis is that relative CS duration should interact with the degree of constraint imposed by the operant baseline schedule in determining the level of suppression. Variable-interval schedules of the type used by Stein et al. impose relatively little constraint; once they are set up, reinforcers remain available until the next reinforcer is set up, and only a single response is required to produce each reinforcer. Thus, response rate can vary widely with little effect on rate of reinforcement. Alternatively, ratio schedules impose more constraint in that every response contributes to earning the reinforcer. Thus, any decrease in rate of responding will result in a loss of reinforcers during a session of fixed duration.

These considerations formed the basis of the present experiment, which was an attempt to replicate the previously reported effects of relative CS duration while varying the degree of response constraint imposed by the baseline operant schedule. Relative CS duration was varied in the context of a multiple schedule that contained both ratio and interval components. If relative CS duration affects suppression solely through reinforcer-based constraints on responding, then suppression should be slight or nonexistent during ratio components, regardless of CS value. If, on the other hand, these effects are independent of reinforcer loss, then response rate should be affected similarly by manipulation of relative CS duration during ratio and interval components. In addition, inasmuch as periodic and aperiodic reinforcer delivery schedules also differ in terms of minimum response requirements, and inasmuch as behavior is known to be sensitive to such differences (e.g., Catania & Reynolds, 1968; Farmer, 1963; Herrnstein, 1964), the operant baseline consisted of a multiple fixed-ratio, random-ratio, fixed-interval, random-interval (FR RR FI RI) schedule.

A second consideration in the design of this experiment was the observation that degree of suppression varies with baseline rates of responding and reinforcement (Blackman, 1966, 1968b; Lyon, 1963). Because these variables represent potential confounds in the present study, an attempt was made to minimize differences in rates of responding and reinforcement as a function of schedule type. Accordingly, a differential-reinforcement-of-low-rate (DRL) contingency was superimposed in each component of the multiple schedule, such that only those responses separated by at least 2 s from the previous response could contribute to meeting the schedule requirement. The DRL and baseline-schedule parameters were chosen so that the maximum reinforcer rate would be the same for all baseline schedules, provided the DRL requirement was met. In all other respects, the fundamental schedule characteristics remained intact: The ratio schedules required that all responses satisfy the DRL requirement, whereas the interval schedules required only one such response per reinforcer; random schedules specified the same average interreinforcer time and response frequency as did fixed schedules, but the minimum values were smaller.

Although the preceding issues are traditionally raised with respect to effects upon behavior during the CS, the present experiment also focuses attention upon behavior during the ITI. Previous work has shown that manipulations similar to those employed here have systematically affected responding during the ITI, even in the absence of measurable effects during the CS (Hurwitz & Davis, 1983).

METHOD

Subjects

The subjects were 4 male Long-Evans rats, supplied by Charles River. Subjects were approximately 60 days old at the start of the experiment and were maintained at 80% (±5%) of their ad-lib weights on powdered Purina Rat Chow. Water was always available in the home cage.

Apparatus

Sessions were conducted in a Scientific Prototype two-bar rat environment, in which only the left lever produced programmed consequences. Reinforcers were 45-mg Noyes food pellets dispensed into a tray centered on the intelligence panel, 2.5 cm above the floor and 10.6 cm below a stimulus lamp (General Electric, Type K; 6-W, 28-V dc). A houselight was mounted on the ceiling of the chamber. The output of a Foringer Model 1293 square-wave click generator could be presented through a 3-inch, 8-Ohm speaker that was mounted behind the intelligence panel, along with a Sonalert tone generator (Model SC628M). Sound masking was provided by white noise played through a second speaker and by noise from the chamber's ventilating system. A Lehigh Valley constant-current shocker/scrambler (Model 713-33) could deliver scrambled shock to the grid floor of the chamber. Experimental control was accomplished with electromechanical equipment located in an adjacent room.

Procedure

All sessions began with placement of the rat in a dark chamber. Houselight onset signaled the beginning of a session, and houselight offset signaled session's end. Prior to a session, a single food pellet was placed in the food tray. This procedure was continued throughout the experiment, and was instituted to increase the likelihood that some nonzero level of responding would be maintained during shock conditions (Aylion & Azrin, 1968).

Bar-press and schedule training. Following magazine training, pressing of the left bar was manually shaped, and each bar press was followed by the simultaneous presentation of a 0.5-s tone from the Sonalert and delivery of one pellet of food to the tray. Each bar press was reinforced in this manner until 100 reinforcers had been delivered.

Following bar-press training, the rats were trained on each of the four schedule types to be used in the multiple schedule, in the following order: FR, RR, RI, FI. Each type of schedule was accompanied by a different frequency click presented through the speaker: FR—5Hz, RR—11Hz, RI—56Hz, and FI—25Hz. A DRL contingency was also in effect during training under the four different schedules, such that only those responses that followed the previous response by 0.5 s or more ("correct responses") produced the 0.5-s tone. In addition, only responses meeting the DRL requirement could contribute to earning the reinforcer under the ratio schedules. Responses that did not meet the DRL requirement reset the DRL interval. Training under each schedule continued until rate of responding appeared stable across sessions, with session length set at 2 hr.

During FR training, ratio size was gradually increased to FR 40. After 24 sessions under FR 40, the rats were switched directly to RR 40. On this schedule, correct responses sampled a probability generator set at p = .025. With these parameters, successive reinforcers could occur after a minimum of 1 response and 0.5 s, but on the average would occur after 40 correct responses—the same nominal value arranged by the FR 40 schedule. To the extent that rats met the DRL requirement, response rates on the RR schedule would also approximate those on the FR, at about 2/s. Note that responding at a fixed rate could reduce or eliminate the postreinforcement pause traditionally found with FR schedules, but would produce the maximum reinforcer frequency possible on both the FR and RR schedules, as well as on subsequently programmed interval schedules. Training under the RR schedule continued for 15 days.

Next, the animals were trained on an RI schedule. On this schedule a probability generator set at p = .025 was sampled every 0.5 s, thus equating minimum interreinforcement times on the RR and RI schedules. Reinforcers were set up by an output from the probability generator. With these parameters, a correct response could produce a reinforcer after a minimum of 0.5 s, and on the average after 20 s—the same nominal values arranged by the FR and RR schedules, assuming a constant rate of 2 responses/s. After 15 days on RI, the rats received 15 days of training on an FI 20-s schedule. Here, the first correct response following 20 s, timed from the previous reinforcer, produced a food pellet.

As on the ratio schedules, a 0.5-s tone followed each correct response under the interval schedules, although correct responses produced a reinforcer only when the reinforcer had been set up by the interval schedule. This feature enhanced comparability with the ratio schedules. Also, it was expected that the tone, owing to its pairing with primary reinforcement, would provide conditioned reinforcement for spaced responding under the interval schedules.

Multiple-schedule training. Following FI training, animals were exposed to a multiple FR RR FI RI schedule in which each component was signaled by the click frequency that had previously accompanied that schedule. Each component was presented once per session and lasted 30 min. Session length continued to be 2 hr. Order of presentation was randomized across four-session blocks, with the restriction that the first component be either FR or RR on 2 out of 4 days in each block. All rats were exposed to the same sequence.

For 20 sessions the rats were run on the multiple schedule using the same parameters established during training with the individual components. During this time there was little evidence that the DRL contingency was effective in reducing differences in response or reinforcer rates across the components. Inasmuch as response rates never reached 2/s, it was reasoned that the 0.5-s DRL requirement was shorter than the majority of prevailing IRTs, and that behavior did not make sufficient contact with the pacing contingency. Accordingly, the DRL requirement was increased in two steps to a final value of 2 s. To avoid substantial increases in mean interreinforcement time, ratio requirements were decreased from 40 to 20 during the second step. Time between samplings of the probability generator on the RI component was increased to 2 s, again to equate minimum interreinforcement times on RR and RI components, producing nominal values of 20 responses spaced 2 s apart for each reinforcer, in all four schedule components. Although this procedure did not eliminate response-rate differences across components, differences were greatly reduced and were not systematic across animals.

Experimental conditions. The experimental manipulation consisted of varying relative CS duration across three phases. As in the procedure used by Stein et al. (1958), this was accomplished by varying cycle (CS + ITI) time. The ITI was defined as the interval between CS offset and CS onset. In the present experiment, CS duration was held constant at 1 min while ITI duration varied. The resulting CS/ITI duration ratios were 1/4 (Phase I), 1/9 (Phase II), and 1/1 (Phase III). In each experimental phase, three conditions were presented: baseline, shock, and extinction (return to baseline). During baseline conditions, the CS (illumination of the stimulus lamp) was presented without the US, at the same relative duration to be used during shock sessions. During shock, the US (a 1-s, 1-mA scrambled foot shock, calibrated weekly) coincided with CS offset. In the extinction conditions, the CS was again presented alone, at the same relative duration used throughout that phase. The baseline procedure was always in effect for eight sessions. In Phases I and II, shock and extinction, respectively, were each in effect for 20 days. However, because behavioral change always ended within 9 to 12 days, those conditions were presented for only 12 sessions in Phase III.

Conditional stimulus and ITI periods alternated in all conditions, and components of the multiple schedule always began with CS onset. Programmed reinforcers were held until a response occurred or until another reinforcer was set up. A reinforcer set up but not delivered during a CS or ITI period remained available during the succeeding stimulus condition. However, reinforcers were not held over from one operant schedule component to the next. In Phases I and II, all four components were presented once per session, using the same block-randomized sequence in effect during training. In Phase III, the FI and FR components were eliminated, shortening session time to 1 hr, in order to reduce rats' exposure time to the high shock frequency produced by the 1/1 relative CS duration.

RESULTS

Although conditioned suppression is typically assessed with a suppression ratio, such measures may obscure effects on responding during the ITI (see Hurwitz & Davis, 1983). The present procedure, like that of Hurwitz and Davis, produced severe suppression during the ITI as well as during the CS. Under these conditions, relative measures are especially inappropriate, because they become highly variable with slight fluctuations in absolute rates and are difficult to interpret (Frankel, 1975; Millenson & de Villiers, 1972). Accordingly, response tendency in the present study was analyzed in terms of absolute rates during the CS and ITI.

Figure 1 presents response rates during the CS (right column) and during the ITI (left column) in each experimental condition, for each schedule component. The first set of points on each graph (Phase I, baseline) indicates that there were no consistent differences as a function of component type. The individual rats adopted different patterns of responding across the four schedule components, but response rates during the CS and ITI were similar prior to the introduction of shock. During shock conditions, rates during the CS showed almost total suppression at all three relative CS durations and on all four components. Across successive baseline and extinction conditions, the ordering of and differences among CS rates on the four schedule components were consistent within animals; individual rats' patterns of responding across schedule components were not affected by the repeated presentation and removal of shock.

Response rates during the intertrial interval, although also greatly suppressed during shock conditions, varied as an inverse function of relative CS duration. Averaged across animals and components, responding during the ITI (compared for Days 1 through 12 because Phase III lasted only 12 days) was generally higher when the CS/ITI ratio was 1/9 (mean = 18.00 responses/min) than at 1/4 (mean = 6.62 responses/min), with almost total suppression at 1/1 (mean = 1.80 re-

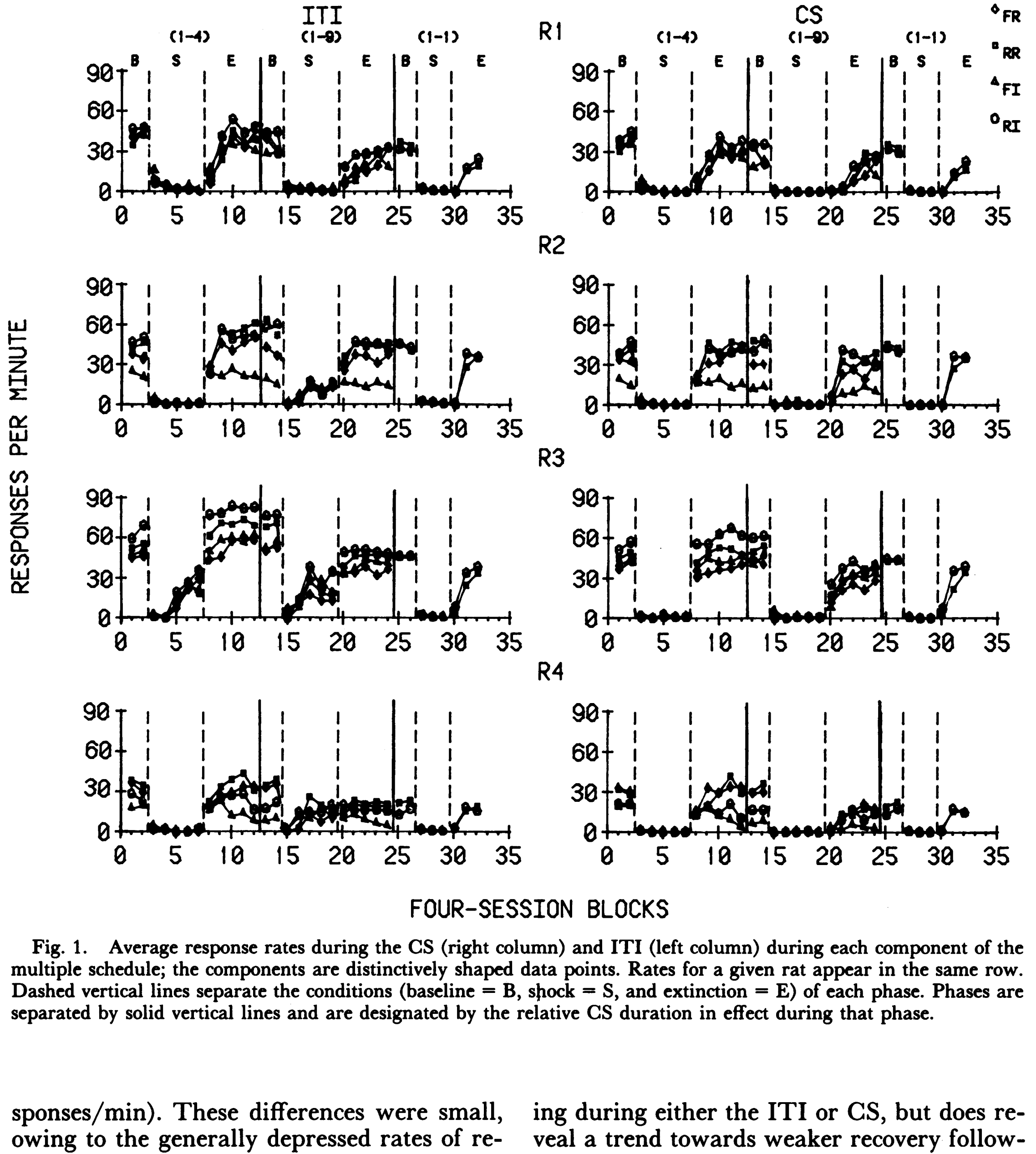

Fig. 1. Average response rates during the CS (right column) and ITI (left column) during each component of the multiple schedule; the components are distinctively shaped data points. Rates for a given rat appear in the same row. Dashed vertical lines separate the conditions (baseline = B, shock = S, and extinction = E) of each phase. Phases are separated by solid vertical lines and are designated by the relative CS duration in effect during that phase.

sponses/min). These differences were small, owing to the generally depressed rates of responding, and were not significantly different statistically, $F(2, 9) = 3.00$, $p = .10$). However, a planned comparison showed that mean ITI response rates were higher at the 1/9 relative CS duration than at the 1/1 ratio, $t(8) = 2.45$, $p < .05$, two-tailed. Figure 1 indicates no systematic differences in ITI rates across component types during shock.

An examination of extinction data in Figure 1 shows no differential loss of suppression as a function of component type for responding during either the ITI or CS, but does reveal a trend towards weaker recovery following each successive shock condition.

Figure 2 shows cumulative records for the RI component of the last shock session at each relative CS duration, for Rat R1 (a rat that responded at low rates) and Rat R3 (a rat that responded at higher rates). The figure shows that where responding occurred during shock conditions, it was initiated immediately following the US, and then decreased either gradually or abruptly during the intertrial interval.

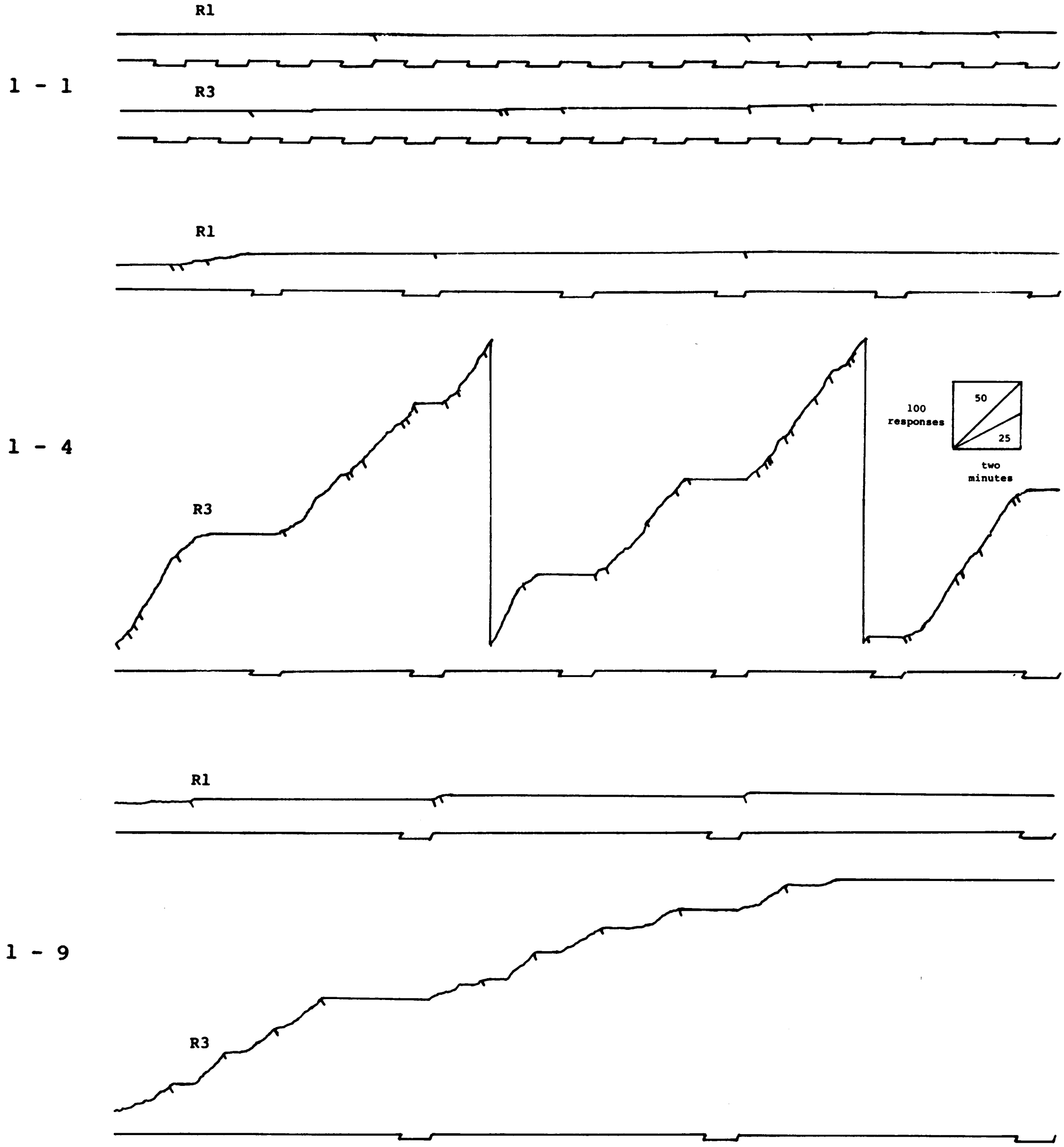

Fig. 2. Cumulative records for Rats R1 and R3 during the RI component of the last shock session, at each relative CS duration, in Experiment 1. Downward deflections of the response pen indicate reinforcer delivery. The response pen reset after 400 responses. Downward deflections of the event marker (located below each response record) indicate CS onset; the upward stroke of the marker indicates CS offset and shock delivery.

Discussion

Owing to extremely low rates of responding during the CS, the reinforcers-lost hypothesis could not be evaluated by means of a traditional analysis. However, other measures failed to support an analysis of conditioned suppression based on constraints imposed by the baseline schedule of reinforcement. Neither changes in ITI rates during shock conditions nor rates of recovery from shock during the CS and ITI varied across the baseline schedules of reinforcement—schedules which, despite the DRL requirement, retained the differences in constraints that historically have been associated with different rates of responding. The possibility that the DRL requirement may have interfered with the schedule constraints, in such a way as to mask or reduce their effects, cannot be assessed without further research. However, it does not seem likely in the present case that DRL requirements, an effect of which is to increase interresponse times, would have prevented a reduction in response rates where the schedule constraints were the weakest.

Because responding during the CS was almost totally suppressed, it is difficult to compare the present data to those from other CER research. However, control of suppression by experimental manipulations was observed in response rates from the ITI. An account of this finding can be based on the notion of differential associative control at different relative CS durations. Associative control refers to control of behavior that is based on the programmed relation between stimulus and reinforcer events. Recent formal treatments of the role of Pavlovian relations share the view that associative control of behavior by the CS is inversely related to control by background cues (e.g., Brown et al., 1982; Gibbon & Balsam, 1981; Rescorla & Wagner, 1972). According to some of these formulations, the reverse should also hold; that is, the degree of control exerted by extra-CS, or ITI, cues varies inversely with control by the CS. Thus, in the present study, cues present during the ITI may have accrued greater control over behavior as relative CS duration increased, as reflected in suppression of responding over longer periods.

An alternative explanation of the observed effects upon response rate during the ITI can be based upon shock-frequency differences. In the present study, as in previous ones (Carlton & Didamo, 1960; Hurwitz & Davis, 1983; Stein et al., 1958), relative CS duration was confounded with shock frequency. In the present case, relative CS duration was varied by changing ITI duration. As relative CS duration decreased, shock frequency also decreased from 30 to 6 shocks/hr. Thus, the previously described reliable difference in response rates during the ITI between the 1/9 and 1/1 conditions may be attributable to confounded variation in shock frequency. Similarly, a reanalysis of Stein et al.'s data shows that suppression ratios (smaller ratios indicated more suppression) from that study were significantly lower at low- as opposed to high-density shock conditions (means = .17 and .25; $t(24) = 2.85$, $p < .005$). A Pearson product-moment correlation between ITI response rate and shock density in their study approached significance [$r(24) = .31$, $p < .10$], whereas the correlation between CS response rates and shock density did not ($r = .08$, N.S.).

The effect of shock frequency could be either associative (involving Pavlovian relationships) or nonassociative. The gradual recovery of ITI responding during extinction (see Figure 1) suggests that suppression during the ITI was under associative control, because nonassociative suppression would be expected to dissipate rapidly (Bolles & Riley, 1973). Another possibility is that changes in response rates in the ITI across conditions may have been simply the result of differing opportunities for high response rates to emerge under differing ITI durations. That is, the longer ITI could have given more time for local recovery from the effects of shock. However, the cumulative records (Figure 2) do not support that explanation; responding, when it occurred, was most rapid immediately following shock at all relative CS durations, and either decreased or ceased prior to the next CS.

The severe depression of responding observed in this experiment, although not unprecedented (see Hurwitz & Davis, 1983), deserves some comment. One consideration is the role of the shock parameters (1 mA at 1 s) used in this experiment. Inasmuch as other studies have reported maintained or facilitated responding using similar or more extreme values (Davis & McIntire, 1969; Finocchio, cited in Blackman, 1968a; Libby, 1951), the massive suppression cannot be attributed solely to this variable. Another explanation follows from the similarity between the behavior of the rats in the present study and that of rats exposed to unsignaled shock procedures, where widespread depression in rate is typical (Seligman, 1968). The low overall rates in the present study may be due to exposure to a weak CS–US relation (as defined above) in Phase I. Initial training with a weak CS–US contingency has been shown to retard acquisition at later, more favorable conditions. For example, Randich (1981), in the first of four experiments, exposed rats to either signaled

Table 1

Experiment 2: Durations of the CS and ITI (in minutes) in each experimental phase.

Group		Phase				
		I(10)	II(2)	III(6)	IV(0)	V(10)
1-5	CS	1	5	1⅔	1⅔	1
	ITI	5	25	8⅓	8⅓	5
3-3	CS	3	15	5	5	3
	ITI	3	15	5	5	3
5-1	CS	5	25	8⅓	8⅓	5
	ITI	1	5	1⅔	1⅔	1

Note. Numbers in parentheses indicate the number of shocks per hour.

or unsignaled shock prior to CS–US training, and found that unsignaled preexposure produced retarded acquisition of conditioned suppression as compared to signaled preexposure. He argued that when the preexposure shocks were unsignaled, situational (context) cues became conditioned to the US and partially blocked later acquisition of conditioned suppression. In Experiment 4 of that study, Randich reported that if the intensity of the preexposure US was initially low and then gradually increased to the level used in his Experiment 1, unsignaled preexposure to shock produced a smaller decrement in acquisition of conditioned suppression. He reasoned that the initially low-intensity US produced weaker context conditioning than did the initially high-intensity US, and therefore less blocking of conditioned suppression. He attributed the weaker context conditioning to the low-intensity US providing a poor context–US relation, and concluded that the weak initial conditioning could not be strengthened by subsequent training with more favorable (higher-intensity US) conditions. A similar analysis may account for the continued severe overall suppression observed during the latter phases of this experiment.

In summary, the present findings replicate the effects of relative CS duration on responding during the ITI. Two accounts are consistent with the present data: Degree of suppression may be controlled by variations in shock frequency or by CS/US relations. However, because shock frequency and relative CS duration covaried, the experiment cannot distinguish between the two alternatives. Experiment 2 was designed to separate the manipulation of relative CS duration and shock frequency, in order to examine these alternatives directly.

EXPERIMENT 2

In this experiment, relative CS duration and shock frequency were unconfounded in a 3 by 3 factorial design in which relative CS duration was manipulated across groups, while shock frequency was manipulated within groups. Shock intensity and duration were reduced to 50% of the values used in Experiment 1.

METHOD

Subjects and Apparatus

Nine male hooded rats, approximately 75 days old at the start of the experiment and maintained at 80% (±5%) of their ad-lib weights, served. Water was always available in the home cage. The apparatus was the same as that used in Experiment 1.

Procedure

Following magazine and bar-press training, each of the next 100 responses produced a reinforcer. Next came exposure to a series of FI schedules ranging from 5 to 30 s, then to an RI 30-s schedule, and finally to an RI 40-s schedule (intersample time = 2 s; p = .05). After 20 1-hr sessions under RI 40 s, the rats were randomly assigned to three groups and were exposed to five experimental phases. During Phases I, II, III, and V, the CS (illumination of the stimulus lamp) was presented alone for either 5 or 15 baseline sessions, followed by 15 shock sessions during which the US (0.5-s, 0.5-mA scrambled foot shock) coincided with CS offset. Relative CS duration was varied across the three groups of rats by manipulating the proportion of the CS–ITI cycle occupied by the CS. The cycle was divided into six bins of equal duration, with the ITI occupying the first 1, 3, or 5 bins in Groups 5-1, 3-3, and 1-5, respectively. The CS occupied the remaining 5, 3, or 1 bins in the cycle. Within groups, shock frequency was manipulated across Phases I, II, and III by varying cycle duration from 6 to 10 to 30 min. Thus, relative CS duration was balanced with respect to shock frequency in this design. As in Experiment 1, reinforcers set up but not

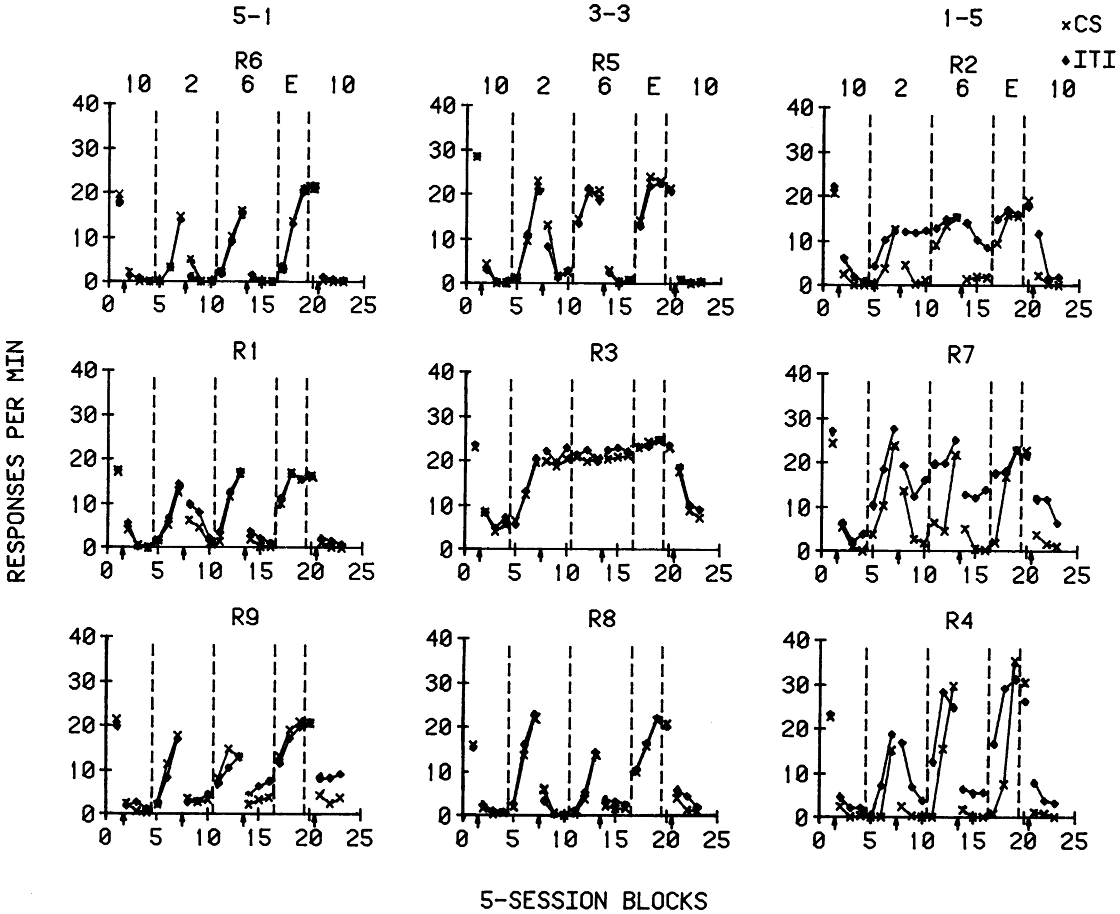

Fig. 3. Response rates during the CS and the ITI. The 3 rats in each group are in the same column. Groups differed in terms of relative CS duration. Dashed lines separate phases, which are designated by the number of shocks per hour or by "E" (extinction). Arrows along the abscissa indicate the onset of shock conditions.

delivered during the CS or ITI were available during the succeeding stimulus condition.

Following Phase III, all rats were exposed to 15 extinction sessions (Phase IV), during which the CS was presented without the US, at the same relative duration as during Phase III. In Phase V, the baseline and shock conditions of Phase I (10 US/hr) were repeated. Baseline conditions were run for only five sessions in Phases I and V because those baselines did not immediately follow shock conditions. These experimental conditions are summarized in Table 1. Sessions were 1 hr in duration in all experimental phases. Thus, total shocks per session varied across phases from 10 shocks per session (6-min cycle) to 2 shocks per session (30-min cycle).

RESULTS

Figure 3 shows response rates during the CS and ITI for individual rats, during each experimental condition. The figure shows that for Groups 5-1 (left column) and 3-3 (center column), responding was virtually eliminated during shock conditions except for Rat R3 and, in later phases, Rat R9.

For Group 1-5 (right column), however, responding was totally suppressed only during the CS. Responding during the ITI was maintained at nonzero levels during all shock conditions for subjects in this group, although rates generally were higher at 2 or 6 US/hr than at 10 US/hr. An ANOVA showed a statistically significant effect of shock frequency on mean response rates during the ITI, av-

Table 2

Experiment 2: Individual and group mean difference scores as a function of shock density.

Group	Rat	Shock density (US/hr)		
		2	6	10
1-5	2	91.25	45.39	3.60
	7	50.78	53.14	13.02
	4	19.34	22.58	7.70
	mean	53.79	45.39	8.11
3-3	5	3.12	0.99	0.36
	3	7.12	8.27	5.43
	8	0.00	7.72	1.24
	mean	3.41	5.66	2.34
5-1	6	8.36	0.02	0.00
	1	0.00	5.82	0.00
	9	8.61	28.01	6.19
	mean	5.66	11.28	2.06

Note. Difference scores are the percentage change in CS response rate, from baseline to shock, minus the percentage change in ITI rate from baseline to shock.

eraged across all rats (means = 7.11, 6.91, and 1.73 responses/min at 2, 6, and 10 US/hr; $F(2) = 6.98$, $p < .01$). During extinction (Phase IV), Group 1-5 continued to show discrimination between the CS and the ITI for several sessions. For all groups, recovery of responding was gradual. An apparent tendency for response rates to rise across successive phases, measured across successive baseline conditions, was not statistically significant for either ITI or CS rates [$F(2, 12) = 3.03$, 2.06, respectively; N.S.]. In addition, statistical analysis revealed that rates during shock were not significantly different between the Phase I and Phase IV US/hr conditions in either the CS or the ITI [$t(16) = 0.59$, 1.01, respectively].

The fact that response rates during the ITI, but not during the CS, appeared elevated at the 1/5 as compared to those at the 3/3 or 5/1 relative CS durations, especially at 2 and 6 US/hr, suggested that some measure of differential responding (i.e., greater suppression during the CS than during the ITI) might be sensitive to effects of the relative-duration manipulation. Because, for reasons discussed in Experiment 1, suppression ratios were inappropriate, an alternative measure was used. A difference score was computed by finding the percentage change in CS and ITI response rates, from baseline to shock, at each of the three shock densities, for each relative CS duration. The data used in this analysis were taken from the last 5 days of baseline and shock for each shock frequency. The difference score was the difference between ITI percentage change and CS percentage change. Table 2 shows individual and group mean difference scores for each shock density. The table shows that, in general, differentiation was greater for Group 1-5 than for Groups 3-3 or 5-1 at all three shock densities, and appeared most pronounced at 2 US/hr. Only for Group 1-5 did difference scores appear to vary systematically with shock frequency. For this group, those scores were greater at 2 and 6 shocks/hr than at 10 shocks/hr. Difference scores were submitted to a 3 by 3 (relative CS duration by shock frequency) ANOVA, which revealed significant main effects of both relative duration [$F(2, 6) = 8.43$, $p = .02$] and shock frequency [$F(2, 12) = 4.76$, $p = .03$], with the interaction reaching $p = .06$.

One-way ANOVAs showed that group mean differences related to relative CS duration were significant only at 2 US/hr [$F(2, 6) = 5.45$, $p = .04$] and at 6 US/hr [$F(2, 6) = 6.41$, $p = .03$]. These differences were investigated further with a 3 by 2 relative duration by shock frequency (2 vs. 6 US/hr) ANOVA, which showed a significant effect of relative CS duration [$F(2, 6) = 7.54$, $p = .02$]. Because there was no main effect of, or interaction with, shock frequency, difference scores were pooled across 2 and 6 US/hr. A t test showed that Group 1-5 had significantly greater difference scores than either Group 3-3 or Group 5-1 [$t(6) = 3.19$ and 3.51; $p = .02$ and .01, respectively], which did not differ from each other [$t(6) = 0.32$; N.S.].

Table 3 shows individual rats' response rates during each of the six intershock bins, averaged over the last five sessions at each shock frequency (Phases I–III). The data indicate reliably decreasing response rates across the entire intershock interval for Group 1-5, but not for Groups 3-3 or 5-1, at all shock frequencies. These data are summarized in Figure 4, which shows group mean rates during each intershock bin, at each shock frequency. The dashed vertical lines indicate CS onset. The figure shows that for Group 1-5 only, not only was responding during the CS suppressed relative to that during the ITI, but

Table 3

Experiment 2: Individual rats' response rates in successive bins of the intershock interval at each shock frequency.

Shock frequency	Rel. CS duration	Rat	Bin					
			1	2	3	4	5	6
2 US/hr	1-5	2	14.7	13.8	11.1	10.6	10.9	1.0
		7	19.5	13.8	15.5	15.9	15.7	1.9
		4	7.3	5.0	2.6	2.1	1.0	0.0
	3-3	5	2.4	2.7	3.2	2.0	2.4	2.5
		3	21.3	24.3	22.9	20.6	21.0	19.4
		8	0.1	0.0	0.0	0.1	0.1	0.0
	5-1	6	0.0	0.0	0.0	0.0	0.0	0.0
		1	2.0	2.6	0.7	0.2	0.0	0.0
		9	4.5	3.1	2.3	2.4	4.1	3.9
6 US/hr	1-5	2	10.2	9.5	8.1	7.9	6.9	1.5
		7	18.4	19.0	12.0	10.7	8.8	0.4
		4	13.7	10.9	5.5	4.6	3.4	0.0
	3-3	5	1.3	0.7	0.8	0.9	0.7	1.0
		3	21.9	22.0	21.9	20.9	21.6	21.2
		8	5.6	1.4	1.3	2.2	1.4	0.8
	5-1	6	0.1	0.0	0.1	0.1	0.2	0.0
		1	1.2	0.5	0.1	0.0	0.1	0.1
		9	7.4	6.0	3.2	2.9	2.9	3.7
10 US/hr	1-5	2	0.0	0.0	0.0	0.0	0.0	0.0
		7	7.2	6.2	2.9	1.0	0.5	0.1
		4	6.8	1.9	1.0	0.2	0.0	0.2
	3-3	5	0.4	0.0	0.1	0.1	0.1	0.1
		3	8.9	6.5	6.0	6.1	5.7	5.3
		8	1.3	0.4	0.4	0.3	0.6	0.5
	5-1	6	0.0	0.0	0.0	0.0	0.0	0.0
		1	0.0	0.0	0.0	0.0	0.0	0.0
		9	1.2	0.5	0.1	0.1	0.1	0.1

Note. Response rates are averaged across the last five sessions at each shock frequency. Bins are equal duration, consecutive segments, of the intershock interval. Duration of the intershock interval, and therefore of the bins, depended upon shock frequency.

also that ITI rates appeared to decrease across successive bins. The group data were representative of the individual rats in terms of patterning, although the elevation for Group 3-3 was affected by the high response rates of Rat R3 (see Table 3).

Straight lines were fitted by the least squares method to the bin-by-bin data for each animal. Data for both CS bins and ITI bins were included in the analysis, despite the different training contexts, because the pattern of responding throughout the intershock interval was of interest and because the variable number of ITI bins across groups would have made difficult a meaningful comparison of only ITI data. Group mean slopes for the functions in Figure 4 are presented in Table 4. Analyses of variance indicated that for Group 1-5, slopes were significantly different from zero at all three shock frequencies [$F(1, 16) = 6.17$, 32.11, and 18.90 for 2, 6, and 10 US/hr; $p < .02$ in all comparisons). For Groups 3-3 and 5-1, the ANOVA revealed that slopes never differed significantly from zero. A relative CS duration by shock frequency ANOVA using slopes revealed a significant main effect of relative duration [$F(2, 6) = 6.43$, $p = .01$], but not of frequency, with no interaction. Individual t tests showed that the slopes for Group 1-5 were significantly steeper than those of Groups 5-1 or 3-3 [$t(6) = 3.61$ and 3.77, respectively; $p = .01$ in both comparisons], which did not differ from each other.

DISCUSSION

A major finding of Experiment 2 was that relative CS duration controlled rats' behavior during a CER paradigm when relative du-

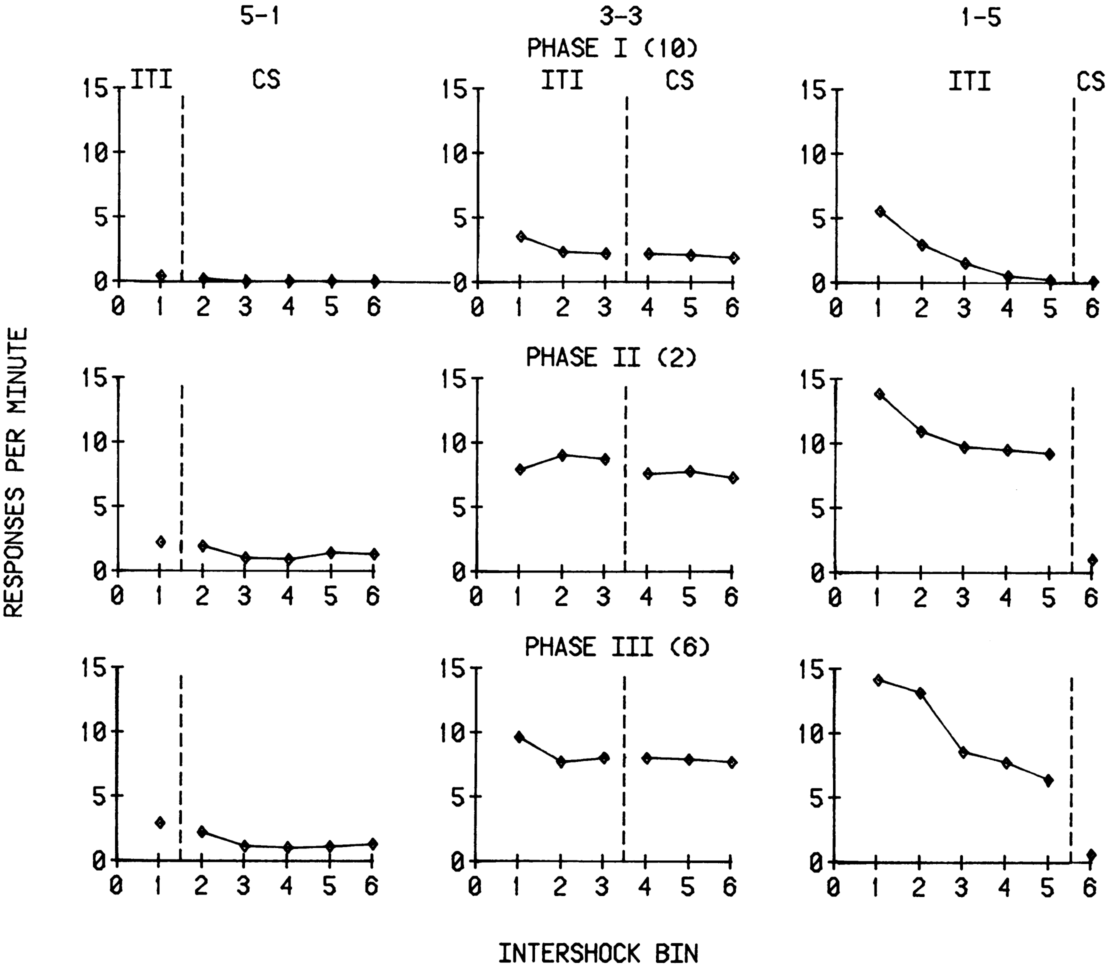

Fig. 4. Group mean response rate in each of the six intershock bins. Groups, represented in columns, differed in terms of relative CS duration. Each row shows rates for one phase. Numbers in parentheses indicate the number of shocks per minute for that phase. Dashed vertical lines indicate CS onset.

ration was not confounded with shock frequency. However, shock frequency also affected responding, and there was evidence suggesting that the two variables interacted. Shock frequency had significant effects on absolute response rates during the ITI; relative CS duration had significant effects on the pattern (slope) of responding between shocks; and both variables affected differentiation in responding between the CS and the ITI.

In this experiment there was less responding during the ITI when the 10-shocks/hr (as compared to 2- or 6-shocks/hr) condition was in effect, and less differential responding when relative CS duration was 5/1 or 3/3 (as compared to 1/5). As in Experiment 1, these differences in differential responding occurred primarily during the ITI because, for most subjects, rates during the CS were severely suppressed during all shock conditions. The finding of control by shock frequency is of interest also in its agreement with a report of "autocontingency" effects by Davis, Shattuck, and Wright (1981). Autocontingency refers to the fact that the occurrence of a shock in a CER paradigm serves as a cue for the absence of shock during the shock-shock interval, and therefore for differential response rates during the ITI as a function of the duration of the shock-free period. However, the bin-by-bin data in Figure 4 indicate that the greatest change in response rate during the intershock interval, at all shock frequencies, occurred for Group 1-5, where the short relative CS duration should have maximized the CS–US relation (cf. Gibbon et al., 1974). In Groups 3-3 and 5-1, little temporal patterning was evident. Because autocontingency effects are apparently greatest where the CS–US relation is weakest (Davis & Memmott, 1983), it is not clear that the autocontingency model provides the most appropriate explanation for the present data.

Although the experimental effects were seen primarily outside of the CS, gradual recovery of rates during extinction (Phase IV) and group differences in the temporal pattern of responding (Figure 4) support the view that ITI responding was under associative control (see Bolles & Riley, 1973). Together with the findings of Ayres and Vigorito (1984), Davis and McIntire (1969), Hunt and Brady (1955), and Hurwitz and Davis (1983), the extinction data of the present experiments are consonant with the hypothesis that responding during the ITI may come under associative control even when behavioral change is not evidenced during the CS.

GENERAL DISCUSSION

The finding of major interest in this study was that rats' food-reinforced bar pressing varied lawfully as a function of a stimulus-stimulus (CS–US) relationship based on the relative duration of the CS. The effect of this variable was seen primarily outside of the CS, and was modulated somewhat by variations in shock density.

Several conceptualizations of associative learning stipulate that stimulus events other than the CS may maintain associative control even following extended CS–US pairings—for example, arousal theory (Killeen, Hanson, & Osborne, 1978), scalar expectancy theory (Gibbon & Balsam, 1981), and the relative-waiting-time hypothesis (Jenkins et al., 1981). Although all of these models can be extended to address ITI conditioning, none currently distinguishes between the ITI, as a separate stimulus event, and the background or context, which is comprised of cues present during both the CS and the ITI. The present data, together with other recent reports of stimulus control during the ITI, suggest that such a distinction may be useful. One model which in its present form permits that distinction is the relative-delay-to-reinforcement (or relative-delay) hypothesis (Brown et al., 1982). According to that model, behavior in the presence of a given stimulus is controlled by the ratio of time to the US from the onset of that stimulus to the sum of the times from all stimulus changes. For the ITI data of the present study, the relative-delay metric would be as follows:

$$\frac{\text{ITI delay}}{\text{CS delay} + \text{ITI delay}},$$

where ITI delay and CS delay refer to time to the US following onset of the ITI and CS, respectively. For both Experiments 1 and 2, rates of responding during the ITI were monotonically related to this metric: Relative ITI delay values in Experiment 1 were .50, .80, and .90 for Conditions 1/1, 1/4, and 1/9, respectively; the values in Experiment 2 were .17, .50, and .83 for Conditions 5-1, 3-3, and 1-5, respectively. As predicted by the relative-delay model, amount of suppression of ITI responding increased as relative ITI delay decreased in both experiments. It is worth noting that the relative-delay metric bears a close formal similarity to the delay-reduction hypothesis developed by Fantino (1969) to describe choice behavior in operant procedures (concurrent-chains procedures) that also arrange spaced signals of reinforcement.

Table 4

Experiment 2: Group mean slopes of response rate across intershock time.

Group	Shock density (US/hr) 2	6	10
1-5	−2.04	−1.99	−1.02
3-3	−0.29	−0.22	−0.24
5-1	−0.33	−0.17	−0.06

It is apparent from this study that manipulation of Pavlovian contingencies in a CER situation has effects on operant responding similar to those observed when comparable manipulations are made under more strictly Pavlovian procedures. Control by relative time to shock seems directly analogous to control by relative time to food in autoshaping. In the present study, consistent differential responding occurred only when CS duration was less than half the US–US interval, the relative duration at which the CS–US relation becomes sufficiently strong for conditioned responding to emerge under autoshaping procedures with pigeons (Gibbon, 1981). Although such disparate means of assessing associative control are rarely compared, such comparisons clearly have heuristic value, inasmuch as the similarity suggests a common process of behavioral control by temporally defined stimulus–stimulus relations. An advantage of the CER paradigm may be in the more direct assessment of associative control by cues other than the CS (i.e., ITI or context cues) because, unlike the case in autoshaping procedures, lawful variation of behavior in the presence of such cues may be readily observed. However, although demonstrations of behavioral control during the ITI provide a means of assessing extra-CS associative effects, they also serve as a reminder that standard measures of the CER (e.g., suppression ratios) should be used only when responding during the ITI can be shown to provide a stable baseline.

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