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RELATIVE CS DURATION IN CONDITIONED SUPPRESSION: SCHEDULING EFFECTS OF THE UNCONDITIONED STIMULUS AND THE OPERANT REINFORCER

by

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ABSTRACT

The effects of varying the relative durations of the conditioned stimulus (light) and the intertrial interval (ITI), in a conditioned suppression paradigm, were investigated as a function of two additional variables -- type of operant baseline schedule and density of the unconditioned stimulus (shock). In Experiment 1 light shock pairings were superimposed on a multiple fixed ratio, random ratio, fixed interval, random interval schedule of reinforcement for rats' bar pressing, in which a differential reinforecment of low response rates contingency had been embedded in order to reduce schedule-specific response and reinforcer rate differences. Using a within-group manipulation subjects were exposed to CS/ITI duration ratios of 1/1, 1/4, and 1/9. During shock sessions bar pressing was totally suppressed during the conditioned stimulus (CS) on all operant schedule components. Responding during the ITI was also suppressed but ITI response rates, which did not vary as a function of schedule contingency, did vary inversely with relative CS duration. However control of ITI responding could not be attributed uniquely to variation in relative CS duration, since the relative duration manipulation produced consequent changes in shock density. In Experiment 2 effects of shock density and relative CS duration were isolated in a factorial design in which relative CS duration was manipulated between groups (CS/ITI duration ratios were 1/5, 1/1, or 5/1) while shock density was manipulated within groups (2, 6, or 10 US/hr). Relative CS duration affected the patterning of responding between successive shocks, shock density was inversely related to absolute response rates during the ITI, and the two variables interacted to control differential responding between the CS and the ITI. As in Experiment 1, responding during the CS was almost totally suppressed during all shock conditions. The results of the two experiments were discussed in terms of associative control of behavior. While the procedures used did not permit a test of the associative basis of shock density effects, tentative support was obtained for the position that relative CS duration controls behavior through aquired sensitivity to relationships between the US and the ITI, independent of CS-US relations.

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III. General Discussion and Appendix B

Relative CS Duration in Conditioned Suppression: Scheduling effects of the Pavlovian Unconditioned Stimulus and the Operant Reinforcer

GENERAL INTRODUCTION

This study was designed to examine how the duration of a conditioned stimulus (CS), relative to that of the intertrial interval (ITI), affects rats' responding during a conditioned suppression paradigm. Conditioned suppression, the reduction in operant response rate during a CS has been shown to decrease as CS duration increases relative to that of the ITI (Stein, Sidman & Brady, 1958). In two experiments, the present study examined in more detail the effects of relative CS duration upon operant behavior. In particular, relative duration effects were tested on four types of baseline schedule (Experiment 1) and across three values of shock density -- 2, 6, or 10 US/hr (Experiment 2). In each experiment, behavior was examined both during and outside of the CS, and in terms of the relationship between suppression and loss of operant reinforcers. In Experiment 2 control of suppression by relative CS duration was assessed in terms of strength of associations between the CS and the unconditioned stimulus (US).

Background

Approaches to understanding conditioned suppression include both highly theoretical accounts, based on stimulus-response conceptualizations of emotionality, and descriptive analyses designed to elucidate the controlling parameters. A discussion of both types of approach is appropriate here for two reasons. First, the descriptive analyses, though more germane to the present study than the emotional/motivational accounts, developed in part as a result of inconsistent support for emotional constructs. Second, portions of the data from the present study bear on emotional/motivational issues as well as on parametric considerations. Each type of approach will be reviewed briefly.

Emotional-Motivational Issues

Conditioned suppression was first examined systematically by Estes and Skinner (1941) in an attempt to describe anxiety ("an emotional state, somewhat resembling fear;" p.390), which occurs in anticipation of a "disturbing stimulus", quantitatively. To produce this emotional state Estes and Skinner superimposed Pavlovian pairings of a tone CS with a shock US on an operant schedule of reinforcement for rats' bar pressing. The authors noted that the rate of lever pressing decreased during the CS, as compared to rates during sessions without CS-US pairings. The magnitude of this conditioned suppression was thought to be a function of the temporal relationship between the CS and the US.

Although Estes and Skinner (1941) were concerned with objectifying procedures and measures for studying anxiety, many follow-up studies focused on the presumed internal mediation of what was then termed "conditioned anxiety" (Hunt & Brady, 1951) or the "conditioned emotional response" (CER) (e.g. Kamin, 1965). Early accounts of conditioned suppression were closely tied to Freud's definition of anxiety as "the expectation of ... trauma on the one hand, and on the other, an attenuated repetition of it" (Freud, 1936; pp 145-146). Just prior to the Estes and Skinner (1941) report Mowrer had recast Freud's definition in stimulus-response terminology:

> ... a so-called "traumatic" (painful) stimulus impinges upon the organism and produces a more or less violent defense (striving) reaction. Furthermore, such a stimulus-response sequence is usually preceded or accompanied by originally "indiffeent" stimuli which, however, after one or more temporally contiguous associations with the traumatic stimulus, begin to be perceived as "danger signals," i.e. aquire the capacity to elicit an "anxiety reaction" (Mowrer, 1939, p. 47).

Mowrer stipulated that anxiety reactions consisted of two parts -- an emotional state, i.e. "a state of heightened tension or 'attention'," (Mowrer, 1939, p. 47), and a motivation "to escape the danger situation, thereby lessening the intensity of the tension ('anxiety')" (Mowrer, 1939, p.48). Accounts of the CER subsequent to the Estes and Skinner (1941) report frequently incorporated Mowrer's interpretation, emphasizing either emotional or motivational states produced by the CS, fear produced by adventitious punishment of operant responding by the US, or incompatibility of defensive behavior motivated by the CS with the baseline operant.

Motivational accounts. Motivational theories of conditioned suppressio argue that the CER reduces motivation for the operant reinforcer, presumably due to anxiety elicited by the CS. Reports of an inverse relationship between motivation (food or water deprivation) and suppression levels lent credence to that view (Hoffman & Fleshler, 1965; Millenson & de Villiers, 1972; Leslie, 1977). Even Estes and Skinner had hinted that operant suppression occurred as a direct consequence of the aversive nature of the CER (1941; p. 395). However several later findings questioned the validity of this view: (1) demonstrations of "positive" conditioned suppression -- suppression of baseline responding during a cue for an appetitive US (Azrin & Hake, 1969; Hake & Powell, 1970; Meltzer & Brahlek, 1970; Miczek & Grossman, 1974). It is difficult to conceive of a food US producing sufficient anxiety to suppress operant behavior. (2) reports of conditioned facilitation -- an increase in operant response rate during a preaversive CS (Blackman, 1968; Finoccio, 1963), and (3) conflicting reports concerning the effectiveness of drugs such as reserpine or chlordiazepoxide, which reduce anxiety in humans, in reducing conditioned suppression (see Blackman, 1977 and Davis, 1968 for reviews).

Since the outcomes noted above make an account of conditioned suppression based solely on anxiety implausible, later motivatinal theories suggested that the CS might elicit a general "underlying emotional state of heighened preparedness" (Azrin & Hake, 1969; p. 172). This state was considered to have motivational properties which might influence instrumental responding, depending on the type of US, modality of operant response, etc. (Rescorla & Solomon, 1967). However this revision of motivational theory adds little of substance, since it still fails to explain how the same emotional state can produce both suppression and facilitation during either a preaversive or a preappetitve CS. In fact the Rescorla and Solomon (1967) model predicts only facilitation, not suppression during a prefood US.

The punishment hypothesis. An alternate conceptualization of the effect of conditioned anxiety on operant behavior suggests that operant suppression during the CS may result from adventitious pairings of the operant with the US (Estes, 1969). Anxiety elicited by the US would become directly associated with both the signal and with operant behavior. Indirect evidence for this position derived from two findings. First, Brady (Brady, 1951; Hunt

& Brady, 1951; Hunt & Brady, 1955) reported nearly complete suppression during a click CS with both contingent (signalled punishment) and noncontingent (conditioned suppression) shocks. The comparable levels of suppression might be attributed to a common mechanism (cf. Mowrer, 1960; Estes, 1969). Second, several studies have reported that degree of conditioned suppression is directly related to the temporal proximity of a shock to an operant response (Church, 1969), suggesting that adventitious response-shock pairings do produce suppression.

However several lines of evidence make the punishment hypothesis less tenable. First, adventitious punishment can not account for conditioned facilitation with a shock US, or for positive conditioned suppression. Second, as noted by Blackman (1977), many studies have reported suppression during the CS even when CS-US training occurred off the baseline, i.e. before, or in a different chamber from, operant sessions (e.g. Rescorla, 1968; Geller, Sidman & Brady, 1955; Hunt & Brady, 1955; Kamin, 1961; Libby, 1951). With this procedure adventitious pairings of shock and response can not occur, since only the CS is presented during operant sessions. Although Lyon (1968) has indicated that portions of the operant response sequence, e.g. head or paw movements, may have been punished during CS-US trials, Hoffman and Barrett (1971) have reported that off-baseline

Pavlovian training has little effect on these movements.

A third argument against the punishment hypothesis is that, although Brady's (1951; Hunt & Brady, 1955) finding of no difference in suppression level between CER and signalled shock procedures was replicated by Leitenber (1966), with pigeons, various studies have reported either that signalled punishment produces greater response decrements than does conditoned suppression, in both rats (Annau & Kamin, 1961; Hearst, 1965) and in pigeons (Azrin, 1956), or vice-versa, that suppression procedures reduce responding more than does punishment (Orme-Johnson & Yarczower, 1974; Hoffman & Fleshler, 1965; both with pigeons). Lyon (1968) attempted to reconcile these different outcomes on the basis of differences in shock intensities, but later studies (e.g. Orme-Johnson & Yarczower, 1974) have failed to conform to that analysis.

A final obsticle for the punishment hypothesis of conditioned suppression is the finding that, even where contingent and noncontingent shock procedures do produce similar levels of suppression during the CS, the two procedures have different effects on other dependent measures. For example, Hunt and Brady (1951) found that response-contingent signalled shock produced greater bar pressing deficits during the ITI than did noncontingent shock (this effect has since been replicated by Valentine &

Barrett, 1981, but see Hymowitz, 1981a for the opposite result). On the other hand, noncontingent shock produced more freezing, urination and defecation, and slower extinction of suppression than did contingent shock.

Interference models. Interference models of conditioned suppression assume that emotional components of the CER are accompanied by autonomic changes, which in turn may produce escape or defense reactions that compete with the operant. Initial evidence for the autonomic link of this sequence was reported by Brady (1951; Hunt & Brady, 1955), who found that superficial measures of autonomic activity, such as urination and defecation rate, tended to covary with conditioned suppression level. In addition, heart rate and blood pressure changes (Stebbins & Smith, 1964; Parrish, 1967) and basal skin resistance (Anderson, Plant & Paden, 1967) have also been shown to change during conditioned suppression. However more refined analyses indicated that, for heart rate and blood pressure at least, autonomic changes are aquired later than, and maintained independently of, changes in operant rate (deToledo & Black, 1966; Nathan & Smith, 1968; Brady, Kelly, and Plumlee, 1969). Kelly (1980) summarized the findings on cardiovascular change during conditioned suppression by stating that, while autonomic change and operant rate may interact, there is no evidence for a causal relationship.

Interference accounts of suppression based on conditioned skeletal activity assume that animals adopt defensive or escape movements, e.g. jumping or freezing, which can reduce shock severity from a scrambled-grid shock source. Any of these responses might remove the animal from the operant manipulandum (Blackman, 1977; Lyon, 1968; Weiskrantz, 1968). Similar assumptions form the basis of the safety signal (Seligman & Binik, 1977) and preparedness (Perkins, 1963) explanations of rats' preference for signalled vs unsignalled shock. However, in the conditioned suppression paradigm this variation of interference theory has consistently failed to find empirical support. For example Hall, Clayton, and Mark (1966) restrained rats such that the only possible movement was in the tip of one paw, which was sufficient to operate the manipulandum. Although crouching and withdrawal from the lever were thereby prevented, responding was completely suppressed during a preshock signal. It is possible that freezing of all skeletal activity occurred during the CS, but a freezing account of conditioned suppression is unlikely in the face of demonstrations that the same intensity shock can produce both suppression and facilitation (Finocchio, in Blackman, 1968a). Similarly, the likelihood that operant suppression results from conditioned interfering escape responses (Weiskrantz, 1968) is reduced by the finding of Stein, Hofman, and Stitt (1971) that all motor responding, not just the reinforced operant, tends to be suppressed during a preaversive signal.

Parametric Issues

The failure of analyses based on emotional or motivational constructs to obtain consistent support and to generalize to a variety of suppression paradigms has led some researchers toward a more descriptive analysis of suppression phenomena. Such analyses typically examine parametrically either operant or Pavlovian variables thought to affect to suppression levels. Several theorists have concluded that both the occurrence of operant rate change, and its direction (suppression or facilitation) depend largely upon stimulus and schedule factors, regardless of whether the Pavlovian US is aversive or appetitive (Kelly, 1973; LoLordo, McMillan & Riley, 1974; Schwartz; 1976).

Operant factors. Research on the effects of operant parameters on conditioned suppression indicates that suppression depends in part upon response modality, and upon interactions between response and stimulus modalities. For example, conditioned suppression of rats' drink tube licking has been established (Hymowitz, 1981a; Burkhard & Ayres, 1978), although this response may be less severely affected than is bar pressing (DeCosta & Ayres, 1971). With pigeons, LoLordo, et al. (1974) reported that a preappetitive light

CS would suppress treadle pressing but would facilitate keypecking, while a tone CS had no effect on either response.

In addition, suppression of a given response modality varies inversely with deprivation level of the operant reinforcer (Hoffman & Fleshler, 1965; [illegible]mowitz; 1981b), and with baseline reinforcer duration (deVilliers & Millenson, 1972).

Of greater relevance to issues raised in the present study are data concerning baseline schedule effects on conditioned suppression. Research has demonstrated suppression of behavior supported by a variety of operant reinforcers aside from food, e.g. milk and water (deVilliers & Millenson, 1972; Geller, 1960), intracranial stimulation (Russell, 1975), and money, with humans (Sachs & May, 1969). However the scheduling of the reinforcers may influence suppression levels in various ways -- through direct or indirect regulation of operant response or reinforcer rate, or through multiple schedule interactions, where behavior in one component of the schedule may be influenced by contingencies present in other components (cf. Bloomfield, 1967). Examples of the latter effect have been reported by Waller and Waller (1963), where the absence of conditioned suppression on a variable interval (VI) component was attributed to avoidance contingencies in an alternate component, and by Stubbs, Hughes, and Cohen (1978), who reported differences in positive conditioned suppression as a function of varying cue-reinforcer conditions in other components.

Investigations of response and reinforcer rate effects on conditioned suppression suggest that both variables affect response decrements during the CS. Lyon (1963) reported more suppression on a VI 4-min component of a multiple schedule, as compared to a VI 1-min component, indicating that high reinforcer density reduces conditioned suppression. Blackman (1967) maintained constant reinforcer rates across three different response rates, and found suppression level varied directly with response rate. Both Blackman (1968b), with a shock US, and Smith (1974), with a food US, manipulated response and reinforcer rates independently of each other, and reported that conditioned suppression was most extreme when high response rate, low reinforcer rate baseline conditions were in effect.

Several studies have noted conditioned facilitation when the operant schedule requires low response rates. For example Blackman (1968a) reported that response levels on a differential reinforcement of low rates (DRL) component of a multiple schedule increased during a pre-shock CS, while "interval-like" or "ratio-like" behavior on an alternate component was suppressed. Smith (1974) and Kelly (1973) also reported conditioned facilitation on spaced responding components of multiple schedules but suppression on random ratio components, with both studies employing a positive suppression paradigm. Conditoned facilitation of a DRL baseline has been replicated both with shock USs (Finnochio, 1963; Brimmer & Kamin, 1963) and with food USs (LoLordo, et al., 1974; Hemmes & Rubinsky, 1982; Henton & Brady, 1970).

However, while the foregoing studies substantiate the role of response and reinforcer rate effects in the CER paradigm, the fact that both suppression and facilitation may occur with the same baseline schedule (e.g. Finocchio, in Blackman, 1968a; LoLordo, et al., 1974) indicates the influence of additional factors. Blackman (1968a) has suggested that conditioned facilitation occurs when collateral, timing behavior, which mediates performance on spaced responding schedules, is disrupted by the CS. However Hemmes and Rubinsky (1982) discounted that possibility, at least in a positive suppression paradigm, by demonstrating that the the probability of a rat's lever press increased at CS onset regardless of what the animal was doing at the time, even if it was already lever pressing. Those authors offered an alternate, non-associateve explanation . Facilitation was said to be an instance of Pavlovian external disinhibition, wherin response inhibition constrained by the DRL contingency was disinhibited by CS presentation.

While the Hemmes and Rubinsky (1982) account requires testing, since those authors had no measure of the inhibitory strength of the DRL schedule, and since a CS- was not included as a control for non-associative effects (cf. Baum & Gleitman & Holmes, 1967), the analysis serves to focus attention on potential interaction of Pavlovian variables with operant contingencies in conditioned suppression paradigms. Such interactions have been reported with other preparations, e.g. multiple schedules (Schwartz & Gamzu, 1977), and conditioned reinforcement (Fantino, 1977). With CER procedures utilizing a DRL baseline, some instances of conditioned facilitation do appear related to operant-Pavlovian interactions. For example Finocchio (in Blackman, 1968a) reported facilitation only when shock intensity was relatively low (1.2 vs 5 mA), and then only when CS duration (2 or 8 min) was shorter than the ITI (5 min). Other CER procedures have shown indications of operant- Pavlovian interaction. For example Henton and Brady (1970) found facilitation to a pre-food CS only with a long signal (80 sec vs 20 or 40 sec), LoLordo, et al. (1974) found facilitation of keypecking and suppression of treadle pressing to a flashing light CS, but no change during a tone, and Rescorla and Solomon (1967) have presented a complex analysis of potential interactions between classical and operant features of an experimental situation. The issue of Pavlovian controls in conditioned suppression will be addressed in the next section.

Pavlovian factors. Research has indicated that a variety of parameters of Pavlovian conditioning can influence responding in the conditioned suppression procedure. The type of US or CS employed can affect the occurrence, severity, and direction of conditioned rate change. X-rays (Morris, 1966), amyl acetate odor (Henton, 1969), humans (Reiter & deVellis, 1976), lights (Geller, 1960), and auditory stimuli (Estes & Skinner, 1941) have all proved to be effective CSs. Yet, while a tone is an effective CS with rats (Estes & Skinner, 1941), it may not be with pigeons (LoLordo, et al., 1974; Leitenberg, 1966). With rats, pairing increased chamber illumination with shock produces suppression during the cue though a decrease in illumination has no effect (Welker & Wheatly, 1977). Also, rats apparently discriminate the absence, but not the presence, of shock, when the cue is a shock-noise sequence (Reberg & Memmott, 1979).

Suppression has also been reported with many types of USs, including morphine withdrawal (Goldberg & Schuster, 1967), extinction of an operant reinforcer (Holmes, 1972), chlorpromazine or lysergic acid diethylamide injection (Cameron & Appel, 1972), and an unpleasant social situation with humans (Reiter & deVellis, 1976). Some USs appear to reliably produce facilitation rather than suppression, e.g. time out from positive reinforcement (Leitenberg, 1966). Yet, as with CS modality, effects of US type may depend on other factors. Shock produces either suppression or facilitation, depending on baseline schedule, US intensity, and relative CS duration (Finocchio, in Blackman, 1968a), and food produces either facilitation, suppression, or no change depending on response and CS modality (LoLordo, et al., 1974).

Other aspects of CS and US presentation found to influence suppression levels include CS intensity (Kamin & Schaub, 1963, although only at intermediate levels of shock intensity; Kamin & Brimmer, 1963), and US duration (Reiss & Ferrar, 1973) and intensity (Annau & Kamin, 1961; Millenson & Hendry, 1967; Kamin & Brimmer, 1963; although shock intensity interacts wth other variables such as deprivation level, deVilliers & Millenson, 1972; Hymowitz, 1981). In addition suppression level has been shown to be a direct function of the conditional probability of shock given a CS (Davis & McIntire, 1969; Rescorla, 1968; Henderson, 1975; Willis & Lundin, 1966) and of both CS location (Schwartz, 1976; Karpicke, Christoph, Peterson & Hearst, 1977) and duration (Libby, 1951; Miczek & Grossman, 1971).

Relative CS duration. Data from several studies indicate that one of the most potent variables in the CER paradigm may be the relative duration of the CS, i.e. CS duration relative to ITI time. Interest in temporal parameters of CS presentation has been evident from the earliest CER studies. As noted in the section on emotional-motivational issues, Estes and Skinner (1941) indicated their belief that the magnitude of conditioned suppression depends upon the temporal relations of the CS and US. This analysis is not surprising since the CS-US interval had long been known as a powerful determinant of classical aversive conditioning (see Jones, 1963, for a review and discussion). An early follow-up to the Estes-Skinner report examined the temporal relationship directly. Libby (1951) varied the CS-US delay interval between groups of rats, in an off-the-baseline training procedure, with the delay interval ranging from 0 to 30 seconds. During a test condition in which all groups received an equal duration CS (but no US) presented over a continuous reinforcement baseline, response frequency during the signal was bitonically related to the CS duration used during training. Maximum response frequency occurred at 0 sec, minimum frequency at 7 sec, followed by a partial recovery of responding which leveled off at 20 sec. While this recovery maximum was not explained by Libby, it agrees with Warner's (1932) conclusion that the maximum "association span" of rats lies between 20 and 30 sec. Interestingly, despite the bitonic relationship between CS duration and response frequency during the signal, and despite the asymptotic recovery at 20 sec, the difference between CS and ITI frequencies continued to increase across the entire range of durations (Libby, 1951, Table I, 10-min test data).

Stein, Sidman, and Brady (1958) examined the CS duration issue in more detail. CS and ITI durations were each varied asystematically from .5 to 50 min. The authors concluded that the absolute duration of neither the CS nor the ITI exerted substantial control over strength of suppression. Instead, suppression ratios (response rate in the CS, relative to rate during the ITI) varied directly with their relative durations. That is, the shorter the CS, relative to ITI duration, the lower the CS response rate relative to that during the ITI. Stein, et al. (1958) maintained that relative CS duration has little "psychological meaning," and instead attributed their results to a direct relationship between relative CS duration and the number of reinforcers to be lost through conditioned suppression. In other words, as relative CS duration increases, so does the proportion of a session's reinforcers that would be lost due to complete suppression during the signal (at least with a fixed-duration session). Stein, et al.'s rats tended to earn about 90 % of the maximum reforcer frequency regardless of relative CS duration. The authors concluded that well trained subjects will suppress during a preaversive signal only to the extent that reinforcers will not be lost -- i.e. only during relatively short CSs.

Variation in relative signal duration can account for much of the control attributed to absolute CS duration. In the Libby (1951) study the opposite result (CS response frequency decreased as CS duration increased from 0 to 7 sec) from the Stein, et al. (1958) effect may be specific to the extremely short CS durations used by Libby; durations in the order of minutes are more usual. Subsequent studies generally corroborated the direct relationship reported by Stein et al. Using aversive CER paradigms, both Carlton and Didamo (1960) and Lyon (1963) attributed increased CS response rate across increased CS duration values to control by relative duration. Analysis of positive suppression data in terms of relative CS duration is less straightforeward but results generally conform to the Stein, et al. pattern. Meltzer and Brahlek (1970) paired a light CS with a sucrose US. The CS produced strong suppression at 12-sec duration, moderate suppression at 40 sec, and facilitation at 120 sec. While the issue of control by relative duration was not addressed directly in that report, the data fit the prescribed pattern of direct relationship between relative duration and suppression ratios. In addition, the transition from suppression to facilitation parallels data by Fincchio (1963) with a shock US. In that study, increases in relative CS duration produced a change in DRL responding from conditioned suppression to conditioned facilitation, at least at lower (1.2 vs 5 mA) shock intensities.

Other positive suppression studies have demonstrated limited support of the relative duration-conditioned suppression relation. Henton and Brady (1970) reported no rate changes during a 20- or 40-sec CS, but facilitation during an 80-sec stimulus. Miczek and Grossman (1971) found suppression during 15- and 30-sec signals and no change with 1-, 2-, or 3-min stimuli. Differences in the results of the two studes may be attributable to the different baseline schedules (VI in Miczek & Grossman, DRL in Henton & Brady; cf Kelly, 1973). In both reports the behavioral changes which did occur can be accounted for by differential relative CS duration. Rates in shorter duration CSs never exceeded those at longer durations, and relative CS duration varied with absolute duration. Finally, Smith (1974) reported facilitation of operant responding during a 5-sec CS, with lower rates during longer signals, on both high response rate and low response rate baselines. Although this inverse relationship contradicts the usual finding it may be that, as in the Libby (1951) study, the very short (5 sec) stimulus produced anomalous data. Excluding the 5-sec data, CS rates generally _increased_ with signal duration for the remaining values of 30 to 120 sec (Smith, 1974, Figure 1).

Aside from the short-duration data of Libby (1951) and Smith (1974) only one study has reported results which appear to contradict the relationship between suppression ratio and relative CS duration. Kamin (1961) used a trace conditioning procedure in which the interval between onsets of the CS and US remained constant, while the trace interval varied. As the duration of the CS increased from .5 to 3 sec Kamin found that suppression also increased. However analysis of this study in terms of control by relative duration is difficult for two reasons. Not only were the CS durations extremely short, but Kamin primarily examined response rates during the trace, not during the signal. However, Kamin's casual description of CS rates indicates that responding during the CS _did_ vary with duration, in accordance with a relative duration analysis.

Impetus for the Present Study

Relative CS duration appears capable of controlling conditioned suppression, yet little systematic research concerning its influence has been reported since the Stein, et al. (1958) study. This is somewhat surprising since the importance of relative durations of stimulus events is currently being recongnized in a variety of other paradigms, e.g. conditioned reinforcement (Fantino, 1977), control of operant behavior through stimulus-reinforcer associations (Brown, Hemmes, Coleman, Hassin, & Goldhammer, 1982), autoshaping (Jenkins, Barnes, & Barrera, 1981; Gibbon & Balsam, 1981) and unconditioned response latency (Brown, Coleman & Elefant, Note 1). The obvious power of this variable indicates the need for additional research.

In the CER paradigm, the conditions under which relative CS duration affects suppression are obfuscated for several reasons. First, the reliability of the effect is unknown. In each of the two CER studies replicating control by relative CS duration, caution is required in drawing conclusions. Carlton and Didamo (1960) used only one value of CS duration, tested only two subjects, and confounded a change in relative CS duration with changes from fixed to variable session duration and variable to fixed number of reinforcers (Phase I vs Phase II). Although suppression ratios increased substantially following these changes, a second, unconfounded, shift in relative CS duration produced little or no change in suppression. Lyon (1963) manipulated relative CS duration by varying the absolute duration of a signal presented once during a session. However, as with the Carlton and Didamo (1960) study, only two subjects were used, and suppression changes attributable to relative CS duration were small, at least in one of the two subjects. Since, in the Stein, et al. (1958) procedure, specific CS/ITI duration ratios generally were not replicated across animals, and were recovered only occasionally within-subjects, the reliability of the effect is largely untested.

A second problem in understanding relative CS duration effects involves the mechanism proposed by Stein, et al. (1958) to account for that effect. The authors maintained that response rates during the signal increase with relative CS duration since continued suppression would result in increases in reinforcer loss. The results reported by Lyon (1963) and by Carlton and Didamo (1960) can be accounted for by this analysis, although the latter data require that reinforcer loss be detected in local, rather than overall (session-wide) delivery rates. However, neither study explicitly tested the reinforcer loss analysis, and alternate explanations are possible. For example, both Stein, et al. (1958) and Carlton and Didamo (1960) confounded changes in relative CS duration with changes in shock density. Since suppression has been shown to vary directly with the probability of US presentation given the

CS (Willis & Lundin, 1966; Davis & McIntire, 1969; Rescorla, 1968) it seems possible that changes in shock density, rather than relative stimulus duration, could have produced much of the behavioral variation in the Stein, et al. (1958) and Carlton and Didamo (1960) data. Lyon's (1963) procedure did not confound US density with relative CS duration, since CS-US pairings occurred only once per session. However the fact that only one of two subjects showed substantial change in suppression might be attributable to a reduced effect of stimulus duration in the absence of concomitant density changes.

A second alternative to the reinforcers-lost account of conditioned suppression is based on Pavlovian associations. Meltzer and Brahlek (1970) reported that a pre-food stimulus produced suppression at 12- and 40-sec durations, but produced facilitation at 120 sec. The authors concluded that the Stein, et al. (1958) analysis could explain the suppression but not the facilitation, since response-contingent reinforcer frequency changed during shorter, but not during the longer, signals. If positive and negative suppression procedures can be considered sensitive to the same schedule and stimulus control parameters (cf. Smith, 1974) then an explanation of relative CS duration effects must account for both suppression and facilitation. Miczek and Grossman (1971) suggested that changes in CS duration necessarily produce changes in the contiguity of CS and US onsets. Contiguity increases as the CS-US interval decreases, strengthening the stimulus-stimulus association. With longer CS durations weak CS-US associative strength allows other stimulus and schedule factors (e.g. US and schedule type) to gain control of responding. Similar associative arguments could be made based on temporally defined differences in CS-US contingency (Gibbon, Berryman & Thompson, 1974) or on cued differences in waiting time to the US (Gibbon & Balsam, 1981; Jenkins, et al., 1981).

The present study was designed to replicate the relative CS duration effect on conditined supression and to evaluate some of its alternative explanations. Experiment I examined the influence of reinforcer loss on suppression level by varying relative CS duration over baseline schedules which differed in terms of response-reinforcer (R-SR) contingencies. Shock density was allowed to vary with relative CS duration in order to replicate the Stein, et al. procedured closely as possible. Experiment II examined whether relative CS duration and shock density have independent effects on conditioned suppression, and whether reinforcer loss varies with either factor. Relative CS duration effects were evaluated in terms of measures of associative strength.

EXPERIMENT 1

Introduction

This experiment was designed to replicate the relative CS duration effect on conditioned suppression reported by Stein, et al. (1958), and to test certain hypotheses concerning its action. As described in the General Introduction, methodological concerns in previous studies of the relative duration effect render their outcomes questionable. In particular, Stein, et al. obtained only one data point for many of the relative durations tested (i.e. there were few within- or between- subject replications). Carlton and Didamo (1960) confounded changes in session and reinforcer scheduling with their relative duration manipulation. In addition, both Carlton and Didamo, and Lyon (1963), used only two subjects, and both studies showed substantial between subject variability. The present experiment examined response suppression as a function of three values of relative CS duration, using a within-subjects manipulation with four rats, and without confounding by session length or reinforcer scheduling.

Theoretical issues regarding control by relative CS duration are also of concern. In particular, the reinforcers-lost hypothesis (Stein, et al., 1958) requires examination. According to that analysis conditioned suppression is inversely related to the number of reinforcers capable of being lost through 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. In Zeiler and Buchman's (1979) terminology, the direct relationship between relative CS duration and potential reinforcer loss constrains the degree of suppression to a response rate just sufficient to obtain most reinforcers. However several considerations suggest that the reinforcers-lost hypothesis is not general, and that it may be valid only for the variable interval (VI) baseline schedules used to date in relative duration studies.

Stein, et al. (1958) used a VI schedule under which a set-up reinforcer could be stored until a second was set up. With relatively short CS durations, not only would few of the session's reinforcers be set up during the CS, but those that were set up could generally be earned after CS offset. However, as relative CS duration increases, so does the frequency of reinforcer set ups that would expire due to suppression. Both theoretical and empirical considerations indicate that the inverse relationship between suppression and reinforcer loss may have been an artifact of the VI baseline, which requires that only one response be emitted for each reinforcer (cf. Fantino, 1973; Blackman, 1977). Although animals typically make many additional responses on interval schedules, they are not constrained to do so by reinforcer requirements. Any additional responses may be differentially suppressed at different relative CS durations, without affecting reinforcer frequency. By comparison, under ratio schedules, all responses contribute towards the reinforcer. Any suppression results in reduced reinforcer frequency, at least in a fixed duration session.

Differences in schedule constraints on responding have been examined previously for non-aversive situations. Zeiler (1977) suggests that reinforcement schedules exert their contraints in two ways -- through "direct" variables, such as responses per reinforcer (R/SR) or interreinforcer time (ISRT) requirements, and through "indirect" (behavioral) variables, such as when ongoing response rates affect subsequent rate by changing ISRT. Figure 1 diagrams direct and indirect schedule constraints. ISRT and R/SR are considered to be direct variables since responding typically changes as they are manipulated. However response rate itself may become an indirect constraint on subsequent responding, on schedules where response rate affects ISRT. Major classes of schedules may be differentiated on the basis of these constraints: ratio, but not interval schedules have strong R/SR constrtaints, fixed and random schedules have the same <u>average</u>, but different <u>minimum</u> ISRT and R/SR requirements, and ISRT varies as a function of response rate on ratio and spaced responding schedules, but generally not on interval schedules. In the conditioned suppression procedure the weak constraints of VI schedules permitted the behavioral variation reported by Stein, et al. (1958), Carlton and Didamo (11960), and Lyon (1963).

Empirical results lend some credence to the view that suppression levels may depend in part upon baseline schedule constraints. In the General Introduction, evidence was reported that suppression is greatest when conditions producing high response rates and low reinforcement rates are in effect (Lyon, 1963; Smith, 1974; Blackman, 1967; 1968b; Finnochio, 1963). In addition, Brady (1955) has shown that ratio schedules frequently maintain high CS response rates during CER procedures. Lyon has confirmed that finding, although he reports that on variable ratio schedules rates may be bimodal, with some instances of zero responding during the CS (Lyon & Felton, 1966a), and that on fixed ratio (FR) schedules of less than 100 R/SR, suppression may be influenced by proximity of CS onset to the next reinforcer (Lyon & Felton, 1966b). Finally, Lyon and Millar (1969) reported that, as with FR schedules, suppression on fixed interval (FI) schedules is dependent on the temporal proximity of CS onset to reinforcement. Since this temporal effect is not evident with either variable ratio or variable interval schedules, Lyon has argued that periodic and aperiodic reinforcer schedules may be differentially susceptible to CER paradigms (Lyon, 1968).

The foregoing considerations argue that a rigouous test of relative CS duration effects on conditioned suppression, and an interpretation of those effects based on reinforcer constraints, must include manipulation of baseline schedule contingencies. Accordingly, the present experiment varied relative CS duration as CS-US pairings were superimposed over a four-component multiple schedule. Due to their different R/SR constraints both ratio and interval components were included in the baseline. If relative CS duration exerts its effects on suppression solely through reinforcer constraints on responding, then suppression should be slight or nonexistent on ratio components, regardless of CS value. If, on the other hand, these effects are independent of reinforcer considerations, then response rate on ratio components should vary with relative CS duration in the same way as do rates on interval components. Since periodic and aperiodic reinforcer delivery also differ in constraint, i.e. in terms of minimum R/SR or ISRT, and since animals are known to be sensitive to such differences (e.g. Farmer, 1963; Catania & Reynolds, 1968; Herrnstein, 1964), the operant baseline consisted of a multiple fixed ratio, random ratio, fixed interval, random interval (Mult FR RR FI RI) schedule.

Previous work has demonstrated that two other schedule constraints, reinforcer rate (or mean ISRT, a direct variable) and response rate (an indirect variable), also affect suppression levels. To minimize the effect of those variables in the present study, a differential-reinforcement-of-low-rates schedule (DRL) contingency was embedded within the multiple schedule such that only those responses separated by at least 2 sec from the previous response could contribute towards producing a reinforcer. This pacing requirement stipulated that reinforcer rate would be maximized at the same average value on all four schedule components provided that the requirement was met. For example, the ratio requirements were FR and RR 20. If the DRL requirement was met reinforcers would be earned, on the average, every 40 sec (20 responses, 2 sec apart). The interval components were therefore made FI 40 sec and RI 40 sec. On those components, a reinforcer, once set up, could be picked up only by a response which succeeded the previous response by at least 2 sec. To the extent that the pacing requirement was met during the ISRT of the interval components, animals would approximate the nominal rates on the ratio components -- 20 responses and 1 reinforcer every 40 sec.

The mean and minimum ISRT and R/SR constraints of the multiple baseline schedule remained intact however, in the sense that ratio components required that all responses meet the DRL contingency, while interval components required only one such response per reinforcer. Random components specified the same average ISRT or R/SR as did fixed components, but the minimum requirements were less: reinforcers could be obtained by as few as one response, and after as little as 2 sec since the previous reinforcer.

Method

Subjects

The subjects were four 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 *ad lib* weight on powdered Purina Rat Chow. Water was always available in the home cage.

Apparatus

Sessions were conducted in a Scientific Prototype 2-bar rat environment, which consisted of a 36cm x 25cm x 20cm plexiglass chamber, mounted in a wooden box with a pressboard soundproofing shell. Only the left lever produced programmed consequences. The lever was located 5.0cm above the grid floor, with its center being 3.8cm from the left edge of the food tray, through which 45mg Noyes food pellets could be dispensed. The tray was centered left-right on the intelligence panel, 2.5cm above the floor, and 10.6cm below a stimulus lamp. A houselight was mounted to the pressboard ceiling.

The following modifications were made to the box: a 36cm x 21cm panel was removed from one wood and pressboard wall , to permit viewing of the plexiglass chamber via a video camera. The opening in the box was covered by clear plexiglass to reduce intrusion of extraneous sound, and the aperture was shielded from outside sources of light. A 3-inch, 8-ohm speaker was mounted from the pressboard liner, through which the output of a Foringer, Model 1293 square-wave click generator could be presented. stimuli could be presented. A Sonalert tone generator, Model SC62M, was mounted behind the intelligence panel.

Sound masking was provided by white noise played through a speaker in the experimental cubicle, and by noise from the chamber's ventilating system. Experimental control was accomplished with electromechanical equipment located in an adjacent room. Sessions could be viewed on Sony Model VM960 video moniter, which was located in the control room, and which was connected to a Sanyo Model VC16000X video camera focused on the rat box.

<u>Procedure</u>

All sessions began with the rat being placed in a dark chamber. Houselight onset segnalled the beginning of a session, and houselight offset signalled session's end. Prior to placing a rat in the chamber, a single food pellet was placed in the food tray. This procedure, termed reinforcer sampling (Ayllon & Azrin, 1968) was continued throughout the experiment, and was instituted to increase the likelihood that some non-zero level of responding would be maintained during shock conditions.

<u>Bar press and schedule training</u>. Following magazine training, rats were trained by manual shaping to press the left bar. Each bar press was followed simultaneously by a .5-sec burst from the Sonalert, and by reinforcement (delivery of one pellet of food to the tray). Bar presses received continuous reinforcement until 100 reinforcers (SRs) had been earned.

Following bar press training 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 schedule was associated with a different frequency click noise, which was presented through the speaker in the rat box. The click frequency for each schedule type was: FR -- 5hz, RR -- 11hz, RI -- 56hz, and FI -- 25hz.

For FR training, ratio size was increased gradually, up to a maximum of FR 40. A DRL contingency was in effect such that only those responses which followed the previous response by at least .5 sec contributed towards producing a reinforcer. This requirement meant that, on FR (and subsequent RR) sessions, only correctly spaced (hereafter termed correct) responses activated a predetermining response counter (or sampled a probability generator). On later FI and RI sessions only correct responses could produce a set up reinforcer. Each response which met the .5-sec DRL criterion produced a .5-sec Sonalert burst, and any terminal (reinforced) response was followed simultaneously by a Sonalert burst and by reinforcement. Incorrect responses (any response not meeting the DRL requirement) reset the DRL clock. Thus, maximally effective response rate on any schedule type would be 2 responses per sec.

Beginning with schedule training, and continuing until the last phase of the experiment, all sessions lasted for 2 hr. Training on each of the four schedule types was continued until stability of response rate (as judged by eye) was achieved. For FR training 24 sessions were required.

Following FR training, rats were switched directly from FR 40 to a RR 40 schedule. On this schedule each correct response sampled a probability generator, which was set to produce an output with a probability of .025. Under these conditions successive reinforcers could occur at a minimum of 1 response and .5 sec following the previous reinforcer, but on the average occurred after 40 correct responses (a minimum of 20 sec), the same nominal values as on the FR schedule. RR training continued for 15 days.

Next, animals were trained on a RI schedule. On this schedule the probability generator was sampled at the beginning of each .5-sec bin. Bin size was set at the nominal interresponse time (IRT) of the DRL requirement, in order to equate minimum ISRT on the RR and RI schedules. Reinforcers were set up by an output from the probability generator, with a probability of .025. With these parameters a correct response could produce a reinforcer after a minimum of .5 sec, and on the average after 20 sec, the same values specified by the FR and RR schedules. Although a Sonalert burst followed each correct response, the DRL contingency had a direct effect only if a reinforcer had been set up. The Sonalert was used on the interval schedules since, due to its pairing with reinforcement, it should act as a conditioned reinforcer for spaced responding during the ISRT. RI training lasted for 15 sessions.

Finally, rats received 15 days of training on an FI 20 schedule. As on prior schedules, every correct response was followed by a Sonalert burst. The first correct response following 20 sec, timed from the previous reinforcer, produced a food pellet.

Multiple schedule training. Following FI training animals were exposed to a Mult FR RR FI RI schedule, in which each component was signalled by the click frequency previously associated with that schedule. Each component lasted for 30 min. The order of presentation was randomized across 4-session blocks, with the restriction that the first component be either FR or RR on two out of four days in each block. This restriction was imposed to insure that the interval components, with their weak R/SR constraints, were not the first components during which rats were exposed to shock for several successive sessions. All rats followed the same sequence. During this and all subsequent conditions correct responses were recorded separately from total (correct plus incorrect) responses.

For 20 sessions the rats were run on the multiple schedule using the same parameters established during training with the individual components. During that time there was little evidence that the DRL contingency was effective in reducing differences in response or reinforcer rates across the components. Since response rates never reached two per sec, it was reasoned that the .5-sec DRL requirement was shorter than prevailing IRTs, and that behvior could not contact the pacing contingency. Accordingly, the DRL requirement was increased across two phases, to a final value of 2 sec. To avoid substantial increases in mean ISRT, ratio requirements were decreased from 40 to 20 during the last phase of training. Table 1 presents the DRL and bin size, nominal ISRT and R/SR, and ratio size specified during each of the three phases of multiple schedule training.

Experimental conditions. The experimental manipulation consisted of varying relative CS duration across three phases. In accordance with the Stein, et al. (1958) procedure this was accomplished by varying cycle (CS + ITI) time. In the present study 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 Recovery. During Baseline conditions the CS was presented alone at the same relative duration to be used during shock sessions. During Shock, the US coincided with CS offset. In the Recovery (extinction) conditions the CS was again presented alone, at the same relative duration used throughout that phase. Basline was always in effect for eight sessions. In Phases I and II Shock and Recovery were each in effect for 20 days. However, since behavioral change always ended within 9-12 days, those conditions were run for only 12 sessions in Phase III.

CS and ITI periods alternated in all conditions. Cycle time was always a fraction of 30 min (the component duration), and components always changed following a CS offset (or shock). 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 density produced by the 1/1 relative CS duration. The CS consisted of illumination of the stimulus lamp, and the US was a 1-sec, 1 mA scrambled foot shock.

Results

Training

Response rates for the three phases of multiple schedule training are presented in Figure 2. In Phase I (DRL = .5sec) only rats R2 and R3 showed any indication of control by the DRL contingency. For all four rats FI rates tended to be lower than rates on other components. In Phase II (DRL = 1 sec) rates on the four components began to merge, although this tendency was slight for rat R4. In Phase III (DRL = 2 sec) rats R1 and R3 showed similar rates on all components. R4's rates continued to merge, although interval and ratio rates never overlapped, and R2 showed nearly identical rates on all but the FI component. Figure 3 shows the cumulative record for session 8 of Phase III, for R1. The general absence of post-reinforcement pausing or scalloping on the FI and FR components indicates that the DRL contingency was effectively spacing responding during Phase III. Although there was some variabilty in performance during this phase, both within and between subjects, all subjects approached or achieved the level of performance shown in the figure during some sessions.

Experimental conditions

Conditioned suppression is typically measured with a suppression ratio, which compares response rates during the CS to rate during the ITI (Stein, et al., 1958), or to overall (CS + ITI) rate (Davis & Memmott, 1983). However the present procedure produced severe suppression during the ITI as well as during the CS. In that situation relative measures are not appropriate, since they become highly variable with slight fluctuations in absolute rates, and are difficult to interpret (Frankel, 1975; Millenson & deVilliers, 1972). Accordingly, response tendency in the present study will be discussed in terms of absolute rates during the CS and ITI.

Figure 4 presents response rate during the CS (right column) and during the ITI (left column) in each experimental condition, for each schedule component. A comparison of the first set of points on each graph (Phase I, Baseline) indicates that there were no consistent differences as a function of schedule type, and that CS and ITI rates were virtually identical prior to the introduction of shock. During Shock conditions CS rates showed virtually total suppression at all three relative CS durations, and on all four components. Within animals, the ordering of, and differences between, rates on the four schedule components were consistent across successive Baseline and Recovery conditions.

ITI rates, while also greatly suppressed during Shock, varied as an inverse function of relative CS duration. Across animals, ITI responding was generally higher during Shock in Phase II (CS/ITI ratio = 1/9) than in Phase I (relative duration = 1/4), with almost total suppression during Phase III (1/1). Although these differences were small, due to the generally depressed responding, ITI rates (which were compared for days 1-12, since Phase III lasted for for only 12 days), averaged across animals and components, showed a near-significant inverse relationship with relative CS duration (F (2,9) = 3.00; p = .10). Although the alpha level did not reach the .05 significance level, the trend appeared strong enough to warrent an exploratory *t*-test, which showed that ITI response rates were higher at the 1/9 relative CS duration than at the 1/1 ratio ($t(9) = 2.45$; $p < .05$, two-tailed).

An examination of Recovery data shows no differential loss of suppression as a function of component type, but does reveal a trend towards weaker recovery following each successive shock condition. However this tendency is apparent only when all responses are included in the rate calculation. Correct rates, i.e. rates of only those responses which met the pacing requirement (Figure 5), appear to recover to about the same level in each phase. Correct rates also fail to show the breakdown of DRL control that appears with overall rates following Shock in Phase I.

Figure 6 shows the percentage of a session's maximum possible number of reinforcers that was earned on each schedule component. The severe response suppression during Shock conditions greatly reduced SR frequency. During the CS, reinforcer frequency was virtually zero during Shock on ratio components, and rarely exceed 25% of maximum on interval components. During the 1/1 Shock condition, SR frequency remained near zero on all components. During the ITI, non-zero frequencies were generally maintained, yet even on interval components SR frequency rarely exceeded 50% of maximum. Unlike response rates, ITI SR frequencies did not vary systematically with relative CS duration, nor is there any evidence that response rates (see Figure 4) depend on SR frequency.

Discussion

The major finding of this experiment was that relative CS duration appeared to control ITI responding during Shock conditions, even though CS rates could not vary due to their total suppression at all duration values. Before discussing that result, some additional effects deserve mention.

DRL procedure

The DRL procedure was only partially successful in reducing response rate differences attributable to the response and reinforcer constraints of the baseline schedule. Substantial homogeneity of response rate did develop during training (Figure 2). This increase in homogeneity is presumably due to the DRL contingency, since only that parameter was manipulated across all three phases. In Phase I of multiple schedule training, differences in response rate among the four components may be attributed to the DRL requirement being shorter than prevailing IRTs. Since IRTs typically exceeded the requirement, the negative contingency of resetting the DRL clock rarely occurred, and could therefore not control behavior. As DRL size was increased across phases, behavior came under better control of the contingency.

However the fact that some differences in rate persisted in Phase III deserves some comment. The consistently lower rate on FI components for R2 and R4 is not surprising, since on that component the DRL contingency could affect SR delivery only once in 40 sec, while on all other components any response not meeting the requirement could delay reinforcement. The fact that control of FI responding emerged at all in 3 out of 4 rats indicates that the Sonalert tone had aquired conditioned reinforcer properties due to its presentation during food delivery. Figure 7 shows rates of correct responding during training. Note that by Phase III correct rates were nearly identical on all components, though below the levels specified by the DRL requirement. This means that differences in total rate were probably attributable to differences in how the DRL contingency interacted with the fundamental schedule constraints. For example on ratio components the strong R/SR constraint typically causes the resulting response rate to interact with ISRT, a "dynamic" (Zeiler, 1977) effect since subsequent rates are affected. In the present experiment the indirect effect which response rate has on ratio schedules could produce periods of short IRTs which failed to meet the DRL requirement. The absence of the R/SR constraint on the FI component means that the effects of response rate should be weaker there, and and control by the DRL requirement should be stronger, than on the other components. This hypothesis is supported by a comparison of figures 2 and 7, which indicate that differences in total responding on the four components are due to differences in the rate of responses not meeting the contingency, since correct rates are so similar. One possible reason for this difference is that DRL contingencies may affect response rate in their role as an indirect variable, a less dynamic role on FI than on other schedule types. If this is the case, the capacity of DRL contingencies to control responding may be limited by the more powerful constraints of direct variables, such as ISRT and R/SR.

Response rate

The extreme response suppression during Shock conditions was surprising. It is unlikely that this effect was due solely to parameters of US intensity (1mA) or duration (1 sec), since other studies have reported maintained responding during the CS and ITI using similar or more extreme values (Libby, 1951; Davis & McIntire, 1969), and have even shown *facilitation* with comparable parameters (Finocchio, in Blackman, 1968a). A comparison of such factors as size and spacing of the bars in the shock grid, type of shock scrambling, etc., might be useful here, but that information is not available for the studies cited. However, one viable possibility is that the shock density in Phase I (6 US/hr) may have produced a partial learned helplessness effect (Seligman & Binik, 1977). Or, the CS-US association might have been weak (see next section) in Phase I, where the relative CS duration was 1/4. The widespread depression of rate is typical of unsignalled shock procedures (Seligman, 1968), and may reflect weak associations between signal and shock (cf Hymowitz, 1981a). Initial training with a weak CS-US association has been shown to inhibit aquisition at later, more favorable, conditions (Gibbon & Balsam, 1981; Randich, 1981), and may account for continued general suppression during subsequent phases.

The tendency for responding to decrease across phases is notable, since the decrease appeared only with total rates -- correct rates remining fairly stable. This discrepancy suggests that the effect of repeated Shock conditions may have been to reduce counterproductive responding, i.e. to eliminate responses which delayed reinforcement by their failure to meet the DRL requirement. Such an effect would be of interest, since it might support the reinforcers-lost hypothesis of Stein, et al. (1958); responding is suppressed only if reinforcement is not jeopardized. However, as shown in the next section, reinforcer constraints do not appear to interact with the relative CS duration manipulation.

Interestingly, the reinforcer sampling (Ayllon & Azrin, 1968) procedure failed to maintain behavior during Shock, especially during the CS. Whether this failure reflects a flaw in theory, or whether some procedural factor prevented the technique from succeeding, is unclear. However casual observation suggested that rats frequently failed to eat the free pellets during Shock, an effect reminiscent of motivational accounts of conditioned suppression. This measure was taken systematically during Experiment 2, and the issue of motivational factors in CER will be discussed further in the General Discussion.

Relative CS duration effects

Response rates during the ITI varied with the relative CS duration manipulation. However several considerations make interpretation of this outcome difficult. First, CS responding, which is generally considered the primary locus of CER effects, was totally suppressed, and therefore undifferentiated with respect to the relative duration manipulation. ITI rates, which are generally ignored in conditioned suppression reports (but see Blackman, 1968b; Rescorla, 1968), did vary with relative CS duration, but the effect was nearly masked by the generally low response rates. Second, there was no indication that reinforcer constraints differentially affected suppression level. The differential suppression of rates during Shock was not dependent on component type, and neither CS nor ITI rates showed differential recovery as a function of component type. Also, reinforcer frequencies were consistently low during shock, even on the FI component where only 1.5 responses per min would have maximized SR frequency.

The preceding considerations make it unlikely that the relative CS duration manipulation affected ITI responding through reinforcer loss, as postulated by Stein, et al. (1958), or that variations in relative duration must directly affect behavior occurring during the CS. The Stein, et al. model's emphasis on reinforcer loss leads to the prediction that, with the present procedure, CS rates should vary with relative CS duration, and should be more suppressed on interval than on ratio components. A logical extension is that, where suppression does occur (of either CS or ITI rates), rates should recover most rapidly on those components with the strongest constraints (i.e. on ratio components). None of these effects was observed.

However, ITI rates during shock conditions did vary systematically. While reinforcer loss does not seem adequate to account for this result, several alternatives are possible. First, in the present case as well as in the Stein, et al. (1958) procedure, manipulation of relative CS duration produced concomitant changes in shock density. In the present study relative CS duration was varied by changing ITI duration. When the relative CS duration was 1/1 (Phase III) shock density was 30 US/hr. With a relative duration of 1/4 (Phase I) shock density was 10/hr, and at 1/9 was only 6/hr. Group mean ITI rates, averaged over Shock sessions 1-12 of each phase, are plotted in Figure 8 as a function of shock density. The figure shows that ITI rates decreased as shock density increased. Since these are the same rates used in the analysis of relative duration effects, the same t-test analysis applies; the difference between 6 and 30 US/hr is significant. A reanalysis of Stein, et al.'s data shows that suppression ratios from that study were significantly lower at low- as opposed to high-density shock conditions (means = .17 and .25; $\underline{t}(24) = 2.85$; $\underline{p} < .005$). It appears that this difference may be attributable in part to changes in ITI rate, but not in CS responding. A Pearson product-moment correlation between ITI rate and shock density approached significance ($\underline{r} = .31$; $\underline{df} = 24$; $\underline{p} < .10$); the correlation between CS rates and shock density did not ($\underline{r} = .08$, N.S.).

The preceding analysis suggests that variations in shock density might account for differential suppression in relative CS duration manipulations. This hypothesis is not undermined by the Lyon (1963) study, where the two factors did not covary, since that study did not show consistently strong effects. However an alternative explanation based on differential associative strength at different relative durations, is possible. As noted in the General

Introduction, Miczek and Grossman (1971) suggested that variations in <u>absolute</u> CS duration might affect suppression level as the result of an inverse relationship between size of the CS-US interval and associative strength. Gibbon, et al. (1974) have since argued that a CS may accrue associative strength as its <u>relative</u> duration decreases. According to this analysis neither reinforcer loss nor shock density contribute importantly to control by relative CS duration, though they may aquire independent control over behavior.

A methodological concern for any of the analyses discussed above is that changes in ITI response rates may have been simply the result of differing opportunities to respond, as ITI duration increased from 1 to 3 min with a consequent difference in opportunity for high rates to emerge. While the opportunity for such a confound can not be ruled out, examination of the cumulative records indicated that time to respond was not an important variable. Most responding during shock conditions was confined to the first few seconds following shock, at all relative CS durations, with response rates decreasing as the ITI progressed.

The present experiment provides no means to test the density or associative explanations suggested above, since shock density and relative CS duration covaried. Experiment

2 was designed to separate the effects of relative CS duration on suppression, from those attributable to shock density.

EXPERIMENT 2

Introduction

The results of Experiment 1 indicate that behavior varies with changes in relative CS duration in a conditioned suppression paradigm, but in ways not predicted by existing explanations of suppression. The present experiment was designed to clarify issues raised in the first experiment, as regards the source, locus, and mechanism of control by relative duration.

In Experiment 1 responding during a preshock CS was totally suppressed at all three relative CS durations tested, although ITI response rates increased as relative duration decreased. This latter finding could not be attributed exclusively to the relative duration manipulation, since changes in relative CS duration were confounded with changes in the rate of shock presentation. Statistical analyses indicated that changes in ITI resoponse rates could be accounted for, at least in part, by variation in shock density. Experiment 2 isolated relative duration and shock density sources of control.

The finding that ITI rates varied during Experiment 1, while CS responding was totally suppresed, raises an issue concerning the locus of behavioral control in that experiment. Conditioned suppression is typically indexed by measuring changes in CS response rates, which are expected to vary relative to responding during the ITI. However, since a floor effect prevented evidence of any effects on CS rate, the question arises as to whether the observed relationship between ITI rates and relative duration was the result of generalization of suppression from the CS, or whether the relative duration/shock density manipulation had a direct effect on the ITI itself. Several experiments have demonstrated control of extra-CS behavior. For example, increases in shock density produce decreases in rats' bar pressing (Annau & Kamin, 1961) during the ITI. Rats' ITI responding also varies with changes in the conditional probabilities of shock given the CS, p(US/CS), or given no CS, p(US/noCS), if CS-US training occurs on-baseline (Davis & McIntire, 1969), though not with off-baseline training (Rescorla, 1968). In addition, Hunt and Brady (1955) reported different rates of ITI urination, defecation, and freezing depending on whether signalled shock was contingent or noncontingent, even though bar pressing during the CS did not differ. These latter sets of results indicate that, under some circumstances at least, CER manipulations may affect behavior occurring outside of the signal, even in the absence of differential behavior within the CS. Experiment

2 examined this issue further.

A final issue raised by Experiment 1 concerns the nature of the mechanism by which changes in relative CS duration controlled ITI rates. Had the effect been seen primarily in CS responding, control would probably be viewed as associative in nature, owing to the contingent relationship between the CS and US. However the inability to demonstrate associative effects within the CS raises the possibility of non-associative control during the ITI. In fact, other extra-CS effects of shock presentation, e.g. post-US response bursts (Faneslow, 1982) and post-US freezing (Bolles & Riley, 1973) have been attributed to non-associative control. But additional considerations suggest that the ITI effects of Experiment 1 may indeed be a result of an associative relationship. The fact that recovery of ITI responding during extinction conditions of Experiment 1 was gradual, and paralleled recovery of CS responding, suggests associative control, since non-associative suppression would be expected to dissipate rapidly. Also, recent studies have indicated that cues present in the experimental background, or context, accrue some associative strength during shock presentation (Martin & Oostendorp, Note 2), and that context cues can affect ITI responding in a CER paradigm (Ayres, Vigorito, Berger-Gross, & Cioffi, Note 3). The present experiment examined these alternatives.

The purpose of Experiment 2 is threefold: to determine whether relative CS duration controls responding when not confounded with shock density, to determine whether differences in relative duration affect ITI rather than, or in addition to, CS rates when duration and density are not confounded, and to test for evidence of associative control.

The first goal was achieved by using a 3 x 3 factorial design, in which relative CS duration was manipulated across groups, while shock density varied within groups. This procedure allowed for evaluation of control by each variable, as well as of any interaction between them.

The second goal of the experiment, that of determining whether relative CS duration effects are still seen in ITI response rates when duration and density do not covary, was also achieved by use of the factorial design. The likelihood that CS responding would be maintained at non-zero levels was increased by reducing the shock intensity and duration values to 50% of those used in Experiment 1, to maximize the opportunity for both ITI and CS responding to vary as a function of experimental manipulations.

The third purpose of Experiment 2, to evaluate the associative status of relative CS duration effects, was undertaken in two ways. First, an extinction phase was presented following exposure to the intermediate shock density. Since nonassociative effects of shock typically occur immediately after the US, and are of brief duration (Bolles & Riley, 1973), it was assumed that associatively maintained suppression should dissipate gradually during extinction, and that different levels of CS and ITI suppression, if due to differences in associative strength, should dissipate differentially. This last assumption was not easily tested in Experiment 1 since ITI response rates were so low. Second, associative control by relative CS duration was assessed quantitatively by analysis of relative CS duration in terms of a statistical measure of CS-US associative strength, the phi coefficient. This measure was chosen since it had been used previously (Gibbon, et al., 1974) to account for relative CS duration effects in the Stein, et al. (1958) study.

Method

Subjects

Subjects were nine male hooded rats, bred from Charles River stock at the Queens College vivarium. Subjects were approximately 75 days old at the start of the experiment, and were maintained at 80% (+- 5%) of *ad lib* weight on powdered Purina Rat Chow. Water was always available in the home cage.

Apparatus

The apparatus was the same as used in Experiment 1, although the speaker and Sonalert were not used during the present experiment. In addition, a SONY video recorder was used to tape portions of some sessions.

Procedure

Pretraining. Following magazine training rats were trained to press the left bar. Rats 4,7, and 9 aquired this response without experimenter intevention. For rats 1,2,3,5,6,and 8 some hand shaping was required. All subjects received continuous reinforcement for bar presses until 100 reinforcers had been earned.

Training with intermittent reinforcement began by switching from continuous reinforcement to a FI 5-sec schedule, and gradually increasing the nominal ISRT to 30 sec. During the same session in which these changes were made, the schedule was again switched, from FI 30 to RI 30 sec (bin size = 1.5 sec, p = .05). On the RI schedule, reinforcers, once set up, could be held only until the end of the bin in which they were set up (limited hold = 1.5 sec). During the subsequent session the RI value was gradually increased to RI 60 sec (bin size = 1.5 sec; p = .025). RI 60 training continued for 20 1-hr sessions.

After 20 sessions, between subject variability in response rate, and generally low rates for most subjects, prompted the use of several corrective procedures for increasing response rate and decreasing intersubject variability. First, the limited hold feature of the RI schedule was removed, on the assumption that animals were receiving too few reinforcers to maintain elevated response rates. From that point, reinforcers were held until picked up or until the next reinforcer set up, which ever occurred first. Second, the value of the RI schedule was reduced, from RI 60 to RI 4 sec, and was gradually increased to RI 40 (bin size = 2 sec; p = .05), over the course of 12 sessions. RI 40 training (no limited hold) continued for 20 sessions.

Following RI training rats were randomly assigned to one of three groups. Table 1 shows the mean response rate and group assignment for each animal, and the resulting group mean rates. Group names refer to the relative CS-ITI duration to be used with that group.

Experimental conditions. Relative CS duration was varied across the three groups of rats by dividing the intershock time (IST) into six bins of equal duration, and varying the ratio of CS to ITI bins across groups. By varying only the proportion of IST occupied by the CS, this technique allowed shock density to remain constant for all three groups. Thus, for Group 1-5, there was one CS bin following five ITI bins between successive shocks. For

Group 3-3 there were three CS bins following three ITI bins, and for Group 5-1 there were five CS bins following only one ITI bin between each pair of shocks. The sequence of ITI, followed by CS, followed shock was continuously repeated throughout a session.

For all groups shock density was manipulated across three phases (keeping relative duration constant), by changing the duration of an IST bin, while keeping the number of bins at six. Thus, for each group, the absolute time between shocks varied across phases, but the proportion of time allotted to the CS or ITI remained constant. The ratio of CS to ITI durations, the shock density, and the absolute CS and ITI durations in each phase are presented in Table 2.

Phases I - III consisted of two conditions each -- Baseline, in which the CS was presented alone at the appropriate bin size for that phase, followed by Shock, in which CS offset coincided with US onset. Baseline conditions were included as a buffer between successive shock conditions, since Experiment 1 demonstrated that shock effects may persist after termination of a shock condition. Phase IV consisted of an extinction condition, during which the CS was presented without the US at the duration values used during Phase III. In Phase V the Baseline and Shock conditions of Phase I were repeated.

Throughout the experiment sessions lasted for 1 hr. The CS consisted of illumination of the stimulus lamp, and the US was a .5 sec, .5mA scrambled foot shock. Baseline conditions were run for only five days in Phases I and V, since those Baselines did not immediately follow Shock conditions. In Phases II and III Baselines were run for 15 sessions. Shock conditions were always in effect for 15 sessions, as was Extinction (Phase IV).

Results

Figure 1 shows CS and ITI response rates for individual rats, at 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, R9). For Group 1-5 (right column) however, only CS responding was consistently suppressed. ITI responding was maintained at non-zero levels during all shock conditions, though rates generally appeared higher at 2 or 6 US/hr than at 10 US/hr. For all groups recovery of responding was gradual during Extinction (Phase IV), even for ITI rates in Group 1-5. For many animals there was an apparent tendency for response rates to rise across successive phases. While this tendency seemed to prevent complete recovery (Phase V) of the original 10-shock performance (Phase I), the increase, measured across successive baseline conditions, was not significant for either ITI or CS rates (F (2,12) = 3.03, 2.06, respectively; N.S.). In addition, neither CS nor ITI rates during shock were significantly different between the two 10-shock conditions (t (16) = 0.59, 1.01; N.S.).

The data from the three original shock conditions are summarized in Figure 2, which shows median ITI (top panel) and CS (bottom panel) response rates as a function of relative CS duration. Medians are shown due to the within-group variability in absolute rates. Analyses of varience (ANOVAs) in mean rates revealed a significant effect only of shock density on ITI responding (F (2,12) = 6.98; p = .01).

The fact that, in Figure 2, ITI rates but not CS rates appeared elevated at the 1/5 relative CS duration, 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 CS duration manipulation. The near-zero rates during shock for 4 out of 6 rats in Groups 3-3 and 5-1 precluded the use of suppression ratios to measure differentiation. Instead, a difference score was computed by finding the percent change in response rate, from Baseline to Shock, at each of the three shock densities, for each relative CS duration. This percent change measure was determined separately for ITI and CS responding, and the difference score consisted of the difference between ITI percent change and CS percent change. Percent change was used to compute difference scores since absolute ITI rates had already been shown to vary as a function of shock density, and could therefore not serve as a stable baseline.

Table 3A shows group mean difference scores for each shock density. The table shows that differentiation was greater for Group 1-5 than for Groups 3-3 or 5-1 at all three shock densities, and that for Group 1-5 only, difference scores appeared to decrease as shock density increased. The difference scores were submitted to a 3 x 3 (relative CS duration by shock density) ANOVA. The analysis revealed significant main effects of both relative duration and shock density, with the interaction reaching the .06 alpha level (see Table 3B for summary statistics).

One-way ANOVAs (Table 4A) showed that group differences related to relative CS duration were significant only at 2 and 6 US/hr. These differences were investigated further with a 3 x 2 relative duration by shock density (2 vs 6 US/hr) ANOVA (Table 4B), which showed a significant effect of relative CS duration. Since there was no main effect of, or interaction with, shock density, difference scores were pooled across 2 and 6 US/hr, and 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.).

Figure 3 shows group mean response rates during each of the six intershock bins. The dashed lines indicate CS onset. For Group 5-1 (left column) CS onset occurred after only one ITI bin, for Group 3-3 (center column) after 3 ITI bins, and for Group 1-5 (right column) after 5 ITI bins. The three panels for each group show mean rates for the last five sessions at each shock density (Phases I - III). The figure shows that, for Group 1-5 only, not only was CS responding suppressed relative to ITI responding during shock, but also that ITI rates appeared to decrease across successive bins. This consistent decrease across the IST is not evident with Groups 3-3 or 5-1. The slopes of these response rate functions are presented in Table 5A. Analyses indicated that, for Group 1-5, slopes were significantly different from zero at all three shock densities (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 slopes never differed from zero. A relative CS duration by shock density ANOVA (Table 5B) revealed a significant main effect of Groups, but not of Phase, with no interaction. An ANOVA of pooled (2, 6, and 10 US/hr) slopes showed a significant effect of relative CS duration (F (2,6) = 9.09; p = .02).

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.

Figure 4 shows reinforcer frequency during the CS and ITI, expressed as the percentage of the maximum possible in a session, for each phase. Substantial differentiation of CS and ITI reinforcer percentages is evident for Group 1-5, but is not seen consistently in the other two groups. SR frequency for Group 1-5 rarely exceeded 25% of maximum during the CS, and during the ITI generally did not exceed 50%. Of Groups 5-1 and 3-3, 4 out of 6 animals failed to exceed 50% of maximum, and were frequently below 25%, during both CS and ITI at all shock densities.

Discussion

A major finding of Experiment 2 was that relative CS duration controlled rats' behavior during a CER paradigm when relative duration was not confounded with shock density. However, shock density also affected responding, and there was suggestive evidence that the two variables may interact.

In this experiment there was less responding when 10-shock/hr, as compared to 2- or 6-shock/hr conditions were in effect, and when relative CS duration was 5/1 or 3/3, as compared to 1/5. As in Experiment 1, these differences occurred primarily in ITI response rates, since CS rates were severely suppressed during all shock conditions. Shock density had significant effects on absolute ITI response rates, relative CS duration had significant effects on the pattern (slope) of responding between shocks, and both variables affected differentiation between the CS and the ITI. The fact that ITI suppression was most severe at high shock density, long relative CS duration conditions suggests that the effects of the two variables may summate. Relevant data from both experiments will be reviewed in the General Discussion.

The nature of the control gained by the present manipulations deserves some comment. That the reduction in ITI rates attributed to shock density is due to density per se, and not to the order of exposure to shock conditions, is confirmed by performance during the Recovery phase. Despite the trend of some rats to increase response rates across phases, the lack of significant differences in responding between Phase I and Recovery indicates that the 10 US/hr condition consistently suppressed operant behavior, as compared to 2 or 6 US/hr. The trend of increasing rates across phases is itself of interest, since it is in direct opposition to the decreasing trend reported in Experiment 1. Possible explanations for this difference include the reduction in shock intensity and duration from Experiment 1 to Experiment 2, and the absence of shock density/relative CS duration confounds in Experiment 2.

The fact that response rates decreased throughout the IST only with Group 1-5 can not be attributed to effects of shock density, since all groups were exposed to the same densities, in the same sequence. However the decreasing rate function for Group 1-5 is consistent with the hypothesis of an increasing expectancy of the US as the ITI elapses (Gibbon, 1977).

As in Experiment 1, the reinforcers-lost hypothesis (Stein, et al., 1958) does not seem to apply to the present effects of relative CS duration. The Stein, et al hypothesis predicts more CS responding in the longer relative CS duration groups, and predicts that reinforcers will be earned at some high (e.g. 90%) level at all relative durations. Neither of these predictions was supported by the present data. Response rates during the CS did not vary systematically with relative CS duration (Figure 2, bottom panel), and reinforcers were rarely maintained at more than 25% of maximum (Figure 4).

An alternate explanation is based on group differences in the CS-US temporal association, defined as the relative CS duration. Although the experimental effects were seen primarily outside of the CS, the extinction (Phase IV) data support the view that ITI responding was under associative control (i.e. that behavioral change was due to an aquired sensitivity to relationships between stimulus events). The fact that ITI responding recovered gradually even for Group 1-5, where ITI and CS suppression was differentiated during shock, is indicative of associative, rather than nonassociative, effects. Together with the findings of Ayres, et al. (Note 2), Hunt and Brady (1955), and Davis and McIntire (1969), the extinction data of the present experiments are consonant with the hypothesis that associative control may be indexed during the ITI, even when behavioral change is not evidenced during the CS.

For the present study, control by temporal association makes sense from several perspectives. First, the relative duration of stimulus events has been shown to be an important variable in accounting for a variety of stimulus-stimulus association phenomena, e.g. conditioned reinforcement (Fantino, 1977), stimulus-reinforcer control of operant behavior (Brown, et al. 1982), autoshaping (Gibbon & Balsam, 1981; Jenkins, et al., 1981), and sign-tracking (Brown, et al., Note 3). unconditioned response potentiation (Brown, et al., Note 3).

Second, Rescorla (1968) has already shown that suppression levels vary with the strength of the CS-US association when associative strength is defined in terms of the conditional probabilities of shock. Rescorla found greater suppression as *p*(US/CS) increases, less suppression as *p*(US/noCS) increases, and no differentiation between CS and ITI responding when *p*(US/CS) = *p*(US/noCS). More recently, Gibbon, Berryman, and Thompson (1974) have argued that contingency size can be specified in temporal terms, regardless of conditional *p*(US), by discretizing the IST into bins of equal duration. Contingency size is measured with the phi coefficient (root mean square contingency), $\phi = \sqrt{\chi^2 / n}$, which may be calculated for the CER case in terms of a comparison of CS bin frequency with ITI bin frequency (Gibbon, et al., 1974). Gibbon, et al. plotted suppression ratios from the Stein, et al. (1958) study as a function of phi, showing a generally linear relationship, but commented that the confounding of relative CS duration with shock density in that study made interpretation difficult.

In the present experiment, relative CS duration varied independently of shock density, yielding a more pure measure of control by relative duration. Figure 5 shows group mean difference scores (see Results) as a function of phi. For the present procedure, where *p*(US/CS) always equals one, and *p*(US/noCS) always equals zero, the transformation of the phi equation for temporal contingency is written,

$$\phi = \sqrt{P1 / 1 + (1 - P1)T1 / T0} \tag{1}$$

(Gibbon, et al., 1974). In this form of the equation P1, which usually specifies p(US/CS), is the ratio of the smallest number of CS bins at any relative CS duration (one, in this experiment), to the number of CS bins for a particular relative CS duration (in this experiment, one, three, or five). T1 is the current CS duration, and TO is the current duration of the ITI (see Appendix A for computation of phi). As Figure 5 shows, there is some tendency for Difference Scores to decrease between phi = .45 and phi = .77, but the most pronounced effect is a substantial increase in differentiation at phi - 1.0, for all three shock densities. The initial decrease at 2 and 6 US/hr is quite small compared to the subsequent increase in the functions. The decrease may be spurious, since the trend appears predominantly in the 6 US/hr function, where the elevated difference score at phi = .45 is accounted for by one animal in Group 5-1 (R9, Figure 1).

Alternately, the decrease in differentiation between phi values of .45 and .77 might have been produced by an "autocontingency" (Davis, Shattuck, & Wright, 1981) for Group 5-1, wherin the US signalls the onset of a discriminable shock-free period (the ITI), with a resultant rise in ITI response rates. But regardless of whether the initial decrease was artifactual or not, the primary effect of decreasing relative CS duration occurs when phi exceeds .77. It is at this point that the CS becomes shorter than the ITI, the relative duration at which a positive contingency between the CS and US emerges (Gibbon, et al., 1974). The fact that differentiation did not occur regularly when the relative CS duration was 3/3 (phi = .77) or greater, is reminiscent of data reported in autoshaping, where speed of aquisition increases with the inverse of relative CS duration, starting from a minimally effective CS/ITI duration ratio of 1/1 (Gibbon, 1981).

The preceding discussion demonstrates quantitatively that relative CS duration effects can be attributed to differences in associative strength. An additional argument in favor of an associative explanation is that the group differences in slope in Figure 2 may be understood in terms of associative mechanisms. In that figure, substantial decreases in responding occur across the six IST bins for Group 1-5 but not for Groups 5-1 or 3-3. For Group 1-5 part of that decelerating function was due to the decrease in response rate following CS onset, indicating that for that group only the CS was an effective predictor of the US. But in addition, rats in Group 1-5 also showed a continuous decrease in rate during the five ITI bins, consistent with the notion of increased expectancy of the CS as the ITI elapsed.

This latter finding may be accomodated by associative models of animal timing. Such models, e.g. Scalar

Expectency theory (or SET, Gibbon, 1977; Gibbon & Balsam, 1981) and relative delay (Brown, et a.; 1982) or waiting time (Jenkins, et al., 1981) theories, maintain that animals make ratio comparisons between times to reinforcement signalled by various cues in the experimental situation. Although some of these models postulate that timing of local temporal contingencies during the ITI does not occur during aquisition, Gibbon and Balsam (1981) have indicated that such timing does emerge as training progresses, and that delayed aquisition of a CS-US association may be the result of failure to temporally differentiate the CS from the inter-US interval. In addition, the assumption that local timing during the ITI does not occur in early training has recently been challenged (Fantino, Note 4; Lucas & Wasserman, 1982; and see the General Discussion in the present report). The apparent temporal discrimination by Group 1-5 may be accounted for by a scalar timing mechanism similar to that postulated for FI or spaced responding schedules (Gibbon, 1977). The important feature of timing behavior here is that it is demonstrated behaviorally only when relative CS duration provides a strong basis for CS-US association. This fact is of theoretical interest since it indicates associative control of behavior even in the absence of differences in a more conventional measure of contingency, the conditional _p_(US).

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. This outcome, along with other results of the study, will be briefly reviewed. Afterward, the implications of these data for current theoretical issues and for future research will be discussed.

Summary of Results

Relative CS duration

In both Experiment 1 and Experiment 2 rate of operant responding varied as an inverse function of the duration of the CS, relative to that of the ITI. In contrast to most CER paradigms, experimental control was evident primarily during the ITI. Response rates during the CS generally remained near zero during all shock conditions of both experiments. The conclusion that control of ITI respopnding derived from the relative duration manipulation was tentative in Experiment 1, since changes in relative CS duration produced coincidental changes in shock density. However Experiment 2 showed control of bar pressing by relative CS duration when shock density was held constant. In that experiment relative CS duration varied across groups while shock density varied within all groups across phases. Only when the CS was shorter than the ITI (Group 1-5) did animals show differential responding between CS and ITI portions of the intershock time (IST). When CS duration was equal to (Group 3-3) or longer than (Group 5-1) that of the I,TI little differentiation occurred in 5 out of 6 rats. Since most animals made few responses during the CS, the effect of relative CS duration was seen primarily as the greater maintainance of ITI than of CS responding by Group 1-5, but not by Groups 3-3 or 5-1; however the failure of the latter two groups to differentiate was evident even where CS responding was maintained at above-zero levels (Experiment 2; Figure 2, R3).

Shock density

In Experiment 2 ITI rates for all groups were suppressed more at 10 shocks per hour than at either 2 or 6 shocks per hour. Independent control by shock density in Experiment 2 suggests that shock density and relative CS duration may have had a combined or summated effect in Experiment 1.

Interaction of relative CS duration with shock density

Even though Group 1-5 of Experiment 2 differentiated between the CS and the ITI at all shock densities, differential responding was reduced at 10 US/hr as compared to 2 or 6 US/hr in both the original (Phase I) and Recovery (Phase V) 10-shock conditions. The failure of Groups 5-1 or 3-3 to show systematic differentiation at any shock density produced a near-significant interaction between density and relative duration.

Figure 1 demonstrates the consistency of duration and density effects. The figure plots median ITI response rates from both experiments as a function of relative CS duration. The data show several trends. First, animals in both Experiment 1 (filled circles) and Experiment 2 (open data points) tended to decrease ITI responding as relative CS duration increased. The slight reversal in Experiment 1 data between relative durations of 1/4 and 1/1 was not evident in group mean data (Experimnt 1, Figure 3), and the decreasing trend was consistent at all relative duration values in Experiment 2. Second, rats in both experiments responded more at low (i.e. 6 or fewer US/hr) than at high (i.e. 10 or more US/hr) shock densities. Third, while animals may be sensitive to high vs low shock density, finer differentiation was not apparent in the data. In Experiment 2 ITI rates were not reliably different between 2- and 6-US/hr shock conditions and, comparing data across the two experiments, 10, 12, and 30 US/hr conditions produced similar suppression of ITI responding. Last, differences attributable to shock density are reduced as relative CS duration increases. If the functions for Experiment 2 were extrapolated, it appears as though the 6-shock function would come close to intersecting the 6-shock point from Experiment 1, indicating the consistency of both the shock density effect, and the density-duration interaction, across the two experiments.

Mechanisms and Measures of Experimental Control

Increases in shock density produced increases in suppression of responding during the ITI for group 1-5. Several hypotheses may be put foreward to account for this result. One, non-associative account, suggests that the effects of repeated US presentation (e.g. physiological enervation) may accumulate to a greater extent as shock density increases. This summation of shock effects might be due either to increased total amount of shock or to decreased time for dissipation of shock effects between successive USs. Alternately, control by shock density may have been associative (learned), if rats aquired sensitivity to the relationship between shock and various elements of the experimental context. For example shock itself might become increasingly associated with subsequent shocks as the intershock time decreases. This possibility has been advanced recently by Davis, et al. (1981) to account for the autocontingency effect of post shock response bursts occurring during CER procedures using high shock densities. Interestingly, in the Davis, et al. study, groups showing the autocontingency effect (i.e. groups exposed to high shock densities) also showed lower average ITI response rates than did groups exposed to lower shock densities. Another view is that associative control of ITI rates by differential shock density may have emerged as a result of pairing shocks with the background or context cues in the experimental environment (issues regarding the possibility of context conditioning will be discussed in subsequent sections). According to this analysis increases in the frequency of US-context pairings should produce greater associative strength accruing to context cues, with consequent increases in suppression during the ITI. The present study was not designed to test alternative accounts of control by shock density. However the following discussion of associative factors in the control of responding by relative CS duration may also be relevant to the shock density issue (see especially Appendix B).

The effects of relative CS duration were confined largely to ITI responding in both Experiment 1 and 2, since CS response rates generally remained at near-zero levels during all shock conditions. Since *p*(US/CS) was always one and *p*(US/noCS) was always zero in both experiments, traditional theories of associative control would predict that the CS would aquire all available associative strength, at least where CS duration was short enough for the CS to be a discrete, salient cue for the US (i.e. all three shock conditions of Experiment 1 and Group 1-5 of Experiment 2). However the gradual recovery of responding during extinction (Experiments 1 and 2), even where rats differentiated between the CS and ITI (Group 1-5, Experiment 2) indicated associative control of ITI responding, maintained by context cues for the US. External support for the view that context cues maintained associative control came from the study by Ayres, et al. (Note 3). In the second experiment of that study two groups of rats received equal numbers of CS-US pairings while bar pressing, but differed in terms of whether or not shock-free operant sessions were interspersed with the conditioned suppression sessions. Those rats not receiving the bar press-alone sessions remained in their home cages on those days. Measures taken during shock sessions indicated that animals receiving the interspersed operant-alone sessions showed less suppression during the ITI than rats left in their home cages. The authors attributed this result to a weakening of fear of the context cues for bar press-alone animals, even though the CS-US relation had not changed. The effect is similar to the difference between giving CS-US training on- vs off-baseline. ITI response rates do vary with changes in *p*(US/CS) and *p*(US/noCS) in the former procedure (Davis & McIntire, 1969), but not with the latter procedure (Rescorla, 1968), indicating that associations between background cues and the US may depend on factors other than (or in addition to) the CS-US contingency.

In sum, the evidence supports the hypothesis that behavioral changes produced by the relative CS duration manipulation in the present study may be attributed to differential associative control by context cues. In the Ayres, et al. (Note 3) study, and in the comparison of on- vs off-baseline training procedures, differences in ITI responding occurred even where CS-US relations were equivilent. In the present study measures were taken of extra-experimental behavior (response classes other than the reinforced operant) which support the control-by-context hypothesis. These data are presented in the next section -- a discussion of the nature of associative control in this study.

Mediational theories

In the General Introduction several theories of conditioned suppression were discussed which postulated that operant behavior is suppressed during a CS due to the action of some mediating variable, e.g. adventitious punishment by the US, conditioned interference with the reinforced operant, or a decrease in motivation for the operant reinforcer. Each of these theories was based on the prevailing conception that the CS and/or US produced an emotional state which was somehow incompatible with operant responding. Each of these mediational theories was compromised by empirical findings, and many later investigations concentrated on more direct analyses of stimulus and schedule factors in the control of conditioned suppression. The present study was conceived in that same spirit.

However several observations made during the course of the two experiments indicated that emotional or mediational constructs might well be reconsidered. Each of these observations concerned changes from baseline to shock conditions in extra-experimental behavior (i.e. in behavior other than the reinforced operant), behavioral changes which in the past have been attributed to changes in emotional state. Recall for instance that, in shock conditions of Experiment 1, rats rarely if ever ate the sample food pellet placed in the tray prior to each session. This observation was coupled with another, that food pellets produced by bar presses were also frequently not eaten, with rats sometimes leaving 8 - 10 pellets in the tray by the end of a session. Together, the two observations prompted an examination of the rats' general eating tendency and it became apparent that all rats required considerably less food to maintain their 80% weights during shock conditions than during baseline conditions.

In addition, it was observed that, during shock conditions, all rats would urinate and defecate in the bucket used to carry them from the vivarium to the experimental room, or in the basket of the scale used for weighing subjects just before the start of a session. Also, by the fifth day of the highest shock density, lowest relative CS duration condition (Phase III), rat R4 began to have daily seizures in the carrying bucket or weighing basket. In observations with the video camera seizures were never detected once the experimental session began, and during the subsequent extinction condition pre-session seizures dissappeared within three days.

Similar observations of increased urination and defecation, and of decreased reinforcer sampling and eating in the home cage, were made in Experiment 2. Accordingly, several analyses were done in an attempt to determine the nature of those behavioral changes. Specifically, the relationship between decreased food requirements in Experiment 1, and potential contributing factors such as changes in shock density, was examined by a multiple regression analysis of food intake, experimental phase, bar press frequency, and body weight. For Experiment 2, ANOVAs of relative CS duration and shock density effects were done for measures of reinforcer sampling, urination, and defecation. These analyses and their implications are presented in detail in Appendix B, but will be briefly summarized here.

The multiple regression of Experiment 1 data indicated that only bar press frequency could have contributed to the reduced food requirement observed during shock conditions. The ANOVAs of Experiment 2 data showed that, as compared to Baseline, the introduction of shock produced decreased reinforcer sampling and increased urination and defecation prior to the start of a session. The effect of shock presentation was modified by variation in relative CS duration and shock density. Casual observations of group differences in activity during the CS contributed to the suggestion that theories of emotional mediation of suppression are inappropriate.

Emotional theories of suppression have pointed to changes in eating, urination, and defecation as autonomic indicators of emotional mediation of skeletal behavior. It is clear from the analyses in Appendix B (see especially Figure 3) that operant suppression is not necessarily tied to fear of a cue for the US, and can not always be explained in terms of freezing or withdrawal responses. Adventitious punishment can not account for differences in ITI response rates since shock density was always equal across groups, and appeals to conditioned punishment by the CS can not account for group differendes in extra-experimental behavior. Instead, group differences in response rate, and the occurrence of shock-related changes in extra-experimental behavior for all groups, can best be described in terms of prevailing stimulus conditions, and the strength of CS and background associations with the US.

Control by associative strength

In general, associative control of ITI behavior may be conceptualized as occurring in two alternate ways. One prominent view of associative learning assumes a complimentary or competing relationship between CS and background associative strengths; as the CS accrues strength associations between the US and the experimental context weaken. In various formulations a strong CS-US association precludes associative control during the ITI, either because context cues in the ITI have no associative strength in that situation (e.g. Rescorla & Wagner, 1972) or because they signal a negative contingency -- if ITI then no US (e.g. Seligman, 1968; Davis & McIntire, 1969).

The foregoing analysis can account for the present findings of greater maintainance of ITI responding at shorter relative CS durations if CS associative strength is assumed to vary inversely with relative CS duration.

However it can not easily explain some of the data discussed in the preceding section. Associative control by context cues was evident even where the CS would traditionally be predicted to accrue all available associative strength, i.e. when relative CS duration was 1/4, 1/5, and 1/9. An alternate conceptualization, which is equally capable of explaining the relative CS duration effects of this study, stipulates that the CS and the ITI aquire associative strength with the US independently, without competing with each other. According to this analysis the strength of US associations with either the CS or the background cues is related to the length of time each type of cue is present prior to a US. For the CS timing begins at CS onset, and for context cues at the previous US offset (Gibbon, 1977; Gibbon & Balsam 1981). Conditioned effects are seen only when CS cues are of sufficiently shorter duration than context cues. In Experiment 2 this means that differential suppression (Table 3A, Experiment 2) and decelerating response rate functions (Figure 3, Experiment 2) would occur only at the 1/5 relative CS duration, which was the actual outcome of that experiment.

Models of association hypothesizing non-competition between the CS and the background are relatively untested. However findings from the present study strongly suggest that stimuli other than the CS do maintain association with the US under conditions not easily explained by the Wagner-Rescorla model. The extinction data of Experiments 1 and 2 indicated that control of ITI responding was associative, even with the strongest CS-US relationships tested. In addition, the analysis of extra-experimental behavior in essence constitutes a transfer of control test, by testing the capacity of context cues to suppress behavior other than the reinforced operant. The fact that cues from the carrying bucket, weighing basket, and food tray produced behavioral changes for all groups supports the hypothesis of context-US associations. The fact that many of these changes were seen outside of the chamber suggests that the conditioning context maintains sufficeint associative strength for second order conditioning of context cues to more tangential stimuli, e.g. the carrying bucket and weighing basket. Experimental demonstrations that the association of background cues with the US is sufficiently powerful to generate such conditioning has recently been provided by Marlin and Oostendorp (Note 2), who produced second order conditioned suppression to a tone paired with the experimental context in which animals had previously been shocked.

Although a non-competition model of associative learning seems best able to account for the the present data, a further consideration related to that issue deserves comment. Gibbon and Balsam (1981) have raised the possibility that non-competition between CS and context for associative strength may hold true only for asymptotic behavior, while speed of aquisition may be affected by CS-background competition. This concern derives from recent demonstrations that prior exposure to unsignalled US presentations or to a weak CS-US contingency can retard or prevent later aquisition of autoshaping, even when the subsequent training occurs with a strong CS-US contingency (see Tomie, 1981 for a review). This context-retardation effect is viewed as evidence that, during early training conditions at least, CS and background cues do compete for associative strength in the manner suggested by Rescorla and Wagner, that the context aquires all available associative strength in the absence of a strong CS-US contingency, and that context-US associations block aquisition of CS-US relationships when CS-context compounds occur in subsequent training.

However the Gibbon and Balsam (1981) non-competition formulation is not compromised by the retardation-of-autoshaping phenomenon if a slight modification to the model is permitted. Models of associative learning which assume non-competition, e.g. Scalar Expectency Theory (SET; Gibbon, 1977; Gibbon & Balsam, 1981), arousal theory (Killeen, 1978), and possibly the relative waiting time (RWT) hypothesis (Jenkins, et al., 1981), contend that conditioning occurs because subjects make a ratio (Gibbon & Balsam, 1981) or difference (Killeen, personal communication, May 13, 1983) comparison of times to the US signalled by the CS (CS duration) and the context or inter-US interval (CS plus ITI time). Conditioned responding emerges when CS time is sufficiently shorter than the inter-US interval, e.g. when the CS is less than one half of the entire inter-US interval. The ITI portion of the inter-US interval is assumed to be irrelevant, since pigeons at least do not appear to discriminate local temporal contingencies within the ITI (Gibbon, et al., 1981; Jenkins, et al., 1981).

But this latter assumption, that the ITI is irrelevant, may be valid only when the US has never been presented during context alone conditions (e.g. during magazine training or during unsignalled US presentations during the ITI). If context-alone US presentations have occurred, the context-US associations formed might be expected to contribute to the ratio or difference comparison, which would then include an estimate of time signalled by the ITI (cf Fantino, Note 4).

A method of assessing such multiple-duration comparisons has recently been reported by Brown, et al. (1982). In their "temporal separation" procedure, those authors used a relative delay to reinforcement (RDR) measure to describe the different delays to response-dependent reinforcement signalled by two cues in prior, unreinforced, components. Control of non-reinforced pecking during the cues was well described by the RDR measure, which consisted of the ratio of the shorter of the two cued delays to the sum of the delays to reinforcement from all key color changes (i.e. the short delay cue, the alternate, longer delay cue, and the white key present during all operant components. Similarly high correlations were found between relative response rates to the two cues and the RDR or RWT metrics.

In the context-retardation of autoshaping situation the RDR metric could be used to measure the effect of including an ITI estimate in the CS/inter-US interval ratio comparison. The inclusion in the denominator of any non-zero estimate for the ITI automatically decreases the ratio. Behaviorally, this means that autoshaped responding is less probable when the ITI maintains associative strength independent from the CS or the inter-US interval. Thus the context-retardation effect in autoshaping can be accounted for without reverting back to the Rescorla-Wagner (1972) competition model of association.

Retention of the non-competiton feature is important for SET since theoretical consistency was reduced by the assumption that the CS and the context compete for limited association during aquisition but maintain associative strength independently at asymptote. In addition, the non-competition feature is useful in accounting for two aspects of the data in the present study. First, it permits explanation of the relative CS duration effects on ITI responding and of the context effects on extra-experimental behavior by the same model of associative learning, i.e. a model which specifies independently maintained associations inside and outside of the CS. The mounting evidence for context-US associations even at asymptotic levels of CS-US training seems to require such a revision in conditioning theory.

Second, there was some indication in the present data that initial training with a weak CS-US contingency, as specified by relative CS duration, produces a retardation effect similar to that seen in context-pretrained autoshaping. In Experiment 1 initial CS-US training occurred at the 1/4 ralative CS duration, which may have been close enough to some critical ratio (cf. Gibbon, 1977; Gibbon & Balsam, 1981) that differential responding between the ITI and the CS was reduced, and that subsequent differentiation was retarded even at the more favorable 1/9 ratio (Phase III). Similarly in Experiment 2, only 1 out of 6 rats in Groups 5-1 or 3-3 ever developed substantial differentiation, even after extended exposure to a pefect

CS-US contingency as specified by conditional p(US). In contrast, Group 1-5 developed some differentiation even at the first (highest density) shock condition, with differentiation increasing at later, less dense, shock conditions. While the procedures used in the present experiments do not permit a proper test of aquisition differences attributable to relative CS duration, the data are in accord with the retardation of autoshaping effects.

The preceding considerations indicate that the present data can be best accounted for by a non-competing model of associative learning. The discussion will return to this issue at the end of the next section, which considers various measures of association.

Measures of CS-US association

In the Discussion section of Experiment 2 the phi coefficient was used to measure the temporal relationship between the CS and US, and to quantify the conditioned effects of relative CS duration on operant behavior. That measure was chosen because it permitted the specification of CS-US contingency size, the prevailing metric of associative strength, and because it had previously been demonstrated to be a useful means of describing effects of temporal variations in the CS-US relation on conditioned suppression (Gibbon, et al., 1974).

However, several recent findings have raised the possibility that CS-US relationships may not be best described by their contingency, regardless of how contingency is specified. In the first place, as shown in the present study and in Gibbon (Gibbon et al., 1980; Gibbon, 1977), contingency manipulations may have varying degrees of effect on behavior depending on other procedural considerations. For example Gibbon,et al., (1980) and Jenkins, et al. (1981) have each reported experiments in which both the occurrence and speed of pigeons' aquisition of autoshaping depend upon the relative durations of the CS and the inter-US interval, with no effect of or interaction with manipulation of $\underline{p}$(US/CS). Yet when the CS-US contingency is degraded by increasing $\underline{p}$(US/noCS) aquisition speed is reduced. This differential outcome has prompted Gibbon (1981) to note that the predictive power of a contingency analysis is not symetrical -- "a condition that eliminates associative responding is identified by the contingency analysis, but the conditions that generate it are not" (p. 288).

Similarly, in the present study, differential control of CS and ITI responding was seen to vary inversely with relative CS duration even though conditional $\underline{p}$(US) was the same at all relative durations. And in the temporal separation procedure of Brown, et al. (1982) differential responding to two cues for subsequent operant reinforcement emerged as a function of different delays to that reinforcement, even though the probability of food signalled by each cue was the same.

A second issue concerning contingency metrics is whether or not they incorporate information which is ignored by a subject. As noted earlier, SET and the RWT hypothesis assume that animals are insensitive to information concerning relationships between the US and the ITI. This assumption is based on several empirical observations. First, speed of aquisition of autoshaping does not vary as the ITI changes from from fixed to variable duration, as long as the average inter-US interval remains the same; in addition, aquisition occurs well before temporal patterning of responding appears (Gibbon & Balam, 1981). Second, varying the temporal location of USs added outside of the CS does not modulate the retarding effect on responding which they produce (Jenkins, et al., 1981). Each of these observations is taken as an indication that pigeons do not respond to local variations in ITI-US relations, but instead form an estimation of the average time between USs and of the average time from CS onset to the US. Gibbon (1981) has therefore concluded that, if local ITI-US contingencies are ignored, $\underline{p}$(US/noCS) (an important element in the phi equation) is irrelevant to the power of training procedures to establish associative responding.

The data from Experiment 2 of the present study could have been as well described by either phi, scalar expectancy or RWT, with each measure being capable of accounting for the observed variation in ITI responding on the basis of differential background associative strength at each relative CS duration. In fact Jenkins and Shattuck (1981) have recently demonstrated a relationship between conditioned suppression and RWT, independent of CS-US contingency. If the abcissa of Figure 4 in Experiment 2 (ITI response rate as a function of phi) was replaced by expectancy (H) or RWT values, the same functions would obtain, with only the spacing of the data points along the abscissa varying with the statistical measure (see Appendix B for computations of H and RWT for the relative durations used in each experiment).

Phi, as a temporal measure of contingency, and SET or RWT appear equally capable of describing the present data. This may be because *p*(US/noCS) was always zero in both experiments; a value of zero for PO in the phi equation means that the phi becomes functionally identical to SET or RWT in considering only the overall *p*(US) (in the present study, and in standard autoshaping procedures overall *p*(US) = *p*(US/CS) (cf Gibbon, 1981), the duration of the CS, and the duration of the ITI or the inter-US interval. Therefore the present study did not specifically test the importance of p(US/noCS), and the data provide no clear support for either the contingency or the SET or RWT positions.

However the fact that control of behavior by context cues was demonstrated in several ways in this study permits the following theoretical commments. Neither traditional contingency theory nor SET can account for all of the present data, since contingency analysis specifies no associative control by context cues with a strong CS-US contingency, and SET is unclear on the conditions under which CS and background associations with the US become independent. But it appears that contingency theory would have to include more additional assumptions to account for the present findings than would SET theory. Contingency theory would be forced to 1) admit to independent context-US associations, 2) account for the fact that, even with a perfect CS-US contingency (specified by conditional p(US)), behavioral change will not occur unless relative CS time is less than some critical value, and 3) that even a temporal contingency analysis such as phi does not predict changes in conditioned responding when CS duration is held constant but ITI duration varies (as shown in Experiment 1 of the present study and in Gibbon, et al., 1980) since, as long as the CS is shorter than the ITI and p(US/noCS) always equals zero, as in Experiment 1 of the present study, phi always equals one (see Appendix A). The only modification of SET (and, presumably the RWT hypothesis) required by the present data is that the feature of independence of CS and context associations be retained, e.g. by including a term for ITI associations when the subject has experienced unsignalled US presentations.

Implications of associative control

During the preceding discussion of associative control it became apparent that operant behavior in the present CER experiments was affected in similar ways, by similar manipulations, as behavior in other procedures utilizing Pavlovian training. Control by relative time to shock seems directly analogous to the findings of SET, RWT, and RDR paradigms. This similarity is noteworthy since while such disparate means of assessing associative control are rarely compared, such comparisons clearly have heuristic value. In the present case the finding of strong effects of relative signal duration is analogous to findings of relative duration effects in autoshaping and to the effects of differential signalling of delays to food in the temporal separation procedure. The similarity suggests a fundamental process of behavioral control by temporally processed stimulus-stimulus associations.

This inference is relevant to an issue raised in the General Introduction, the possibility that positive and negative CER paradigms might be sensitive to similar kinds of stimulus control. A number of similarities between the two procedures were detailed, for example that response rates during the CS were likely to be lower as operant reinforcer rate decreases an as baseline response rate, relative CS duration, or US intensity increase. The similarity between the present findings and those of other Pavlovian procedures supports the contention that the extent of operant rate change in both positive and negative procedures can be controlled by similar stimulus manipulations. In this regard it might be useful to conceive of conditioned responding during positive and negative CER paradigms as representing parallel sets of points along a continuum which varies from complete suppression to facilitation. Most aversive paradigms produce response suppression although some, e.g. using a low rate operant baseline with a mild shock, may produce facilitation. Most appetitive procedures produce facilitation although some, like using low rate reinforcer schedules with short relative CS durations, might produce suppression. Thus positive and negative procedures appear to occupy different, but overlapping positions along the response continuum (cf. Kelly, 1973). Most experimental manipulations produce effects of similar direction with either procedure. For example, reducing baseline response rate requirements generally produces increases in CS response rates in both negative and positive CER studies. What differ are the endpoints of response rate values, and possibly the scaling units of the two procedures, along the continuum.

Directions for Future Research

Parametric studies

The findings of this study, and their relevance to findings in other areas of research, indicate a number of productive lines for future investigation. At the most basic level, parametric analyses of some of the variables examined in these experiments would be useful. Only a limited set of values of relative CS duration or shock density were tested. Filling in the intermediate and extreme values would be helpful in determining the shape of the functions relating behavior to those variables. In addition, both density and relative duration data indicated that subjects respond differentially to high and low values of both density and relative duration, but the exact cutpoints are as yet unknown. For relative CS duration the data indicate that the cutpoint lies between CS/ITI duration ratios of 1/1 and 1/4, since differential responding was evident at relative durations of 1/4 (Experiment 1) and 1/5 (Experiment 2), but not at 1/1 (Experiment 1, Phase III; Experiment 2, Group 3-3). This appears to place the cutpoint for differentiation at or near the cutpoint for aquisition of autoshaping (Gibbon, 1981). The shock density cutpoint appears to lie between 6 and 10 US/hr, with little indication of finer sensitivity, especially at the shorter relative CS durations.

ITI association studies

Several features of the present data suggest that a fruitful line of inquiry would be to pursue the question of maintainance of associative strength during the ITI. Although there were several kinds of evidence that the conditioning context does retain associations with the US independent of CS-US relationships, the evidence was indirect. Conclusions of context associations were drawn from ITI extinction data and from extra-experimental behavior, which means that tests of associative control were made outside of the shock situation where associative control is likely to be strongest. A more direct approach would be to extend the second order conditioning procedure used by Marlin and Oostendorp (Note 2). In that study context cues present during shock were used to condition suppression to a tone. However the the shocks were unsignalled during context training, so differential CS-US -- context-US associations could not develope. To directly test the possibility that the conditioning context maintains associative strength independently of CS-US conditioning, CS-US pairings could be presented in a given context, at varying relative CS durations, and part or all of the context cue compound could then be tested for its capacity to generate second order conditioned effects. Comparisons between context conditioning at different relative CS durations would be of interest, as a systematic investigation of changes in context-US associative strength as a function of differences in the CS-US relation. Of particular concern would be data from the shortest relative duration conditions, where contingency measures of both conditional *p*(US) and temporal relationship (phi) would lead to the prediction that no second order conditioning should be possible.

Relative CS duration interactions

A third direction in which research might be pursued would be to test for interactions between relative CS duration and other variables which might affect suppression. In Experiment 1 relative duration effects were examined with four different types of baseline schedule. No differences in behavior were found that were attributable to schedule type. It is possible that the R/SR and minimum ISRT differences in those schedules do not interact with relative CS duration. Previous reports of schedule effects on suppression might be attributed to differences in response or reinforcer rate, which were reduced in Experiment 1 by the pacing requirement. This could be tested by removing the pacing requirement in a replication. If schedule differences occur, then response or reinforcer rate characteristics of schedules, but not R/SR or minimum ISRT considerations, are important in relative CS duration manipulations. If schedule differences do not occur than the relative duration manipulation might be said to be insensitive to schedule differences.

Other possible interactions are suggested by the shock density effects in Experiment 2. Increases in shock density produced decreases in responding in all groups, but the effect was seen only in ITI rates in Group 1-5. This interaction suggests that other means of varying shock occurrence, e.g. p(US/CS), might provide informative data. In conditioned suppression studies suppression typically varies directly with p(US/CS) (Rescorla, 1968; Davis & McIntire, 1969; Willis & Lundin, 1966). However in autoshaping p(US/CS) has been reported to have only weak effects at best (Gibbon, et al., 1980; Gibbon, 1981). Gibbon and Balsam (1981) attribute this weak effect to an apparent tendency of pigeons to integrate both signal time and inter-US interval time, and to compare the averages of these times. Since the ratio of signal to inter-US interval time does not change as a function of p(US/CS), only the averages of the absolute durations change, aquisition of autoshaping should not be affected by the probability manipulation.

The analysis offered by Gibbon & Balsam (1981) does not address the issue of why aversive and appetitive Pavlovian procedures should generate such different results with the same manipulation. However the possibility exists that the difference is not a real difference in behavioral effects, but an artifact of measurement technique. Gibbon, et al. (1980) report that a number of Pavlovian manipulations show no effects of variations in _p_(US/CS) if all trials to aquisition are counted, but if the primary aquisition measure is number of _reinforced_ trials then _p_(US/CS) has a demonstrable effect. In CER paradigms the typical measure of Pavlovian control is the suppression ratio, taken at asymptote. It may be that if the same measure of conditioning were used in both CER and autoshaping procedures the discrepancy in _p_(US/CS) effects would disappear.

Aquisition studies

Reporting aquisition measures such as trials to criterion in CER studies could facilitate comparison with other Pavlovian preparations where such measures are usual. In addition, an aquisition study could provide information concerning a suggestion raised in the General Discussion, that initial CER training with a weak CS-US relationship might retard later CS-ITI differentiation, even with more favorable subsequent training conditions. Retardation effects, which have been widely reported in autoshaping studies, could be studied in a suppression paradigm by using a latin square design to assess the effects of prior treatment conditions. Using a procedure similar to that of Experiment 2, relative CS duration would be manipulated across groups. However relative duration would also be varied within groups, with each group receiving a different sequence of relative durations. Differentiation between the CS and the ITI would be tested at a final relative CS duration, chosen to maximize the CS-US relationship. Group differences in that test phase would be attributable to differences in associative strength in initial training conditions. Results could be compared to other paradigms where prior training has theoretical importance, e.g. in autoshaping and in learned helplessness (Seligman, 1968).

Summary

In two experiments the effects of variation in the relative duration of a CS for shock were investigated in a CER paradigm. In Experiment 1 relative CS duration was varied by holding CS duration constant and changing ITI duration. On four types of basline schedule responding was suppressed completly during the CS at all relative CS durations, but responding during the ITI varied inversely with relative CS duration. Since the relative duration manipulation produced subsequent changes in shock density, behavioral control was not uniquely attributable to relative CS duration in Experiment 1.

In Experiment 2 relative CS duration and shock density were manipulated independently. CS response rates were again severely suppressed at all relative durations tested. ITI rates varied inversely with both relative duration and shock density, with a tendency for the two variables to interact at higher shock density values.

Control of ITI behavior was shown to be associative in nature, with control apparently deriving from US-context associations. Implications for models of associative learning, for the generality of effects of stimulus control manipulations on Pavlovian procedures, and for future

research were discussed.

Appendix A:

Computation of Phi for Experiments 1 and 2

The formula given by Gibbon, et al. (1958) for computing phi when *p*(US/CS) always equals one and *p*(US/noCS) always equals zero is

$$\phi = \sqrt{P1 / (1 + (1 - P1)T1 / T0)} \qquad (1).$$

Wnen contingency is specified by relative CS duration: P1 is the ratio of the smallest number of CS bins at any relative CS duration (one, in this study), T1 is the current CS duration, T0 is the current ITI Duration.

Experiment 1

1/1 $\phi = \sqrt{1 / (1 + (1 - 1)1 / 1)} = \sqrt{1 / 1 + 0} = 1$

1/4 $\phi = \sqrt{1 / (1 + (1 - 1)1 / 4)} = \sqrt{1 / 1 + 0} = 1$

1/9 $\phi = \sqrt{1 / (1 + (1 - 1)1 / 9)} = \sqrt{1 / 1 + 0} = 1$

Experiment 2

1/5 $\phi = \sqrt{1 / (1 + (1 - 1)1 / 5)} = \sqrt{1 / 1 + 0} = 1$

3/3 $\phi = \sqrt{1 / (1 + (1 - 1/3)3 / 3)} = \sqrt{1 / 1\ 2/3} = .77$

5/1 $\phi = \sqrt{1 / (1 + (1 - 1/5)5 / 1)} = \sqrt{1 / 1 + 4} = .45$

Appendix B:
Analysis of Extra-Experimental Behavior

In an attempt to determine the nature of the decreased food requirement in Experiment 1, an analysis was made of the relationship between changes in daily food consumption and potential contributing factors, e.g. changes in experimental conditions or in body weight. It was reasoned that motivational effects of the CS or US would be reflected in a relationship between food intake and relative duration or shock density without concurrent changes in body weight. In addition, it seemed possible that reduced food intake during shock conditions might be simply the result of reduced bar pressing during shock, with a resultant decrease in energy requirments. Difference scores were computed for changes from Baseline to Shock in daily food ration, body weight, and number of bar presses. A multiple regression analysis was performed, with food intake (grams of food consumed in the chamber and in the home cage as the outcome variable and body weight, experimental phase, and number of bar presses as the predictor variables. For all variables the mean for the last five days for each shock and baseline condition was entered into the regression. With a multiple R of .89, the only significant partial correlation was with changes in bar press frequency (r = .86; $p < .001$), with no significant intercorrelations among the predictor variables.

According to the regression analysis, changes in rats' eating behavior during shock were largely accounted for by reductions in bar pressing. This relationship makes a motivational account of behavioral suppression unlikely, at least in the usual sense. Typically, motivational theories maintain that emotions produced by the CS or US decrease food motivation, thereby reducing operant behavior (e.g. deVilliers & Millenson, 1972). In the present situation bar pressing was reduced during shock, with no direct statistical link between eating and shock density or CS duration conditions, with a strong correlation between eating and bar pressing. It seems more promising at present to simply note that stimulus control of bar pressing was obtained by varying conditional p(US/CS) between Baseline and Shock conditions, and varying relative CS duration and shock density across phases, with resultant changes in food requirements.

While the multiple regression analysis appeared to rule out direct motivational effects of shock on eating, it was silent regarding the other behavioral changes, e.g. seizures, urination, and defecation prior to experimental sessions. During the early phases of Experiment 2 it was again observed that rats failed to sample the reinforcer, and urinated and defecated in the bucket or scale basket, prior to shock sessions. Beginning with the shock condition of Phase II (6 US/hr) and continuing through Phases IV (6 US/hr Extinction) and V (10 US/hr Recovery), daily recordings were made of whether or not each rat urinated or defecated prior to being placed in the chamber, and whether or not the sample food pellet was eaten prior to the start of the session. Figure 2 shows the change in these behaviors from Baseline to Shock conditions for the 6-US/hr and 10 US/hr shock densities. Each data point represents a group mean Change Score, from Baseline to Shock, in the number of days (out of the last five of each condition) during which reinforcer sampling, urination, and defecation were observed. For 6 US/hr, since recordings were begun following the Baseline condition for that Phase, Baseline was considered to be the last five days of Recovery, where CS duration parameters were the same as those used in the 6-shock condition. Note in the figure that, for each measure, there is an inverse relationship between relative CS duration and Change Score at 6 US/hr, but that at 10 US/hr that relationship disappears in all but the reinforcer sampling measure. The data from each condition were submitted to 3 x 2 x 2 Groups x Stimulus Condition (Baseline vs Shock) x Shock Density (6 vs 10 US/hr) ANOVA (separate ANOVAs for each dependent measure). Results (Tables 1-3) showed a reliable main effect of Stimulus Condition for all three dependent measures, and a significant effect of Groups on reinforcer sampling and urination. Shock density interacted with Groups and with Stimulus Condition on reinforcer sampling, and tended to interact with Groups (p = .07) on defecation. The interaction between Stimulus Condition and Groups was significant on reinforcer sampling and approached significance (p = .09) on defecation. These effects were examined further by computing 1-way ANOVAs of group effects on each measure at each shock density. Results (Table 4) show that group effects were significant only on defecation at 6 US/hr and on reinforcer sampling at 10 US/hr. t-tests show that, at 6 US/hr, Group 1-5 defecated on significantly fewer days than Group 5-1 (t(6) = 3.74; p = .01) with a near-significant difference from Group 3-3 (p = .08), and at 10 US/hr sampled the reinforcer on significantly more days than either Group 5-1 or 3-3 (t(6) = 7.12 and 6.02, respectively; p < .001 in both comparisons).

The foregoing analyses demonstrate that, during shock conditions, rats were more likely to urinate and defecate, and less likely to sample the reinforcer, than during baseline conditions. The group comparisons indicate that the effects of shock presentation are modulated by changes in relative CS duration and shock density. Such effects have previously been viewed as an index of emotionality.

For example Hunt and Brady (1955) attributed higher rates of freezing, urination, and defecation during the ITI of conditioned suppression, as compared to signalled punishment procedures, to there being greater conditioned fear produced by the former paradigm. The analyses discussed above do not specifically test for an emotional factor in the behavioral changes observed in Experiment 2. However two additional pieces of evidence suggest that these changes are sufficiently explained by differences in stimulus conditions, and that mediational constructs are unnecessary or inappropriate.

First, recall that the multiple regression of Experiment 1 data showed that reduction in food intake was attributable to reductions in bar pressing, and not to the experimental changes that controlled ITI response rates across phases. There is no empirical reason to assume that failure to eat reinforcer samples, which were given prior to the start of a session, is functionally different from failure eat in the home cage. Both may be attributed to reduced food requirements during periods of reduced bar pressing. It is interesting to not in this regard that in Figure 2 Group 1-5 was less likely to leave the food sample than were Groups 5-1 or 3-3, and that Group 1-5 generally showed higher response rates (in the ITI) during shock than did the other groups. In addition, R3 of Group 3-3 maintained elevated response rates during shock and was more likely to eat the reinforcer sample than were other rats in that group (R3 ate on 7 out of the 10 shock days examined, R5 ate on 1 out of 10 and R8 ate on 2 out of 10 days).

The preceding considerations are in accord with the multiple regression analysis from Experiment 1 in not finding support for motivational effects on these extra-experimental behaviors. An additional observation makes other theories of mediated control also appear unlikely. While monitering animals' behavior during Experiment 2 it became apparent that rats in Group 1-5 were considerably more active during the CS than were rats in Groups 5-1 or 3-3. In the latter groups rats (except R3) tended to move towards the rear of the chamber at CS onset, and sit until the shock was delivered. In Group 1-5, on the other hand, rats would also stop bar pressing during the CS, but were frequently observed to engage in a variety of alternate behaviors, e.g. grooming, stretching, and exploring. Figure 3 shows R7 engaging in a not infrequent behavior for Group 1-5 -- sniffing the CS stimulus lamp. All three animals in that group were observed to spend considerable time with the lamp during the CS; three times the plexiglass cover for the lamp was chewed through by these rats and had to be replaced, and the cover was frequently pulled out and pawed or bit during the CS until a more permanent installation was arranged. It is clear that, for Group 1-5 at least, suppression was not dependent on freezing or withdrawal from the CS.

Appendix C

Computation of Expectancy and Relative Wait for Experiment2

Expectancy equals the ratio of expectancies during the inter-US cycle (HC) and the signal (HT), where:

$HT = H/T = H/U(P(S*/T))$

$HC = H/C = H/U(P(S*))$

$P(S*)$ is the unconditional probability of a US

$P(S*/T)$ is $p(US/CS)$

U is the unit of timing (always one in Experiment 2)

Relative Wait equals the ratio of signal to inter-US interval durations.

Relative CS	Expectancy	Relative Wait
1/5	HT = H/1 HC = H/6 H = 6/1	1/6
3/3	HT = H/3 HC = H/6 H = 6/3	3/6
5/1	HT = H/5 HC = H/6 H = 6/5	5/6

Table 1
Experiment 1: Schedule Values
For the Three Phases of Pretraining

	DRL	RI Bin	*p*	Ratio(a)	ISRT(b)	R/SR(c)		Response Rate(d)
Phase						FR-RR	FI-RI	
I	0.5	0.5	.025	40	20	40	1	2.0
II	1.0	1.0	.025	40	40	40	1	1.0
III	2.0	2.0	.050	20	40	20	1	0.5

Note. Time units for DRL, BIN, ISRT, and response rate are sec.

(a) Number is the actual value for fixed ratio, and the mean value for random ratio.
(b) Number is the actual value for fixed schedules, and the mean value for random schedules.
(c) Number of responses meeting the DRL requirement required for each reinforcer.
(d) Specified response rates are determined by the DRL value.

Table 1
Experiment 2: Group Assignments
and Response Rates

GROUP					
5-1		3-3		1-5	
Subject	Rate	Subject	Rate	Subject	Rate
6	23	5	29	2	27
1	19	3	22	7	25
9	18	8	20	4	22
X	20	X	24	X	25

Note. All rates are responses per min, and are the mean of the last five sessions of RI training.

Table 2
Experiment 2: Durations of CS and ITI
in Each Experimental Phase

		Phase				
Group		I(10)	II(2)	III(6)	IV(0)	V(10)
1-5	CS	1	5	1 1/3	1 1/3	1
	ITI	5	25	8 2/3	8 2/3	5
3-3	CS	3	15	5	5	3
	ITI	3	15	5	5	3
5-1	CS	5	25	8 2/3	8 2/3	5
	ITI	1	5	1 1/3	1 1/3	1

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

Table 3
Experiment 2:
A. Difference scores(a) as a
Function of Shock Density

	Soock Density (US/hr)		
Group	2	6	10
1-5	53.79	40.37	8.11
3-3	3.41	5.66	2.34
5-1	5.66	11.28	2.06

B. 3 x 3 Relative CS Duration by Shock Density ANOVA
of Difference Scores(a)

Source	*df*	Mean Square	*F*	*p*
Relative CS Duration	2	2540.68	8.43	.02
Error	6	301.39		
Shock Density	2	762.10	4.76	.03
Relative CS x Density	4	482.64	3.01	.06
Error	12	160.27		

(a) Difference score is the per cent change in CS response rate, from Baseline to Shock, minus the per cent change in ITI rate from Baseline to Shock.

Table 4
Experiment 2:
A. ANOVAs of difference scores between relative CS durations
For 2, 6, and 10 US/hr

Source	*df*	Mean Square	*F*	*p*
2 US/hr	2	2429.83	5.45	.04
Error	6	445.44		
6 US/hr	2	1041.22	6.41	.03
Error	6			
10 US/hr	2	34.91	2.47	.17
Error	6	14.14		

B. 3 x 2 Relative Duration by Shock Density (2 vs 6 US/hr)
ANOVA of difference scores(a)

Source	*df*	Mean Square	*F*	*p*
Relative CS Duration	2	3316.14	7.54	.02
Error	6	439.95		
Shock Density	1	15.38	0.09	.77
Relative CS x Density	2	154.91	0.92	.45
Error	6	167.84		

(a) Difference score is the per cent change in CS response rate, from Baseline to Shock, minus the per cent change in ITI rate from Baseline to Shock.

Table 5

Experiment 2:

A. Group Mean Slopes of Response Rate Across Intershock Time

	Shock Density (US/hr)		
Group	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

B. 3 x 3 Relative CS Duration by Shock Desity ANOVA of Slopes of Intershock Time Response Rates

Source	*df*	Mean Square	*F*	*p*
Relative CS Duration	2	6.43	9.09	.01
Error	6	0.71		
Shock Density	2	0.49	1.25	.32
Relative CS x Density	4	0.27	0.68	.62
Error	12	0.40		

Table 1
Appendix B:
3 x 2 x 2 Relative CS Duration by Stimulus Condition (CS vs ITI) by Shock Density (6 vs 10 US/hr) ANOVA for Reinforcer Sampling

Source	*df*	Mean Square	*F*	*p*
Relative CS	2	21.44	19.79	.002
Error	6	1.08		
Shock Density	1	0.44	1.45	.27
Relative CS x Density	2	2.11	6.91	.03
Error	6	0.31		
Stimulus Condition	1	58.78	39.92	.001
Rel. CS x Stim.	2	11.44	7.77	.02
Error	6	1.47		
Dens. x Stim.	1	5.44	7.84	.03
Rel. CS x Dens. x Stim.	2	0.44	0.64	.56
Error	6			

Table 2
Appendix B:
3 x 2 x 2 Relative CS Duration by Stimulus Condition (CS vs ITI)
by Shock Density (6 vs 10 US/hr) ANOVA for Urination

Source	*df*	Mean Square	*F*	*p*
Relative CS	2	2.58	5.47	.04
Error	6	0.47		
Shock Density	1	0.11	0.15	.71
Rel. CS x Den.	2	1.69	2.26	.19
Error	6	0.75		
Stimulus Condition	1	40.11	84.94	.0001
Rel. CS x Stim.	2	1.03	2.18	.19
Error	6	0.47		
Den. x Stim.	1	0.11	0.10	.76
Rel. CS x Den. x Stim.	2	1.69	1.56	.28
Error	6	1.08		

Table 3
Appendix B:
3 x 2 x 2 Relative CS Duration by Stimulus Condition (CS vs ITI) by Shock Density (6 vs 10 US/hr) ANOVA for Defecation

Source	*df*	Mean Square	*F*	*p*
Relative CS Duration	2	4.53	2.30	.18
Error	6	1.97		
Shock Density	1	0.44	0.76	.42
Rel. CS x Den.	2	2.53	4.33	.07
Error	6	0.58		
Stimulus Condition	1	36.00	24.45	.002
Rel. CS x Stim.	2	5.58	3.79	.09
Error	6	1.47		
Den. x Stim.	1	0.11	0.10	.76
Rel. CS x Den. x Stim.	2	3.69	3.41	.10
Error	6	1.08		

Table 4
Appendix B:
One-way ANOVAs Between Relative CS Durations, for Reinforcer Sampling, Urination, and Defecation, at 6 and 10 US/hr

Source	*df*	Mean Square	*F*	*p*
6 US/hr				
Reinforcer Sampling	2	7.44	1.97	.22
Error	6	3.78		
Urination	2	5.33	2.82	.14
Error	6	1.89		
Defecation	2	16.44	7.05	.03
Error	6	2.33		
10 US/hr				
Reinforcer Sampling	2	16.33	29.40	.001
Error	6	0.56		
Urination	2	0.11	0.09	.91
Error	6	1.22		
Defecation	2	2.11	0.76	.51
Error	6	2.77		

Figure 1. Direct and indirect variable constraints on responding. Direct constraints, e.g. R/SR and ISRT are indicated with solid lines. These variables are considered to have direct effects on rate since rate typically varies as they are manipulated. However response rate itself may become an "indirect" constraint (dashed line) on future rates, on schedules where response rate affects ISRT.

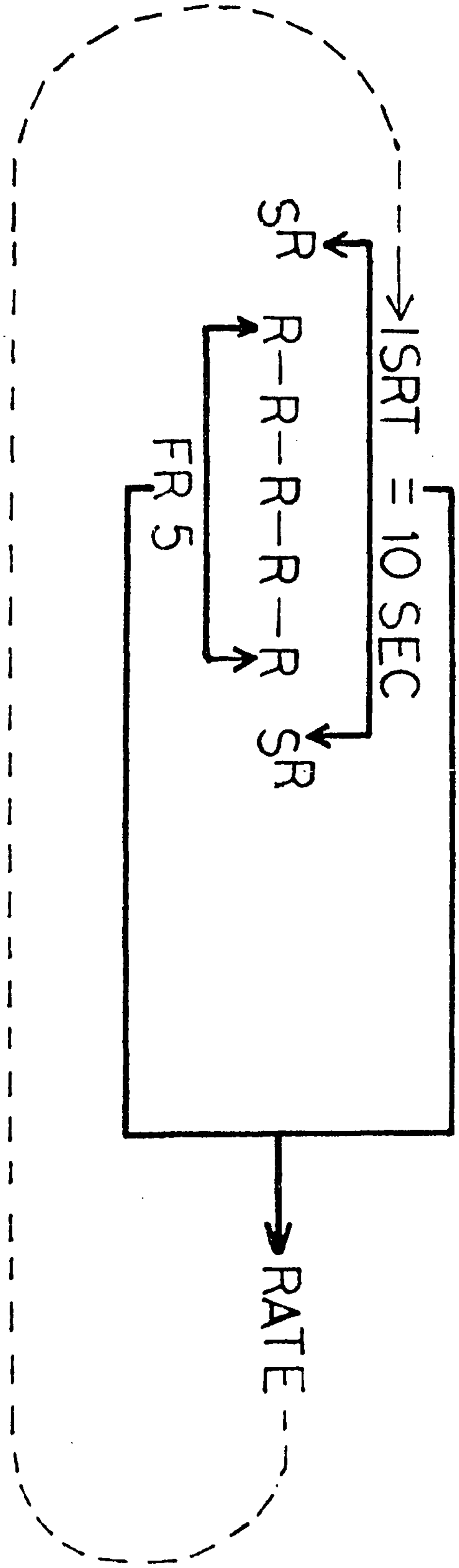

ISRT = 10 SEC
SR
R—R—R—R—R
SR
FR 5
RATE

Figure 2. Response rates on the four components of the multiple schedule during the three training phases. Dashed lnes separate the phases -- Phase I: DRL = .5 sec; ISRT = 20 sec. Phase II: DRL = 1 sec; ISRT = 40 sec. Phase III: DRL = 2 sec; ISRT = 40 sec.

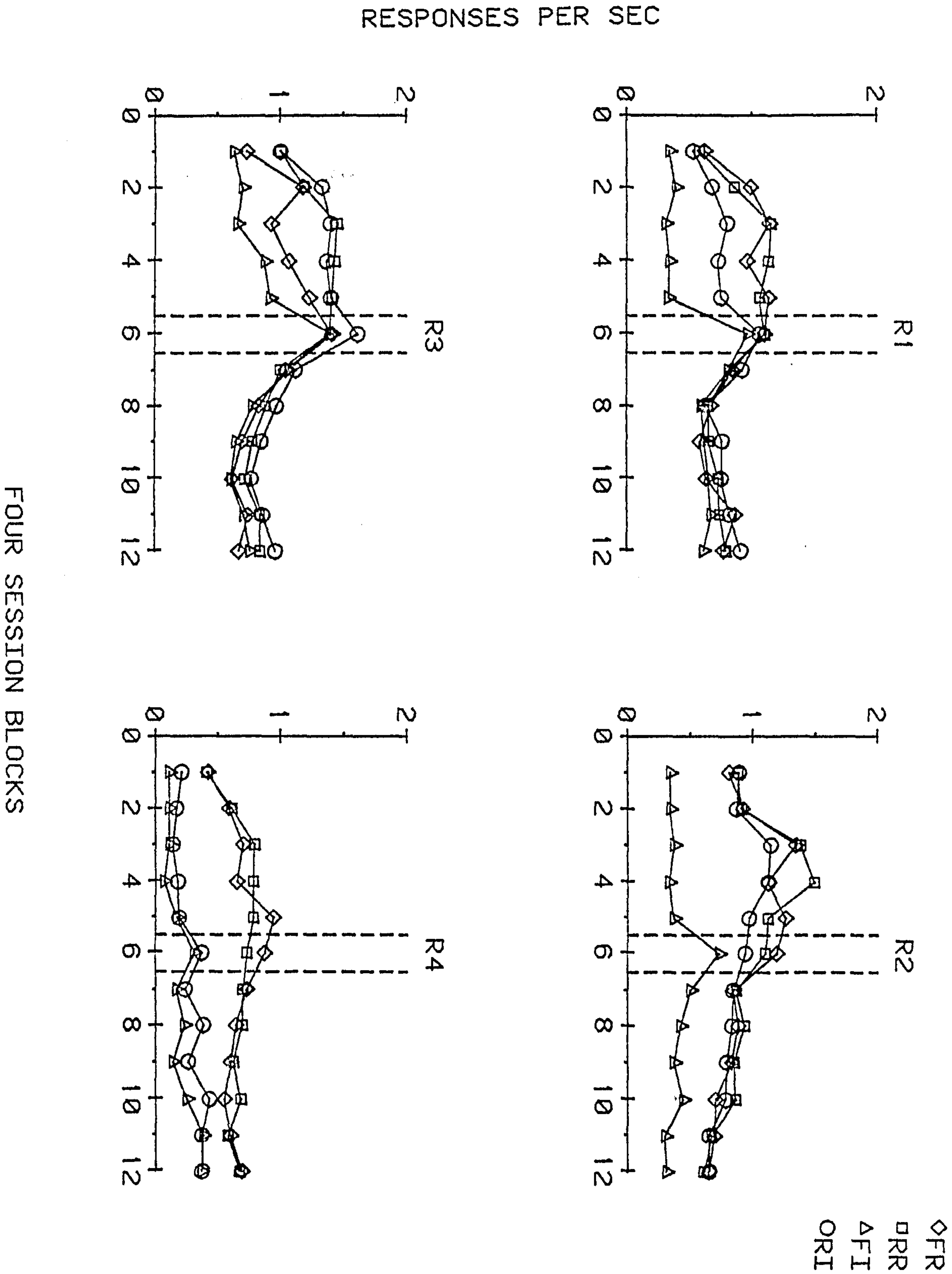

RESPONSES PER SEC
FOUR SESSION BLOCKS
R1
R2
R3
R4
0
1
2
0
2
4
6
8
10
12
◇FR
□RR
△FI
○RI

Figure 3. Cumulative record from session 8 of the 1/1 relative CS duration, for R1. The pen reset after 400 responses or at the end of a component (i. e. after 30 min).

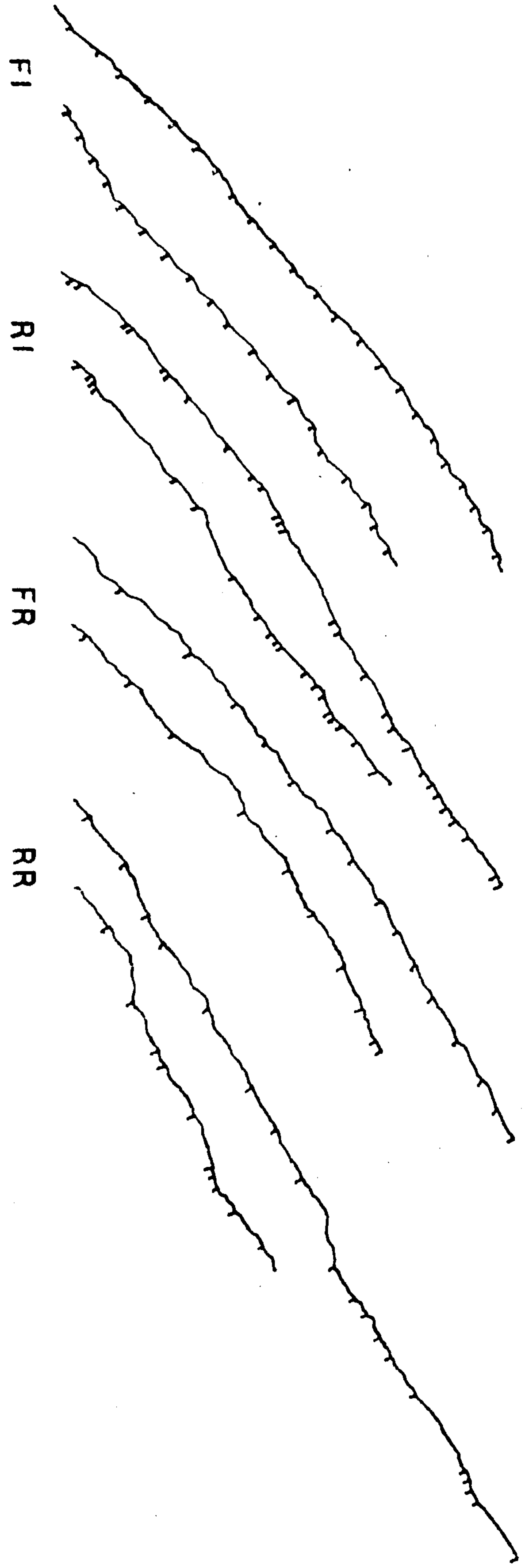

FI
RI
FR
RR

Figure 4. CS (right column) and ITI (left column) response rates on each component Vertical lines separate the three conditions of the multiple schedule. CS and ITI rates for a given rat appear on the same row. (Baseline, Shock, and Recovery) of each phase. Phases are separated by solid vertical lines, and are designated by the relative CS duration in effect during that phase.

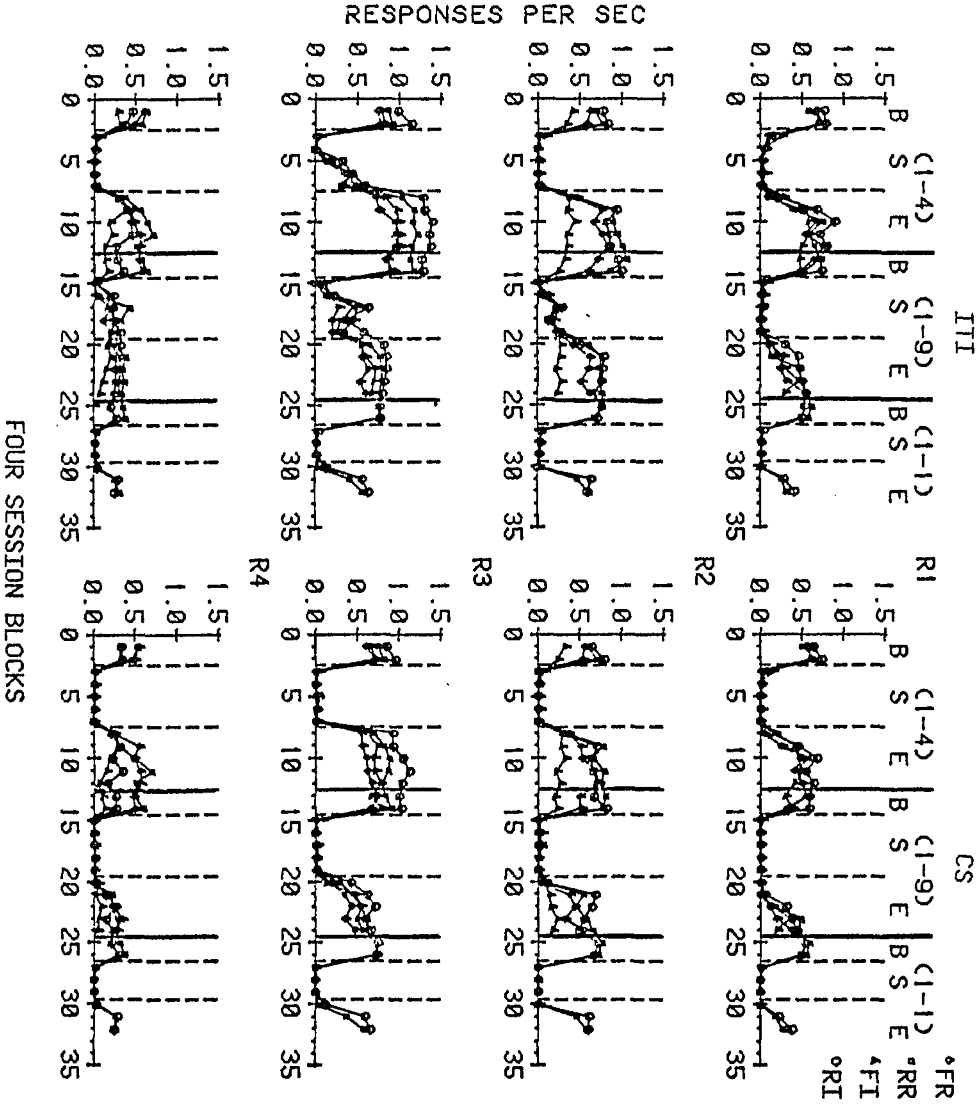

ITI
CS
(1-4)
(1-9)
(1-1)
B
S
E
B
S
E
B
S
E
FR
RR
FI
RI
R1
R2
R3
R4
RESPONSES PER SEC
FOUR SESSION BLOCKS
0.0
0.5
1.0
1.5
0
5
10
15
20
25
30
35

Figure 5. Rate of correct responses (responses which met the DRL requirement) on each component. CS (right column) and ITI (left column) rates are in the same row for each animal. Dashed vertical lines separate the three conditions (Baseline, Shock, and Recovery) for each phase. Phases are separated by solid vertical lines, and are designated according to the relative CS duration in effect.

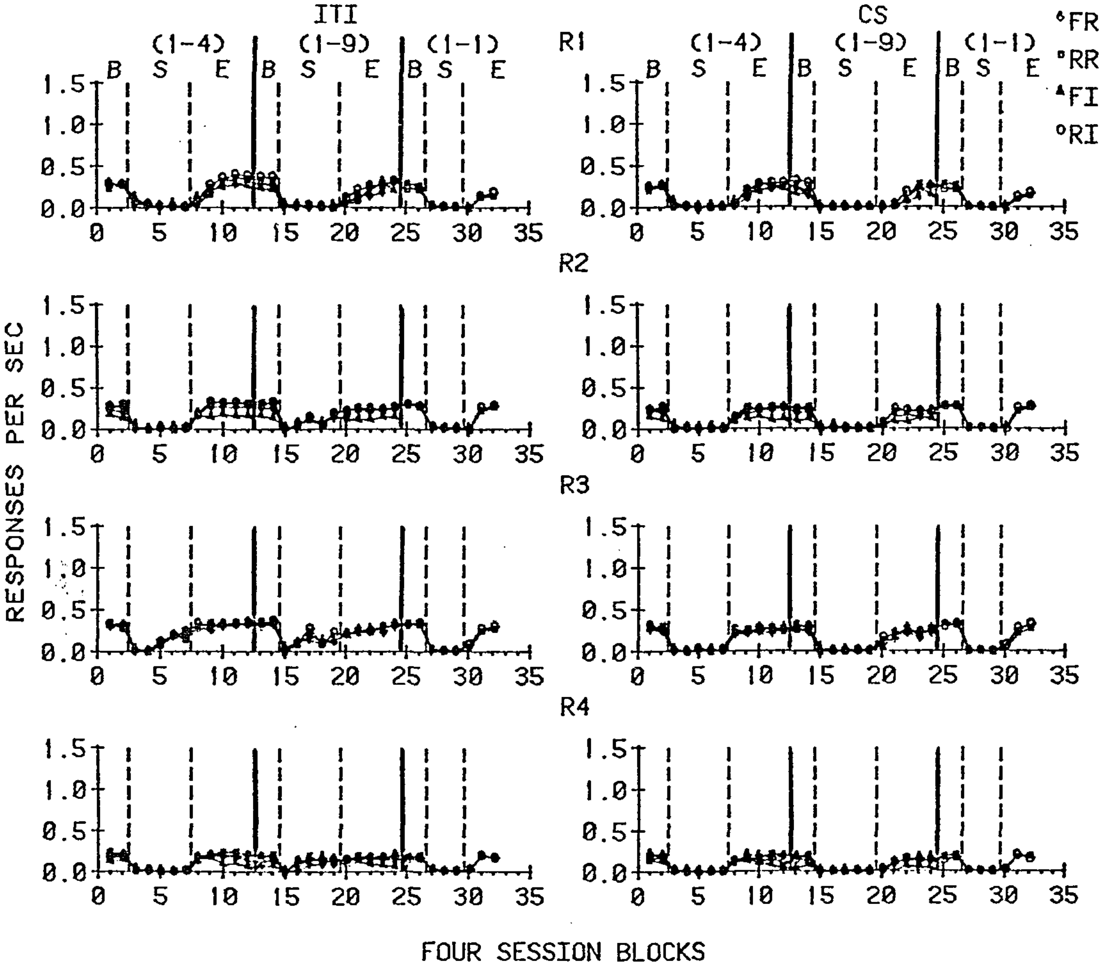

ITI
CS
(1-4)
(1-9)
(1-1)
B
S
E
R1
R2
R3
R4
FR
RR
FI
RI
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
RESPONSES PER SEC
FOUR SESSION BLOCKS

Figure 6. Reinforcer frequency during the CS (right column) and the ITI (left column), on each component of the multiple schedule. Frequency is plotted as as the percentage of the maximum possible during a session. Dashed vertical lines separate the three conditions (Baseline, Shock, and Recovery) of each phase. Phases are separated by solid vertical lines, and are designated according to the relative CS duration in effect. CS and ITI frequencies for a given animal are presented in the same row.

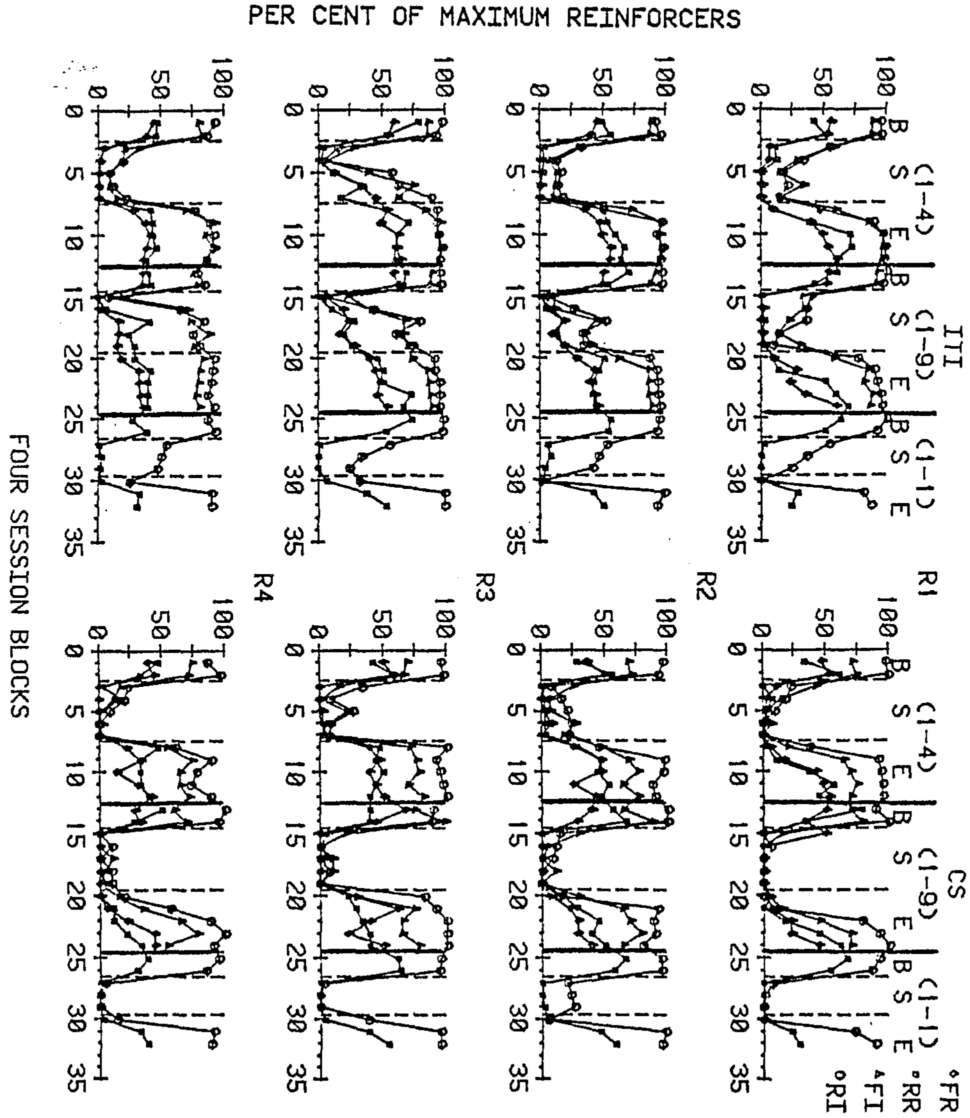

PER CENT OF MAXIMUM REINFORCERS
ITI
CS
(1-4)
(1-9)
(1-1)
B
S
E
R1
R2
R3
R4
FR
RR
FI
RI
0
50
100
0
5
10
15
20
25
30
35
FOUR SESSION BLOCKS

Figure 7. Rate of correct responses (responses meeting the DRL requirement) during the three training phases. Dashed lines separate phase. Phase I: DRL = .5; sec; ISRT = 20 sec. Phase II: DRL = 1 sec; ISRT = 40 sec. Phase III: DRL = 2 sec; ISRT = 40 sec.

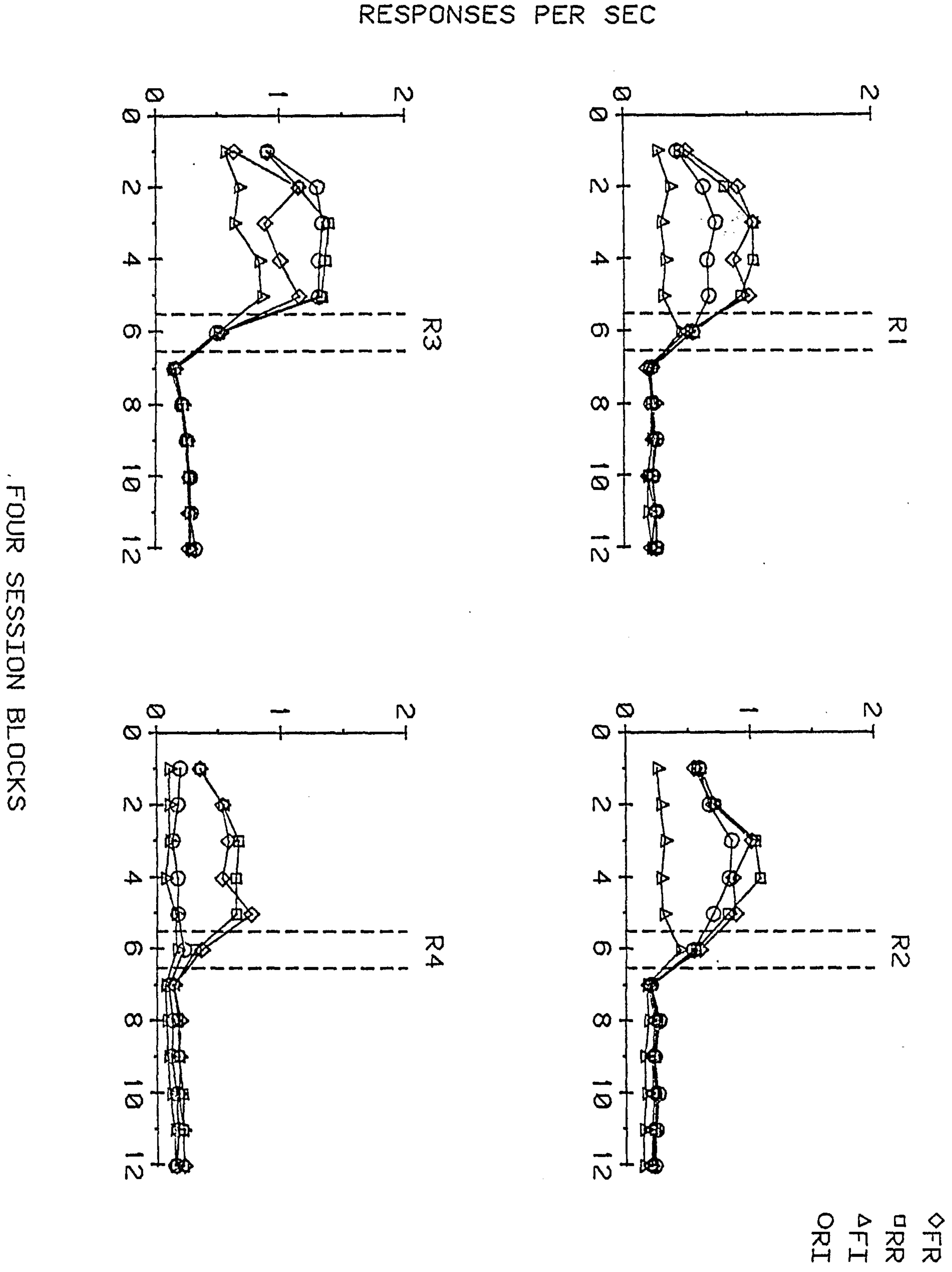

RESPONSES PER SEC
FOUR SESSION BLOCKS
R1
R2
R3
R4
0
1
2
0
2
4
6
8
10
12
◇FR
□RR
△FI
○RI

Figure 8. Mean ITI total response rate during days 1-12 of each phase as a function of shock density.

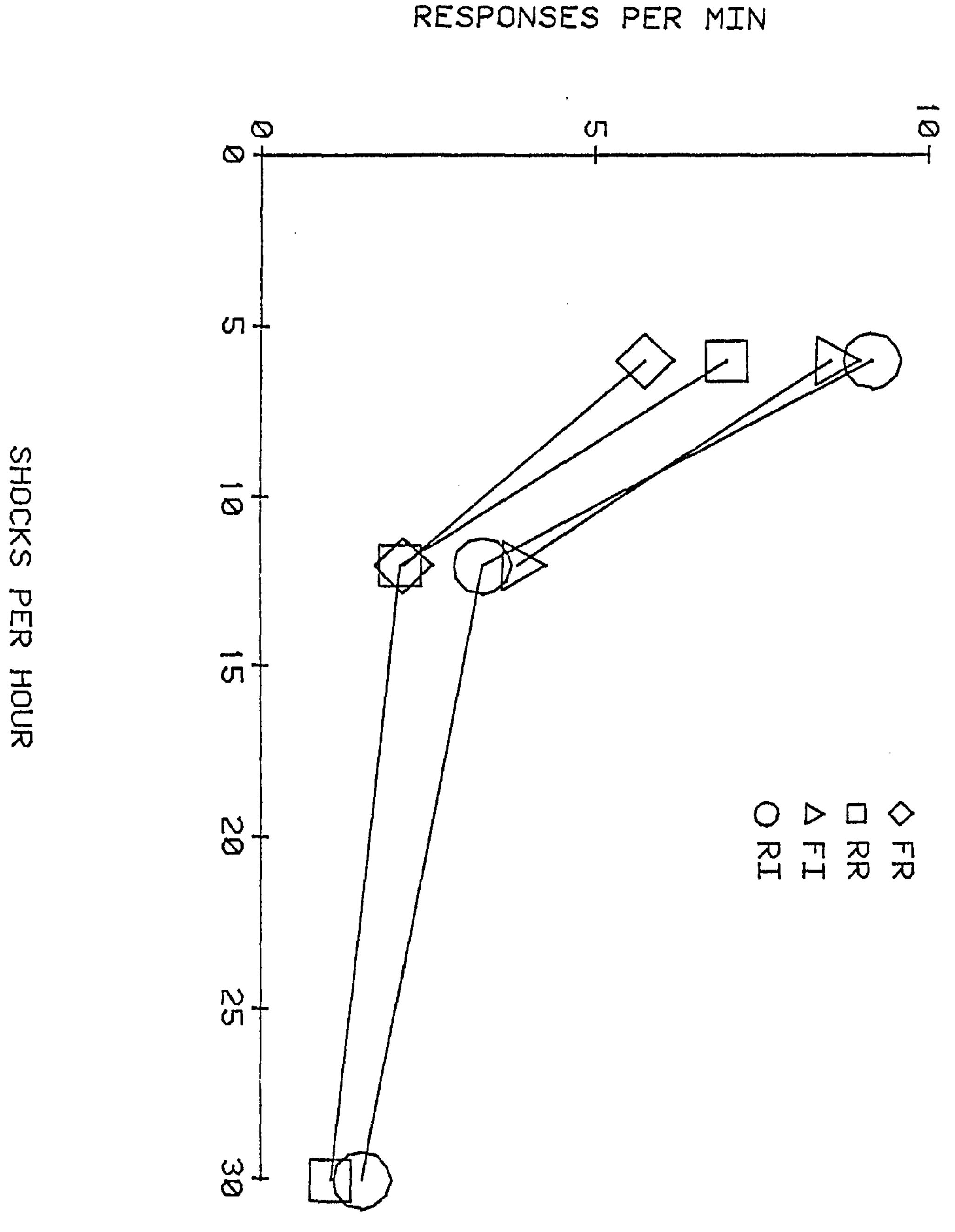

RESPONSES PER MIN
0
5
10
SHOCKS PER HOUR
0
5
10
15
20
25
30
◇ FR
□ RR
△ FI
○ RI

Figure 1. Response rates during the CS and the ITI. The three rats in each group are in the same column. Dashed lines separate phases, which are designated by the number of shocks per hour, or by "E" (Extinction). Arrows along the abcissa indicate the onset of shock conditions.

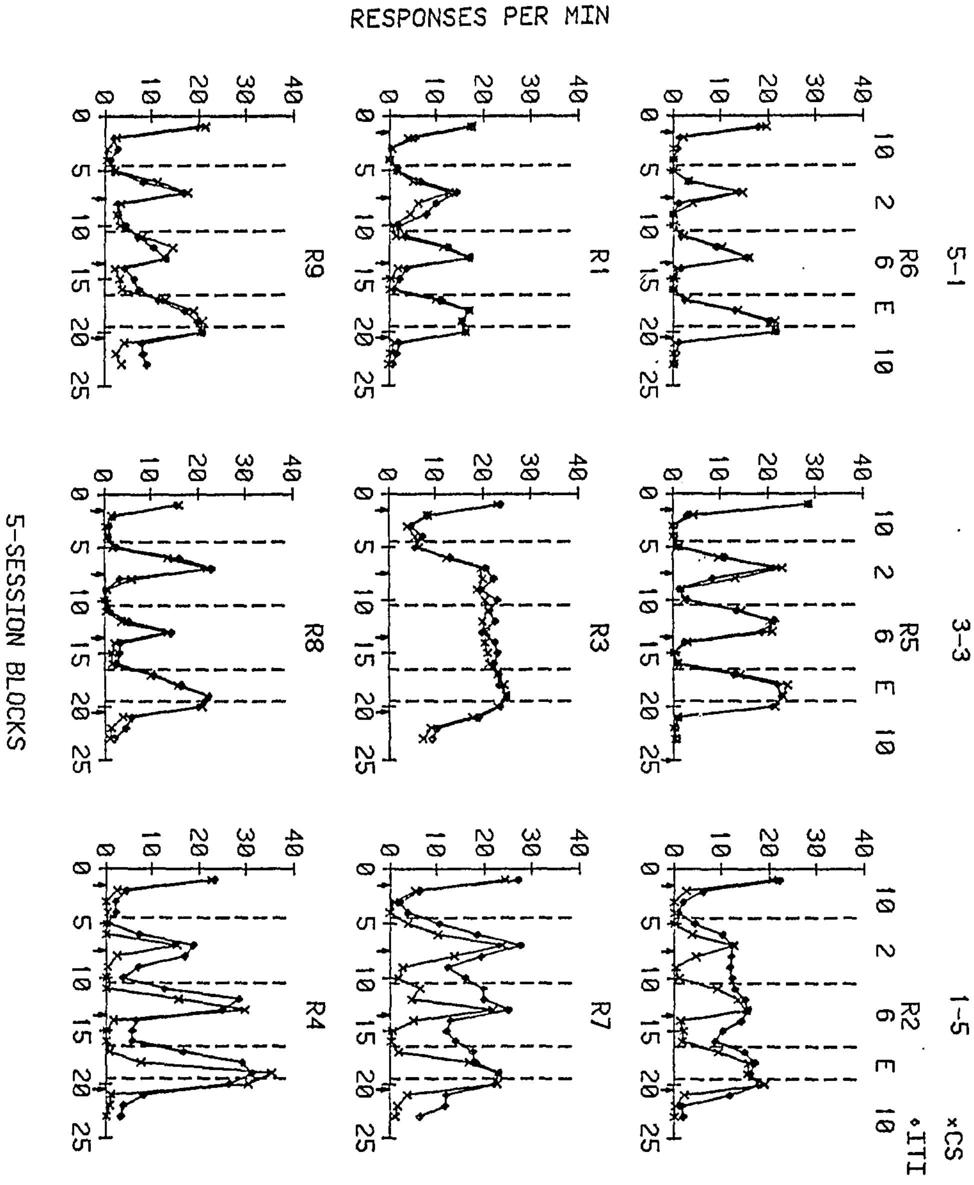

5-1
3-3
1-5
×CS
•ITI
10 2 6 E 10
R6
R5
R2
R1
R3
R7
R9
R8
R4
RESPONSES PER MIN
0
10
20
30
40
5-SESSION BLOCKS
0
5
10
15
20
25

Figure 2. Median response rate during the ITI (top panel) and during the CS (bottom panel) as a function of relative CS duration.

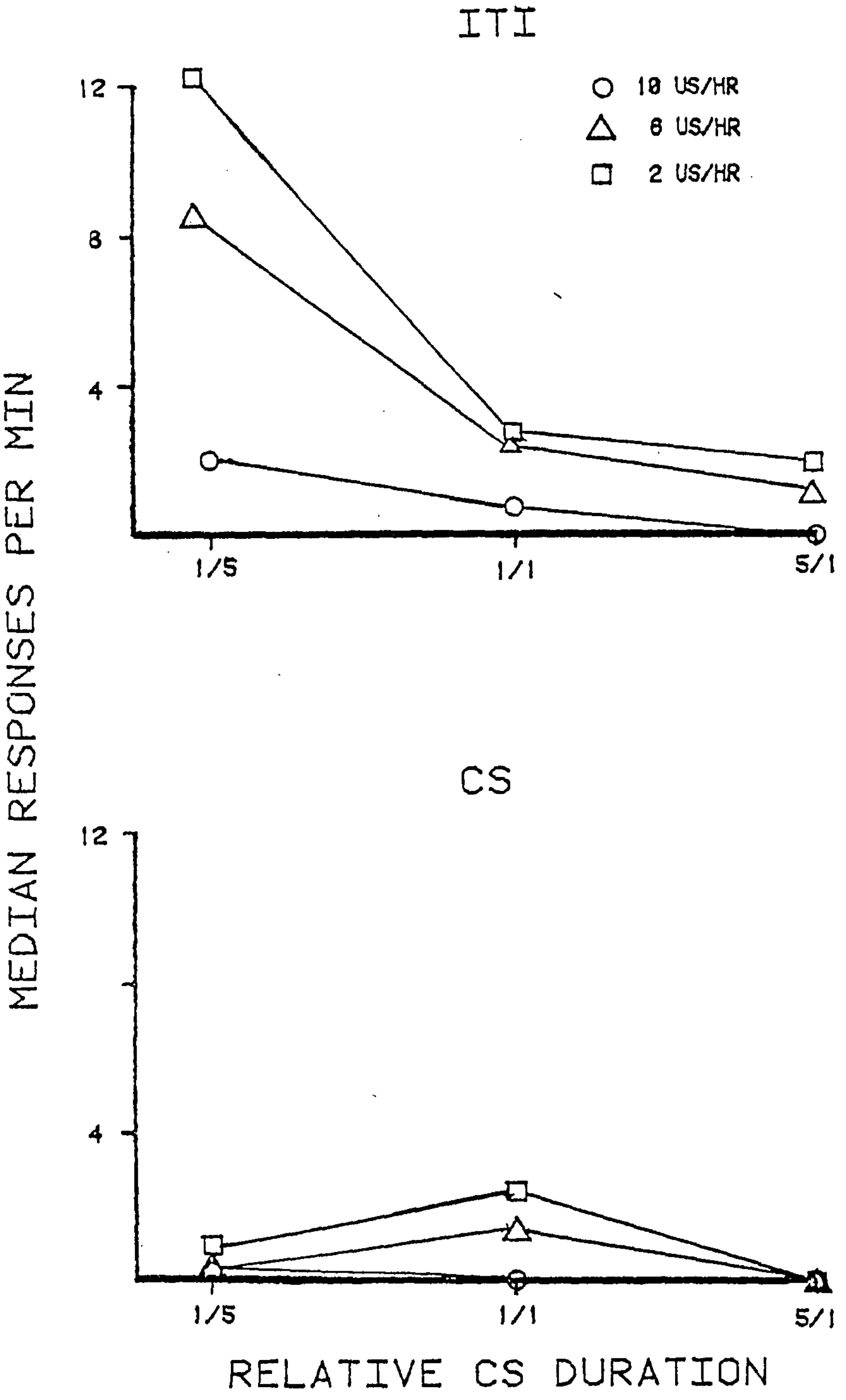

ITI
○ 10 US/HR
△ 6 US/HR
□ 2 US/HR
12
8
4
1/5
1/1
5/1
CS
12
4
1/5
1/1
5/1
MEDIAN RESPONSES PER MIN
RELATIVE CS DURATION

Figure 3. Group mean response rate in each of the six intershock bins. Each row shows rates for one phase. Numbers in parentheses indicate the shock density for that phase. Dashed vertical lines indicate CS onset.

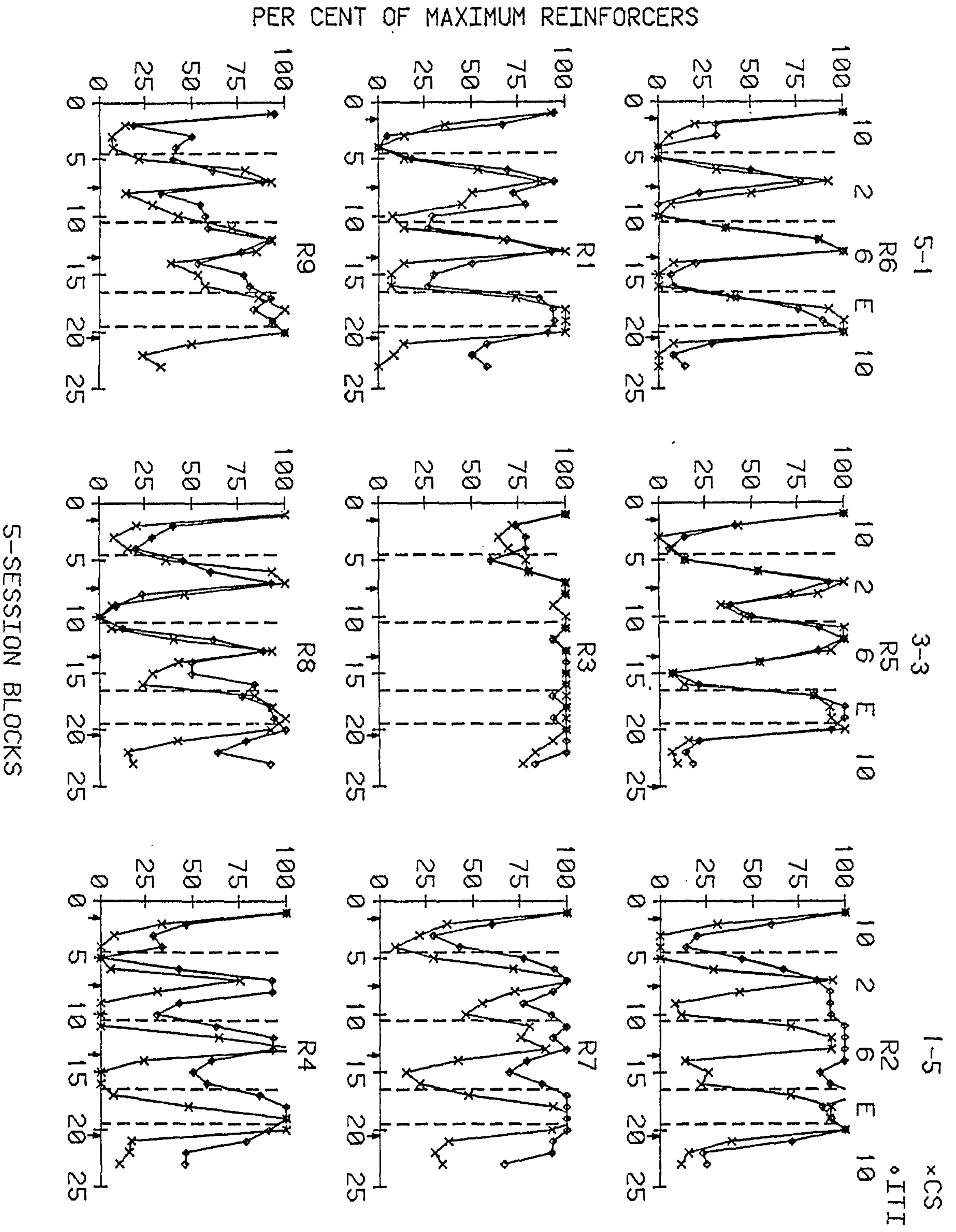

PER CENT OF MAXIMUM REINFORCERS
5-SESSION BLOCKS
5-1
R6
R1
R9
3-3
R5
R3
R8
1-5
R2
R7
R4
10
2
6
E
10
×CS
•ITI
0
25
50
75
100
0
5
10
15
20
25

Figure 4. Per cent of maximum reinforcer frequency during the CS and the ITI. The three rats in each group are in the same column. Dashed vertical lines separate phases, which are designated by the number of shocks per hour, or by "E" (Extinction). Arrows along the abcissa indicate the onset of shock conditions.

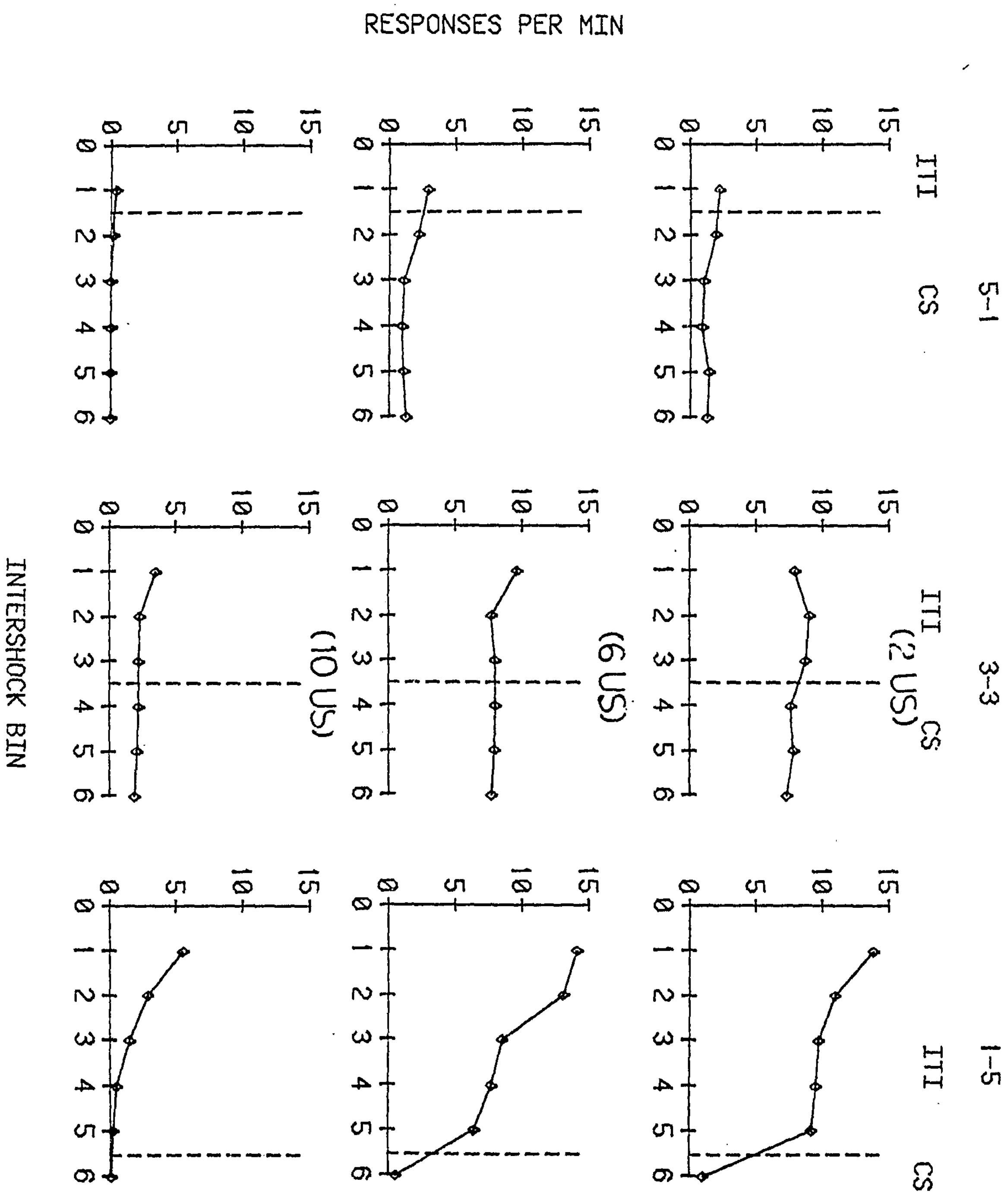

RESPONSES PER MIN
5-1
3-3
1-5
ITI
CS
(2 US)
(6 US)
(10 US)
0
5
10
15
0 1 2 3 4 5 6
INTERSHOCK BIN

Figure 5. Group mean difference scores (see Results) as a function of phi. Numbers in parentheses indicate the relative CS duration corresponding to each phi value.

GROUP MEAN DIFFERENCE SCORES

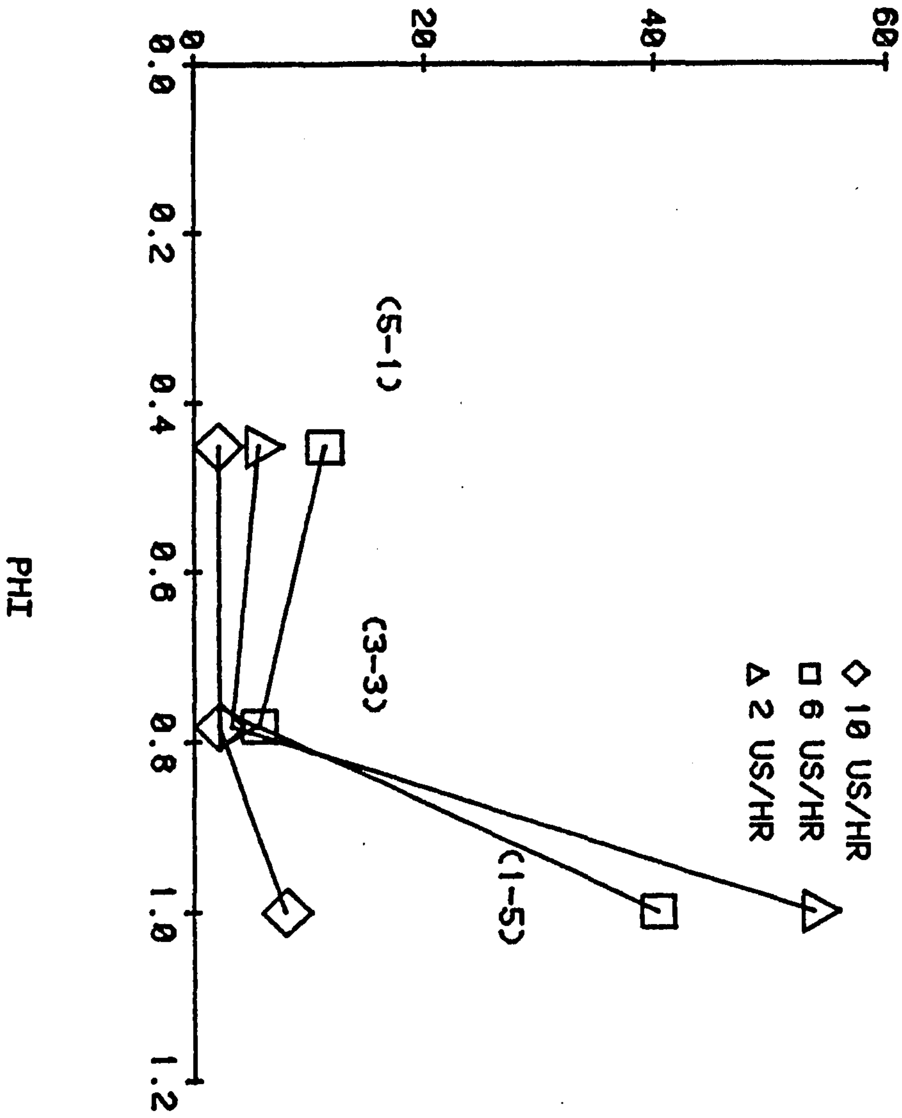


Figure 1. Median ITI response rates from Experiment 1 (open points) and Experiment 2 (filled points), as a function of relative CS duration. Data from Experiment 1 consist of the median (for the four subjects) of the ITI rates averaged across components. Experiment 2 data are the group median at each shock density at each relative CS duration. Numbers in parentheses indicate the shock density at each relative CS duration in Experiment 1.

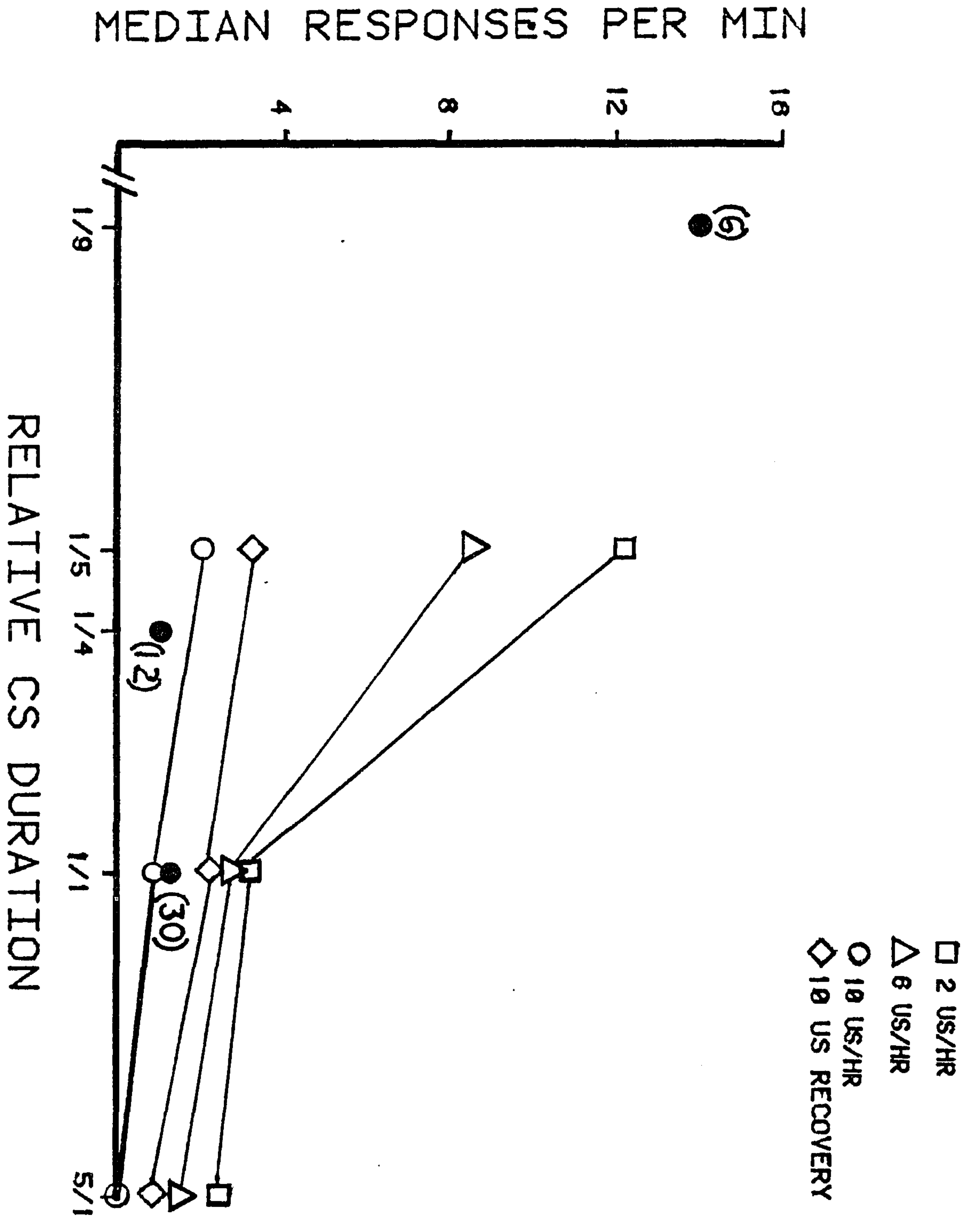
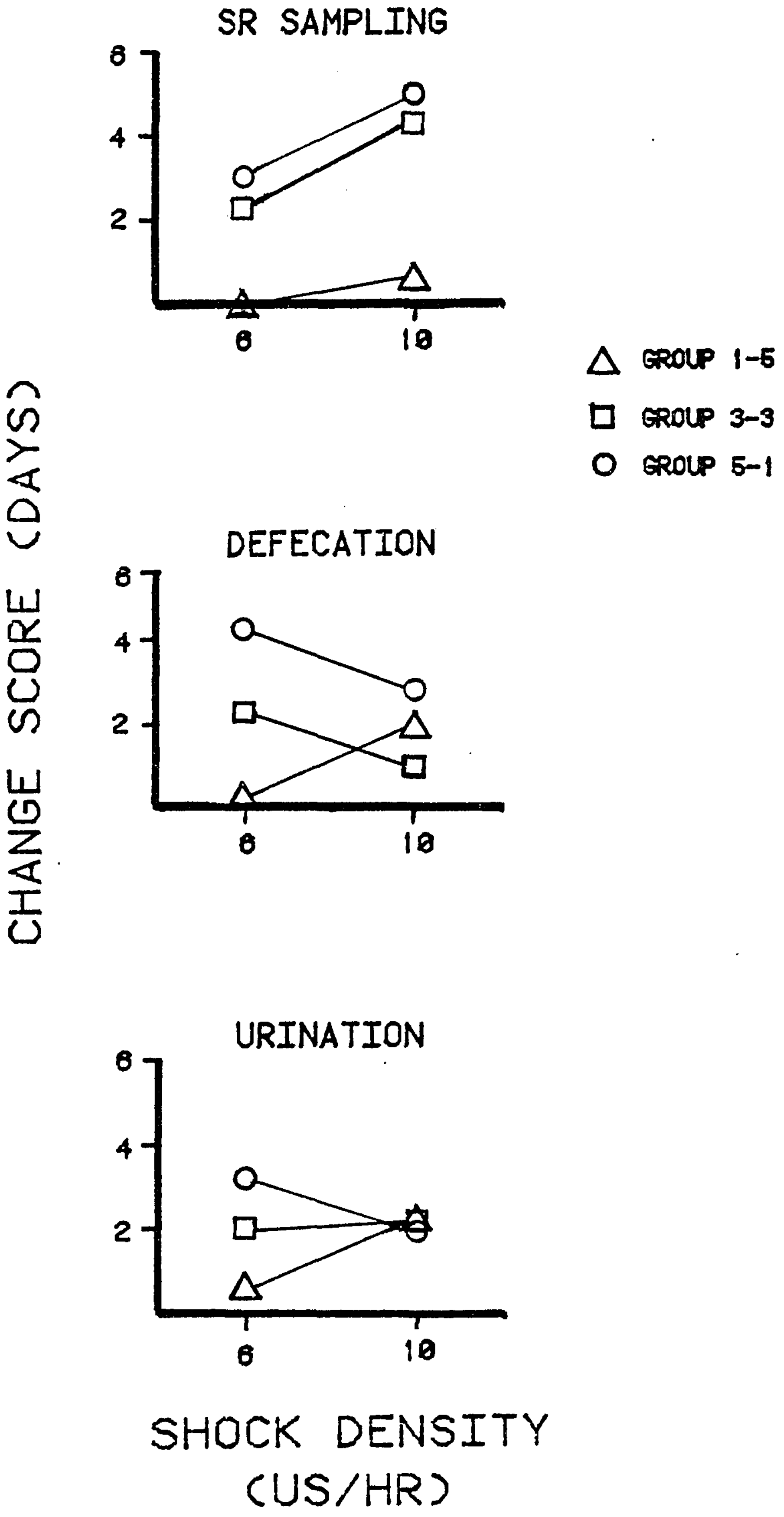

MEDIAN RESPONSES PER MIN
4
8
12
18
RELATIVE CS DURATION
1/9
1/5
1/4
1/1
5/1
(6)
(12)
(30)
□ 2 US/HR
△ 6 US/HR
○ 10 US/HR
◇ 10 US RECOVERY

Figure 2. Reduction in reinforcer sampling, urination, and defecation, from baseline to shock, at 2 and 6 US/hr.


SR SAMPLING
DEFECATION
URINATION
CHANGE SCORE (DAYS)
6
4
2
6
10
△ GROUP 1-5
□ GROUP 3-3
○ GROUP 5-1
SHOCK DENSITY
(US/HR)

<u>Figure 3</u>. R7 (Group 1-5) sniffing the CS lamp during the signal (shock condition, Phase V).

Reference Notes

Brown, B.L., Coleman, D.A.Jr., & Elefant, S. Consumatory response latency and the stimulus-reinforcer relation in autoshaping. Manuscript submitted for publication.

Marlin, N.A. and Oostendorp, K.E. Extinction of a contextual S1 in second-order conditioning. Paper presented at the Annual Meeting of the Eastern Psychological Association, Philadelphia, April, 1983.

Ayres, J.J.B., Vigorito, M., Berger-Gross, P., and Cioffi, C. Post-US suppression is a many splendered thing. Paper presented at the Annual Meeting of the American Psychological Association, Baltimore, April, 1982.

Fantino, E. Concluding remarks on timing. Paper presented at the New York Acadamy of Sciences Convention on Timing and Perception, New York, May, 1983.

References

Anderson, D., Plant, C., & Paden, P. Conditioned suppression of a running response as related to competing responses, drive, and basal skin resistance level. _Journal of Comparative and Physiological Psychology_, 1967, _63_, 282-287.

Annau, Z. & Kamin, L.J. The conditoned emotional response as a function of the intensity of the US. _Journal of Comparative and Physiological Psychology_, 1961, _54_, 428-432.

Azrin, N. and Hake, D.F. Positive conditioned suppression using positive reinforcers as the unconditioned stimulus. _Journal of the Experimental Analysis of Behavior_, 1069, _12_, 167-173.

Blackman, D.E. Effects of response pacing on conditioned suppression. _Quarterly Journal of Experimental Psychology_, 1967, _19_, 170-174.

Blackman, D.E. Conditioned suppression or facilitation as a function of the behavioral baseline. _Journal of the_

Experimental Analysis of Behavior, 1968, 11, 53-61.(a)

Blackman, D.E. Response rate, reinforcement frequency, and conditioned suppression. Journal of the Experimental Analysis of Behavior, 1968, 11, 503-516.(b)

Blackman, D.E. Conditioned suppression and the effects of classical conditioning on operant behavior. In W.K. Honig and J.E.R. Staddon (Eds.), Handbook of Operant Behavior. Englewood Cliffs, N.J.: Prentice-Hall, 1977.

Bloomfield, T.M. Behavioral contrast and relative reinforcement frequency in multiple schedules. Journal of the Experimental Analysis of Behavior, 1967, 10, 151-158.

Bolles, R.C. and Riley, A.L. Freezing as an avoidance response: Another look at the operant-respondent distinction. Learning and Motivation, 1973, 4, 268-275.

Brady, J.V. The effect of electroconvulsive shock on a conditioned emotional response: The permanence of the effect. Journal of Comparative and Physiological Psychology, 1951, 44, 507-511.

Brady, J.V., Kelly, D., & Plumlee, L. Autonomic and behavioral responses of the rhesus monkey to emotional conditioning. Annals of the New York Acadamy of Sciences, 1959, 159, 959-975.

Brimmer, C.J. and Kamin, L.J. Disinhibition, habituation, sensitization, and the conditioned emotional response. Journal of Comparative and Physiological Psychology, 1963, 56, 508-516.

Brown, B.L., Hemmes, N.S., Coleman, D.A.Jr., Hassin, A., and Goldhammer, E. Specification of the stimulus-reinforcer relation in multiple schedules: Delay and probability of reinforcement. Animal Learning and Behavior, 1982, 10, 365-376.

Burkhardt, P.E. and Ayres, J.J.B. CS and US duration effects in one-trial conditioning as assessed by conditioned suppression of licking in rats. Animal Learning and Behavior, 1978, 6, 225-230.

Cameron, O.G. and Appel, J.B. Conditioned suppression of bar-pressing behavior by stimuli associated with drugs.

Journal of the Experimental Analysis of Behavior, 1972, *17*, 127-137.

Carlton, P.L. and Didamo, P. Some notes on conditioned suppression. *Journal of the Experimental Analysis of Behavior*, 1960, *3*, 255-258.

Catania, A.C. and Reynolds, G.S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, *11*, 327-383.

Church, R.M. Response suppression. In B.A. Campbell and R.M. Church (Eds.), *Punishment and Aversive Behavior*. New York: Appleton-Century-Crofts, 1969.

Davis, H. Conditioned suppression: A survey of the literature. *Psychonomic Monograph Supplements*, 1968, *2*, 283-291.

Davis, H.D. and McIntire, R.W. Conditioned suppression under positive, negative, and no contingency between conditioned and unconditioned stimuli. *Journal of the Experimental Analysis of Behavior*, 1969, *12*, 633-640.

Davis, H. and Memmott, J. Autocontingencies: Rats count to three to predict safety from shock. *Animal Learning and Behavior*, 1983, *11*, 95-100.

Davis, H. Shattuck, D., and Wright, J. Autocontingencies: Factors underlying control of operant baselines by compound tone/shock/no-shock contingencies. *Animal Learning and Behavior*, 1981, *9*, 322-331.

DeCosta, M.J. And Ayres, J.J.B. Suppression of operant vs consummatory behavior. *Journal of the Experimental Analysis of Behavior*, 1971, *16*, 133-142.

deToledo, L.E. and Black, A.H. Heart rate: Changes during conditioned suppression in rats. *Science*, 1966, *152*, 1401-1406.

Estes, W.K. and Skinner, B.F. Some quantitative properties of anxiety. *Journal of Experimental Psychology*, 1941, *29*, 390-400.

Estes, W.K. Outline of a theory of punishment. In B.A. Campbell and R.M. Church (Eds.), *Punishment and Aversive*

Behavior. New York: Appleton-Century-Crofts, 1969.

Faneslow, M.S. The postshock activity burst. *Animal Learning and Behavior*, 1982, *10*, 448-454.

Fantino, E. Emotion. In J.A. Nevin (Ed.), *The Study of Behavior: Learning, Motivation, Emotion, and Instinct*. Glenview, Ill.: Scott, Forseman, 1973.

Fantino, E. Conditioned reinforcement: Choice and information. In W.K. Honig and J.E.R. Staddon (Eds.), *Handbook of Operant Behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.

Farmer, J. Properties of behavior under random interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1963, *6*, 607-616.

Finocchio, D. Changes in temporally spaced responses as a measure of conditioned emotional behavior. Cited in Blackman, D.E. Conditioned suppression or facilitation as a function of the behavioral baseline. *Journal of the Experimental Analysis of Behavior*, 1968, *11*, 53-61.

Freud, S. *The Problem of Anxiety*. New York: Norton, 1936.

Geller, I. The aquisition and extinction of conditioned suppression as a function of the baseline reinforcer. *Journal of the Experimental Analysis of Behavior*, 1960, *3*, 235-240.

Geller, I., Sidman, M., and Brady, J.V. The effect of electroconvulsive shock on a conditoned emotional response: A control for aquisition recency. *Journal of Comparative and Physiological Psychology*, 1955, *48*, 130-131.

Gibbon, J. Scalar expectancy theory and Weber's law in animal timing. *Psychological Review*, 1977, *84*, 279-325.

Gibbon, J. and Balsam, P. Spreading association in time. In C.M. Locurto, H.S. Terrace, and J. Gibbon (Eds.), *Autoshaping and Contingency Theory*. New York: Academic, 1981.

Gibbon, J., Berryman, R., and Thompson, R.L. Contingency spaces and measures in classical and instrumental conditioning. *Journal of the Experimental Analysis of*

Behavior, 1974, 21, 585-605.

Gibbon, J. Farrell, L., Locurto, C.M., Duncan, H.J. and Terrace, H.S. Partial reinforcement in autoshaping with pigeons. Animal Learning and Behavior, 1980, 8, 45-59.

Gleitman, H. and Holmes, P.A. Retention of incompletely learned CER in rats. Psychonomic Science, 1967, 7, 19-20.

Goldberg, S.R. and Schuster, C.R. Conditioned suppression by a stimulus assoicated with nalorphine in morphine-dependent monkeys. Journal of the Experimental Analysis of Behavior, 1967, 10, 235-242.

Hake, D.F. and Powell, J. Positive reinforcement and suppression from the same occurrence of the unconditioned stimulus in a positive suppression procedure. Journal of the Experimental Analysis of Behavior, 1970, 14, 247-257.

Hall, R.D., Clayton, R.J., and Mark, R.G. A device for the partial restraint of rats in operant conditioning studies. Journal of the Experimental Analysis of

Behavior, 1966, *9*, 143-145.

Hearst, E. Stress-induced breakdown of an appetitive discrimination. *Journal of the Experimental Analysis of Behavior*, 1965, *8*, 135-146.

Hemmes, N.S. and Rubinsky, H.J. Conditional acceleration and external disinhibition of operant lever pressing by prereward, neutral, and reinforcing stimuli. *Journal of the Experimental Analysis of Behavior*, 1982, *38*, 157-168.

Henderson, R.W. Compounds of conditioned fear stimuli. *Learning and Motivation*, 1975, *6*, 28-42.

Henton, W.W. Conditioned suppression to odorous stimuli in pigeons. *Journal of the Experimental Analysis of Behavior*, 1969, *12*, 175-185.

Henton, W.W. and Brady, J.V. Operant acceleration during a pre-reward stimulus. *Journal of the Experimental Analysis of Behavior*, 1970, *13*, 205-209.

Herrnstein, R.J. Secondary reinforcement and rate of primary reinforcement. Journal of the Experimental Analysis of Behavior, 1964, 7, 27-36.

Hoffman, H.S. and Barrett, J. Overt activity during conditioned suppression: A searc for punishment artifacts. Journal of the Experimental Analysis of Behavior, 1971, 16, 343-348.

Hoffman, H.S. and Fleshler, M. Stimulus aspects of aversive controls: The effects of response-contingent shock. Journal of the Experimental Analysis of Behavior, 1965, 8, 89-96.

Hunt, H.F. and Brady, J.V. Some effects of electroconvulsive shock on a conditioned emotional response. Journal of Comparative and Physiological Psychology, 1951, 44, 88-98.

Hunt, H.F. and Brady, J.V. Some effects of punishment and inter-current "anxiety" on a simple operant. Journal of Comparative and Physiological Psychology, 1955, 48, 305-310.

Hymowitz, N. Effects of signalled and unsignalled shock on schedule-controlled leverpressing and schedule-induced licking: Shock intensity and body weight. *Journal of the Experimental Analysis of Behavior*, 1981, *35*, 197-207.(a)

Hymowitz, N. Effects of diazepam on schedule-controlled and schedule-induced behavior under signalled and unsignalled shock. *Journal of the Experimental Analysis of Behavior*, 1981, *36*, 119-132.(b)

Jenkins, H.S., Barnes, R.A., and Barrera, F.J. Why autoshaping depends on trial spacing. In C.M. Locurto, H.S. Terrace, and J. Gibbon (Eds.), *Autoshaping and Contingency Theory*. New York: Academic, 1981. Jenkins, H.M. and Shattuck, D. Contingency in fear conditioning: A reexamination. *Bulletin of the Psychonomic Society*, 1981, *17*, 159-162. Jones, J.E. Contiguity and reinforcement in relation to CS-US intervals in classical average conditioning. *Psychological Review*, 1962, *69*, 176-186.

Kamin, L.J. Trace conditioning of the conditioned emotional response. *Journal of Comparative and Physiological* Psycholo

__________, 1961, 54, 149-153.

Kamin, L.J. Temporal and intensity characteristics of the conditioned stimulus. In W.F. Prokasy (Ed.), Classical Conditioning. Englewood Cliffs, N.J.: Prentice-Hall, 1965.

Kamin, L.J. and Brimmer, C.J. The effects of intensity of conditioned and unconditioned stimuli on a conditioned emotional response. Canadian Journal of Psychology, 1963, 17, 194-200.

Kamin, L.J. and Schaub, R.E. The effects of conditioned stimulus intensity on the conditioned emotional response. Journal of Comparative and Physiological Psychology, 1963, 56, 502-507.

Karpicke, J., Christoph, G., Peterson, G., and Hearst, E. Signal location and positive vs negative conditioned suppression in the rat. Journal of Experimental Psychology: Animal Behavior Processes, 1977, 3, 105-118.

Kelly, D.D. Suppression of rando-ratio and acceleration of temporally spaced responding by the same pre-reward stimulus in monkeys. Journal of the Experimental Analysis of Behavior, 1973, 20, 363-373.

Kelly, D.D. Enhancement of conditioned autonomic responses in monkeys when preshock signals occasion operant suppression. Journal of the Experimental Analysis of Behavior, 1980, 33, 275-284.

Leitenberg, H. Conditioned acceleration and conditioned suppression in pigeons. Journal of the Experimental Analysis of Behavior, 1966, 9, 205-212.

Libby, A. Two variables in the aquisition of depressant properties of a stimulus. Journal of Experimental Psychology, 1951, 42, 100-107.

Lolordo, V.M., McMillan, J.C., and Riley, A.L. The effects upon food-reinforced pecking and treadle-pressing of auditory and visual signals for response-independent food. Learning and Motivation, 1974, 5, 24-41.

Lucas, G.A. and Wasserman, E.A. US duration and local trial spacing affect autoshaped responding. Animal Learning and Behavior, 1982, 10, 490-498.

Lyon, D.O. Frequency of reinforcement as a parameter of conditoned suppression. Journal of the Experimental Analysis of Behavior, 1963, 6, 95-98.

Lyon, D.O. Conditioned suppression: Operant variables and aversive control. Psychological Recor, 1068, 18, 317-338.

Lyon, D.O. and Felton, M. Conditioned suppression and variable ratio reinforcement. Journal of the Experimental Analysis of Behavior, 1966, 9, 245-250.(a)

Lyon, D.O. and Felton, M. Conditioned suppression and fixed ratio schedules of reinforcement. Psychological Record, 1966, 16, 433-440.(b)

Lyon, D,O. and Millar, R.D. Conditioned suppression on a fixed interval schedule of reinforcement. Psychonomic Science, 1969, 17, 31-32.

Meltzer, D. and Brahlek, J.A. Conditioned suppression and conditioned enhancement with the same positive UCS: An effect of CS duration. Journal of the Experimental

Analysis of Behavior, 1970, *13*, 67-73.

Miczek, K.A. and Grossman, S.P. Positive conditioned suppression: Effects of CS duration. *Journal of the Experimental Analysis of Behavior*, 1971, *15*, 243-247.

Millenson, J.R. and Hendry, D.P. Quantification of response suppression in conditioned anxiety training. *Canadian Journal of Psychology*, 1967, *21*, 242-252.

Millenson, R. and deVilliers, P.A. Motivational properties of conditioned anxiety. In R.M. Gilbert and J.R. Millenson (Eds.), *Reinforcement*: *Behavior Analysis*. New York: Academi, 1972.

Morris, D.D. Threshold for conditioned suppression using x-rays as the pre-aversive stimulus. *Journal of the Experimental Analysis of Behavior*, 1966, *9*, 29-34.

Mowrer, O.H. A stimulus-reponse analysis of anxiety and its role as a reinforcing agent. *Psychological Review*, 1939, *46*, 553-565.

Mowrer, O.H. *Learning Theory and Behavior*. New York:

Wiley, 1960.

Nathan, M.A. and Smith, O.A.Jr. Differential conditional emotional and cardiovascular responses -- a training technique for monkeys. Journal of the Experimental Analysis of Behavior, 1968, 11, 77-82.

Orme-Johnson, D.W. and Yarczower, M. Conditioned suppression, punishment, and aversion. Journal of the Experimental Analysis of Behavior, 1974, 21, 57-74.

Parrish, J. Classical discrimination conditioning of heart rate and bar press suppression in the rat. Psychonomic Science, 1967, 9, 267-268.

Perkins, C.C.Jr., Levis, D.F., and Seymann, R. Preference for signal-shock vs shock-signal. Psychological Reports, 1963, 13, 375-378.

Randich, A. The preexposure phenomenon in the conditioned suppression parauigm: A role for conditioned situational stimuli. Learning and Motivation, 1981, 12, 321-341.

Reberg, D. and Memmott, J. Shock as a signal for shock or no-shock: A feature-negative effect in conditioned suppression. Journal of the Experimental Analysis of Behavior, 1979, 32, 387-397.

Reiter, L.A. and DeVellis, D.M. Conditioned suppression in humans produced by a human stimulus. Journal of Personality and Social Psychology, 1976, 34, 223-227.

Rescorla, R.A. Probability of shock in the presence and absence of CS in fear conditioning. Journal of Comparative and Physiological Psychology, 1968, 66, 1-5.

Rescorla, R.A. and Solomon, R.L. Two-process learning theory: Relationships between Pavlovian conditioning and instrumental learning. Psychological Review, 1967, 74, 151-182.

Reiss, D. and Farrar, C.H. UCS duration and conditioned suppression: Aquisition and extinction between groups and terminal performance within-subjects. Learning and Motivation, 1973, 4, 366-373.

Russell, P.J.D. Conditioned suppression of behavior maintained by intracranial stimulation as a function of stimulation intensity. Journal of the Experimental Analysis of Behavior, 1975, 23, 277-283.

Sachs, D.A. and May, J.G.Jr. the presence of a temporal discrimination in the conditioned emotional response with humans. Journal of the Experimental Analysis of Behavior, 1969, 12, 1003-1007.

Schwartz, B. Positive and negative conditioned suppression in the pigeon: Effects of the locus and modality of the CS. Learning and Motivation, 1976, 7, 86-100.

Schwartz, B. and Gamzu, E. Pavlovian control of operant behavior: An analysis of autoshaping and its implications for operant conditioning. In W.K. Honig and J.E.R. Staddon (Eds.), Handbook of Operant Behavior. Englewood cliffs, N.J.: Prentice-Hall, 1977.

Seligman, M.E.P. Chronic fear produced by unpredictable electric shock. Journal of Comparative and Physiological Psychology, 1968, 66, 402-411.

Seligman, M.E.P. and Binik, I. The safety signal hypothesis. In H. Davis and H.M.B. Hurwitz (Eds.), *Pavlovian-Operant Interactions*. Hillside, N.J.: Erlbaum, 1977.

Smith, J.B. Effects of response rate, reinforcement frequency, and the duration of a stimulus preceding response-independent food. *Journal of the Experimental Analysis of Behavior*, 1974, *21*, 215-221.

Stebbins, W. and Smith, O. Cardiovascular concomitants of the conditioned emotional response in the monkey. *Science*, 1964, *144*, 881-885.

Stein, L., Sidman, M., and Brady, J.V. some effects of two temporal variables on conditioned suppression. *Journal of the Experimental Analysis of Behavior*, 1958, *1*, 154-162.

Stein, N., Hoffman, H.S., and Stitt, L. Collateral behavior of the pigeon during conditioned suppression of keypecking. *Journal of the Experimental Analysis of Behavior*, 1971, *15*, 83-93.

Stubbs, D.A., Hughes, J.E., and Cohen, S.L. Positive conditioned suppression: An explanation in terms of multiple and concurrent schedules. *Journal of the Experimental Analysis of Behavior*, 1978, *30*, 329-343.

Tomie, A. Effect of unpredictable food on the subsequent aquisition of autoshaping: Analysis of the context-blocking hypothesis. In C.M. Locurto, H.S. Terrace, and J. Gibbon (Eds.), *Autoshaping and Contingency Theory*. New York: Academic, 1981.

Valentine, J.O. and Barrett, J.E. Effects of chlordiaepoxide and *d*-amphetamine on responding suppressed by conditioned punishment. *Journal of the Experimental Analysis of Behavior*, 1981, *35*, 209-216.

Waller, M.B. and Waller, P.F. The effects of unavoidable shocks on a multiple schedule having an avoidance component. *Journal of the Experimental Analysis of Behavior*, 1963, *6*, 29-37.

Warner, L.H. The association span of the white rat. *Journal of Genetic Psychology*, 1932, *41*, 57-90.

Welker, R.L. and Wheatley, K.L. Differential aquisition of conditioned suppression in rats with increased and decreased luninence levels as CS+s. *Learning and Motivation*, 1977, *8*, 247-262.

Weiskrantz, L. Emotion. In L. Weiskrantz (Ed.), *Analysis of Behavioral Change*. New York: Harper and Row, 1968.

Willis, R.D. and Lundin, R.W. Conditioned suppression in the rat as a function of shock reinforcement schedule. *Psychonomic Science*, 1966, *6*, 107-108.

Zeiler, M.D. Schedules of reinforcement: The controlling variables. In W.K. Honig and J.E.R. Staddon (Eds.), *Handbook of Operant Behavior*. Englewood Cliffs, N.J.: Prentice-Hall, 1977.

Zeiler, M.D. and Buchman, I.B. Response requirements as constraints on output. *Journal of the Experimental Analysis of Behavior*, 1979, *32*, 29-49.