EFFECTS OF PARTIAL VERSUS CONTINUOUS REINFORCEMENT ON CLASSICALLY CONDITIONED HEART RATE IN THE RAT WITH NUMBER OF UNCONDITIONED STIMULI EQUATED

by

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R. M. V.

This paper is dedicated to my wife, Rochelle.

R. M. V.

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INTRODUCTION

A certain number of reinforced training trials are required to develop a stable conditioned response (CR) in acquisition. The customary definition of a reinforced trial specifies the pairing of a conditioned stimulus (CS) with an unconditioned stimulus (US). In most cases the concept of "paired stimuli" is poorly defined. However, the CS and US are usually regarded as being paired when the time-period between CS onset and US onset (CS-US interval) is such that conditioning occurs. For nonreinforced trials, the CS and US are not paired. A partial, or intermittent, reinforcement schedule is defined operationally as the presentation of both reinforced and nonreinforced trials in acquisition. Partial reinforcement schedules are conventionally identified by their relative frequency of reinforced trials, e.g., "50% partial reinforcement" refers to a training schedule where half of the trials are reinforced. The relative frequency of reinforcement in a partial schedule may vary between but not include 0% (extinction) and 100% or "continuous" reinforcement.

Another parameter that may be varied in a partial reinforcement schedule is the pattern of reinforcements. A random partial reinforcement schedule is one where reinforced and nonreinforced trials are arranged in a chance sequence. For alternating partial reinforcement, the two types of trials occur in a regular alternating sequence such that a given number of reinforced trials is followed by an equal number of nonreinforced trials, with this pattern repeating throughout the schedule

A variety of methods for providing nonreinforced trials in a partial reinforcement schedule have been used. The simplest and most frequent procedure is to omit the US (CS-alone trials). This means that, for an equal number of trials, a partial reinforcement schedule contains fewer USs than does a continuous schedule. Such a procedure is often termed a matched trials technique. To control for between-schedule differences in number of USs, a matched reinforcements technique is sometimes employed. This method involves giving the same number reinforced trials in both schedules (often with the same US-US intervals) but more CS-alone trials in the partial schedule.

Another method of providing nonreinforcement is the "interpolated-US" procedure. In a partial reinforcement schedule, nonreinforced trials of this type consist of a presentation of the CS alone and then the US alone at the midpoint of the intertrial (CS-CS) interval. Interpolated-US trials equate the number of USs for partial and continuous reinforcement schedules but not the number of reinforced trials.

The "delayed-US" or "extended-interval" method provides nonreinforced trials by specifying a CS-US interval longer than that for reinforced trials. The particular CS-US interval used is determined empirically, and ideally is the minimum interval which produces no conditioning. When considered in terms of operational definitions, the extended-interval technique may be regarded as a special case of the interpolated-US technique and omitting the US as the limiting case (infinitely long CS-US interval).

Early evidence of the effects of partial reinforcement in classical conditioning was obtained in a human eyelid conditioning study by Humphreys (1939). He found that the levels of performance in acquisition were not different for continuous and partial reinforcement groups. However, it was reported that the partial reinforcement group was superior in performance to the continuous group during extinction. These results were interpreted as a serious challenge to the then widely accepted view that level of performance in acquisition and resistance to extinction were roughly comparable indices of the amount of conditioning which was built up on reinforced training trials.

Since that time it has been established that partial reinforcement produces reliable effects on the performance of human Ss in certain eyelid conditioning situations. The effects in these situations are a lower level of performance in acquisition and greater resistance to extinction for partial as compared to continuous reinforcement. However, the phrase "partial reinforcement effect" (PRE) by convention designates only the extinction result. This is due to the fact that increased resistance to extinction following partial reinforcement has been regarded as a general phenomenon which was trans-situational in nature. In contrast, the acquisition phenomena were thought to be less general, and they have not been included under the term "PRE". For purposes of the present discussion, however, "PRE" will refer to both the acquisition and the extinction result unless it is specifically stated otherwise.

Grant and Schipper (1952) obtained a set of results that has come to be accepted as the standard PRE in acquisition and extinction for human eyelid conditioning. Performance was studied under conditions of 0, 25, 50, 75, and 100 percent reinforcement. It was found that the frequency of CRs in acquisition was directly related to the percentage of reinforcement. During extinction, the 50% and 75% groups performed at higher levels than the continuous reinforcement group. In a similar experiment (Grant, Schipper, & Ross, 1952) where percentage of reinforcement and intertrial interval were varied, partial reinforcement produced inferior acquisition performance and greater resistance to extinction relative to 100% reinforcement.

The standard PRE for human Ss was also obtained by Reynolds (1958) in an investigation where, for half of the Ss, nonreinforcement was defined as a trial with a 2400-msec. CS-US interval (delayed-US method). Under all conditions, 100% reinforcement resulted in higher performance levels than partial reinforcement during acquisition. In extinction, the performance of the 50% groups was superior to that of the continuously reinforced groups.

Recent evidence and a theoretical formulation provided by Spence and his associates (Spence, 1966) suggest that the extinction PRE for human eyelid conditioning may be influenced to a great extent by verbally-mediated "set" factors and that it may be abolished by certain experimental procedures which tend to prevent the formation of such sets. This evidence will be considered with Spence's model in a subsequent section which deals more directly with theoretical aspects of the PRE.

In the case of classical conditioning with infra-humans, which is the main topic of this paper, partial reinforcement has produced variable results. Gonzales, Longo, and Bitterman (1961) made objective measures of the conditioned agitation response in goldfish with three conditions of reinforcement. During acquisition, a reinforced trial consisted of a paired presentation of CS and US using a 4.5-sec. CS-US interval. A nonreinforced trial for one group involved the omission of the US while, for another group, the US was presented 30 sec. after CS onset. A 100% reinforcement group performed slightly better than the 50% groups throughout acquisition, although this difference was not statistically significant. Similarly, there were no reliable differences in extinction. The two nonreinforcement procedures had no differential effects during acquisition or extinction. A second experiment that was discussed in the same report involved a 2 X 2 factorial design in which two percentages of reinforcement and two amounts of training were compared. The various treatments produced no differences in performance among the groups during acquisition and extinction or in a series of retrainings followed by extinction.

A conditioned agitation response in pigeons was studied by Longo, Milstein, and Bitterman (1962). Here all Ss were trained to asymptotic levels of performance with continuous reinforcement, after which half of the Ss were given 50% partial reinforcement. Comparison groups for matched trials and matched reinforcements were included in the design. Following the shift to partial reinforcement, performance levels rose above those of a group that was not shifted. During the 180 trials of extinction, the 50% group performed at a slightly higher level than the 100% group and this difference was significant. In a second experiment, training conditions were similar, except that the groups were given either 50% or 100% reinforcement from the start of acquisition. This resulted in superior performance for the 100% reinforcement group in acquisition and extinction.

Another study of partial reinforcement in the classical conditioning of fish (mouthbreeders) was conducted by Gonzales, Eskin, and Bitterman (1963). A 100% reinforcement group received 100 pairings of light and shock during acquisition, while a 50% group was given 200 trials, half of which were presentations of the CS alone. A second random partial reinforcement group received 40 trials of continuous reinforcement followed by 60 trials with partial reinforcement. Extinction consisted of 35 CS-alone trials for all groups. The acquisition procedures resulted in significantly lower performance levels for the 50% groups. Both partial reinforcement groups showed greater resistance to extinction than the consistently reinforced group. This is one of the few studies to obtain the PRE with infrahuman Ss in classical conditioning.

A series of seven studies of partial reinforcement in goldfish was reported by Berger, Yärczower, and Bitterman (1965). The effects of intermittent reinforcement were investigated with equated reinforcements and with equated trials, with constant and with variable CS-US intervals, with long and with short runs of nonreinforcement, with balanced and with biased patterns of partial reinforcement, and with two different extinction procedures. The only differential effects on extinction performance were produced under conditions of long runs of nonreinforced trials that tended to occur early in acquisition (early-biased partial reinforcement schedule). This effect was reflected in a Treatments X Trials interaction, with the continuous reinforcement group extinguishing more rapidly than the partial reinforcement group that received long runs of nonreinforced trials early in acquisition. The authors concluded that an interaction of the type obtained in this investigation should not be regarded as unequivocal evidence for a PRE in extinction. Differential performance in extinction was analyzed in the context of an "extinctive carryover" model which will be discussed in a subsequent section.

Slivka and Bitterman (1966) investigated classical appetitive conditioning in the pigeon with continuous and partial reinforcement. The CS was a change in illumination and the US was a small quantity of grain. On reinforced trials these stimuli were presented with a 10-sec. CS-US interval. Conditioned responding was measured as the difference between mean activity occurring in the CS-US interval and that observed for an equal period of the intertrial interval. During acquisition, Ss were given 150 reinforced trials and then either 100% or 50% reinforcement for 225 trials. All Ss then received 90 trials of extinction with the US omitted. Frequency of reinforcement had no reliable effect in acquisition. There was no significant overall difference in performance levels of the two experimental groups during extinction, but a statistically significant

Groups X Trials interaction was obtained. Again it was concluded that the interaction effect did not represent an extinction PRE.

The effects of partial reinforcement on a classically conditioned eyelid response in rabbits were investigated by Thomas and Wagner (1964). One group of 10 Ss received 220 acquisition trials in a 100% reinforcement schedule. A second group was given 440 acquisition trials with 50% random partial reinforcement. The CS was a 600-msec. tone and the US was a 4-psi air puff. On reinforced trials these stimuli were paired such that the US overlapped the last 100 msec. of the CS. Nonreinforced trials consisted of presentations of the CS alone. The rate of acquisition for the 50% group was reliably slower than that of the continuously reinforced group, although both groups reached approximately the same asymptote. However, 60 trials of extinction revealed no differences between the two groups in CR frequency. No reliable between-group differences in CR latency were obtained for acquisition or extinction. A detailed analysis of the acquisition data revealed significantly lower CR percentages on trials following nonreinforcements. It was concluded that the PRE did not occur because infra-humans lack the complex verbal processes which mediate the effect in humans.

The investigators whose research on infra-humans has been reviewed here regard the PRE as being controlled by rather complicated processes, such as differential discriminations between reinforcement schedules. These processes have been proposed to explain the failure to obtain a PRE in certain situations, i.e., infra-humans are assumed to be incapable of such complex discriminations. However, a number of experiments involving invertebrate Ss have reported an extinction PRE, which suggests that the assumptions about its complex determinants may be untenable.

Wyers, Peeke, and Hertz (1964) used a tactile CS and an intense light as the US to condition a retraction or withdrawal response in earthworms. A continuous reinforcement group received 150 reinforced trials, while a partial reinforcement group first received 20 reinforced trials and then 130 trials with 50% partial reinforcement. The reinforcement procedures produced no differential effects in acquisition performance, but the 50% group performed at a higher level than the 100% group during extinction.

A subsequent study by these authors (Peeke, Hertz, & Wyers, 1965) involved the same specie of S and a similar experimental design. Three levels of training (50, 100, and 150 acquisition trials) were made orthogonal to two reinforcement schedules (100 and 50 per cent). In addition, separate conditions were provided to control for sensitization and pseudo-conditioning. The results of their previous investigation with earthworms were substantiated; for all levels of training, Ss given partial reinforcement performed comparably to the groups receiving consistent reinforcement during acquisition and showed greater resistance to extinction than consistently reinforced Ss.

Crawford, King, and Seibert (1965) investigated the effects of partial reinforcement on classical conditioning in 20 planaria. The CS was a 3-sec. light, and a 1-sec. shock was the reinforcer. For reinforced trials, these stimuli were paired using a 2-sec. CS-US interval. The experimental design included four treatment groups.

A continuous reinforcement group received 120 light-shock trials in acquisition, while a sensitization control group was given the same number of trials with the CS and US unpaired (separated by 30 sec.). A 50% partial reinforcement group had CS-US pairings on 60 acquisition trials and 60 presentations of the CS alone. The second sensitization control group received 120 acquisition trials where the US was present but not paired with the CS on half of the trials. All groups were given 32 CS-alone trials in extinction. The performance of the partial reinforcement group did not differ from that of the 100% group in acquisition. A significant Treatments X Trials interaction was obtained in extinction, with the 100% group extinguishing more rapidly than the intermittently reinforced group.

Three groups of 6 planaria received 48 presentations of a photic CS and 48 shocks per day for 5 days in a study by Kimmel and Yarenko (1966). On conditioning trials, light and shock were paired using a 2-sec. CS-US interval. The minimum intertrial interval was 15 sec. A CR was defined as cephalic turning, curling, or contraction during the first 2 sec. of the CS. For one group, acquisition involved pairing light and shock on 100% of the trials. Another group received 50% paired presentations of light and shock, while 50% of the trials consisted of the CS alone. A third group was given 0% reinforced trials in order to provide an estimate of sensitization and pseudo-conditioning levels. All groups received 50 extinction trials on the sixth day of the experiment. Both the 100% and 50% groups performed at levels that were significantly higher than the control group during acquisition. There were no reliable differences between the acquisition performance levels of the two conditioning groups. In extinction, the 50% group exhibited higher response percentages than the 100% and control groups. However, there was no significant difference between the performance of the 100% group and the control group in extinction. These results for invertebrates suggest than an extinction PRE may be observed under conditions where it seems unlikely that complex discriminations could be an important determinant of performance.

An experiment by Fitzgerald (1963) dealt with an aversive conditioned salivary response in dogs. The reinforcement schedules employed were 25%, 50%, and 100%. The CS was a tone and the US was dilute acetic acid. In this study, the acquisition performance levels of both partial reinforcement groups were lower than those of the continuously reinforced group. In extinction, a significant Groups X Trials interaction was obtained, with the 100% group extinguishing more rapidly than the other groups. No reliable differences between acquisition or extinction performance were observed for the two partial reinforcement groups.

Wagner, Siegel, Thomas, and Ellison (1964) investigated the effects of partial reinforcement on an appetitive conditioned salivary response in dogs. An auditory CS was paired with a food pellet using a 20-sec. CS-US interval on reinforced trials. A 50% reinforcement group tended to perform at lower levels than a continuously reinforced group in acquisition. A significant Groups X Trials interaction was obtained during extinction indicating that the 50% group extinguished more slowly than the 100% group. There were no differences in overall performance for the two reinforcement groups.

Two experiments involving a conditioned heart-rate response in dogs were reported by Fitzgerald (1966). A tone was the CS and the reinforcement was provided by a shock. The reinforcement schedules employed were 0%, 50%, and 100%. In the first experiment, no PRE was obtained in acquisition or extinction. The second experiment, where the number of reinforcements was equated for the two experimental groups, produced a Treatments X Trials PRE in extinction. No overall differences between the performance levels of the experimental group were obtained in acquisition or extinction. The lack of evidence for a PRE in the first experiment was explained in terms of the relatively small number of reinforced trials (six) occurring in the partial reinforcement schedule. It was suggested that 6 reinforced and 6 nonreinforced trials established only a minimal amount of response strength. In the second experiment, where both the 100% and 50% groups received 12 reinforcements, conditioning levels were sufficient to reveal an interaction PRE.

Fitzgerald, Vardaris, and Teyler (1966) studied the effects of partial reinforcement followed by continuous reinforcement on a classically conditioned heart-rate response in dogs. In one condition a group received partial reinforcement on the first day of acquisition and was then switched on the next day to continuous reinforcement. Another condition provided partial reinforcement on both days. A group receiving continuous reinforcement on both days was also included. In this experiment, partial reinforcement produced a decrement relative to a 100% group on the first day of acquisition. During extinction, a group that received only partial reinforcement in acquisition showed greater resistance to extinction than did a continuously reinforced group. Subjects given partial reinforcement and then continuous reinforcement before extinction tended to extinguish more gradually than the 100% reinforcement group, although the difference was not statistically significant. Shifting from partial to continuous reinforcement presumably made the extinction situation less similar to acquisition, and therefore extinction should have been rapid as compared to the unshifted group. It was concluded that this evidence did not support explanations of the PRE that postulate differential discrimination of extinction from acquisition as the mechanism underlying the effect.

Fitzgerald, Vardaris, and Brown (1966) conducted an experiment in which classical conditioning of heart-rate was studied in rats. For this investigation, three different groups of Ss received either 100%, 50%, or 0% reinforcement. All groups were given 42 acquisition trials and 24 trials of extinction. The CR observed for the 100% and 50% groups was a deceleration in heart rate. In acquisition, frequency of reinforcement had no differential effect on performance. Because the extinction procedure failed to produce performance decrements, it was not possible to assess the effects of partial reinforcement in extinction.

The effects of frequency and pattern of reinforcement on eyelid conditioning in dogs were investigated by Vardaris (1967). A continuous reinforcement group received 300 reinforced trials (tone paired with air puff) in acquisition, while two groups receiving partial reinforcement each were given 150 reinforced and

150 nonreinforced (CS alone) trials. One of the 50% groups was trained on a random partial schedule whereas the other received an alternating sequence of reinforced and nonreinforced trials. For all groups extinction consisted of 200 presentations of the CS alone. Although the 100% group received twice the number of reinforced trials and twice as many USs in acquisition as the partial reinforcement groups, there was no reliable effect of percentage of reinforcement during acquisition or extinction. Similarly, pattern of reinforcement did not effect performance differentially. A statistically significant Treatments X Trials interaction was obtained in extinction, but this was due to multiple crossings of the performance curves rather than differential rates of decrement.

Extinction of conditioned fear (as revealed by the degree of suppression of bar-pressing in rats) has been investigated after partial and continuous reinforcement (Wagner, Siegel, and Fein, 1967). Fear conditioning was administered either in the bar-press situation or away from this instrumental response situation. Under the former conditions, a sizeable PRE was obtained. This was indicated by greater suppression of responding during extinction for the partial reinforcement group than for the group given continuous reinforcement. However, no PRE was observed in extinction when the fear conditioning was administered away from the bar-press situation. The authors concluded that the PRE is more likely to be observed when the aftereffects of reinforcement and nonreinforcement are "probable salient features of the stimulus complex". It was argued that the PRE for infra-humans may be due entirely to reinforcement-aftereffect mechanisms, so that extinction occasions discriminably greater stimulus change for continuous than for partial reinforcement.

In summary it may be stated that many of the studies concerned with partial reinforcement of the classically conditioned eyelid response in humans have found that intermittent reinforcement produces inferior performance in acquisition and more resistance to extinction. The PRE in such investigations has taken the form of a significant difference between treatment-group means, with a 100% group performing at higher levels than a partially reinforced group during acquisition and a 50% group performing above a continuous reinforcement group in extinction.

The results for infra-human Ss have been much more variable. Effects of partial reinforcement may be reflected in overall mean differences, or Treatments X Trials interactions. In some experiments no differential effects of reinforcement schedule were observed. The most common result in acquisition is one of approximately equal performance levels for partial and continuous reinforcement groups. Frequency of reinforcement did not affect acquisition performance differentially in the majority of experiments using infra-humans, whereas partial reinforcement often produced a decrement during acquisition with humans. Only two studies obtained a result similar to the PRE in acquisition and extinction for humans (Gonzales, et al., 1963; Fitzgerald, et al., 1966). Although the acquisition findings for infra-humans are relatively consistent from experiment to experiment, the extinction results are not. In general, the type of result obtained for extinction does not appear to be systematically related to the response system investigated or the species serving as Ss. Increased resistance to extinction after partial reinforcement was obtained in some of the experiments with animals, but other findings such as interactions or no differences are relatively more common for infra-humans.

It is clear that any comprehensive theoretical explanation of the PRE in classical conditioning must be able to predict a number of replicable findings in a variety of experimental situations. It may be stated that at present no single theory is capable of explaining all the results obtained in studies of classical conditioning with partial reinforcement.

Humphreys' "expectancy" hypothesis is an example of an early theory that attempted to explain the PRE in a variety of situations. His view was that an expectation of consistent reinforcement is acquired during conditioning trials involving regular presentations of US following CS. Humphreys assumed that it is easier to change from an expectation of this kind to one of regular nonreinforcement (extinction) than it is to change from an expectation of irregular (partial) reinforcement to regular nonreinforcement. The difficulty in changing expectancies after partial reinforcement presumably would produce the increased resistance to extinction exhibited by groups receiving this treatment. It will be noted that his model is general enough to explain the extinction PRE in some conditioning situations but by the same token, it is so general as to be unamenable to precise experimental test.

The stimulus-generalization decrement hypothesis, which was developed by Hull (1943) and later extended by Sheffield (1949), provided another general explanation of the PRE. According to this conception, the stimulus aftereffects of a reinforced trial become part of the CS complex (CS') acting at the start of the subsequent trial. Similarly, the perseverative stimulus traces of nonreinforcement become part of the CS complex operating during the following trial. Such persisting cues of nonreinforcement are regarded as being exactly those which follow the usual extinction trial where the US is omitted. In partial reinforcement, the response becomes conditioned to a combination of reinforcement and extinction-like cues. Acccording to the principle of stimulus generalization, the partial-reinforcement CS' is then more similar to the extinction CS' than is the continuous-reinforcement CS'. Therefore, there is less generalization decrement and more resistance to extinction following partial reinforcement.

Bitterman has advanced a theoretical alternative to the perseverative-stimulus models (Gonzales, Eskin, & Bitterman, 1963; Gonzales & Bitterman, 1964). His notion is that "extinctive carry-over" mediates the PRE in classical aversive conditioning with infrahumans. As in other formulations, it is assumed that resistance to extinction varies with similarity of extinction to acquisition. Two hypothese are involved in this assumption: the greater the similarity, the greater the resistance to extinction (generalization hypothesis); the less the similarity, the less the resistance to extinction (discrimination hypothesis). Another assumption is that nonreinforcement during acquisition exerts an effect which is independent of its tendency to produce extinction. This effect is a contribution to the stimulus situation in acquisition, such that partial reinforcement Ss are reinforced in the presence of extinction-like cues. Therefore, the conditions of training and extinction are more similar for partial than for continuous reinforcement. Extinctive carryover from acquisition mediates the increased resistance to extinction that often is observed after partial reinforcement. It will be noted that the extinctive-carryover model is similar in most respects to the stimulus-generalization decrement hypothesis.

Another formulation which considers the similarity of conditions in extinction to those in acquisition is the discrimination hypothesis that was advanced by Mowrer and Jones (1945). Essentially, it was contended that extinction may be prolonged by procedures in acquisition which make it difficult for the S to discriminate between training and extinction. Some of the conditions that were regarded as making this discrimination relatively easy are continuous reinforcement, regular patterns of partial reinforcement, and changes in the stimulus (CS) complex from acquisition to extinction. Therefore, extinction would progress relatively rapidly after such procedures. Random partial reinforcement would tend to retard extinction because it would make extinction more difficult to discriminate from acquisition. The underlying mechanisms of this model are essentially similar to those of the stimulus-generalization decrement and extinctive-carryover theories.

Recently Spence (1963, 1966) has extended and modified the discrimination hypothesis to account for certain results obtained in the human eyelid conditioning situation. In his discussion of factors influencing extinction of the human eyelid CR (1966), it was pointed out that extremely rapid extinction is usually observed with human Ss. In contrast, infra-humans often extinguish at roughly the same rate as they learn. It was suggested that the rapid decrement in humans may result from an inhibitory "set" which is adopted when extinction procedures are begun. Some data that bear on this aspect of human eyelid conditioning were provided by McAllister (1953). More gradual decrements were obtained under conditions where the US was present on extinction trials and the 500-msec. CS-US interval in acquisition was extended to 2400 msec. in extinction. Training involved an 80% partial reinforcement schedule. The relatively slow extinction was interpreted in terms of the US maintaining general motivational levels on nonreinforced trials. However, recent findings have suggested that the results are best understood as reflecting the operation of a "set" factor. Reynolds (1958) found that using an extended CS-US interval decreased the rate of extinction only after partial reinforcement in acquisition. Subjects who had received continuous reinforcement during acquisition extinguished at the usual rapid rate. These findings were substantiated in a more recent investigation by Spence, Rutledge, and Talbott (1963). It has been suggested that a simple motivational interpretation of the effects on extinction of the delayed-US technique is unsatisfactory (Spence, 1963), since rapid extinction is obtained with this procedure if the conditioning history involves continuous reinforcement. Using a probability learning task and the long CS-US interval to mask changes in the experimental situation when extinction was initiated, Spence and Rutledge (1964) found that approximately one third of the Ss did not extinguish at all, whereas the others stopped responding after the second or third extinction trial. It was concluded that the delayed US is reinforcing for some Ss and therefore is not a satisfactory method of maintaining motivational levels in extinction. Three methods of providing nonreinforcements in extinction were compared in an experiment by Spence (1966). Two of the techniques were intended to maintain motivational levels in extinction (delayed US and randomized presentations of CS and US) while the third involved presentation of the usual CS-alone trials. All conditioning procedures were imbedded in a probability learning situation. Subjects receiving CS-alone trials in extinction extinguished very rapidly. Some Ss who were given trials with the US delayed showed little or no decrement, while others receiving this treatment extinguished immediately. Randomized presentations of CS and US proved to be the most effective method for producing gradual decrements in all Ss during extinction.

It has been mentioned that extinction of the human eyelid CR normally progresses at an inordinately high rate. If nonreinforcement in extinction is accomplished by using a long CS-US interval instead of omitting the US, the rate of performance decrement may be retarded. Apparently, the extended CS-US interval is effective in retarding extinction only after partial reinforcement in acquisition. It was hypothesized (Spence, 1966) that partial reinforcement provides Ss with the experience of nonreinforcement in acquisition and, therefore, makes the extinction procedures less discriminable from acquisition. Subjects not receiving partial reinforcement in acquisition easily discriminate the extinction procedures and adopt an inhibitory "set". This set factor is assumed to result from self-instructions on the part of Ss and explains the precipitous course of extinction after continuous reinforcement. Certain masking procedures such as a probability learning situation have been effective in making extinction less discriminable from acquisition. This is revealed by relatively slow extinction in Ss trained under such conditions. Spence's theoretical formulation differs from other versions of the discrimination hypothesis in that it introduces an inhibitory set factor and is specifically limited to conditioning situations involving Ss with verbal capabilities.

Another specific model for the PRE has been developed by Fitzgerald (1966). Although this conception was advanced to explain certain results obtained for heart-rate conditioning in dogs, it may be applicable to other organisms and response systems. Since punishment is suggested as the essential factor, the model is best suited for experimental situations employing an aversive US. According to this notion, a partial reinforcement schedule in acquisition provides an opportunity for extinction-like responses to be conditioned to the CS on nonreinforced trials. In conditioning situations where the reinforcer is aversive, these extinction-like responses are punished by the US when they occur on reinforced trials. Therefore, partially reinforced groups would be expected to show greater resistance to extinction because responses assumed to produce performance decrements in extinction would have been suppressed by punishment in acquisition.

Capaldi (1966) has presented an analysis of the PRE in terms of sequential events that occur in a partial reinforcement schedule. The model was developed in the context of instrumental conditioning, but has been extended to include other partial reinforcement situations. The basic assumptions of the hypothesis are that nonreinforced trials (with the US omitted) produce a distinctive "internal" stimulus which is incrementally modified by successive nonreinforcements. This stimulus-modification is assumed to influence resistance to extinction by means of three sequential variables: length of runs of nonreinforced trials; number of runs of differing length; number of occurrances of each different run-length. A further assumption is that resistance to extinction is a simple asymptotic growth function of the three variables, either singly or in combination. Although it is not specified in the theory, the increment in resistance to extinction resulting from the operation of these variables must be relative to some specified value produced by continuous reinforcement. This fact becomes evident when it is considered that the three variables would be evaluated at zero in a continuous schedule, and there would be no resistance to extinction. Since there is resistance to extinction after continuous reinforcement, the operation of the sequential variables must be to increase extinction performance relative to performance after continuous reinforcement. The predictions of this model take the form of differences in rate of extinction. In contrast, most of the other theorists have attempted to predict overall mean differences in extinction performance. The extinction PRE is usually defined in terms of differences in asymptote rather than differences in rate of approach to a common asymptote.

Clearly the majority of theories assume differential stimulus change as the mechanism underlying increased resistance to extinction following partial reinforcement. Another feature of these theories is that they deal with extinction performance but do not consider the effects partial reinforcement may have in acquisition. It has been suggested that the PRE is usually defined as differential resistance to extinction. However, it is evident from the PRE in human and some animal experiments that partial reinforcement frequently produces a differential effect during acquisition. Since many of the human studies have found that asymptotic acquisition performance is a positive function of frequency of reinforcement, it may be that most theorists feel the acquisition phenomena are adequately explained by traditional reinforcement assumptions, i.e., performance is a direct function of number or rate of reinforcements. Nevertheless, a substantial proportion of the investigations with infra-humans have found no significant differences in acquisition performance for consistently and intermittently reinforced groups. Such results are not consistent with current models of reinforcement and seem frequent enough to warrant further theoretical analysis.

One of the difficulties with investigating the effects of partial reinforcement in an aversive classical conditioning situation is that the US serves both as a reinforcing stimulus and as a source of motivation for behavior. It is often assumed that the US has persisting and cumulative effects, such that the motivational level at any given time is a function of the number or rate of US presentations. Therefore a partial reinforcement schedule where nonreinforced trials are provided by omitting the US would result in a lower motivational level than would a continuous reinforcement schedule. The simple omission of the US for a given proportion of acquisition trials produces a situation such that a partial reinforcement group differs from a group receiving continuous reinforcement both in motivation and number of training trials. That is, associative and motivational variables are confounded under these conditions.

As indicated earlier, one of the techniques that has been widely used with human eyelid conditioning to equate acquisition motivational levels in the partial reinforcement situation is to extend the CS-US interval. After demonstrating that little or no conditioning occurred with a CS-US interval of 2400 msec. or longer, McAllister (1953) used a partial reinforcement schedule where nonreinforced trials consisted of a presentation of CS and US with a 2400-msec. interstimulus interval. Reinforced trials involved the usual 500-msec. CS-US interval. Since the US was present on nonreinforced trials, presumably nonreinforcement was accomplished without a corresponding decrement in motivation (Spence, 1966; Spence and Platt, 1967). However, Spence (1966) found that the extended-interval procedure may be reinforcing for some _S_s. In contrast, Moore and Gormezano (1963) have reported that the extended interval method may actually depress acquisition performance relative to other techniques for equating motivation. Taken together, these findings argue against the use of the extended-interval method to equate motivational level. It may be mentioned also that this method probably is inappropriate for conditioning of autonomically-mediated responses where it is known that relatively long CS-US intervals produce reliable levels of conditioned responding (cf., Pavlov, 1927; Fitzgerald, 1963).

Several of the previously discussed experiments involving infra-human Ss used the matched reinforcements technique to control motivation (Longo, et al., 1962; Gonzalez, et al., 1963; Thomas and Wagner, 1964; Berger, et al., 1965; Fitzgerald, 1966). This method equates motivation by maintaining identical US-US intervals and the same total number of USs for partial and continuous reinforcement groups. An unavoidable consequence of the technique is that the CS-CS intervals differ between partial and continuous reinforcement groups. That is, either the intertrial interval is shorter for a partial reinforcement group, or, when intertrial interval also is controlled, the experimental session is twice as long for the partial reinforcement Ss. In Fitzgerald's investigation (1966), which was designed so as to evaluate the possible effect of such factors, it was found that they did not influence performance differentially. However, the matched reinforcements technique did prove to be an important variable, since a Treatments X Trials interaction was obtained for extinction performance with reinforcements equated, whereas no such effect was observed without the control for motivational level.

Another technique that has been employed to provide nonreinforcement without omitting the US is the interpolated-US procedure. As described above, this method consists of presenting the CS alone followed by the US at the midpoint of the intertrial interval. Since the US is present on nonreinforced trials, the number of US presentations is equated for partial and continuous reinforcement. However, the US-US and US-CS intervals differ between schedules. If it is assumed that the motivational level at any given instant is a function of the time between US presentations, then motivation is not necessarily equated for the two schedules on a trial-to-trial basis. In addition, if it is assumed that the US provides relatively persistant sensory events which become part of the stimulus complex for the subsequent trial (Sheffield, 1949), it follows that between-group variability in US-CS intervals is a possible source of experimental bias. One seemingly appropriate experimental control for these factors is an additional partial reinforcement schedule where nonreinforcement is achieved by interpolating the CS at the midpoint of the intertrial interval while maintaining the US-US intervals the same as in the continuous schedule. Thus the possible differential effects of variable US-US and US-CS intervals produced by the interpolated-US technique are controlled by counterbalancing with an interpolated-CS technique.

It has long been recognized that simple omission of the US is not the indicated method for investigating performance decrements during extinction (Kimble, 1961). When the US is omitted to produce nonreinforcement in extinction, it is evident that performance reflects decrements both in motivational and associative influences. Therefore, it is difficult to estimate the effects of only one of the variables under such conditions. A related consideration is that omission of the US during extinction results in a change in stimulus conditions from acquisition. Furthermore, this change is greater for continuously reinforced _S_s than for _S_s receiving partial reinforcement unless the number of USs is equated in acquisition. It was pointed out previously that such relationships have been used as the basis for the stimulus-generalization decrement hypothesis (Sheffield, 1949; Lewis, 1960).

As is the case for acquisition, it is possible to provide nonreinforced extinction trials without omitting the US. However, if the interpolated-US technique is used, even though the number of USs in extinction will be the same as in acquisition, there will be a change in US-US intervals from acquisition to extinction. The indicated control measure would be to counterbalance the possible effects of such changes with an interpolated-CS schedule where the US-US intervals do not change from acquisition to extinction.

The present investigation was designed to study the effects of partial reinforcement on a classically conditioned heart-rate response in rats with motivational level and stimulus change controlled. The interpolated-US technique was adopted to equate motivation between groups in acquisition. Presence of the US on nonreinforced trials for some of the experimental groups in extinction permitted the investigation of performance decrements produced by associative variables but presumably not affected by corresponding decrements in motivational level. Possible effects of stimulus change as a result of the interpolated-US procedure were controlled by interpolated-CS treatments both in acquisition and extinction. In addition, differential stimulus change from acquisition to extinction was minimized by the interpolated-US technique. The design includes ordinary continuous and partial reinforcement procedures as well as CS-alone trials in extinction, so that further information concerning the traditional PRE might be obtained.

METHOD

Subjects

Subjects for the experiment were 200 Hooded Long-Evans rats weighing 170-300 gm. They were purchased from Kilpack animal suppliers and housed in individual cages. Ad libitum feeding and watering schedules were maintained as well as a constant level of illumination.

Apparatus

Two sound-attenuating refrigerator shells served as the experimental chambers. Each chamber contained two speakers, a house light, a fresh air supply, leads for recording and stimulating, a clear plastic holder to restrain the rats, and a movement transducer. The plastic holder was contoured to fit tightly around the rat. Its length could be adjusted to accomodate rats of different sizes by means of flat plastic panels that were inserted into slots at both ends of the holder. Since this device conformed closely to the general body shape of the Ss, free movement was prevented without undue discomfort. In addition, holes were drilled at appropriate points along the sides of the holder for inserting recording and stimulating electrodes.

Three 22-gauge hypodermic needles were used as ECG recording electrodes. Two of the electrodes were placed in the skin bilaterally on the lateral aspects of the mid-thoracic area, while a third electrode was inserted more rostrally to ground the Ss. An eight-channel electronencephalograph was modified to display the ECG and the stimulus events. Counting of the heart beats was accomplished by means of micro-switch closures which were produced by pen deflections that corresponded to the R-wave of each beat. The micro-switch was positioned on a plastic platform above the pens such that the moveable arm of the switch was in contact with the pen that traced the ECG. This switch was adjusted to operate on the R-wave of the ECG complex. Switch closures activated a solid-state counter that was connected to a digital printer. The printer was programmed to provide a permanent record of the number of beats in 1-sec. time periods. To obtain a record of gross body movement, the rat holder was positioned on strips of polyurethane foam such that the base of the holder rested on the stylus of a stationary crystal phonograph cartridge. Movement generated a voltage change in the cartridge which was integrated and frequency-coded in terms of pulses, each having a duration of 100 msec. These pulses activated a digital printout counter to provide a permanent record of movement. Presentations of stimuli, intertrial intervals, and heart-beat counting periods were timed and programmed automatically by a three-channel punched-film transport and solid-state logic modules. The conditioned stimulus (CS) was a 7-sec. 1-kHz., 100-db (sound pressure level) tone presented against a background of 85 db white noise and air hiss.[2] A 1.8-mA, 60-Hz, AC shock of 1 sec. duration served as the unconditioned stimulus (US). The US was delivered through the ECG electrodes by means of a relay that switched the recording leads from the S into the shock circuit at the time of US presentation.

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[2] Sound pressure levels were measured with a Rudmose Associates Inc. Sound Analyzer, model RA-100, which was calibrated electronically and acoustically to be accurate within ± 0,5 db.

Procedure

For the purposes of the present investigation, a reinforced trial was defined as a paired presentation of the CS and the US. The CS-US interval on reinforced trials was 6 sec. with the US overlapping the final second of the CS. The intertrial (CS-CS) intervals varied randomly among 160, 180, and 200 sec. with a mean of 180 sec. Two methods of providing nonreinforcement were used: a presentation of the CS alone, or a presentation of the CS and then the US near the midpoint of the intertrial interval (85, 90, or 95 sec. after a CS).

Heart beats were counted in 17 1-sec. periods for each reinforced trial. The first six counting periods preceeded the CS to provide a measure of basal heart rate, and the next six periods coincided with the 6-sec. CS-US interval. Heart beats were not counted during the US (when the ECG electrodes were switched into the shocking circuit) or during the 1-sec. period immediately following the US (when the recording amplifier was partially blocked due to switching the input). Post-US heart beats were counted in 5 consecutive periods beginning 1 sec. after US offset. For the method of providing a nonreinforced trial where the US was omitted, the counting sequence was similar to that for a reinforced trial, with the exceptions that heart beats were counted during the final second of the CS and during the 1-sec. period immediately following CS offset.
For the second method, where the US was presented midway in the intertrial interval, a separate counting sequence was provided for the CS and the US. Heart-beat counting for the CS on such trials was identical

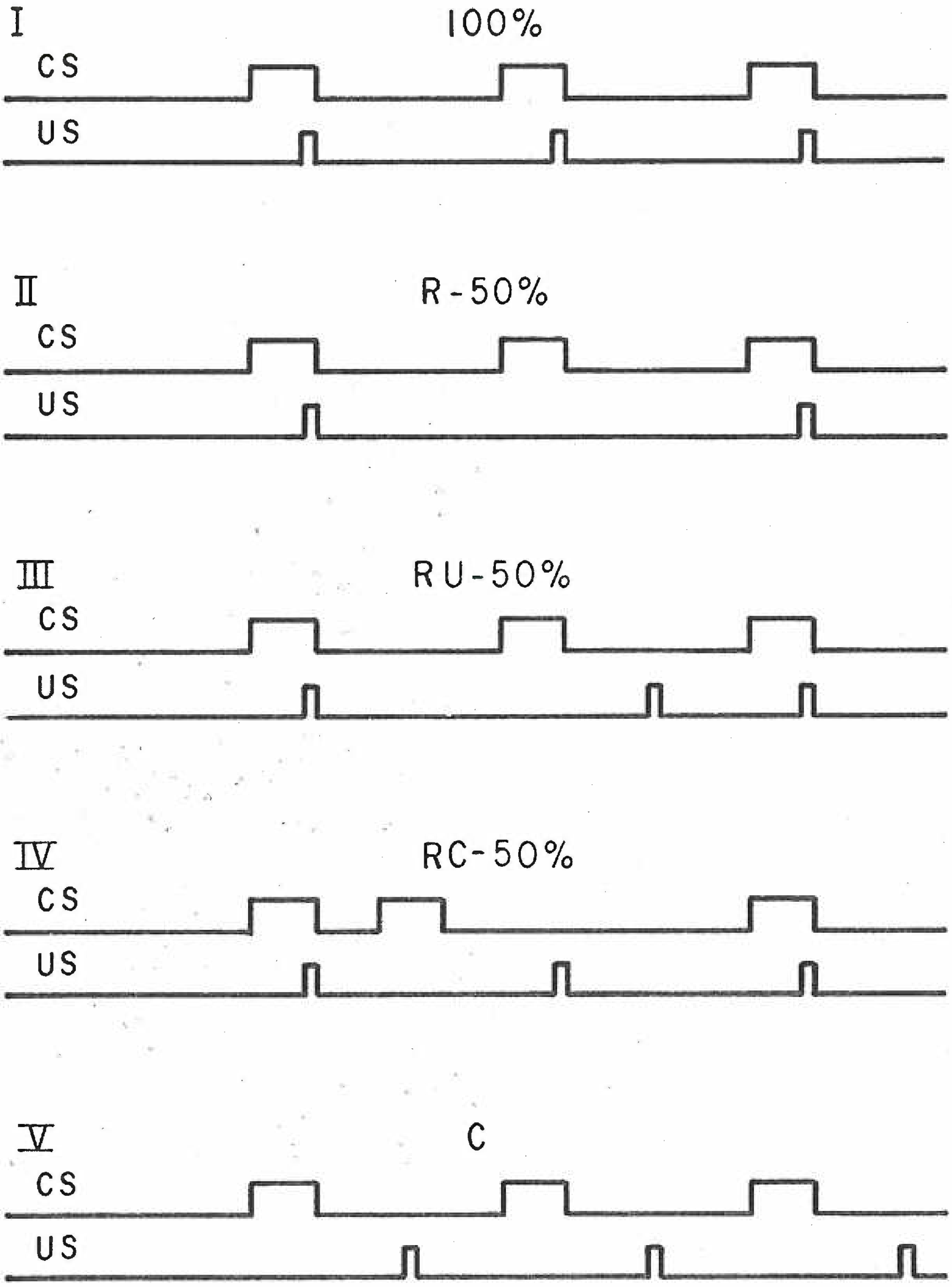
to that for reinforced trials. Subjects were trained in pairs in separate refrigerator shells, with both members of the pair receiving the same experimental treatment.

At the start of an experimental session, Ss received 30 min. of adaptation to restraint in the holders. During this time, 5 samples of heart rate were taken, each consisting of 19 consecutive 1-sec. counting periods. The 5 samples were taken 0, 5, 10, 20, and 30 min. after adaptation to restraint was begun. Following adaptation, 20 trials of habituation to the CS alone were given, with a counting sequence consisting of 19 consecutive 1-sec. periods for each trial and a 90-sec. intertrial interval. After habituation to the CS, Ss were given 30 trials of acquisition followed by 30 extinction trials. Subjects received all adaptation, habituation, acquisition, and extinction procedures in one experimental session which lasted approximately 4 hr.

Experimental design

Pairs of Ss were assigned randomly to one of 5 treatment groups for acquisition, each group consisting of 40 Ss. Figure 1 is a schematic representation of the reinforcement schedules employed for the various groups during acquisition. This figure shows the typical relationships between CS and US on 3 consecutive trials for each group. One group (100%) received 30 reinforced acquisition trials, and this continuous-reinforcement treatment is illustrated in paradigm I of Figure 1. Another group (R-50%) was given 50% partial reinforcement, with 15 reinforced and 15 nonreinforced trials

Figure 1. Schematic representation of the reinforcement schedules used in acquisition. Paradigms for the 5 treatment groups illustrate the relationship between CS and US.

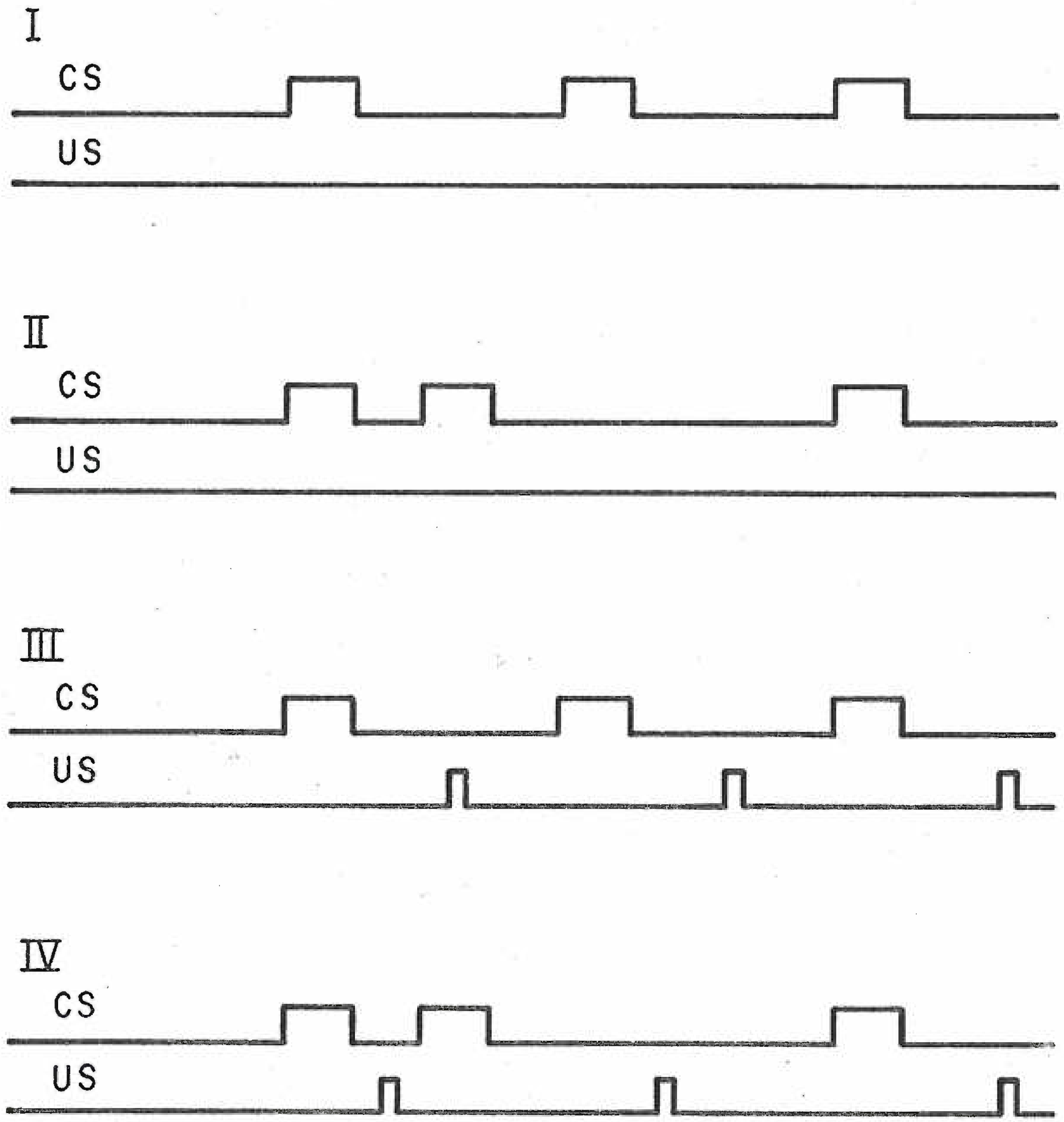

I
100%
CS
US
II
R-50%
CS
US
III
RU-50%
CS
US
IV
RC-50%
CS
US
V
C
CS
US

occurring in a random Gellermann order (Hilgard, 1951). For this group, nonreinforced acquisition trials consisted of a presentation of the CS alone. The nonreinforcement technique for group R-50% is represented in paradigm II of Figure 1, with the second trial being nonreinforced. An additional 50% random partial reinforcement group (RU-50%) received the same sequence of reinforced and nonreinforced trials in acquisition as group R-50%, but the US was interpolated 85, 90, or 95-sec. after the onset of the CS on nonreinforced trials (interpolated-US schedule). Therefore, group RU-50% received the same number of USs as the 100% group, which presumably would tend to make the motivational levels comparable for the two groups. However, as may be seen from a comparison of paradigms I and III in Figure 1, the intervals between USs for the RU-50% group were not the same as in the continuous schedule. That is, although the intervals between CSs for the two groups were the same, the interpolated-US procedure for group RU-50% resulted in a situation such that the US-US intervals differed. To control for this difference between the RU-50% and 100% groups in US-US intervals, group RC-50% was given the same reinforcement schedule in acquisition as groups RU-50% and R-50%, but on nonreinforced trials the CS was interpolated 85, 90, or 95 sec. before the US (interpolated-CS schedule). Paradigm IV in Figure 1 illustrates the fact that, for group RC-50%, the US-US intervals were identical to those in the continuous reinforcement schedule, but the intervals between consecutive CSs differed from those for the 100% group. Group C served as a conditioning control group and received 30 nonreinforced trials of the interpolated-US type. As is indicated in paradigm V of Figure 1, this group was given a sequence of stimuli such that the US-US intervals were the same as for groups 100% and RC-50%, while the number of USs was the same as for the 100%, and RU-50% groups. In addition, the CS-US and US-CS intervals were identical to those employed for nonreinforced trials with the US present in the partial reinforcement schedules.

Each of the 5 acquisition groups was divided into two subgroups for extinction. One subgroup was given extinction trials where the US was omitted. The other subgroup received nonreinforced trials with the US present. The percentage of nonreinforced trials with the US present matched the schedule of reinforcement in acquisition. For example, the US was present on all extinction trials for a subgroup that received 100% reinforcement in acquisition, whereas it was present on only half the extinction trials for a subgroup that was given 50% partial reinforcement in acquisition. The resulting subgroups were further subdivided: half of each subgroup was given the interpolated-US schedule, while the remaining half received the interpolated-CS schedule. For subgroups receiving extinction with the US omitted, half the Ss were given the same CS-CS intervals as in the interpolated-US schedule. In contrast, the remaining Ss received CS-CS intervals that were identical to those in the interpolated-CS schedule.

Figure 2 schematically indicates the relationships among stimuli on 3 typical extinction trials. The 4 basic paradigms that were used to provide nonreinforced extinction trials are illustrated in the figure. It may be seen that paradigms I and II contain only

Figure 2. Schematic representation of relationships among stimuli on 3 typical extinction trials. The 4 paradigms for nonreinforcement in extinction are illustrated.


I
CS
US
II
CS
US
III
CS
US
IV
CS
US

CS-alone trials, whereas the US is present but not paired with the CS in paradigms III and IV. The control for change in intervals between stimuli from acquisition to extinction is reflected in the differences between paradigms I and II or III and IV where the effects of such changes are counterbalanced. Since each of the 5 acquisition groups were divided into four subgroups for extinction, there were 20 different extinction groups, each consisting of 10 _S_s.

RESULTS

Data processing

The number of heart beats in 1-sec. periods was tabulated for each trial in the adaptation, habituation, acquisition, and extinction phases of the experiment. These data were coded on IBM punched cards in standard computer format and were entered into the computer memory in tabular form as sums over either five or six 1-sec. counting periods. As part of a data screening program, the mean, median, range, and standard deviation for each block of trials were obtained. Inspection of these values for the individual experimental groups revealed general trends in the data and facilitated the selection of the appropriate statistical analyses. All statistics were computed on sums of consecutive 1-sec. periods.[1]

An index of conditioned responding during acquisition was calculated for each trial as a change in heart rate (HR) relative to a basal value. That is, the total number of heart beats occurring in the 6 sec. preceeding the onset of the CS (pre-CS) was subtracted from the total for the 6-sec. CS-US interval. This calculation was done the same way for both reinforced and nonreinforced trials in acquisition and extinction. Since the CR was consistently a deceleration in HR, the difference scores (D-scores) were of negative sign. This same index was used during the habituation phase of the experiment in order to show the original HR response to the CS. Clearly the D-score index could be influenced either by responses to

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[1] The raw data (number of heart beats in 1-sec. periods), punched on standard IBM cards, are available from the author upon request.

the CS or by systematic changes in pre-CS HR, or both. In order to obtain an estimate of the extent to which D-scores might have been affected by changing pre-CS HR, analyses of the latter values were also carried out.

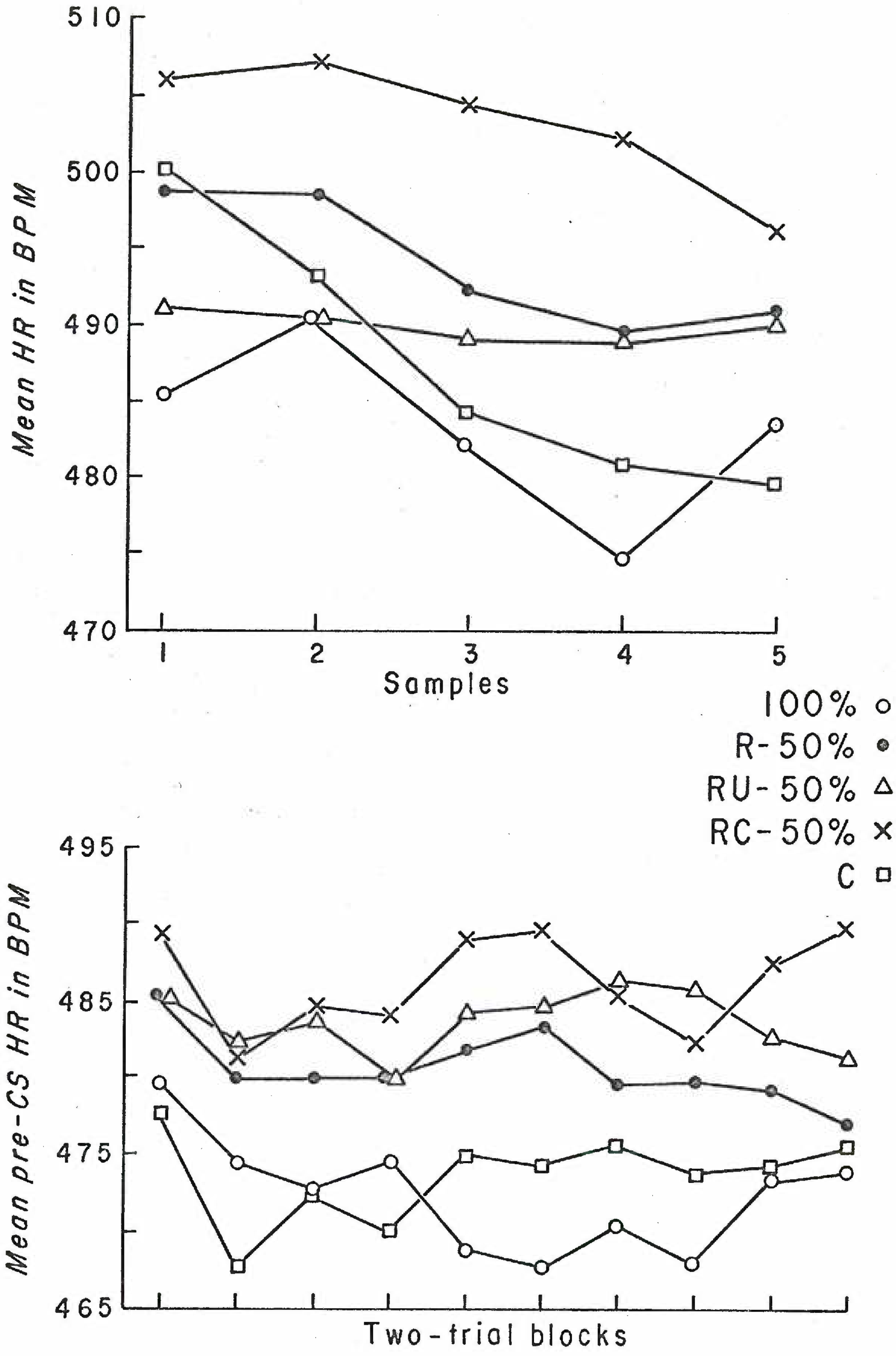
Adaptation

In the top half of Figure 3, mean HRs during the 5 consecutive sampling periods during adaptation are plotted for all of the main treatment groups. It may be seen from this figure that, in general, there is a decreasing trend in the means over the 5 samples, with an apparent difference in mean HR between groups. In order to test the reliability of these effects, a standard analysis of variance for repeated measures (Winer, 1962) was computed. The only statistically significant factor in the data was the change in HR over samples (F (4,780) = 7.14, $p < .001$). It was concluded that there was a reliable decrease in basal HR as a function of time during adaptation.

Habituation

The bottom half of Figure 3 shows the mean pre-CS HR in blocks of 2 habituation trials for the 5 groups. A small decrease in HR over trials may be seen in this figure. There also appear to be differences in overall HR among the various experimental groups. A Treatments X Trial-blocks analysis of variance revealed a significant mean difference between groups ($F(4,195) = 7.92$, $p < .001$) and a significant effect of Trial-blocks ($F(9,1755) = 2.56$, $p < .005$).

Figure 3. Pre-CS HR during adaptation and habituation. The top half of the figure shows mean pre-CS HR in 5 sampling periods for all 5 of the main treatment groups during adaptation. Mean pre-CS HR is shown for habituation in the bottom half of the figure, where values are plotted for consecutive blocks of 2 habituation trials for all 5 treatment groups.



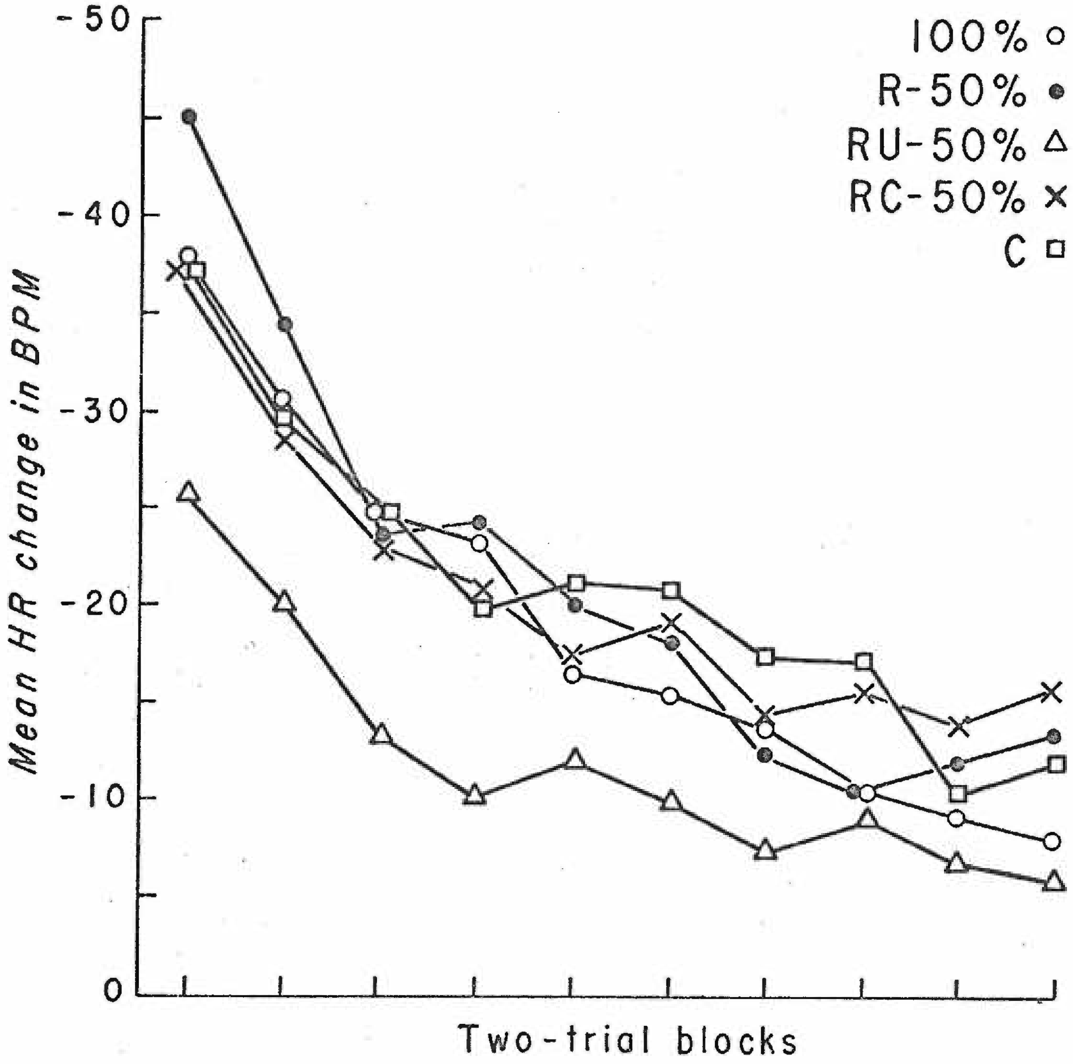
510
500
490
480
470
Mean HR in BPM
1
2
3
4
5
Samples
100% ○
R-50% ●
RU-50% △
RC-50% ×
C □
495
485
475
465
Mean pre-CS HR in BPM
Two-trial blocks

The mean D-score HR responses of each group to 20 presentations of the CS alone are plotted for blocks of 2 trials in Figure 4. Inspection of the figure reveals that the original response to the CS was decelerative and that there is a pronounced decreasing trend in the amount of deceleration as a function of CS presentations. The performance of one experimental group (RU-50%) appears somewhat lower than that of the other 4 groups. The reliability of these changes was tested in a Treatments X Trial-blocks analysis of variance where the decreasing trend for Trial-blocks was found to be significant ($\underline{F}(9,1755) = 70.35$, $\underline{p} < .001$). There also was a significant Treatments X Trial-blocks interaction ($\underline{F}(36,1755) = 2.32$, $\underline{p} < .001$), although the overall differences among groups were not reliable. This outcome indicates that the habituation procedure was effective in decreasing the HR response to the CS. The Treatments X Trial-blocks interaction indicates that the rate of habituation was different for the 5 groups. Since the groups did not receive differential treatment during habituation, it was concluded that the significant interaction was attributable to sampling error.

Acquisition

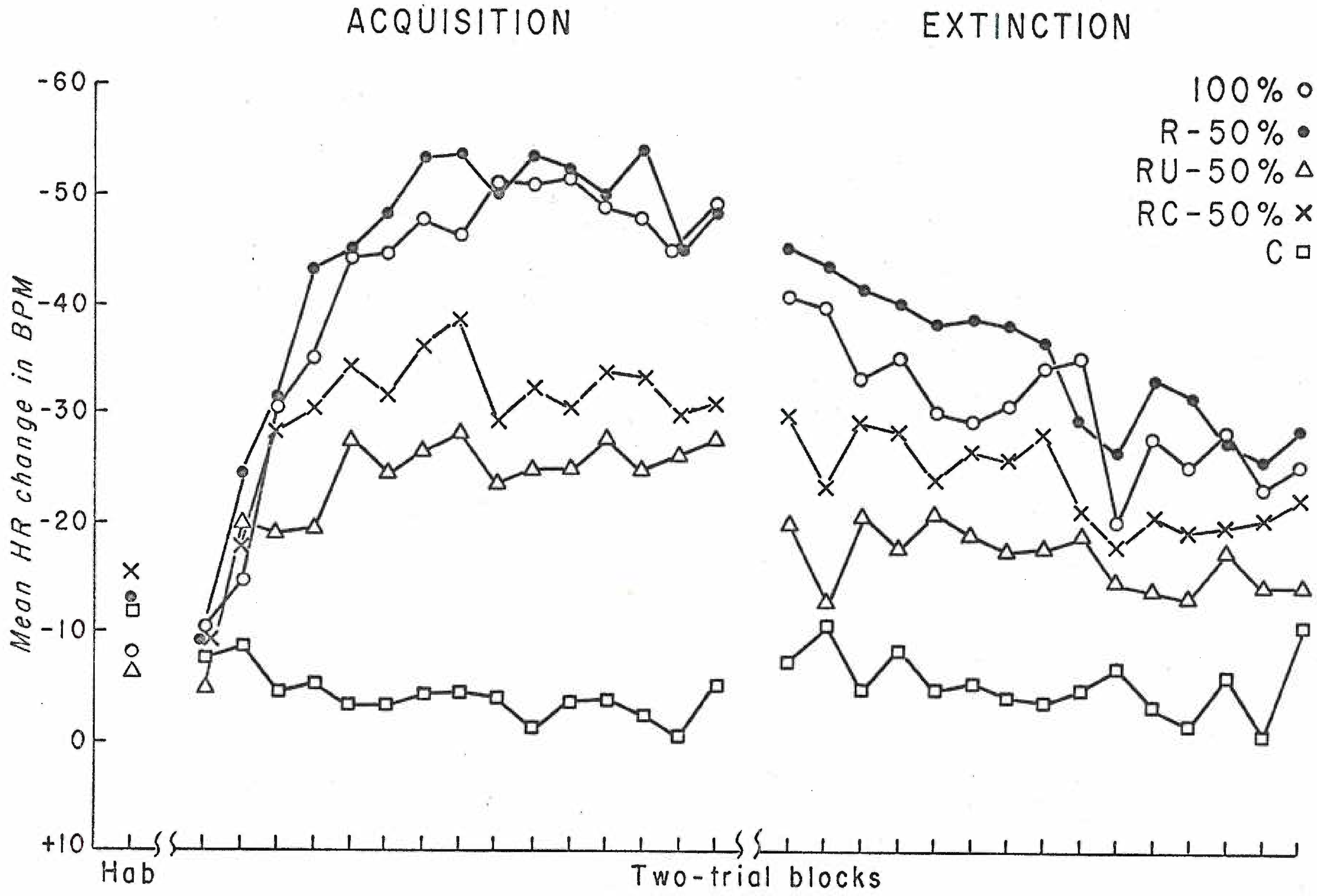
The left half of Figure 5 depicts the acquisition performance for each of the 5 main treatment groups. The data-points on the far left represent the mean heart rate responses to the CS on the last two trials of habituation. The curves in this figure are plotted in terms of mean D-scores for successive 2-trial blocks. It may be seen from inspection of Figure 5 that the various acquisition treatments resulted in consistent performance differences.

Figure 4. Mean D-score during habituation. Mean HR response to the CS during habituation is shown for all 5 main treatment groups.



100% ○
R-50% ●
RU-50% △
RC-50% ×
C □
-50
-40
-30
-20
-10
0
Mean HR change in BPM
Two-trial blocks

Figure 5. Mean performance levels for acquisition and extinction in blocks of 2 trials. The left half of the figure shows the average conditioned change in HR during acquisition. Mean extinction performance is shown in the right half of the figure. A separate curve is plotted for each of the main treatment groups.


ACQUISITION
EXTINCTION
100% ○
R-50% ●
RU-50% △
RC-50% ×
C □
-60
-50
-40
-30
-20
-10
0
+10
Mean HR change in BPM
Hab
Two-trial blocks

The 100% and R-50% groups attained the highest asymptotic values, and these values are approximately the same for the two groups. Performance of groups RU-50% and RC-50% is lower, and the differences between these two groups are relatively small. Group C (the conditioning control group) shows the lowest level of response in acquisition, its performance being well below that of the conditioning groups. All 4 conditioning groups exhibit an increasing trend over trial-blocks, whereas the control group performance does not show a consistent increase or decrease. In order to test the statistical reliability of these observed tendencies, a Treatments X Trial-blocks analysis of variance was computed for the acquisition D-scores. A significant effect of Treatments was found ($\underline{F}(4,195) = 32.17$, $\underline{p} < .001$), as well as a significant Treatments X Trial-blocks interaction ($\underline{F}(56,2730) = 6.75$, $\underline{p} < .001$). These outcomes supported the impression that there were differential overall performance levels among the treatment groups and differential increasing trends. Newman-Keuls Tests were applied to the differences between group means as a comparison of the performance for all possible pairs of groups (Winer, 1962). Each of the 4 conditioning groups performed at reliably higher levels than the control group ($\underline{p} < .05$), while the 100% and R-50% groups both were above the Ru-50% group ($\underline{p} < .05$). No other differences between group means were statistically significant.

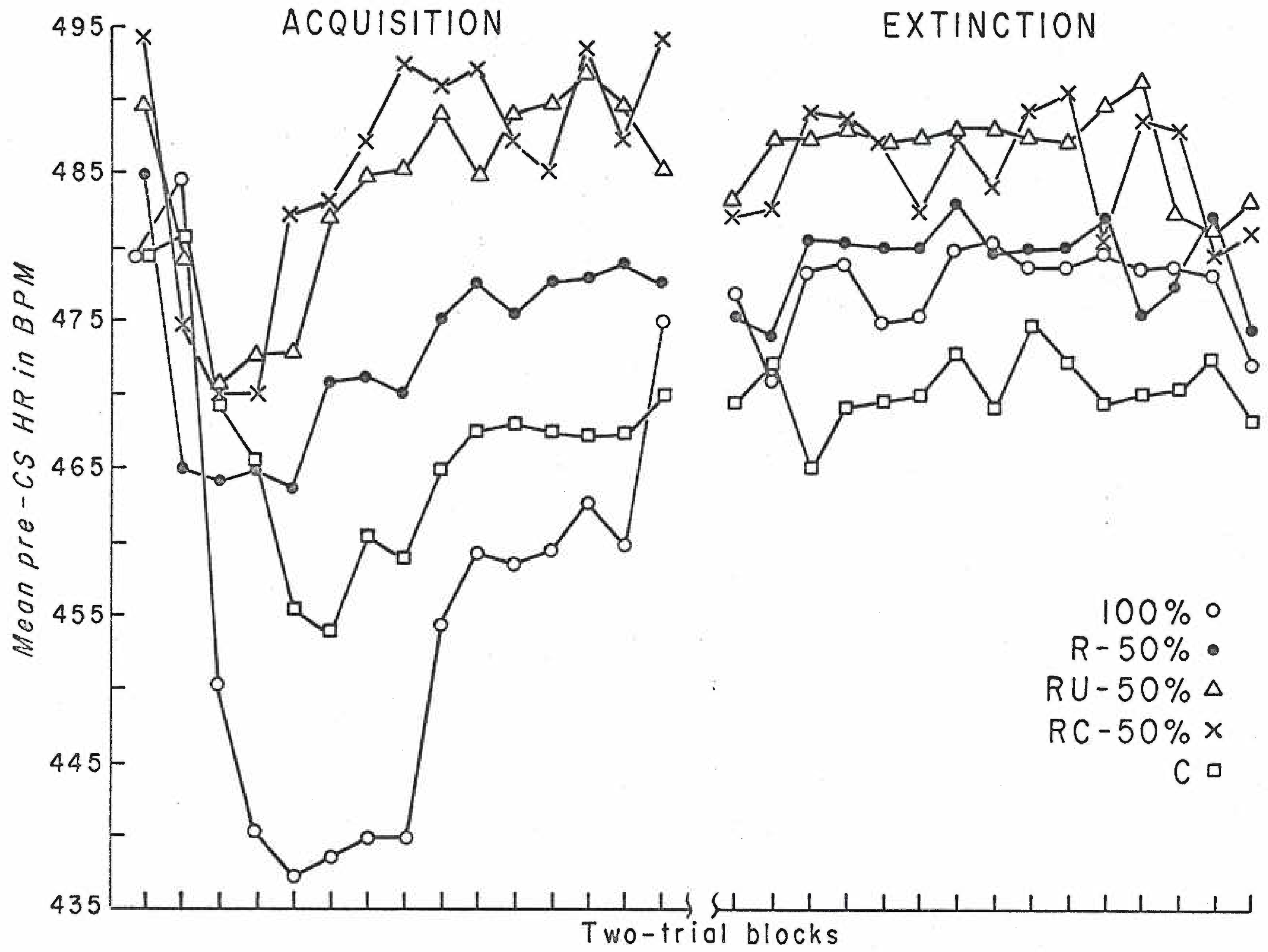
Since all 4 conditioning groups were shown to differ in performance from the control group, an additional Treatments X Trial-blocks analysis of variance was computed for the D-scores of the 4 conditioning groups. As in the original analysis, the Treatments effect was statistically significant ($\underline{F}(3,156) = 9.69$, $\underline{p} < .001$), as well as the interaction of Treatments with Trial-blocks ($\underline{F}(42,2184) = 3.83$, $\underline{p} < .001$). A Newman-Keuls procedure was used to test the difference between group means for all possible pairs of groups. This pattern of significant differences between the performance levels of the 4 conditioning groups was identical to that obtained in the test for all 5 treatment groups.

The mean pre-CS HR in blocks of 2 acquisition trials for each treatment group is plotted in the left half of Figure 6. It may be seen that all groups exhibit a large decrease in pre-CS HR after the first few blocks of trials. Subsequently, the HR returns to values that are comparable with those at the start of acquisition. The magnitude of this transient decrease differs among the groups, and there are differences in overall mean HR. A Treatments X Trial-blocks analysis of variance was used to test the significance of these tendencies. The difference in group means proved to be reliable ($\underline{F}(4,195) = 3.54$, $\underline{p} < .005$), and the effect of Trial-blocks was significant ($\underline{F}(14,2730) = 42.31$, $\underline{p} < .001$). The interaction of Treatments with Trial-blocks also was statistically reliable ($\underline{F}(56,2730) = 7.87$, $\underline{p} < .001$). These tests confirmed the observation that the sudden decrease of pre-CS HR early in acquisition was differential for the various treatment groups and that the groups differed with respect to overall mean HR.

Extinction

The right half of Figure 5 shows the mean D-scores for the 5 main treatment groups in extinction. All of the main groups except the control group exhibit a general decreasing trend in

Figure 6. Mean pre-CS HR during acquisition and extinction in blocks of 2-trials. The left half of the figure shows mean pre-CS HR for each of the main treatment groups in acquisition. Mean pre-CS HR during extinction is shown in the right half of the figure for each of the groups.


ACQUISITION
EXTINCTION
495
485
475
465
455
445
435
Mean pre-CS HR in BPM
Two-trial blocks
100% ○
R-50% ●
RU-50% △
RC-50% ×
C □

performance. Further inspection of the curves reveals that the mean performance levels of the various treatment groups are ordered as in acquisition.

A complete factorial analysis of variance was computed for the extinction D-scores in order to determine the effects on extinction performance of the 5 acquisition treatments, presence or absence of the US on nonreinforced trials in extinction, interpolated-US or interpolated-CS schedule in extinction and trial-blocks in extinction. Since no significant higher-order interactions were revealed in this analysis, the main effects and the Treatment X Trial-blocks interaction were tested. The influence of acquisition treatments on extinction performance was reliable ($\underline{F}(4,180) = 27.63$, $\underline{p} < .001$), as was the effect of US present vs. US absent in extinction ($\underline{F}(1,180) = 6.27$, $\underline{p} < .01$). The general decreasing trend over trials that was observed for the 4 conditioning groups proved to be significant ($\underline{F}(14,2520) = 14.72$, $\underline{p} < .001$), as well as the Treatments X Trial-blocks interaction ($\underline{F}(56,2520) = 4.11$, $\underline{p} < .001$). A Newman-Keuls test was employed to test the reliability of difference in overall means between pairs of the 5 main treatment groups. The pattern of significant differences was identical to that found with a similar test in acquisition: all 4 conditioning groups were reliably above the control group ($\underline{p} < .05$) while groups R-50% and 100% performed at higher levels than the RU-50% group ($\underline{p} < .05$).

Mean values of pre-CS HR in extinction are displayed for all 5 treatment groups in Figure 6. Inspection of this figure reveals that with the possible exception of the control group there are no consistent differences in pre-CS HR among groups during extinction. However, there appears to be a slight decreasing trend over trials. When tested by a factorial analysis of variance, the only significant factor was that of Trial-blocks, ($F(14,2520) = 3.80$, $p < .001$).

The outcomes of these analyses indicate that some of the acquisition treatments were effective in producing differential levels of performance in extinction. It should be emphasized at this point that the pattern of differences in overall mean D-scores was the same in acquisition and extinction; the R-50%, 100%, RC-50%, and RU-50% groups all performed at higher levels than the control group while both 100% and R-50% were above RU-50%. It was concluded that reliable extinction had occurred for the conditioning groups, and that the curves for the groups converged. In addition, the effect of the US being present on nonreinforced extinction trials apparently was to depress performance relative to that for extinction with the US omitted. However, as will be shown below, this effect was the result of initial differences between the groups in acquisition.

Extinction as a function of acquisition

In view of the fact that most of the significant effects in extinction closely paralleled those of acquisition, a more detailed examination of acquisition performance was required. An attempt was made to establish whether the observed performance differences in extinction reflected differential resistance to extinction as a function of the various experimental manipulations, or whether the differences were primarily attributable to varying acquisition performance levels for the extinction groups. When rephrased in terms of curve parameters, the problem becomes one of determining whether the slopes of the extinction functions differ significantly when acquisition asymptote is controlled.

Although not all of the experimental variables in extinction were represented during acquisition, it was, of course, possible to examine acquisition performance with the same factorial analyses of variance that were used in extinction. It should be pointed out that significant effects for experimental variables which were not actually manipulated in acquisition may be attributed to sampling error. When acquisition performance was analyzed factorially, two additional significant effects were observed: a two-way interaction of US present vs. US absent with trial-blocks ($\underline{F}(14,2520) = 2.04$, $\underline{p} < .025$); and a three-way interaction of US present vs. US absent with the 5 main acquisition treatments and with trial-blocks ($\underline{F}(56,2520) = 1.94$, $\underline{p} < .001$).

An analysis of covariance (Winer, 1962) was used to detect significant differences between the 4 main treatment groups in slope of the extinction curves with acquisition asymptote controlled statistically. Before proceding with this analysis, it was necessary to determine whether the observed relation of asymptote to slope was reliable and whether this relation was of the linear form that is assumed for analysis of covariance. Basically, the method involved finding the acquisition asymptote (A) and slope of the extinction function (S') for each S. Values of A were computed as the average D-score on the last two blocks of acquisition trials. A least-squares technique was employed to solve an equation of the general from $y = bX + c$ for each *S*. When this set of equations was evaluated, the S's could be calculated directly ($S' = b$ in the equation). Using A as the independent variable and S' as the dependent variable, a standard regression analysis was computed. The ratio of mean-squares for regression to mean-squares residual indicated that a straight line of the type $S' = bA + c$ was a significantly good fit to the relationship between S' and A ($F(1,158) = 33.86$, $p < .001$). This outcome indicated that it would be appropriate to assume a linear model for the analysis of covariance, and that slope of the individual extinction curves was a negative linear function of the individual acquisition asymptotes. Another interpretation of this result is that resistance to extinction was a negative function of acqusition asymptote. In addition slope was negatively correlated with asymptote; i.e., large negative values of slope were associated with large positive values of asymptote, and small negative values of slope were associated with large positive values of asymptote ($r = -.42$, $df = 158$, $p < .001$).

An analysis of covariance was then computed with A as the covariate and S' as the criterion variate. This technique permitted partioning of the total variance in slope into components related either to treatments or to error. A reliable effect of acquisition treatments on slope of the extinction curves was found ($F(3,155) = 25.76$, $p < .001$). That is, there were significant differences in slope among the 4 main conditioning groups during extinction even when differences in acquisition were accounted for.

Separate analyses of covariance were used to test the difference in slope for each combination of 2 groups. It was found that the 100% and RC-50% groups differed reliably in slope ($F(1,77) = 39.09$, $p < .001$) such that 100% had a faster rate of extinction than RC-50%. The 100% group extinguished more rapidly than RU-50% ($F(1,77) = 28.44$, $p < .001$). There was no significant difference in slope between the 100% and R-50% groups. In addition, group R-50% had a reliably steeper extinction slope than the RC-50% group ($F(1,77) = 47.77$, $p < .001$) and RU-50% ($F(1,77) = 28.60$, $p < .001$). There was a slight but significant difference in slope between groups RC-50% and RU-50% ($F(1,77) = 6.14$, $p < .05$) with RC-50% extinguishing at a faster rate than RU-50%.

The effect on slope of US present vs. US absent for nonreinforced trials during extinction was tested in a similar analysis of covariance. These treatments did not influence rate of extinction differentially when acquisition asymptote was controlled statistically.

It was concluded from the outcomes of these analyses of covariance that two of the groups given partial reinforcement in acquisition (RC-50% and RU-50%) showed greater resistance to extinction than the group receiving continuous reinforcement (100%). The "standard" partial reinforcement group extinguished more rapidly than either of the groups given partial reinforcement with the US present on nonreinforced trials. There was a difference in rate of extinction between the two groups that received partial reinforcement with the US present; the group given the interpolated-CS schedule in acquisition extinguished more rapidly than the group receiving the interpolated-US schedule. The treatments where the US was present on nonreinforced trials, or absent on such trials in extinction, did not affect slope differentially. There was no reliable difference in rate of extinction between the continuous reinforcement group and the standard partial reinforcement group.

DISCUSSION

The major findings of the experiment are summarized below. In this summary, effects on performance, as reflected by significant differences in mean D-score, are listed for habituation, acquisition, and extinction. The adaptation results are presented in terms of absolute mean HR.

Adaptation

1) There was an overall decrease in HR during adaptation.
2) No reliable differences between groups in mean HR or in the amount of adaptation were observed.

Habituation

1) The response to the CS alone during habituation was a deceleration in HR.
2) There was a decrease in the amount of this deceleration as a function of habituation trials.
3) Although there was no overall difference between groups in responding, a Treatments X Trial-blocks interaction indicated that the groups habituated at different rates.

Acquisition

1) For acquisition the CR was a deceleration in HR.
2) The magnitude of this decelerative CR increased over the course of conditioning.

3) There were overall differences in amount of conditioning among the 5 main treatment groups, with all 4 conditioning groups performing at higher levels than the control group.

4) Both the group given continuous reinforcement (100%) and the group receiving partial reinforcement with the US omitted on nonreinforced trials (R-50%) exhibited more conditioning than the partial reinforcement group that had the US present on nonreinforced trials such that CS-CS intervals were the same as in the continuous reinforcement schedule (RU-50%).

Extinction

1) As in habituation and acquisition, the HR response during extinction was decelerative.

2) There was an overall decrease in the amount of this deceleration as a function of nonreinforced trials in extinction.

3) The 5 main treatment groups differed with regard to the amount of conditioned responding shown in extinction

4) The pattern of between-group differences in overall response was identical to that obtained for acquisition; the 4 conditioning groups were above the control group, while groups 100% and R-50% were above RU-50%.

5) When differences in acquisition asymptote were controlled by analyses of covariance, there was a reliable effect of acquisition treatment on rate of extinction:

   a) The groups given partial reinforcement with the US present on nonreinforced trials during acquisition extinguished more slowly than the continuous reinforcement group.
   b) There was no difference in rate of extinction between the continuous and standard partial reinforcement groups.
   c) The groups given partial reinforcement with the US present on nonreinforced trials during acquisition showed more gradual extinction than the standard partial reinforcement group.
   d) Of the two partial reinforcement groups receiving nonreinforced trials with the US present during acquisition, the group given the interpolated-US schedule extinguished more slowly than the group given the interpolated-CS schedule.

6) US present vs. US absent in extinction did not affect rate of extinction differentially.

Before discussing the principle results of this study, a consideration of the experimental controls that were employed is warranted. Although the pre-CS measure of HR exhibited reliable changes in all phases of the experiment, it may be shown that such fluctuations were not related in any consistent fashion to experimentally-produced changes in D-score. For example, there was a significant decrement in pre-CS HR over the course of habituation, but the magnitude of the change was not great enough to account for the large decrease in D-score that was observed. In addition, the reliable differences between groups on the pre-CS measure did not occur for the D-scores. It may be concluded that habituation performance was relatively independent of fluctuations in HR.

Clearly the changes in pre-CS HR that occurred during acquisition do not account for the experimental effects on D-score. The change in pre-CS HR that occurred after the first few blocks of training trials was in a direction that would tend to depress the D-scores. It should be observed that this decrease in preCS rate occurred at the point in acquisition where the mean D-scores were increasing most rapidly. Although the magnitude of the change in preCS HR was different for the various treatment groups, this effect does not explain the group differences in acquisition performance, since the groups showing the highest conditioning levels (R-50% and 100%) also exhibited the greatest decrement in preCS HR of all the conditioning groups. It may be concluded from these relationships that the amount of conditioning was not related to any concomitant changes in pre-CS HR.

A related finding was reported in the study by Fitzgerald, Vardaris, and Brown (1966) which was discussed previously. The conditioning groups in this experiment showed a marked loss in CR magnitude between the first and second 2-trial blocks on the second day of acquisition. Since a similar decrease in pre-CS HR occurred at the same time, and the HR levels during the CS did not change, it was concluded that the transient depression of D-scores was entirely attributable to this fluctuation in pre-CS HR. At no other time in the experiment were there reliable changes in pre-CS HR over trials, nor were there any significant overall differences between groups in this measure. The fact that the pre-CS level of the control group decreased in a similar manner to that of the conditioning groups was interpreted as indicating that the effect was not a function of paired CS-US presentations. It should be noted that the control group in the present investigation also showed the transient decrease in pre-CS HR. This suggests that the decrease was independent of conditioning effects, as was the case for the study of Fitzgerald, et al.

Although the procedures of the two experiments differed in several important respects, it is possible to consider an explanation of the divergent results. For the experiment by Fitzgerald, et al., the pre-CS decrease occurred at a point in training where it may be assumed that relatively stable levels of asymptotic performance had been established. In contrast, the decrease in pre-CS HR occurred near the beginning of acquisition for the present investigation, and coincided with the rapid increase in conditioned responding to the CS. It may be that this strong excitatory tendency which resulted from conditioning obscured the depressing effect of non-specific decreases in preCS HR.

Although a reliable decrease in preCS HR was observed in extinction, the magnitude of the effect was relatively small and could not account for the large decreases in D-score that occurred in this phase of the experiment. Furthermore, there were no significant differences in preCS HR among the various treatment groups, while a number of reliable differences in D-score were observed. It was concluded from such relationships that there was no important influence of non-specific changes in pre-CS HR on performance during habituation, acquisition, or extinction. This outcome is inconsistent with the "law of initial values" (Lacey, 1956) according to which the magnitude of an increasing autonomic reaction to a stimulus is an inverse function of the level of autonomic activity preceding the stimulus. Where the autonomic reaction is a decrease, as was the case in the present investigation, its magnitude is a positive function of the pre-stimulus level. According to this law, a large decrease in pre-CS values should result in a small response to the CS. However, as has been mentioned previously, no such consistent relationship was observed.

It should not be assumed that the pre-CS measure was unnecessary. The fact that there were reliable fluctuations in pre-CS HR suggests that absolute HR during the CS was subject to similar non-specific changes. Therefore, computing responses to stimuli as a difference between pre-CS and CS levels had the desirable effect of normalizing the data and filtering out non-specific changes that almost certainly would have contributed to variability.

The conditioning control group was included in the experiment to provide a statistical estimate of potential pseudo-conditioning and sensitization. The performance of this control group is relevant to a recent theoretical analysis of conditioning control groups by Rescorla (1967). He pointed out that a control procedure of the type employed in the present investigation may in effect set up a contingency where Ss learn that the CS will not be followed by the US. That is, the CS signals a "safe" period. According to this interpretation, such a control actually provides inhibitory training and may not be considered neutral. In addition it was stated that "if inhibition can be acquired it seems reasonable that it can be extinguished". It should be pointed out that Rescorla's predictions concerning the inhibitory effect were derived to explain behavior in an instrumental conditioning situation. Nevertheless, the performance of the control group in the present investigation may be examined to determine whether the inhibition was in fact developed in acquisition and dissipated in extinction. It was indicated previously that the control group exhibited no consistent changes in performance during acquisition or extinction, and therefore the results do not appear to support Rescorla's theoretical formulation. However, the possibility exists that the acquired inhibition functions to prevent changes in HR. This interpretation would be consistent with the performance of the control group.

Adaptation and habituation

All experimental groups exhibited a gradual decrease in basal HR during adaptation. This indicates that the Ss adapted to restraint in the apparatus and to the non-specific stimulus conditions of an unfamiliar environment. The relatively saml1 decrease for the present experiment (an average of 8 bpm) is in sharp contrast to a value reported by Black, Fowler, and Kimbrell (1964) where HR in rats was found to decrease by an average of 80 bpm over a 20-min. adaptation period. They interpreted this large change as being due to greatly elevated initial HR as a result of handling the animals and a subsequent decline when Ss became accustomed to the small testing chamber. The initial HR in their investigation (440 bpm) was somewhat lower than that of the present experiment (497 bpm). It may be that the differences in initial rate and amount of adaptation were due to differential effects of the restraining devices employed, although there were a number of procedural variations that might account for the difference.

The continued gradual decrement in pre-CS HR over the course of habituation for the present experiment indicates that the adaptation process carried over into the second phase of the experiment. The original HR response to the CS alone at the start of habituation was a marked deceleration. This response became less decelerative with repeated presentations of the CS, which indicates that a habituation procedure is desirable in experiments such as the present one where the original response to the CS is similar to the CR. It is conceivable that the early course of acquisition might have been obscured without prior habituation because of the strong initial tendency for a deceleration in HR to occur to the CS. Similar considerations were reviewed by Black (1964) in a report where a HR response in rats to single presentations of auditory stimuli was discussed. He observed a reliable deceleration as the original response during a single stimulus, but there was a deceleration of much greater magnitude that occurred after the offset of the stimulus. In the present study, a tendency for large decelerative responses to occur with the offset of the first CS in habituation also was noted. This post-stimulus responding was not observed for subsequent presentations of the CS during habituation.

Acquisition

There was clear evidence of conditioning for all 4 of the experimental groups, with performance reaching asymptotic levels on about the fifteenth acquisition trial. That the increasing magnitude of the CR during training did not reflect simple dishabituation of the original response as a function of US presentations was indicated by the failure of similar increases to occur for the conditioning control group. This lack of change in performance for the control group also suggests that pseudo-conditioning effects were negligible in the present experiment.

The finding of a consistently decelerative CR is in agreement with the observations by Fitzgerald, Vardaris and Brown (1966) and Holdstock and Schwarzbaum, (1965) in experiments which were similar to the present study in many respects. However, a number of investigators have reported that the HR response for rats changed direction such that an early decelerative CR was replaced by an acceleration as training progressed (cf., McDonald, Stern, & Hahn, 1963; Fehr & Stern, 1965; Black & Black, 1967). In these experiments, the Ss were relatively free-moving, while in the present study, as well as in the investigation by Fitzgerald, et al. and Holdstock and Schwartzbaum, Ss were restrained. It seems likely that the difference in direction of the conditioned change in HR is explainable in terms of the degree of physical restraint imposed upon the Ss during training. The suggestion is that a decelerative CR occurs when conditioning is carried out on restrained Ss, whereas a CR which changes direction is produced in conditioning situations where Ss may move about relatively freely. Conceivably, restraint might inhibit responses of the skeletal musculature that would cause an acceleration in HR indirectly (Fitzgerald, et al., 1966) or it is possible that the difference in form of the response is more directly related to emotional factors which might be differentially affected by varying degrees of restraint.

Despite the fact that the continuous reinforcement group (100%) received twice as many reinforced trials as the standard partial reinforcement group (R-50%) their acquisition performance levels did not differ reliably, i.e., no PRE of the type usually obtained with human Ss was observed in acquisition. This outcome is similar to the results of several studies where the effects of partial reinforcement on classical conditioning were investigated in infra-humans (cf., Wyers, et al., 1964; Fitzgerald, Vardaris, & Brown, 1966; Slivka & Bitterman, 1966; Vardaris, 1967). As was indicated previously, such results are not consistent with the widely accepted view that conditioning performance is a positive function of the number or porportion of reinforced trials (Hull, 1943; Spence, 1956). For example, it would be predicted from the usual assumptions concerning the effects of the number of reinforcements in acquisition, that a group given partial reinforcement (with the US omitted on nonreinforced trials) would exhibit lower asymptotic levels of performance than a group given the same number of trials with continuous reinforcement (Spence, 1956). However, for a very large number of trials, the partial reinforcement group might be expected to reach the same asymptotic level as the group given continuous reinforcement, with the rate of approach to asymptote being slower for partial than for continuous reinforcement (Spence, 1956).

One of the groups that received partial reinforcement with the US present on nonreinforced trials (RU-50%) performed at reliably lower levels than the continuous reinforcement group and the group given partial reinforcement with the US omitted on nonreinforced trials. It may be recalled that the groups which received partial reinforcement with the US present on nonreinforced trials were included in the experimental design to provide conditions where motivational level and stimulus aftereffects were equated for partial and continuous reinforcement. It has been assumed (Spence, 1963, 1966) that the presence of the US on nonreinforced trials during partial reinforcement would tend to elevate performance relative to that of a partial reinforcement group receiving nonreinforced trials with the US omitted. A similar effect would be predicted from the stimulus-generalization decrement hypothesis (Mowrer & Jones, 1945; Sheffield, 1949) since the presence of the US on nonreinforced trials presumably would make the stimulus aftereffects of such trials more like those of reinforced trials than would be the case for partial reinforcement with the US omitted. That is, lower performance levels might be expected for a standard partial reinforcement group because of the generalization decrement resulting from a reduced effective CS after nonreinforced trials with the US omitted. Obviously, the result obtained was inconsistent with both of these theoretical notions.

Although there are rather important methodological differences between the present investigation and the one by Moore and

Gormezano (1963) which was discussed previously, it is possible to consider certain similarities in the results of the two studies. In a standard human eyelid conditioning situation, Moore and Gormezano compared 25%, 50%, and 75% partial reinforcement of the US-omitted type with the same percentages of reinforcement where nonreinforcement was provided by the delayed-US technique. It was found that the delayed-US method led to lower levels of performance in acquisition and extinction than did omission of the US on nonreinforced trials. It was concluded that US-delay did not have the same effect as omitting the US, i.e., there appeared to be some inhibitory factor operating over and above non-contiguity of CS and US under the former conditions. Certain results were cited (Reynolds, 1958; Ross, 1959; Ross & Spence, 1960) where the conditioning performance of continuous reinforcement groups was superior to that of groups given partial reinforcement with the delayed-US technique. It was suggested that the use of nonreinforced trials with the US delayed in these studies may have resulted in over-estimation of the depressing effects of partial reinforcement during acquisition. As to the mechanism of these effects, it was hypothesized that delaying the US on nonreinforced trials may lead to the conditioning of a response that is incompatible with the eyelid CR. A basic assumption was that the presentation of the US results in a covert emotional response (r_e) having a long latency and certain stimulus consequences. For a continuous reinforcement group this r_e would occur after the termination of each trial. The response-produced stimulation from r_e elicits incompatible responses which also occur after each trial. Therefore, for a continuous reinforcement group being trained with a relatively short CS-US interval, the incompatible responses are never reinforced by the US. However, in the case of partial reinforcement with the delayed-US technique, the long-latency r_e may occur in the long CS-US interval. When this happens the response-produced stimulation from r_e elicits the competing response such that it is reinforced by the US and may become conditioned. In contrast, partial reinforcement with the US omitted on nonreinforced trials does not provide the conditions where such a competing response would be reinforced.

It has been mentioned that the delayed-US technique may be regarded as a special case of the interpolated-US method which was used in the present investigation. The above theoretical formulation is applicable to the results of the present study only to the extent that the two techniques of nonreinforcement (and other experimental conditions) were similar. It should be noted that the CS-US intervals on nonreinforced trials for group RU-50% were considerably longer than for the delayed-US groups in the study by Moore and Gormezano (85, 90, or 95 sec. vs. 2400 msec.). Since the exact latency of r_e was not specified, it is difficult to evaluate the applicability of the model to the present results on the basis of similarities or discrepancies in CS-US interval. However, it may be recalled that the conditioning control group (C) received a sequence of stimuli such that the CS-US intervals were identical to those on nonreinforced trials with the US present in the partial reinforcement schedule for group RU-50%. Therefore, any tendency for incompatible responses to be conditioned during these long CS-US intervals might be revealed as a gradual decrease in performance for the control group during acquisiton. As has been pointed out previously, no such consistent changes were observed. This suggests that there was little or no conditioning of incompatible responses on nonreinforced trials with the US present. An alternative interpretation would be that incompatible responses actually were conditioned and acted to suppress decelerative responses in the control group and in the RU-50% group. The result of such influences would be consistent with the observations--lower performance levels for RU-50% and no apparent change in the control group performance.

It should be noted at this point that Rescorla's formulation, which was discussed previously, could conceivably explain the depressed performance of group RU-50% during acquisition. Essentially his assumption was that Ss learn that the CS signals a "safe" period on nonreinforced trials with the US present. Since the conditioning schedule for RU-50% contained such trials it is possible that this type of learning occurred during conditioning. If that were the case, then the performance of the RU-50% group might be expected to reflect an algebraic summation of excitatory and inhibitory tendencies which were being built up during acquisition. The performance would then be at some intermediate level between that of the standard partial reinforcement group and the conditioning control group. The relationships between the actual performance levels of these three groups are consistent with this prediction. However, as has been mentioned previously, examination of the control group performance revealed no evidence of a gradually acquired inhibitory tendency during the training period. Although there was no direct evidence of this type of inhibition in the control group performance, the possibility remains that the acquired inhibition acted to prevent change as such, i.e., the inhibitory tendency may have depressed performance for RU-50% without exerting an observable effect on the performance of the control group.

Although both the RU-50% and RC-50% groups received partial reinforcement with the US present on nonreinforced trials, only RU-50% exhibited acquisiton performance levels that were reliably different from those of the continuous reinforcement group and the group given partial reinforcement with the US omitted on nonreinforced trials. It may be recalled that the US-US intervals were the same for the RC-50% and 100% groups, but differed for the RU-50% and 100% groups. Since the performance of RU-50% was lower than that of 100%, there is some indication that US-US interval may have been an important factor in determining acquisition performance levels. However, this outcome is somewhat ambiguous due to the fact that there was no reliable difference in performance between the RU-50% and RC-50% groups.

Extinction

There was a reliable decrement in performance as a function of extinction trials, although the terminal extinction levels for the conditioning groups were somewhat higher than that of the control group. In the experiment by Fitzgerald, Vardaris, and Brown (1966) there was little evidence of decreasing performance during extinction. It may be mentioned that the present experiment included six more extinction trials than in the study by Fitzgerald, et al., but this relatively small difference in number of trials does not seem adequate to account for the divergent results. Possibly the difference in extinction performance is attributable to other procedural variations between the two studies.

It has been shown that the significant overall differences in mean performance levels during extinction were similar to the overall differences during acquisition. In the interest of unambiguous interpretation, it seemed adviseable to analyze the extinction data such that the effects of differential acquisition performance were controlled. It may be recalled that this was accomplished by analyses of covariance, with acquisition asymptote as the covariate and slope of the extinction curves for individual Ss as the criterion variate. Significant effects then represented differences in slope or rate of extinction.

Previously it was pointed out that the extinction PRE is usually defined in terms of differences in mean performance, with a partial reinforcement group performing at higher levels than a group given continuous reinforcement. In order to determine whether a PRE was present in the extinction data, significant differences in slope were regarded as reflecting similar differences in mean performance levels. This was made possible by the analysis of covariance technique which, in effect, equated the extinction curves for point of origin (acquisition asymptote). It will be recognized that if such curves differ reliably in slope, there must also be a significant difference in mean levels. In more specific terms, a difference between treatment groups in rate of extinction indicates that the groups also differ in overall mean level, and both differences may be regarded as reflecting differential resistance to extinction.

From a preliminary regression analysis it was learned that rate of extinction was a negative linear function of acquisition asymptote. In other words, the higher the acquisition asymptote, the more negative the slope of the extinction curve. Therefore it was concluded that acquisition performance levels influenced slope of the extinction curves as well as the mean performance levels during extinction and that analyses of covariance were appropriate under these circumstances.

An analysis of covariance was done on the slopes and asymptotes of the 4 conditioning groups. The results of this analysis indicated that there were reliable differences in resistance to extinction among the groups even though the differential influence of acquisition asymptote had been removed. Further analyses were aimed at detecting possible differences in resistance to extinction between the 4 conditioning groups when they were compared two at a time. It was found that the continuous reinforcement and standard partial reinforcement groups did not differ reliably in rate of extinction. This outcome is similar to the findings of other experiments on infra-humans where either there was no evidence of an extinction PRE or the evidence was ambiguous (cf., Berger, et al., 1965; Fitzgerald, 1966; Vardaris, 1967). However, the results of the present investigation for standard partial reinforcement are inconsistent with other results where frequency of reinforcement in acquisition did affect resistance to extinction differentially

(Gonzales, Eskin, & Bitterman, 1963; Wyers, et al., 1964; Peeke, et al., 1965; Fitzgerald, Vardaris, & Teyler, 1966; Kimmel & Yarenko, 1966; Wagner, et al., 1967). It may be mentioned at this point that the experiments by Gonzales, et al., Fitzgerald, et al., and Kimmel & Yarenko all equated motivational level between continuous and partial reinforcement groups by means of the matched reinforcements technique. Since the number of studies in which motivation level was controlled is equal to the number where this variable was not controlled, it appears unlikely that an unambiguous PRE in extinction depends solely on equated motivational level.

For the current study, where a condition for equating motivational level was also provided, the groups given partial reinforcement with the US present on nonreinforced trials during acquisition exhibited a slower rate of extinction than the group receiving continuous reinforcement in acquisition. This outcome may be regarded as clear evidence of an extinction PRE; there was increased resistance to extinction after partial reinforcement when the US was present on nonreinforced acquisition trials. Since these groups also showed greater resistance to extinction than the standard partial reinforcement group, the indication is that equating motivational level was a crucial variable for the PRE under the conditions of the present experiment. However, as was pointed out above, there is no clear evidence that equated motivational level is either necessary or sufficient for the occurrence of an unambiguous PRE in extinction when comparisons between the results of previous studies are made. That is, the PRE in extinction has been observed for studies where motivational level was controlled and for other investigations where there was no provision to equate motivation between continuous and partial reinforcement groups.

Of the two groups that received partial reinforcement with the US present, the interpolated-US group extinguished at a slower rate than the interpolated-CS group. This indicates that equating CS-CS interval between the continuous and partial reinforcement groups produced greater resistance to extinction as compared to a group where the intervals differed for continuous and partial reinforcement. It will be noted that this result is relevant to the stimulus-generalization decrement hypothesis. One of the assumptions of this hypothesis is that the effective CS on any given trial is in part determined by the intertrial (CS-CS) interval. That is, the perseverative aspects of stimulation from trial <u>n</u> become part of the effective CS complex on trial <u>n</u> + 1. Since these perseverative processes are assumed to decay over time, the influence of previous stimulus events on the effective CS complex for a given trial are a function of the length of the intertrial interval. It should be pointed out that the average intertrial interval for the interpolated-CS group was longer than that for the interpolated-US group. Therefore, it might be assumed that the effective CS complex for the interpolated-CS group was different from that of the interpolated-US group. From the assumptions of the stimulus-generalization hypothesis these groups might be expected to show differences in resistance to extinction, since there might be differential change in the CS complex from acquisition to extinction. However, it will be recalled that this type of change was controlled in the present experiment by providing separate extinction treatments where the

CS-CS interval was either the same or different from that in acquisition. These treatments did not affect rate of extinction differentially, and therefore the stimulus-generalization decrement hypothesis does not explain satisfactorily the increased resistance to extinction when CS-CS interval was equated. Nevertheless, it is conceivable that the difference in CS-CS intervals affected rate of extinction by some mechanism that has not been specified as yet.

The analysis of covariance revealed that the groups receiving extinction with the US present did not exhibit rates of performance decrement which were reliably different from those of the subgroups given extinction with the US omitted. Similarly, interpolated-CS vs. interpolated-US treatments during extinction did not influence slope differentially. It may be inferred from this set of results that only "historical" variables had a significant effect on resistance to extinction. That is, some of the acquisition treatments resulted in differential rates of extinction, but none of the experimental manipulations during extinction affected rate of extinction reliably.

For the present investigation the PRE in acquisition and extinction occurred only when the US was present on nonreinforced training trials. Under these conditions, the acquisition performance of the group given partial reinforcement was depressed relative to that of the continuous reinforcement group, and the partial reinforcement group showed greater resistance to extinction than did the group given continuous reinforcement. In contrast, no reliable differences in performance between the continuous reinforcement and standard partial reinforcement groups were observed either in acquisition or in extinction. Clearly the presence of the US on nonreinforced trials acted to depress performance during acquisition and yet produced increased resistance to extinction. This paradoxical result could be attributable to certain possible inhibitory effects of having the US present on nonreinforced trials during acquisition. It may be recalled that when various mechanisms for this possible inhibition were considered, it was concluded that the evidence of the present investigation did not support them unequivocably.

Including the current study, there have been only three reports of an unambiguous PRE both in acquisition and in extinction for aversive classical conditioning with infra-humans. Each study has employed a different specie of Ss: Gonzales, et al., (1963), used mouthbreeders; Fitzgerald, Vardaris, and Teyler, (1966) used dogs; and rats were used in the present case. Furthermore, the procedural variations among the three studies were rather considerable. As a result it is difficult to establish whether there were any treatments other than partial reinforcement which may have been common to the three investigations and which may account for the occurrence of the PRE. However, all of these studies provided some type of control for differences in motivational level between continuous and partial reinforcement groups. Although this similarity in the three studies is suggestive, it may not be assumed that the appearance of a PRE in acquisition and extinction depends on equated motivational levels, since the extinction PRE has been observed when this variable was not controlled.

SUMMARY

An experiment was conducted to determine the effects of partial reinforcement on a classically conditioned HR response in rats with motivational level and stimulus change controlled. Three percentages of reinforcement, 100%, 50%, and 0% were employed in acquisition. The following methods of partial reinforcement were compared: standard random partial reinforcement with the US omitted on nonreinforced trials; random partial reinforcement with the US present on nonreinforced trials and US-US intervals the same as in the continuous reinforcement schedule; random partial reinforcement with the US present on nonreinforced trials and CS-CS intervals the same as in the continuous reinforcement schedule. For each acquisition treatment extinction performance was observed under conditions of the US present or absent on extinction trials and CS-CS interval or US-US interval equated.

The CS was a 7-sec., 1-kHz. tone, and the US was a 1-sec., 1.8 mA electric shock. The CS-US interval was 6 sec., with the US overlapping the last second of the CS. A reinforced trial in acquisition was a paired presentation of CS and US, while a nonreinforced trial was either a presentation of the CS alone or a presentation of the CS followed by the US at the mid-point of the intertrial interval. One treatment group received 100% reinforced trials (continuous reinforcement) in acquisition, and a conditioning control group was given 100% nonreinforced trials where the US was interpolated at the mid-point of the intertrial interval. One of the partial reinforcement conditions involved random partial reinforcement where 50% of the trials were reinforced and the remaining

trials consisted of presentations of the CS alone. Another partial reinforcement treatment consisted of the same sequence of reinforced and nonreinforced trials, but on nonreinforced trials the US was interpolated at the mid-point of the intertrial interval such that the CS-CS intervals were the same as in the continuous reinforcement treatment. The third partial reinforcement treatment also involved the same reinforcement schedule, except in this case the US-US intervals were identical to those in the continuous reinforcement schedule. For extinction, each of the 5 acquisition groups was divided into 4 subgroups so that presence or absence of the US on extinction trials was made orthogonal to the interpolated-CS and interpolated-US methods of providing nonreinforcement in extinction. There were a total of 20 distinct treatment groups represented in extinction. The experiment was conducted in the following phases all of which occurred in one experimental session: adaptation, where 5 equally-spaced samples of basal HR were taken; habituation, in which HR responses to 20 presentations of the CS alone were recorded; acquisition, where 30 conditioning trials were given; extinction, in which there were 30 nonreinforced trials. All responses to stimuli were scored as differences in HR between the CS period and an equal pre-CS period. The principle findings were:

Adaptation

HR decreased slightly but reliably over the course of a 20-min. period of adaptation to restraint in the apparatus.

Habituation

The decelerative original response to the CS alone in habituation showed a significant decrease as a function of repeated presentations of this stimulus.

Acquisition

1) All 4 conditioning groups exhibited reliable increases in the magnitude of a decelerative CR as a function of training trials.
2) The partial reinforcement group having the US present on nonreinforced trials such that CS-CS intervals were the same as in the continuous reinforcement treatment performed at lower levels than the standard partial reinforcement group and the continuous reinforcement group.
3) There was no reliable difference in performance levels between the continuous reinforcement and standard partial reinforcement groups.

Extinction

1) All 4 conditioning groups exhibited reliable decrements in the magnitude of a decelerative CR as a function of nonreinforced trials in extinction.
2) The partial reinforcement groups given nonreinforced trials with the US present in acquisition both showed greater resistance to extinction than the continuous reinforcement group.

3) Of the two partial reinforcement groups showing increased resistance to extinction, the group having CS-CS intervals equated to those in the continuous reinforcement schedule during acquisition extinguished more gradually than the group with US-US intervals equated.

4) The continuous reinforcement and standard partial reinforcement groups did not differ in resistance to extinction.

5) The various extinction treatments (US present vs. US absent, and equated-US vs. equated-CS) did not affect resistance to extinction differentially.

These results were interpreted as indicating that the PRE in acquisition and extinction occurred only when partial reinforcement was given with the US present on nonreinforced trials. The results were discussed with regard to their relevance to the stimulus-generalization decrement hypothesis and the concept of motivational level.

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