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OPERANT RESPONSE EFFECTS AND HEART RATE UNDER TEMPORALLY DEFINED SCHEDULES OF SIGNALED ELECTRIC SHOCK

Petrus Franciscus Marie Kop

A dissertation submitted to the Graduate Faculty in Psychology
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ABSTRACT

OPERANT RESPONSE EFFECTS AND HEART RATE UNDER TEMPORALLY DEFINED SCHEDULES OF SIGNALED ELECTRIC SHOCK

Petrus Franciscus Marie Kop

Adviser: Professor William N. Schoenfeld

Two independent reinforcement probabilities, the first that a response (R) will result in the presentation of an electric shock, $p(S^{-R}|R)$, and the second that not responding ($\not R$) will result in shock presentation, $p(S^{-R}|\not R)$, have been applied to procedures of aversive control, so as to investigate possible relationships between hitherto procedurally unrelated schedules of negative reinforcement. Experiments were designed within the organizational framework of the t-system, in which an experimental session is subdivided into recurring time cycles (T) each of which is further divided into two alternating fixed periods: one period, t^D, during which a specified behavior specimen enables the reinforcement probability $p(S^{-R}|R)$ or $p(S^{-R}|\not R)$ and a second period, t^Δ, during which responses would have no experimental consequences. The 10 sec t^D periods occurred at the end of the 200 sec T-cycle, and were signaled by a visual stimulus. The reinforcing stimulus was a brief intense electric shock delivered at the end of the t^D period, depending on the behavior and the values of the $p(S^{-R}|R)$ and $p(S^{-R}|\not R)$ parameters.

Three groups of four Rhesus monkeys each were subjected to different sequences of procedures by systematically varying the two parameters $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$. All groups started with the combination $p(S^{-R}|R) = 0$ and $p(S^{-R}|\not{R}) = 1.0$, a procedure which closely resembles the "discriminated avoidance" condition, further to be notated as p(0, 1.0) the $p(S^{-R}|R)$ mentioned before the $p(S^{-R}|\not{R})$ value. After 1000 trials on p(0, 1.0), Group 1 was moved successively to parameter values of p(0.33, 1.0), p(0.67, 1.0), and then to p(1.0, 1.0) at which the procedure resembles the Pavlovian conditioning paradigm. After this procedure, the animals were subjected to procedures in which the $p(S^{-R}|\not{R})$ gradually decreased: p(1.0, 0.67), p(1.0, 0.33) and p(1.0, 0). The last set of values constitutes a "discriminated punishment" procedure. A second group received 1000 trials on each of the combinations p(0, 1.0), p(0, 0.67), p(0, 0.33) and p(0, 0). After the "extinction" procedure, the $p(S^{-R}|R)$ value was gradually increased through the $p(S^{-R}|R)$ parameter values of 0.33, 0.67, and 1.0 with $p(S^{-R}|\not{R})$ retained at zero. Group 3 received 1000 trials each of the combinations p(0, 1.0), p(0.33, 0.67), p(0.67, 0.33) and p(1.0, 0). After the "discriminated punishment" procedure all groups were returned to the original p(0, 1.0) combination for 1000 trials. Response rate measures were recorded for the entire T-cycle, and heart rate was taken during each t^D period of the last 100 trials.

The initial result of a higher shock probability for R was an increased response rate that gradually disappeared. Generally, response rates declined as the $p(S^{-R}|R)$ value increased. When responding would result in more shocks than not responding, response distributions during t^D indicated that most responses occurred at the beginning of the 10 sec period. When not responding would result in more shocks than responding, most responses occurred near the end of t^D.

Positively accelerated response patterns during t^Δ were observed under the p(0.33, 0) and p(0.67, 0) procedures. The accelerating response pattern during t^Δ could be observed even when the t^D response distribution was declining. When all animals were returned to the original avoidance condition (p(0, 1.0)) almost no recovery was observed for the group that had reached "discriminated punishment" through Pavlovian procedures, immediate recovery for the animals that had reached the p(1.0, 0) through "extinction" p(0, 0), and intermediate recovery for the animals for which both parameters had been varied simultaneously. The extent to which the responding and the shocks that had been delivered had been independent during preceding procedures, correlated highly with the number of trials to reach a criterion during the recovery phase. Heart rate during t^D was generally accelerated, even when the response distribution assumed a decreasing function.

Acknowledgements

I wish to thank Professor W. N. Schoenfeld for his continuous advice and guidance throughout the course of this study and the years that preceded it. The help of Drs. R. M. Kadden and A. G. Snapper is gratefully acknowledged; their assistance and patience made this study possible. I am grateful to more people than can be mentioned here for building apparatus, animal care-taking, drawing graphs, typing, editorial assistance and valuable suggestions. I am indebted to Professor J. Kremers, Katholieke Universiteit, Nijmegen, for opportunities provided and continuous interest.

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TABLE OF CONTENTS

Page

The experimental paradigm

Historically, several procedures have been devised to investigate the effects of aversive stimulation on behavior. Early workers, like Pavlov and Watson, measured a variety of responses during "neutral" stimuli which were, or had been, paired with the aversive event. The presentation of paired stimuli was by a schedule determined by the experimenter. Later investigators introduced "contingent" procedures in which the presentation of the aversive stimulus depended on some aspect of the behavior of the subject (the "response"). Some procedures, e.g., discriminated avoidance, prescribed that the aversive stimulus would follow the neutral stimulus only if no response was made during the latter stimulus. Other procedures, e.g., discriminated punishment, scheduled the presentation of the aversive stimulus only if a response were made in the presence of the neutral stimulus. These two schedules can each be considered to occupy one extreme of an intermittency continuum in which not every response during the neutral stimulus results in the presentation or the omission of the aversive event. The schedules are similar, however, in that it is the subject's behavior that determines the occurrence of the aversive stimulus. Another series of procedures has as one limiting case those schedules, such as Pavlovian conditioning, in which the aversive stimulus is always presented regardless of the responding during the neutral stimulus; the other extreme of this continuum is the "extinction" schedule in which aversive stimuli are no longer scheduled.

The validity of experiments in which a subject's behavior determines the presentation of stimuli relies heavily on an adequate classification of responding. Since behavior is a continuous process, it is desirable that response definitions be broad enough to cover as much of the behavioral spectrum as possible. In response-contingent procedures, the determining behavior itself is the datum of interest. In order to measure the effects of stimulus presentations on the behavior of the subject, a discrete classification system needs to be imposed upon the behavior. On the one hand, the definition of a response should include the greatest possible variety of behavior, so as to implement dependency completely, and on the other hand, a response definition should be precise enough to make refined measurement of the effect of the independent variable possible.

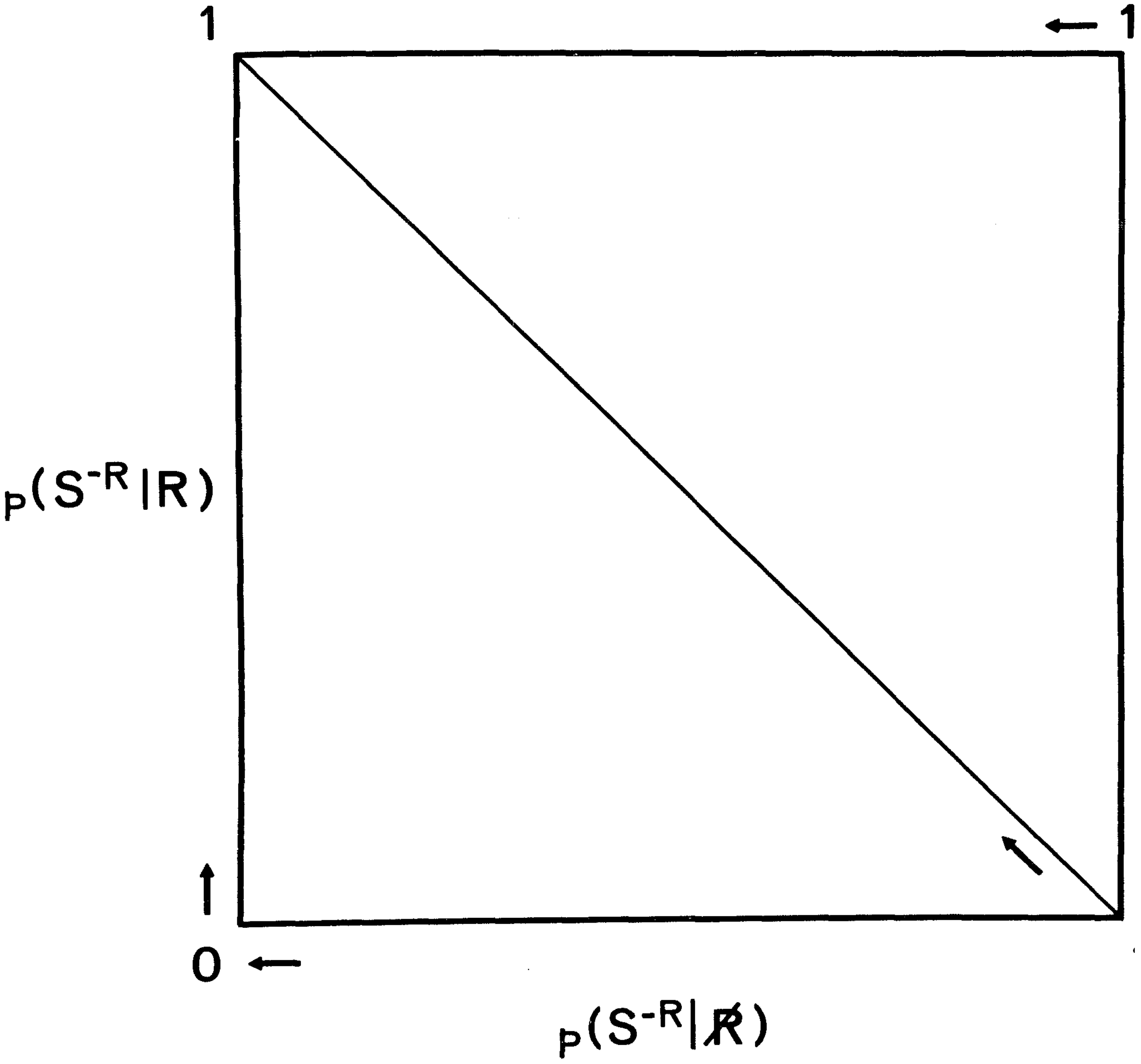
Recently, Schoenfeld and Farmer (1970) have proposed to record not only the experimentally specified response (R), but also occurrences of no responding (not-R, or $\not{R}$) defined as time periods in which R does not appear. The classes R and $\not{R}$ are independent, and independent contingency procedures for them may be in effect simultaneously. Although these two response classes can be considered as exhausting the behavior stream, they by no means enumerate all the features that ongoing behavior may have. Scheduling of dependencies usually results in a close temporal relationship between a predetermined aspect of the behavior and the presentation of experimental stimuli. Temporal relationships may exist, however, regardless of the monitoring of the stimuli by the experimenter. Cyclical biological systems, e.g., EEG, breathing and heart rate, are inevitably in a close relationship with experimental stimuli, and, therefore may also undergo changes. As parts of the behavior become related to the environmental stimuli, the response class upon which the presentation of experimental stimuli is made "contingent" is said to be conditioned in a response-dependent manner.

Schoenfeld, Cumming & Hearst (1956) have presented a system in which stimuli and responses are brought into a temporally organized framework. This system divides an experimental session into recurring time cycles (T), each divided into two usually alternating fixed periods: one period, t^D, during which R determines the stimulus presentation schedule, and a second period, t^Δ, during which R affects the experimental program to a lesser degree, or not at all. The probability values with which R results in stimulus presentation remain constant throughout the t^D and t^Δ periods.

More recently, some investigators (e.g., Catania, 1969; Church, 1969; Gibbon, 1970) have attempted to relate the literature of classic schedules of aversive control by means of a contingency space defined by two independent dimensions: the probability of stimulus presentation given a response, and the probability that not-responding will result in presentation of the stimulus. Similarly, Seligman, Maier, & Solomon (1971) have described a "predictability" space bounded by the probability that a neutral stimulus (CS) will be terminated with an aversive stimulus (S^{-R}), and the probability that an aversive stimulus will be presented in the absence of the CS.

These probability parameters may be combined with the scheduling procedure of the t-system. If the presentation of a brief intense electric shock (S^{-R}) is set at the end of the t^D period, and if the t^D period is accompanied by a neutral stimulus, then a variety of aversive schedules may be generated by varying the probability of S^{-R}

Figure 1. Contingency space defined by $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ for all values of p. The coordinates of any point in the space will be notated by their relation to the ordinate and abcissa, in that order; e.g., in p(0.33, 0.67), the $p(S^{-R}|R)$ is mentioned before $p(S^{-R}|\not{R})$. The classical schedules of aversive control are at the corners of the square: p(0, 1.0) yields "discriminated avoidance", p(1.0, 1.0) is Pavlovian conditioning, p(0, 0) is "extinction", and p(1.0, 0) is "discriminated punishment". The diagonal describes the set of simultaneous inverse variations of $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ ranging between zero and unity. The arrows indicate the three directions employed in this experiment to travel from "avoidance", p(0, 1.0), to "punishment", p(1.0, 0).


1
1
p(S-R|R)
0
p(S-R|R̸)

occurrence given a response during the signal, $p(S^{-R}|R)$, and by varying the probability of S^{-R} occurrence if no response is made during the signal, $p(S^{-R}|\not{R})$. Discriminated avoidance is a procedure that omits presentation of S^{-R} if a response has occurred during the signal; this condition may be described as the zero-probability of S^{-R} given a response in t^D, or $p(S^{-R}|R) = 0$. When no response occurs in t^D, the discriminated avoidance procedure provides for presentation of an aversive stimulus: $p(S^{-R}|R) = 1$. Similarly, in Pavlovian conditioning an S^{-R} will always be presented for both R and $\not{R}$ occurrences in t^D: $p(S^{-R}|R) = p(S^{-R}|\not{R}) = 1$.

The restrictions employed in the present experimental design, that the t^D period be a fixed part of the t-cycle, that the neutral stimulus remain on for the entire duration of t^D, and that shocks be delivered at the end of t^D, implies that the temporal relation between response during t^D and S^{-R} depends on the S's responding only. The condition designated as p(0, 1.0) resembles "discriminated avoidance" in that the impending S^{-R} is preceded by a signal during which a response may prevent the occurrence of S^{-R}. Such a response need not, as is usually the case in discriminated avoidance procedures, terminate the signal. Neither would a response in the absence of a stimulus (i.e., during t^{Δ}) postpone the onset of the following neutral stimulus or the occurrence of the next S^{-R}, as is often programmed for the free-operant variety of discriminated avoidance schedules (Sidman, 1955).

CS in Avoidance

Although the free-operant avoidance procedure has been successfully employed without a stimulus preceding the impending S^{-R} in bar-press situations (e.g., Sidman, 1953), shuttle box (e.g., Bolles & Grossen, 1969; Rescorla, 1968), and wheel turning (e.g., Verhave, 1959), the literature indicates that acquisition is more rapid in discriminated avoidance than in non-discriminated. Although responses before the stimulus onset would postpone the onset of the stimulus as well as the occurrence of the shock, the addition of a neutral stimulus preceding the aversive stimulus is reported to result in a shift of the response distribution into the stimulus period, with a decrease in responding in the absence of the stimulus (Sidman, 1955). When the neutral stimulus has signaled a period during which a response does not postpone the occurrence of a shock, a shift of responding in the reverse direction has been reported, resulting in an increased rate in the non-stimulus period (Sidman & Boren, 1957a). A decrease of responding during the stimulus period becomes also evident when responding during the stimulus is less likely to postpone the shock than responding prior to stimulus onset (Sidman & Boren, 1957b); a return to the increased rates during the stimulus has been obtained when the stimulus duration was made independent of responding and shock delivery (Sidman & Boren, 1957c).

In general, differential response rates before and during the stimulus can be manipulated by varying the programmed stimulus availability in the stimulus and non-stimulus periods (Sidman, 1957).

The discriminated avoidance literature contains relatively few experiments in which the duration of CS is independent of the responding of the subject. The procedures that do not allow termination of the warning stimulus by a response have sometimes been viewed as "extinction" methods (e.g., Kamin, 1956). Investigators who employed procedures in which the termination of the neutral stimulus by a response was delayed, report that the rate of avoidance responses dropped under these conditions. Many of the experiments in this category, however, have been done in shuttle boxes, and in most cases the shuttle box procedures allow a response to terminate S^{-R} once the subject has permitted its onset by his failure to respond during the neutral stimulus (e.g., Bolles & Grossen, 1969; Bolles & Grossen, 1970; Kamin, 1956; Kamin, 1957a; Kamin, 1957b; Katzev, 1967; Reynierse & Rizley, 1970). Although Bolles, Stokes, & Younger (1966) found that termination of the CS by a response did not significantly contribute to avoidance acquisition in a shuttle box when a brief inescapable electric shock was employed, no parallel studies are known with the bar press response. Moreover, the shuttle box avoidance-escape experiments all report impairment of avoidance when a response during CS does not immediately terminate the CS. One study (Verhave, 1959), employing the avoidance-escape procedure in a wheel turning apparatus, reported that the effect of delaying the termination of the CS upon avoidance responding eventually disappeared, although throughout the experiment greater variability remained evident for animals under the delayed termination procedure.

In general, when a stimulus cannot immediately be terminated by a response, avoidance behavior has been shown to be impaired if the original avoidance training included CS termination.

Hyman (1969) showed that the CS duration is of little importance once a stable avoidance rate has been reached. Biederman (1969) showed that CS duration may affect avoidance behavior, but that the CS duration under which avoidance behavior had been trained did not influence the later performance under other CS durations. Elimination of the CS reduced avoidance behavior, but resulted in an increase in intertrial responding. Hyman (1971) proved that removal of the CS after rhesus monkeys had achieved stable behavior on a discriminated avoidance schedule resulted in increased response rates, a higher shock frequency, and a shift to shorter interresponse times. Biederman (1969) reported that the addition of a CS after training on non-discriminated avoidance resulted in decreased response rates and lower shock frequency. The use of a CS thus appears to enhance the acquisition of avoidance behavior as well as sustain avoidance behavior once it is acquired.

Behavior during the CS may be affected by the type of shock used and the presence of an escape contingency during discriminated avoidance. Hurwitz (1964) ran one group of rats that could avoid or escape a continuous electric shock that was preceded by a 7.5 sec light, while a second group received pulsed shocks under the same conditions. The latter group reached a high level of avoidance responding, but the first group resorted mainly to allowing the shock to come on and then to terminating it. When the shock for the first group was made inescapable (10 sec), the subjects turned almost exclusively to avoidance during the preceding stimulus.

One of the very few investigations within the t-system on the location of the CS during avoidance conditioning was done by Hurwitz, Dillow & DeNise (1971). These investigators trained rats on a temporally defined schedule in which responding during t^{Δ} had no effect, while responding in t^{D} would prevent the occurrence of an otherwise escapable shock (2.5 sec) at the end of t^{D}. When a signal accompanied the t^{D} period, the response rate dropped considerably when a response was allowed to terminate the signal; the number of avoided shocks decreased slightly. When only a brief signal at the beginning or the middle of t^{D} was presented, the avoidance rates increased again, but the number of t^{D} periods in which no shocks were delivered did not alter significantly. When the brief signal was presented at the end of t^{D}, preceding the shock, fewer shocks were avoided and the rates in both t^{D} and t^{Δ} dropped. The investigators concluded that brief stimuli regardless of their proximity to the shock are ineffective in controlling avoidance behavior. After retraining on the original discriminated avoidance procedure, some of the subjects were submitted to a procedure in which the signal during t^{D} could not be terminated, although a response would avoid or terminate the shock. Under this condition, discriminative control of responding was observed, but avoidance responding could not be maintained at the original level.

Bolles & Grossen (1969) have suggested that the CS in discriminative avoidance has an "informational" value. A brief signal at some distance preceding the shock was shown to have a similar effect as a warning signal that stayed on until a response or shock occurred. These authors also presented data to show that the end of a "safe" period, during which no shocks would be scheduled, would have as much informational value as the onset of a warning signal (Bolles & Grossen, 1970;

Bolles, Hargrave & Grossen, 1970). They argue, in the same vein, that the reinforcement would come from the onset of the "safe" period rather than from the termination of the warning signal. Gilbert (1971) used separate signaled safe and warning periods during a lever press avoidance-escape schedule. He observed that the probability of lever pressing increased at the onset of the warning stimulus; when the warning stimulus was eliminated, responding increased at the offset of the safe signal. Avoidance behavior during the "safe" period increased when neither signal was available.

The duration of the CS and its location with respect to the shock determine the local response rates in different parts of the unsignaled and "safe" periods and during the CS. The length of the CS itself is of minor importance beyond a minimal value.

Extinction

The most common extinction procedure used in the aversive control literature is the one where S^{-R} is eliminated from the experiment. There is some disagreement about the precise meaning of the word "extinction". It usually means elimination of the stimulus that has been used as the reinforcer. A somewhat broader definition describes an "extinction procedure" as one in which the dependencies of stimulus delivery and responses are removed. The extinction procedure for avoidance behavior is sometimes thought to be the reversal of the contingencies (i.e., the response does not prevent a programmed S^{-R}), whereas during the conditioning of avoidance behavior responding postpones stimulus presentation or prevents it (e.g., Rosen & Smith, 1970).

Difficulties with the precise definition of avoidance (Schoenfeld, 1969) may be at the root of the diversity of extinction procedures in aversive control studies. In extinction procedures in which no UCS is delivered for a failure to respond, the frequency of $\not{R}$-periods is of importance. If preceded by extensive training under avoidance schedules, the procedure may not result in a rapid decline of response rates (e.g., Solomon & Wynne, 1954). If, on the other hand, shocks are delivered independently of responding, it may be expected that responding would cease if it resulted in a substantial increase in shock frequency, as compared with the original avoidance procedure. Some experimenters (e.g., Kelleher, Riddle & Cook, 1963; Sidman, Herrnstein & Conrad, 1957) have shown, however, that responding may be maintained for long periods of time by response-independent shocks only. In the case of a preceding discriminated avoidance training, response-independent shock presentation would result in a Pavlovian conditioning procedure. In the first procedure, in which no shocks are ever presented, the dependencies for R are eliminated; in the latter, the dependencies for $\not{R}$ are abolished. For both procedures, $p(S^{-R}|R) = p(S^{-R}|\not{R})$. This relationship holds for any combination of parameter values, falling on the diagonal from p(0, 0) to p(1.0, 1.0) in Figure 1. Since neither responding nor not-responding affects shock frequency, Seligman et al. (1971) have called this line the line of "uncontrollability". If extinction is defined as removal of the contingencies, and the contingency square of Figure 1 is accepted, with the binary division of behavior in R and $\not{R}$ as representing all possible behaviors, the "uncontrollability" line describes the possible range of extinction procedures. When the extinction procedure involves the elimination of S^{-R}, avoidance behavior is said to be very persistent (e.g., Brogden, Lipmann & Culler, 1938; Brush, Brush & Solomon, 1955; Solomon, Kamin & Wynne, 1953; Solomon & Wynne, 1954). An analogy is presented with the "superstitious" behavior described by Skinner (1948), and it may be presumed that, in avoidance extinction as well, detailed features of the behavior are likely to change before responding eventually drops out.

Kimble & Kendall (1953) attempted two methods of extinction of discriminated avoidance. The "exhaustion" method required that all experimental stimuli except S^{-R} be presented, while the "toleration" method prescribed that S^{-R} be eliminated and that the CS initially be presented at low intensities and in successive trials have its intensity gradually increased until the original value was reached. This was followed by "exhaustion" trials as in the former group. When the CS had reached its original level, the regular "exhaustion" method was applied. The "toleration" group responded less in all extinction trials than the first group in the "exhaustion" trials only. These results have been replicated by Weiss & Monohan (1968). Kamin (1956) has argued that the termination of the stimulus itself may become a source for the maintenance of responding in extinction. Owen, (1963) produced results showing that CS continuation resulted in faster extinction of a rat's running responses than when those responses terminated the CS. Similar results are reported by Katzev (1967): response rates barely declined in an extinction procedure in which no shocks were delivered but all other experimental conditions remained the same. The second group in Katzev's experiment underwent an extinction procedure in which responses delayed CS offset by 20 sec, while on $\not{R}$-trials the CS ended after 5 sec. The latter group showed rapidly declining response rates. The amount of delay of CS termination was shown to be in inverse relation to the number of responses in extinction. The variability in response rates increased for the first group, but stable response rates were obtained when responses delayed CS offset. Similar results have been obtained by Delprato (1969). Kamin's (1957a, 1957b) gradient of delayed CS termination of avoidance in acquisition may be valid for extinction.

In Katzev's (1967) procedure, responding postponed termination of the CS, and when no responses were emitted, the CS was terminated after a fixed time. Davenport & Olsen (1968), in an escape-avoidance experiment, eliminated the original avoidance contingency during extinction, i.e., the response would only terminate the CS after the US had come on, changing the avoidance-escape procedure into an escape procedure during extinction. Animals trained under long CS durations showed better acquisition than when short CSs were employed, but these animals also showed higher response rates in the CS during the first extinction sessions. After a few extinction sessions, all Ss reached comparable response levels as their counterparts that had been trained on an escape-only procedure. The equivalent extinction procedure for non-discriminated free operant avoidance (ineffectiveness of the response to postpone brief shocks) has been shown to produce rapid extinction when a reasonable avoidance level was acquired during training (Davenport, Roger & Spector, 1970). Marsh & Paulson (1968) showed that the results obtained by Katzev could be replicated in goldfish. In addition, these investigators report that no rapid decrement in responding could be observed under the delayed CS offset and shock omission extinction procedure, when shocks were omitted on some trials during training and CS termination occurred with a delay of 20 sec after the response.

The conclusion from the preceding studies is that elimination of both response-dependencies, CS termination and shock avoidance, produces rapid response decrements, especially when these response dependencies have been in effect continuously throughout the training period.

Reminiscent of the "extinction" procedures is the recent treatment of Pavlovian conditioning by Rescorla (1967). He has argued for a "truly random control" group in which he believes it possible that CS and US be distributed randomly and independent of each other throughout a session. Previous control procedures, according to Rescorla, were only concerned with eliminating CS-UCS contingency. The implication is that a control procedure may not include cases in which CS and US are paired, where "pairing" is defined by an arbitrary temporal criterion. Rescorla's control procedure removes the "contingency" by scheduling the CS and the US independent of each other. When conditioning occurs, it occurs through a contingency relationship between CS and US, according to this theorist, and removal of the relationship produces the logical reference point against which all conditioning has to be evaluated. Nevertheless, no matter how non-contingent procedures are produced, they will always (given a limited session duration) result in a _post hoc_ specifiable temporal relationship between CS and US, and one may speculate that a frequency distribution of CS-US temporal relationships would produce a reliable predictor of conditioned responding. Rescorla has argued that the "truly random control" procedure may also serve as an unbiased extinction procedure, since it would remove the contingent aspects of the procedure, while leaving the "non-associative effects" intact. If "contingent" means that the CS predicts the US with various probabilities and various temporal relationships, the "truly random control" procedure is valid only if all temporal relationships occur and have the same probability of occurrence. A similar argument can be made for the "inhibitory" procedures in Pavlovian conditioning, where the CS would predict that the US would not occur: the "truly random control" procedure would teach the animal that the occurrence of the CS is irrelevant to the occurrence of the US.

Rescorla (1968, 1969) and others (Bull & Overmier, 1968; Ayres & Quincy, 1970), have produced results showing that no conditioning occurs under the "truly random control" procedure, but that suppression could be observed in a CER control procedure if the probability that a US would occur during a CS was reduced to zero ("explicitly unpaired"). One may raise the question whether or not a CER paradigm is similar to Pavlovian conditioning, but more important objections have been heard from investigators who have been less than successful in obtaining unchanged response rates during the CS from the "truly random control" procedure. Kremer and Kamin (1970, 1971) have obtained suppression during a CER experiment for a "truly random control" group, whereas only transitory suppression was observed for an "explicitly unpaired" group. The suppression in the "truly random group" was retained over 20 days and could be manipulated by CS modality and duration. Considering the numerous failures to obtain positive results with very long trace conditioning intervals in which contingency is maximal but contiguity minimal, the temporal relationship may well be considered more important than the "contingency" relationship. Benedict & Ayres (1971) found that, in a "truly random" procedure, conditioning did not covary with the number of pairings (US during the CS), or with the separate frequencies of CS and US. However, conditioning did occur when more pairings were given in the beginning of the session than chance would dictate, even if the total number of pairings was less than for a group that received pairings only in the middle and the end of the session. In these studies close temporal relation between CS and US in early training seemed to be critical. The same authors (Benedict & Ayres, 1971) also found that the "truly random" procedure does not produce extinction, whereas other control procedures do. This result is comparable with the observation that response-independent shocks alone may maintain previously established avoidance behavior (Sidman *et al*., 1957).

Discriminated Punishment

The procedure described by $p(S^{-R}|R) = 1$ and $p(S^{-R}|\not{R}) = 0$ may be called a punishment procedure, or, if the t^D period (during which shocks are produced by responses) is accompanied by a signal, a "discriminated punishment" procedure. The literature on discriminated punishment (e.g., Dinsmoor, 1952; Hunt & Brady, 1955) frequently reports that response rates are reduced during a stimulus in whose presence responses are followed by shocks, even when an intermittent punishment schedule is applied (e.g., Azrin, 1956). Azrin & Holz (1966) alternated periods in which responses resulted in shocks with periods in which responses were not punished; the responding was sustained on a variable interval (VI) food-reinforcement schedule. When shocks were initially introduced, responding was suppressed under both conditions. After 15 sessions, responding was restored under both components, but rates were higher during the non-punishment component, and responding re-appeared much later under the punishment component. Boe (1971) found no difference between fixed-ratio (FR) and variable ratio (VR) punishment schedules.

When response-dependent shocks are presented with some delay between response and shock, response rates are reported to vary directly with the amount of delay between response and shock, (Cohen, 1968; Kamin, 1959; Randall & Riccio, 1969; Solomon, Turner & Lessac, 1968).

When response-dependent shocks are introduced on a avoidance baseline, the response rates are observed to increase, at least initially, if the shocks are programmed on a fixed interval (FI) schedule (e.g., McKearney, 1968). When low valued FR schedules of response-dependent shocks are programmed, response rates are reported to decrease (Jones, 1969; McIntire, Davis, Cohen & Franch, 1968; Powell & Morris, 1969; Sandler, Davidson & Holzschuh, 1966).

Generally speaking, the introduction of a punishment contingency to behavior established by an avoidance procedure, results in decreased response rates. Increased response rates, or maintained responding has been reported only for periodic punishment schedules. Kadden (1971) observed that periodic response-dependent shocks yielded higher response rates than aperiodic punishment schedules. Response-independent shocks, according to this investigator, resulted in initial increased response rates, and the extent of the increase was directly related to the variability in the distribution of the response-independent shocks.

Rationale for current study

The contingency square of Figure 1, combined with the t-system, invites investigation. The $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ parameters allow systematic investigation of aversive schedules which hitherto have been seen as disparate procedures. The t-system enables the investigation of behavior not sustained by additional schedules or baselines. This eliminates certain problems involved in CER studies, where the behavioral consequences of response-independent shock affect the stimulus delivery schedule of the baseline schedule. The behavioral effects during t^D may reflect the combination of the two parameter values. The behavior during t^Δ, while not affecting the stimulus delivery schedule, may still reflect the presentation of the experimental stimuli at the end of t^D. When a relatively short t^D period is accompanied by a signal, response distributions during t^D may present additional information about the effects of the combinations of parameter values. Patterns of responding during t^Δ may develop for response-independent stimulus presentation schedules.

Method

Subjects

Twelve experimentally naive Rhesus monkeys (Maccaca mulatta) obtained from a commercial importer served as subjects. The animals had been living in individual cages in the vivarium of the laboratory for at least 6 months before the beginning of the experiment. They were maintained on a diet of 165 grams of banana biscuits (Rockland Laboratory Primate Diet), supplemented with one half apple a day. Water was always available during non-experimental hours. Tuberculin testing, as well as for other diseases, had been carried out at regular intervals. The animals were estimated to be two to three years old at the start of the experiment.

Apparatus

For the duration of the experiment, subjects were in restraint chairs (BRS Foringer, PC-002) equipped additionally with a thoracic plate. Four of the available chairs were permanently installed in wooden enclosures (BRS Foringer, PHC-002) lined with Armstrong Cushiontone accoustic tile; the remaining chairs were normally located in the vivarium, but for experimental sessions were wheeled into isolation booths similar to those of the other four subjects. All isolation booths were equipped with an exhaust fan, and an overhead speaker (Quam, 901B, 3.2 ohms) driven by a Grason Stadler white noise generator (901B) set at 10 db below 1.5 V.

Visual stimuli were provided by a set of indicator lights (Dialco, 24 V., 101-3830-0975-201, with No 327 bulbs) mounted on a minibox and positioned about 20 cm in front of the subject's face during sessions. The minibox contained two rows of lights. The top row consisted of two blue Dialco lights on each side and a red light in the middle, separated 3 cm, center-to-center. The blue lights served as session lights and remained lit for the duration of the session; the red light served as response light and stayed on as long as the response manipulandum was dislocated from its center position. The lower row of lights, 3 cm under the top row, consisted of five white lights, 2 cm apart center-to-center, which were lit during the t^D period of each t-cycle.

A General Electric pushbutton unit (CR104G29 mounted on contact block CR104G4) with a 5.08 cm wobble stick that closed a set of contacts when pressed in any direction from the center, served as response manipulandum. During sessions the lever was positioned within easy reach of the monkey's hands, under the neckplate.

Electric shocks were delivered through tail electrodes, consisting of a tenfold layer of aluminum foil (approximately 1 x 2 cm) sewn onto Velcro strips. To assure good contact, the animals' tails were shaved regularly and electrode paste was applied between the electrodes and the skin surface. Constant current AC shock from a 650 V transformer passed through a set of capacitors that allowed monitoring of the shock intensity. Switching circuitry for the shocking device, designed according to Ramsay, Knapp & Zeiss (1970), eliminated most of the switching transients by removing the animal from the circuit until shock delivery at which point the animal became the only through connection in the shock circuit. Shock onsets and offsets occurred only at zero voltage in the AC cycle by means of a synchronous switch; shock duration was therefore measured in number of AC cycles. Shock offset was set to occur at the first zero voltages after 0.280 sec; generally shocks lasted 17 cycles (0.283 sec).

Pulse rate data were obtained with a pulse sensor (Narco-Bio-Systems photo electric pulse pick up, 705-012) strapped to the tail, about 5 cm above the ground shock electrode near the base of the tail. Signals were conducted through a Transducer-Monitor-Coupler unit (Narco-Bio-Systems, MK II) to a Beckman Type R Dynograph, which recorded pulses, responses, and stimuli for the last 15 sec in t^{Δ} and for the entire t^{D} period. Pulse rate data were hand counted to avoid errors caused by inadvertent noise in the cardiac signal arising from subject movements not eliminated through electronic filtering. Pulse rate data are presented for days 17 and 18 of each phase, for all animals except B-2, B-4, B-6 and A-44, for which pulse rate data only from days 15 and 16 are available.

Stimulus delivery and response recording were monitored through a PDP-8 computer using a "notation system" especially devised for behavioral experiments (Snapper & Kadden, in press), and were also recorded on Gerbrands cumulative recorders.

Procedure

The experiment was conducted in three passes; i.e., two animals of Group 1 (A-42, A-46) and two of Group 2 (A-58, A-54) were put through the first 6 phases of the experimental procedure before the remaining two animals in each of those groups started the experiment.

Group 3 was started after the first four animals had completed all 8 phases of the experiment.

Each subject was seated in his restraint chair at least two weeks prior to the start of experimentation, which was not begun with any animal until it was adjusted to the sitting situation, as judged by eating and drinking habits and bowel movements. The experiment was conducted in blocks of 20 daily sessions (phases); after each block, one day of rest intervened before the start of the next phase.

About half an hour before each session, the subject's tail was tied to the base structure of the chair, and electrodes and pulse sensor were strapped to it. The stimulus unit and the response manipulandum were brought into position, and the chair was then moved, if necessary, from the vivarium into its isolation booth.

Initial sessions, before the start of the experiment proper, were devoted to shaping the lever press response. All animals were given at least one two hour session in which trials were separated by 30 sec periods. In addition, the experimenter could start a trial by means of a pushbutton any time after the previous trial. The start of a session was indicated by the onset of the blue lights on the stimulus unit. A trial was started with the illumination of the row of five white lights on the stimulus unit, which was followed after 8 sec by a 5 ma shock. A lever press by the animal, or a pushbutton press by the experimenter, terminated both light and shock stimuli. Lever presses during the light stimulus, but before the shock onset, also terminated the light stimulus and prevented shock delivery, i.e., terminated the trial. Two animals (A-58 and B-16) who had not learned to terminate the light before shock after two 2 hour sessions were then given one or more sessions in which an auditory (Mallory sonalert, SC628, 24 V) stimulus was coupled with the visual stimulus during a trial. Once all animals had acquired this discriminated avoidance behavior, two more sessions were given in which a brief (0.280 sec) inescapable shock (10 ma for the first session and 13.5 ma for the second session) was presented if the light stimulus was not terminated within 8 sec by a lever press. For all but one animal, this completed the shaping procedure. The one animal (B-16) which did not maintain a reasonable level of responding was then given two extra sessions on the latter procedure with 16 ma shocks. Throughout the experiment, shock intensities were fixed at 13.5 ma for all animals but B-16 for which the shock intensity was set at 16 ma. No pulse rate recordings were made during the initial sessions preceding the first phase of the experiment.

For all groups, the first phase of the experiment consisted of a procedure in which a fixed time cycle (T) of 200 sec was divided into a t^D and a t^Δ period. The T-cycle started with a 190 sec t^Δ period during which responses had no effect on the stimulus presentation schedule. The last ten seconds of the cycle comprised t^D and was demarcated by lighting the five lamps on the stimulus unit. If no response was made in the presence of the t^D light, a shock was delivered at the end of t^D; responding itself had no other immediate effect, besides preventing the shock presentation, and only the first response in t^D affected the stimulus delivery schedule. Shocks, lights and T-cycles terminated simultaneously, and a new T-cycle was started immediately thereafter, until a total of 50 T-cycles had been presented, at which point the session ended. Responding in t^{Δ} was recorded in 30 sec periods during the first 180 sec and in 2 sec periods for the last 10 sec of t^{Δ} and the entire t^{D} period. Latencies for the first response in t^{D}, total shocks presented for failure to respond in t^{D}, and total shocks for R (in later phases), as well as total number of T-cycles in which responses in t^{D} were emitted, were recorded electronically. Pulse rate recordings were taken during the last 25 sec of each T-cycle. Each phase consisted of 18 sessions of 50 T-cycles. In addition, each phase consisted of two more sessions in which a generalization program was in effect. During generalization testing, the same contingencies as in the previous 18 sessions were in effect, but during the t^{Δ} period either 0, 1, 2, 3, or 4 of the white lights would come on in the last 10 sec preceding the t^{D} period. As before, responses in t^{Δ} did not affect the stimulus delivery schedule. The generalization sessions are not reported here. Superficial examination of the data reveals no apparent differences from the data of previous t^{D} periods. Generalization tests were given to all animals during the last two days of each phase.

After the initial phase, in which shocks were delivered for all groups only for every failure to respond in t^{D}, the subsequent phases for the groups diverged procedurally. Group 1 (A-42, A-46, B-2 and B-4) went through a series of phases in which shocks were also delivered, with an increasing probability, for responding in t^{D} (shocks were always delivered at the end of t^{D}). So, in the second phase, for Group 1, responding in t^{D} would also result in shock delivery 1/3 of the time:

$p(S^{-R}|R) = 0.33$, with $p(S^{-R}|\not{R})$ remaining at 1.0. In what follows, this condition is written as p(0.33, 1.0), the first number representing the $p(S^{-R}|R)$, and the second the $p(S^{-R}|\not{R})$. In the next phases, the $p(S^{-R}|R)$ increased gradually with $p(S^{-R}|\not{R})$ staying at 1.0: p(0.67, 1.0) and p(1.0, 1.0). After the p(1.0, 1.0) phase, in which every t^D ended with shock, the $p(S^{-R}|\not{R})$ decreased through the next three phases, while the $p(S^{-R}|R)$ remained at 1, yielding conditions p(1.0, 0.67), p(1.0, 0.33) and p(1.0, 0). After the last set of contingencies, p(1.0, 0), which constituted "discriminated punishment", the animals were returned to the first procedure of "discriminated avoidance", p(0, 1.0).

Group 2[A-58, A-54, B-6 and A-44] proceeded, after the initial p(0, 1.0) phase, with procedures in which decreasing values of $p(S^{-R}|\not{R})$ came into effect (0.67 and 0.33) while $p(S^{-R}|R)$ remained at zero, until the p(0, 0) condition was reached in which no shocks were ever presented. This "extinction" phase was followed by three phases in which the $p(S^{-R}|R)$ increased, while $p(S^{-R}|\not{R})$ remained at 0: p(0.33, 0), p(0.67, 0) and p(1.0, 0). After the p(1.0, 0) procedure, all animals were returned to the original p(0, 1.0) condition.

Procedures for Group 3 [B-10, A-56, B-14 and B-16] were characterized by simultaneous but inverse changes in $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ through the following paired values: p(0, 1.0), p(0.33, 0.67), p(0.67, 0.33) and p(1.0, 0). After the last procedure, in which shocks would occur only for responses in t^D, the animals were returned to the original p(0, 1.0) condition.

Programming of the probabilities for $(S^{-R}|R)$ was accomplished by having the programming apparatus produce alternating 0.01 and 0.02 sec periods in which the $p(S^{-R}|R)$ would be either 1 or 0 (the "random ratio" procedure; c.f. Brandauer, 1958; Schoenfeld and Cumming, 1960). If the first R in t^D occurred during the component with $p(S^{-R}|R) = 1$, a shock would be set up for the end of the t^D period in which the response occurred. When the procedure for a phase required a $p(S^{-R}|R)$ value of 1 or 0, only one component was in effect.

Programming of the $p(S^{-R}|\not{R})$ was done by a series of 9 trials explicitly programmed to contain either three or six shocked $\not{R}$ trials; the program went through the series as the $\not{R}$ trials occurred. Since the $\not{R}$ frequency was expected to be low in most of the phases, one "randomized series" of 9 trials was used repetitively.

Table 1

Table of procedures

Animal time of year and season	Successive phases							
Group 1								
A-42, A-46 Aug. - Jan. 14:00-17:00	p(0, 1.0)	p(0.33, 1.0)	p(0.67, 1.0)	p(1.0, 1.0)	p(1.0, 0.67)	p(1.0, 0.33)	p(1.0, 0)	p(0, 1.0)
B-2, B-4 Jan. - June 8:00-11:00	p(0, 1.0)	p(0.33, 1.0)	p(0.67, 1.0)	p(1.0, 1.0)	p(1.0, 0.67)	p(1.0, 0.33)	p(1.0, 0)	p(0, 1.0)
Group 2								
A-58, A-54 Aug. - Jan. 17:30-20:30	p(0, 1.0)	p(0, 0.67)	p(0, 0.33)	p(0, 0)	p(0.33, 0)	p(0.67, 0)	p(1.0, 0)	p(0, 1.0)
B-6, A-44 Jan. - June 11:30-14:30	p(0, 1.0)	p(0, 0.67)	p(0, 0.33)	p(0, 0)	p(0.33, 0)	p(0.67, 0)	p(1.0, 0)	p(0, 1.0)
Group 3								
B-10, A-56 March - June 8:00-11:00	p(0, 1.0)	p(0.33, 0.67)			p(0.67, 0.33)		p(1.0, 0)	p(0, 1.0)
B-14, B-16 March - June 11:30-14:30	p(0, 1.0)	p(0.33, 0.67)			p(0.67, 0.33)		p(1.0, 0)	p(0, 1.0)

Results

The findings are collected separately by principal variables, and then by simultaneous change of the two parameters. The cardiac data and the results of the second exposure to the "discriminated avoidance" procedure, follow after.

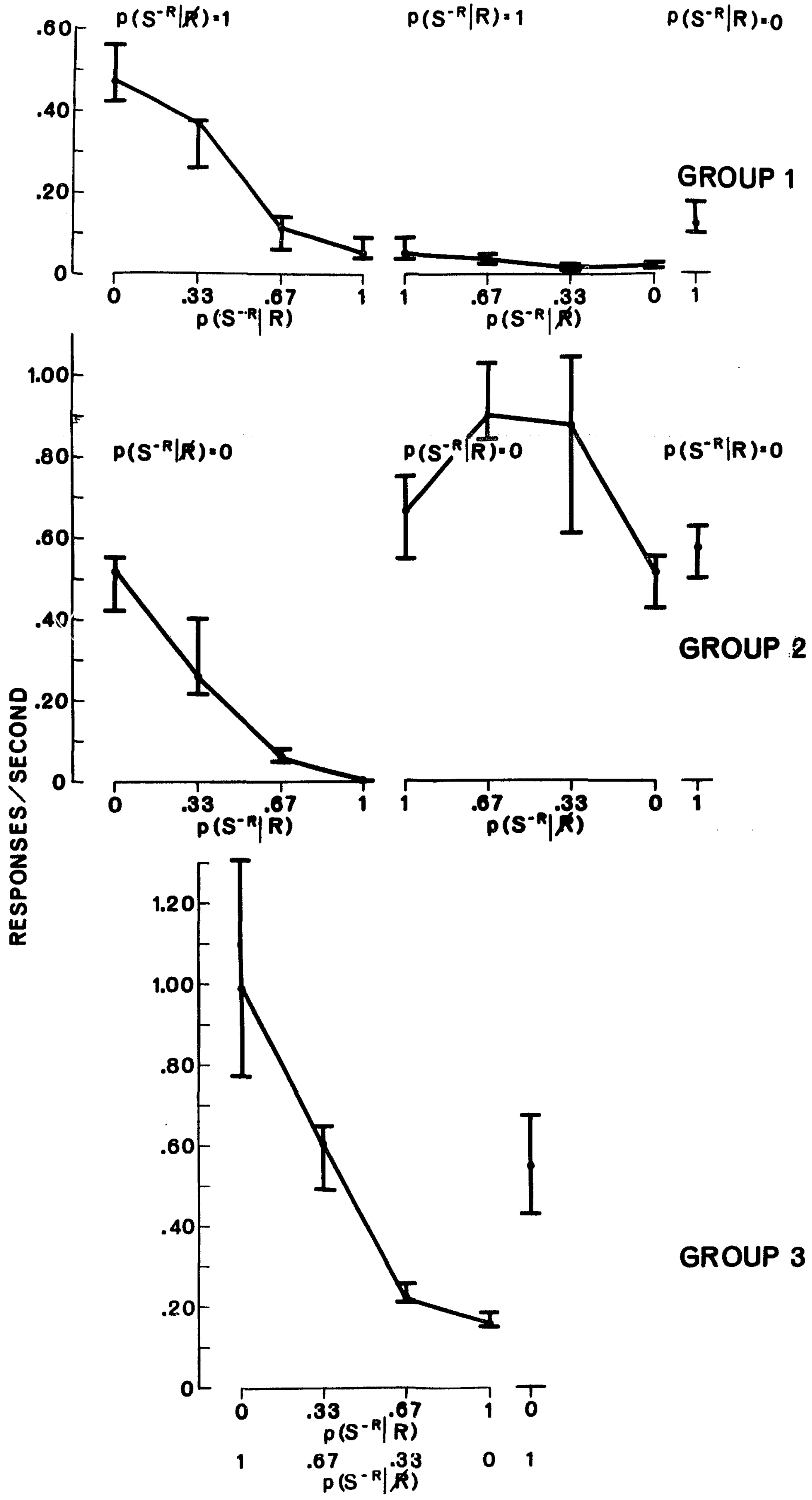
A. Group 1: $p(S^{-R}|R)$ increasing, $p(S^{-R}|\not{R}) = 1.0$

1. Responding in t^D

Response rate in t^D decreased as $p(S^{-R}|R)$ increased while $p(S^{-R}|\not{R})$ remained at 1.0. In Figure 2 the medians of the response rates of the last six days for each S are averaged for the four animals in each group. The interquartile ranges, as well as the median response rates of individual animals (Fig. 3), show that the effect is quite consistent for the last six days for each animal for all Ss. Figure 4 compares the mean rates of all four animals, for the first and last six days in each phase. The increase in $p(S^{-R}|R)$ resulted initially [i.e., after the transition from p(0, 1.0) to p(0.33, 1.0)] in increased response rates in t^D. The differences between response rates of the first and last six days gradually diminished as $p(S^{-R}|R)$ approached zero, although initial rates were always higher.

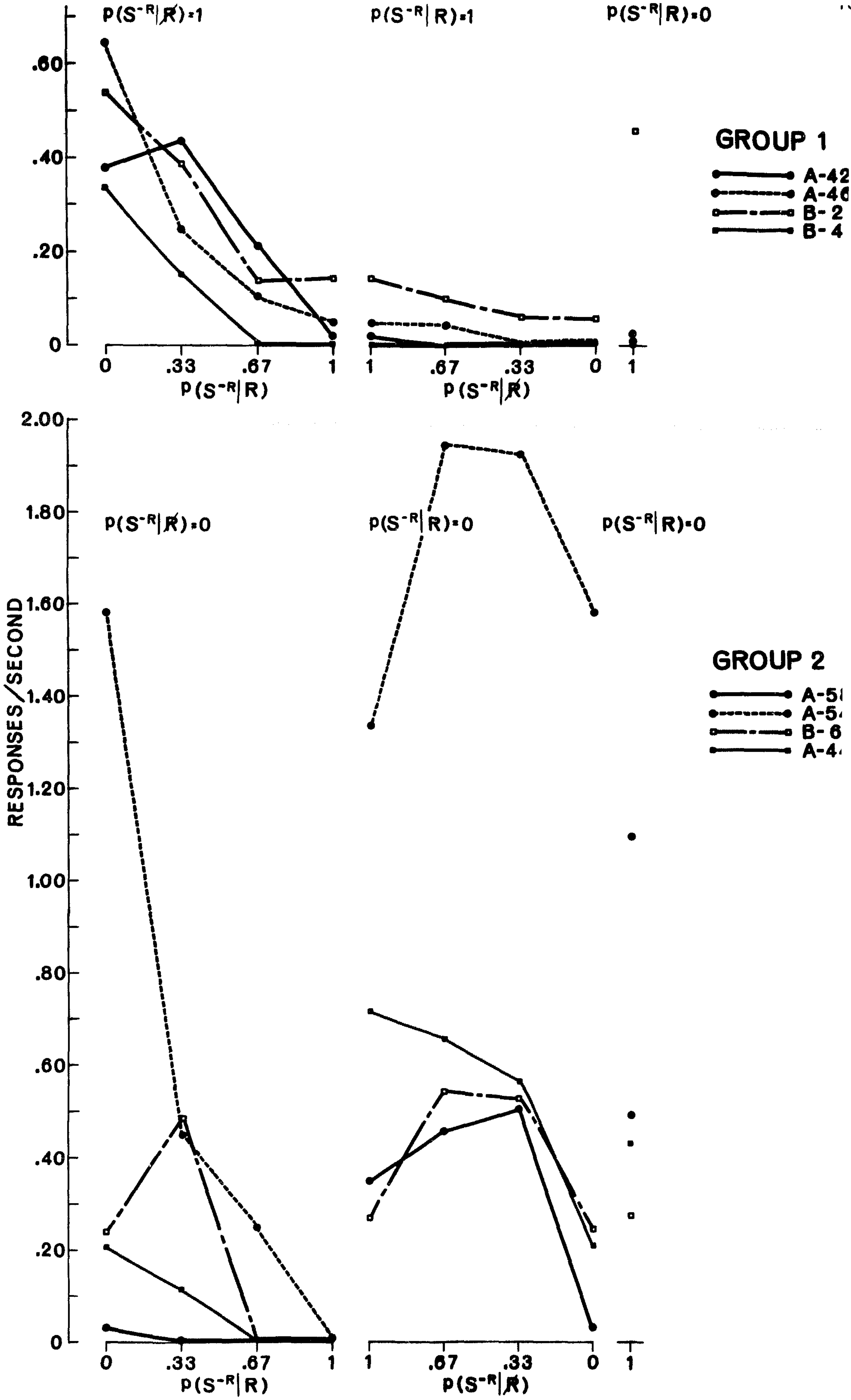
The relative frequency distributions of responding in t^D (Fig. 5) assume negatively accelerated forms under the initial

Figure 2. Median response rate during t^D. Each point represents the median of the response rates during the last 6 days. The medians were then averaged for the four animals in each group; interquartile ranges (Q_1 - Q_3) are indicated by vertical lines. When the combination of two values of each parameter [p(1.0, 1.0) for Group 1 and p(0, 0) for Group 2] could be the last value of one changing parameter and the beginning of parametric variations on the hitherto constant parameter, the data for these points are presented twice. Thus, the last data point above the $p(S^{-R}|R)$ axis for Group 1 is repeated as the first point above the $p(S^{-R}|\not{R})$ abcissa; similarly, the last point on the $p(S^{-R}|\not{R})$ axis is the same as the first point above the $p(S^{-R}|R)$ abcissa for Group 2. Data from the re-exposure to p(0, 1.0) phase are represented by isolated points at the right side of each figure. Since the order in which the experimental phases followed each other is, for Group 2, not identical with the order of presentation of the data, the recovery points were not connected to the main function.



RESPONSES/SECOND
GROUP 1
$p(S^{-R}|\not R)=1$
$p(S^{-R}|R)=1$
$p(S^{-R}|R)=0$
.60
.40
.20
0
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
1
$p(S^{-R}|\not R)$
GROUP 2
1.00
.80
.60
.40
.20
0
$p(S^{-R}|\not R)=0$
$p(S^{-R}|R)=0$
$p(S^{-R}|R)=0$
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
1
$p(S^{-R}|\not R)$
GROUP 3
1.20
1.00
.80
.60
.40
.20
0
0
.33
.67
1
0
$p(S^{-R}|R)$
1
.67
.33
0
1
$p(S^{-R}|\not R)$

Figure 3. Median of response rates in t^D taken from the last 6 days of each phase, for individual animals for each combination of parameter values. Combinations of parameter values that fall on both abcissae [p(1.0, 1.0) for Group 1, and p(0, 0) for Group 2] are represented twice. Recovery data are presented at the right of each figure as isolated points.


$p(S^{-R}|\not R)=1$
$p(S^{-R}|R)=1$
$p(S^{-R}|R)=0$
.60
.40
.20
0
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
$p(S^{-R}|\not R)$
1
GROUP 1
A-42
A-46
B- 2
B- 4
2.00
1.80
1.60
1.40
1.20
1.00
.80
.60
.40
.20
0
RESPONSES/SECOND
$p(S^{-R}|\not R)=0$
$p(S^{-R}|R)=0$
$p(S^{-R}|R)=0$
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
$p(S^{-R}|\not R)$
1
GROUP 2
A-5
A-5
B- 6
A-4

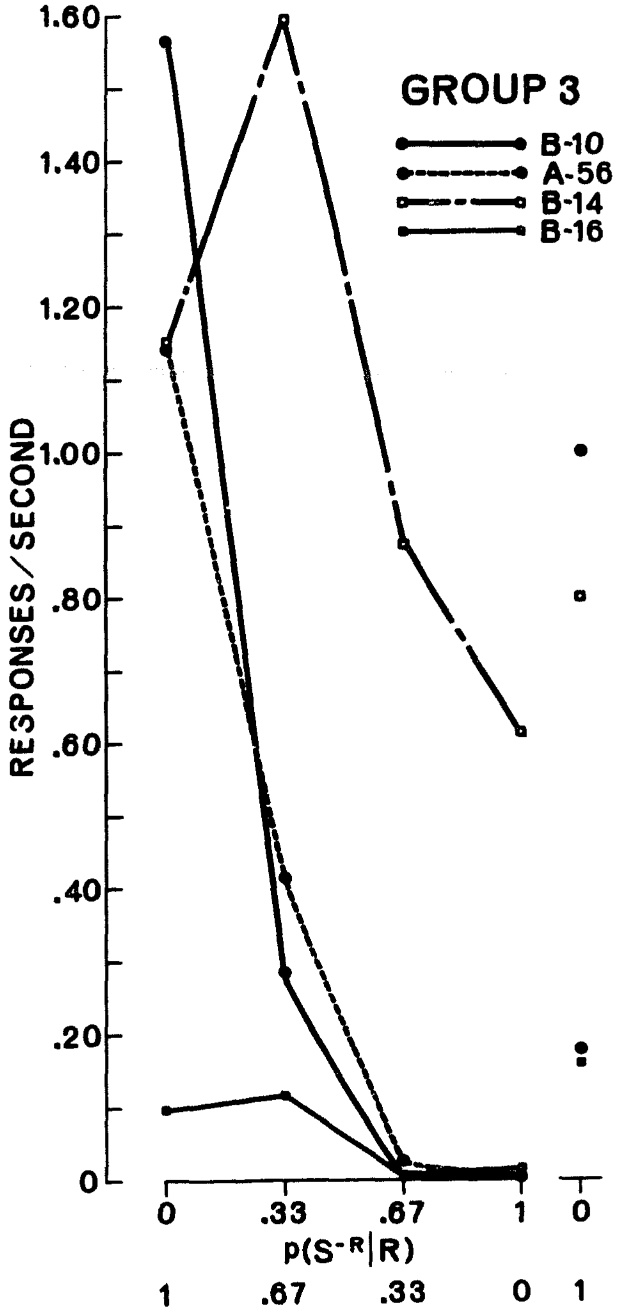

GROUP 3
B-10
A-56
B-14
B-16
RESPONSES/SECOND
1.60
1.40
1.20
1.00
.80
.60
.40
.20
0
0
.33
.67
1
0
p(S^-R|R)
1
.67
.33
0
1
p(S^-R|R̸)

Figure 4. Mean response rates in t^D, averaged over all Ss in a group, for all combinations of parameter values. Data are taken from the first 6 days (broken lines) and from the last 6 days (solid lines) of each phase. Combinations of parameter values which in the contingency space of Figure 1 define a corner, are presented twice to indicate that the combination is the last point of one changing variable and the first point on another parametric change.

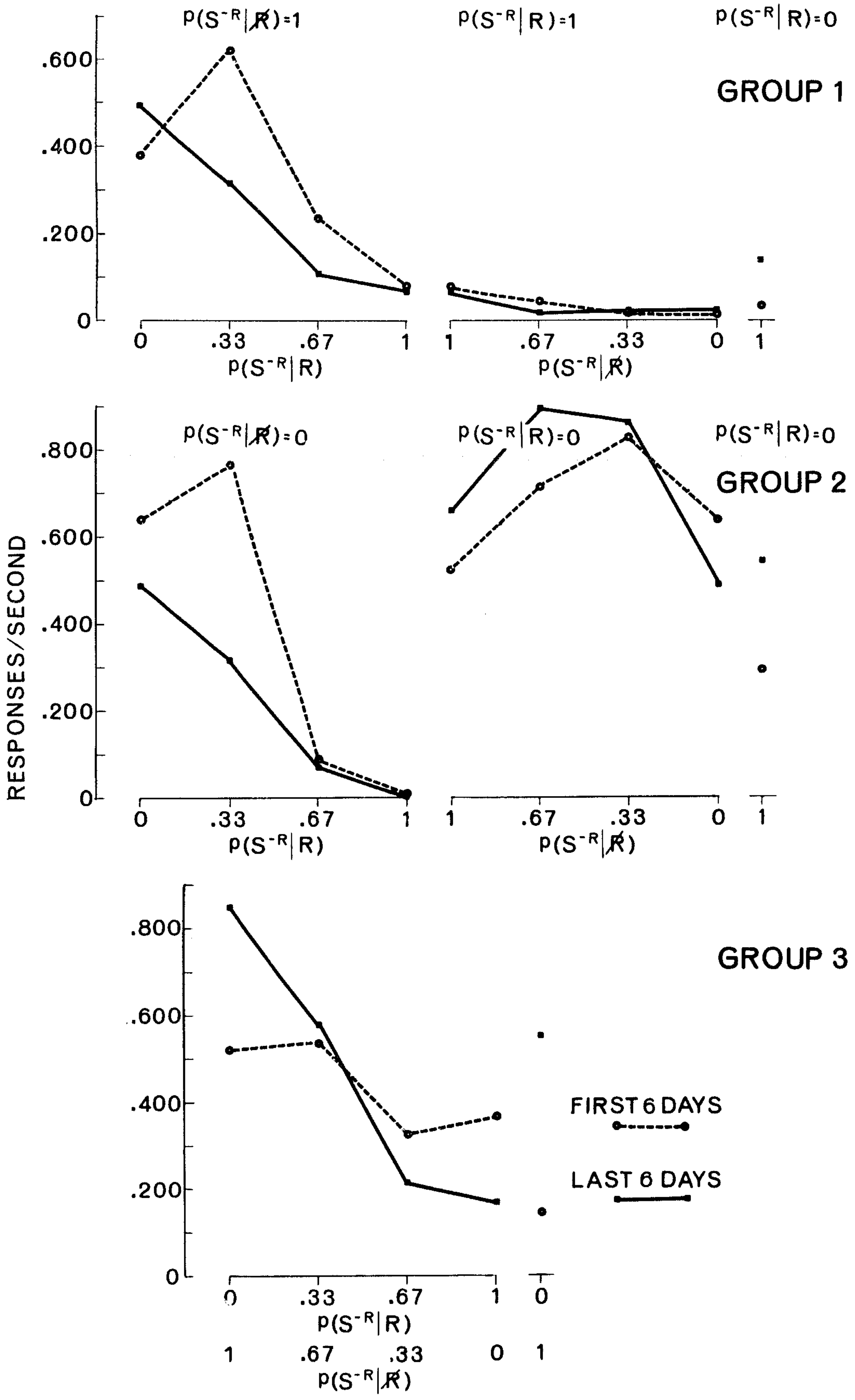
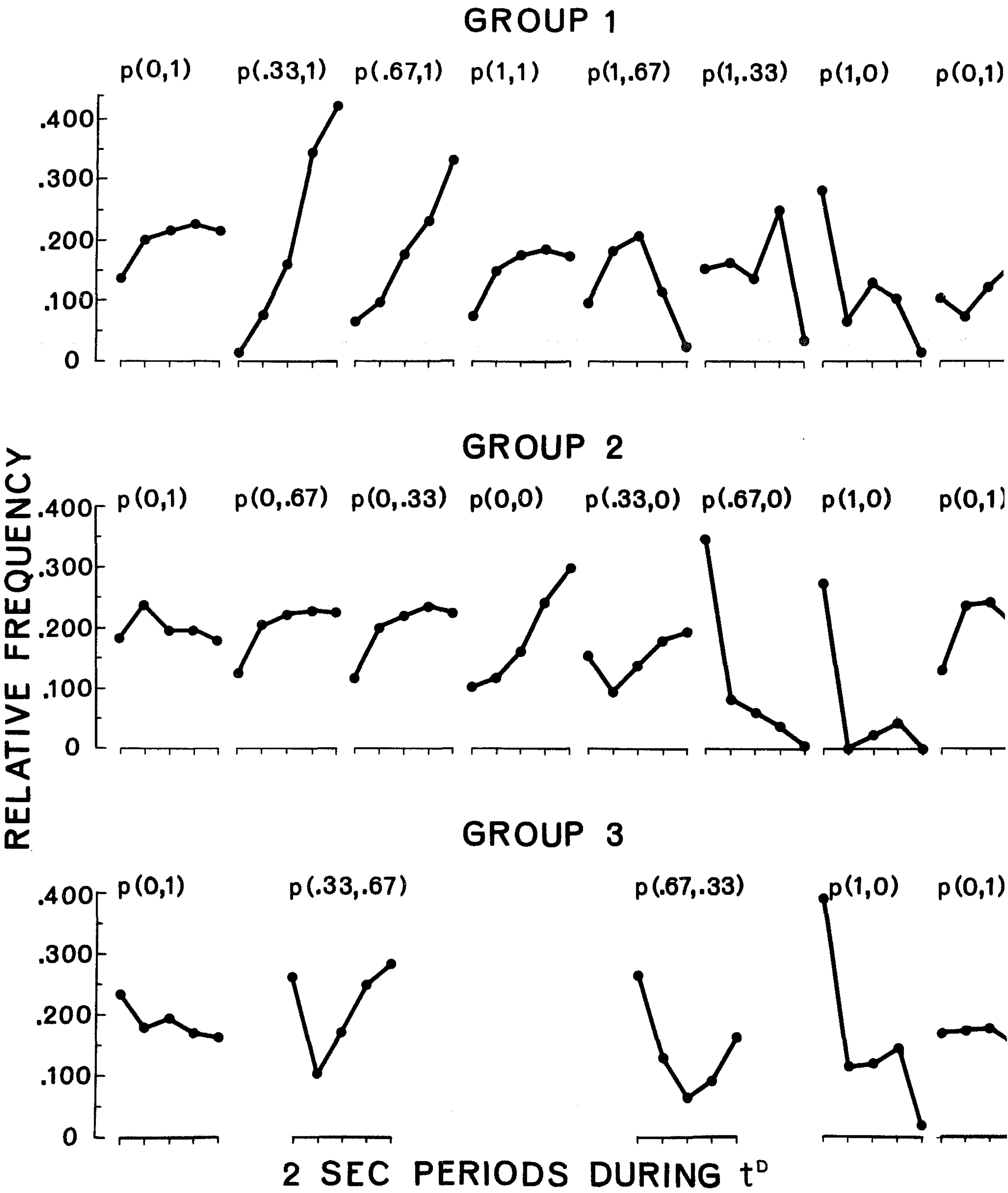

RESPONSES/SECOND
GROUP 1
GROUP 2
GROUP 3
$p(S^{-R}|\not R)=1$
$p(S^{-R}|R)=1$
$p(S^{-R}|R)=0$
$p(S^{-R}|\not R)=0$
$p(S^{-R}|R)=0$
$p(S^{-R}|R)=0$
0
.200
.400
.600
.800
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
$p(S^{-R}|\not R)$
FIRST 6 DAYS
LAST 6 DAYS

Figure 5. Relative frequency distributions of responding during t^D by successive 2 sec periods presented as percentage of total responses in t^D. The data are taken from the last 6 days in each phase and represent the mean of the four animals in each group. The order in which the successive phases are presented is the order in which they occurred in the experiment. The probability values above the data for each phase represent the probabilities in effect during that phase, the first number representing the $p(S^{-R}|R)$ and the second number $p(S^{-R}|R)$.


GROUP 1
p(0,1)
p(.33,1)
p(.67,1)
p(1,1)
p(1,.67)
p(1,.33)
p(1,0)
p(0,1)
GROUP 2
p(0,1)
p(0,.67)
p(0,.33)
p(0,0)
p(.33,0)
p(.67,0)
p(1,0)
p(0,1)
GROUP 3
p(0,1)
p(.33,.67)
p(.67,.33)
p(1,0)
p(0,1)
RELATIVE FREQUENCY
.400
.300
.200
.100
0
2 SEC PERIODS DURING t^D

"discriminated avoidance" condition: p(0, 1.0). As the $p(S^{-R}|R)$ increased above the zero value, increasingly more responses were made near the end of t^D and fewer responses in the beginning. The relative frequency distributions for some animals (Fig. 6) became bimodal as $p(S^{-R}|R)$ increased further, and the highest response rate occurred before the end of the t^D period. Curvature index values for the t^D period were computed according to Fry, Kelleher and Cook (1960). This measure expresses the response pattern as a single value by comparing the area under a cumulative response record between two time marks, to the area under the straight line connecting the first time mark with the point of total responses at the second time indicator. If more responses have been emitted in the first half of the time period, the value will be between -1 and 0; if responding is concentrated near the end of the time period, the curvature index assumes values between 0 and +1. Generally, as shown in Figure 7, the curvature indexes were above zero for all phases of increasing $p(S^{-R}|R)$, and highest when shocks for responses were first introduced. The bimodal pattern is indicated by gradually decreasing curvature indices as p(1.0, 1.0) is approached. Curvature index values were initially lower on the first six days, but eventually lower values for the last six days were observed in later phases of $p(S^{-R}|R)$ change.

Latencies for the first response in t^D (Fig. 8 and Fig. 9) reflect the change in response distribution in t^D. Mean latencies became longer when $p(S^{-R}|R)$ assumed the 0.33 value but decreased near the p(1.0, 1.0) condition. Latencies are not included for those animals who responded in fewer than ten t^D periods during the six days for which measures are presented. Latencies for the first six days in p(0.33, 1.0) were considerably shorter than for the last six days, confirming the findings of the curvature index data (Fig. 7) that response patterns in t^D developed slowly through the 18 day period.

Looking at Figure 10, showing the average number of trials in which no responses during t^D occurred for the first and last six days on each phase, it will be seen that, as $p(S^{-R}|R)$ increased, fewer t^D periods showed responses, and that the number of $\not{R}$ trials increased within each phase. Since the number of shocks was programmed to increase as $p(S^{-R}|R)$ increased when $p(S^{-R}|\not{R}) = 1$, it is noteworthy in Figure 11 that at p(1.0, 1.0) the number of shocks for R slightly decreased.

2. Responding in t^Δ

The averaged median t^Δ response rate (Fig. 12) did not change systematically, and differences between animals (Fig. 13) were greater than for t^D response measures. Response rates for the first six days were again higher after the transition to p(0.33, 1.0) than for the last six days in each phase (Fig. 14), but the greatest difference was reached at the p(1.0, 1.0) condition.

Responding in t^Δ was recorded separately in six periods of 30 sec each, and, for the last 10 sec of t^Δ, by 2 sec periods. Response distributions are expressed as relative response ratios, i.e., if the

Figure 6. Relative frequency distributions for each animal of the three groups. The data for each group are presented in the order in which the experiment was conducted; the combination of parameter values is indicated above each figure.

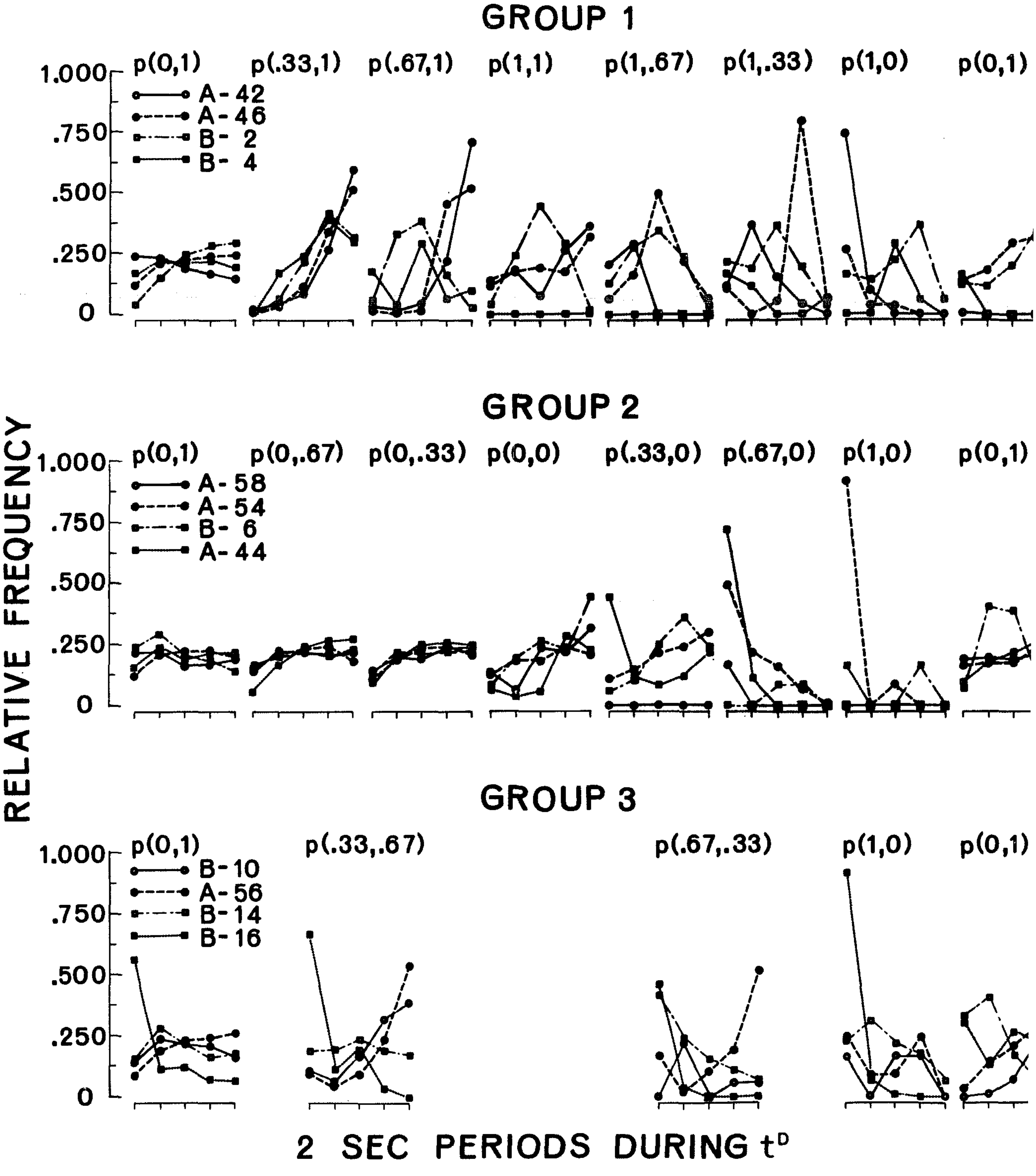
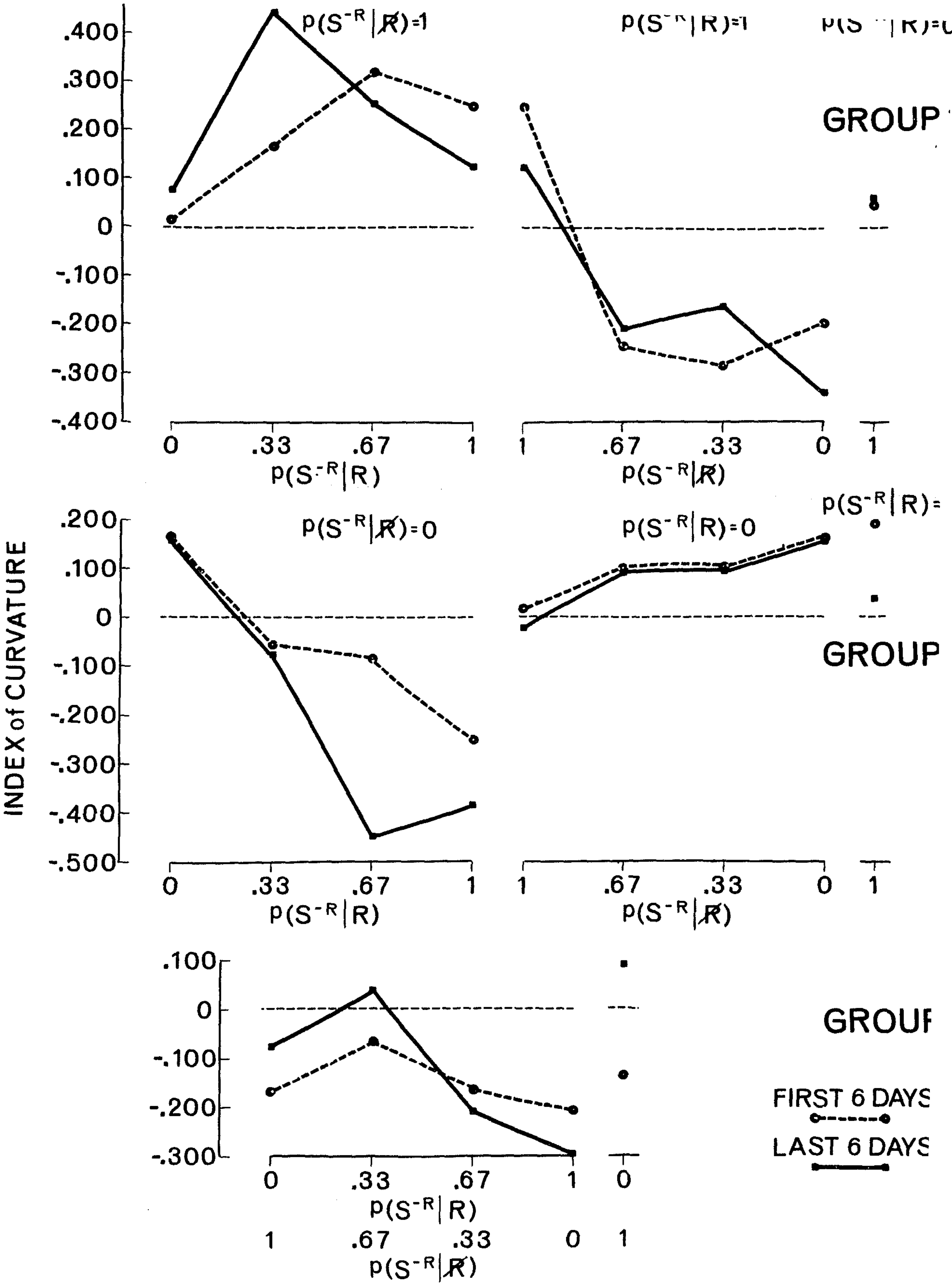

GROUP 1
p(0,1)
p(.33,1)
p(.67,1)
p(1,1)
p(1,.67)
p(1,.33)
p(1,0)
p(0,1)
A-42
A-46
B-2
B-4
GROUP 2
p(0,1)
p(0,.67)
p(0,.33)
p(0,0)
p(.33,0)
p(.67,0)
p(1,0)
p(0,1)
A-58
A-54
B-6
A-44
GROUP 3
p(0,1)
p(.33,.67)
p(.67,.33)
p(1,0)
p(0,1)
B-10
A-56
B-14
B-16
1.000
.750
.500
.250
0
RELATIVE FREQUENCY
2 SEC PERIODS DURING t^D

Figure 7. Mean curvature index of t^D responding for the first (broken lines) and last 6 days (solid lines), averaged for all animals in a group. Combinations of parameter values falling on both abcissae are presented twice [p(1.0, 1.0) for Group 1, and p(0, 0) for Group 2]. Recovery data, at the right, are not connected to the main functions.



INDEX of CURVATURE
$p(S^{-R}|\not{R})=1$
$p(S^{-R}|R)=1$
$p(S^{-R}|R)=0$
GROUP
.400
.300
.200
.100
0
-.100
-.200
-.300
-.400
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
1
$p(S^{-R}|\not{R})$
$p(S^{-R}|R)=$
$p(S^{-R}|\not{R})=0$
$p(S^{-R}|R)=0$
GROUP
.200
.100
0
-.100
-.200
-.300
-.400
-.500
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
1
$p(S^{-R}|\not{R})$
GROUP
.100
0
-.100
-.200
-.300
0
.33
.67
1
0
$p(S^{-R}|R)$
1
.67
.33
0
1
$p(S^{-R}|\not{R})$
FIRST 6 DAYS
LAST 6 DAYS

response rates were equally spread throughout t^{Δ}, the values on Figure 15 and Figure 16 would be 1; values higher than "expected" are above 1, and lower than "expected" values range from 1 to 0. The ratio consists of:

$$\frac{r}{\frac{t}{T} \times R}$$

where: r = number of responses in a sub-division (bin) of t^{Δ}

t = length of bin

T = total t^{Δ} duration

R = total number of responses in t^{Δ}

Not included are data when a subject emitted fewer than 10 responses in t^{Δ} during the entire 6 day period.

Response distributions for individual animals (Fig. 16) as well as averaged distributions (Fig. 15) are typically decelerating with most responses occurring in the first 30 sec, and the remainder equally spread over the remaining t^{Δ}. The increase in $p(S^{-R}|R)$ accentuated this pattern more, as more shocks were delivered. Curvature index values decreased also when shocks for responses were first introduced (Fig. 15). The response distributions on the first 6 days after a higher $p(S^{-R}|R)$ value was programmed, became more skewed to the right with the changing parameter, but curvature indices following p(0.33, 1.0) remained at a steady level for the last 6 days.

Figure 8. Latencies of the first response in t^D for the first and last days in each phase, averaged for 4 Ss in each group, for all combinations of parameter values. The p(1.0, 1.0) data for Group 1, and the p(0, 0) data for Group 2 are presented twice. Recovery data are plotted as isolated points at the right.

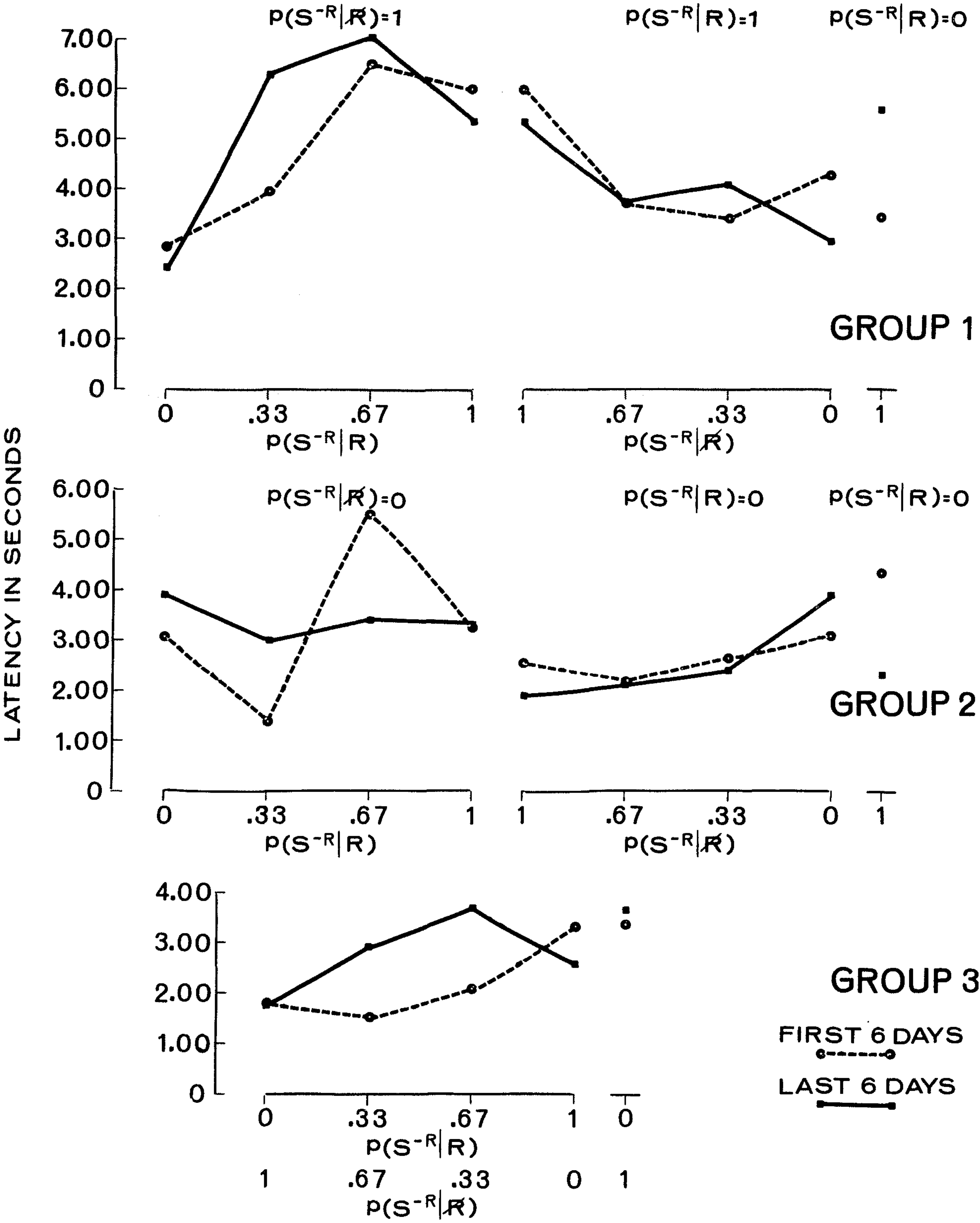
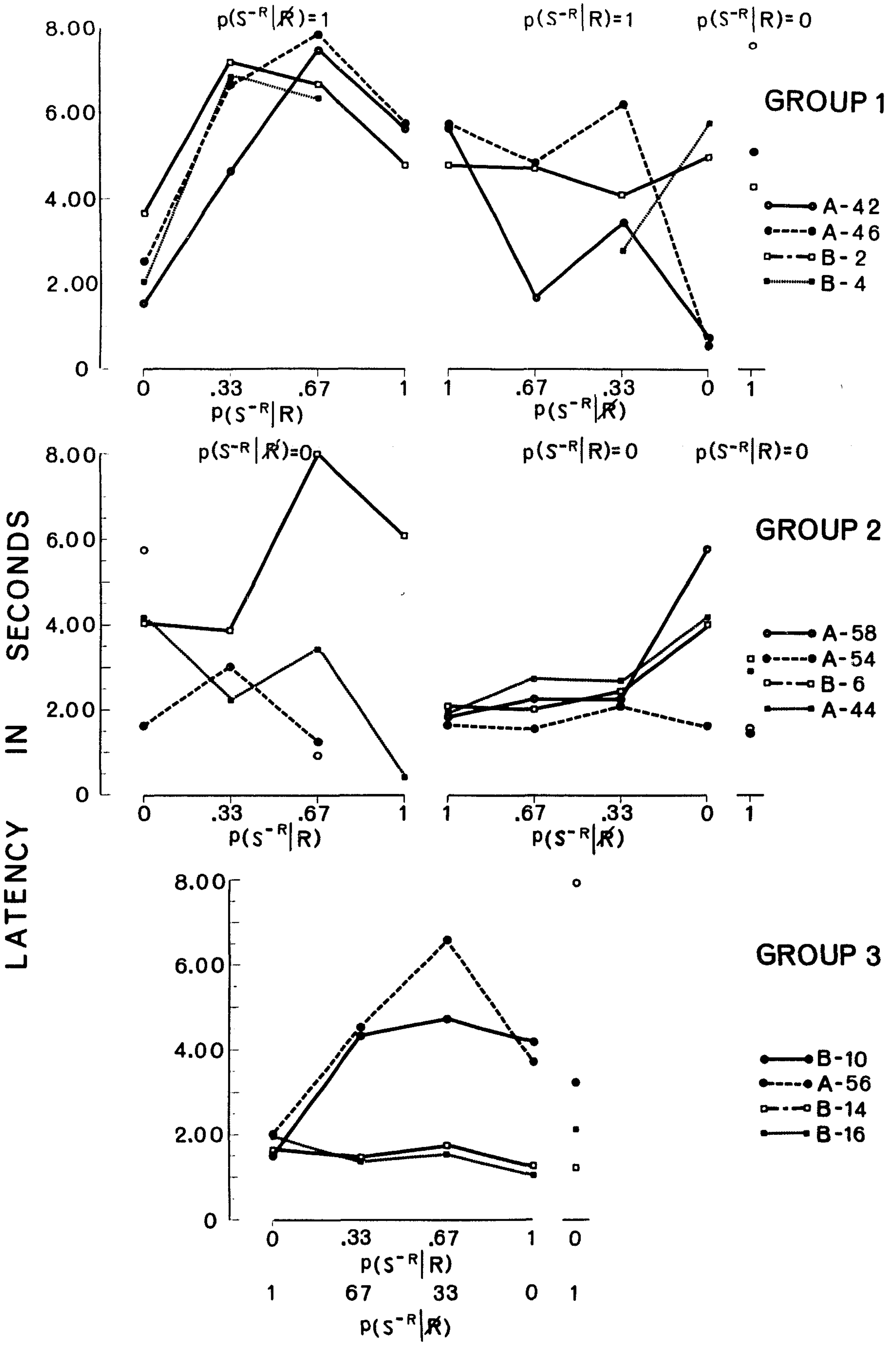

LATENCY IN SECONDS
GROUP 1
p(S^-R|R̸)=1
p(S^-R|R)=1
p(S^-R|R)=0
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
0 .33 .67 1
p(S^-R|R)
1 .67 .33 0
p(S^-R|R̸)
1
GROUP 2
p(S^-R|R̸)=0
p(S^-R|R)=0
p(S^-R|R)=0
6.00
5.00
4.00
3.00
2.00
1.00
0
0 .33 .67 1
p(S^-R|R)
1 .67 .33 0
p(S^-R|R̸)
1
GROUP 3
4.00
3.00
2.00
1.00
0
0 .33 .67 1 0
p(S^-R|R)
1 .67 .33 0 1
p(S^-R|R̸)
FIRST 6 DAYS
LAST 6 DAYS

Figure 9. Latencies of the first response in t^D for each animal for the last 6 days of each phase.


LATENCY IN SECONDS
$p(S^{-R}|\cancel{R})=1$
$p(S^{-R}|R)=1$
$p(S^{-R}|R)=0$
GROUP 1
A-42
A-46
B-2
B-4
8.00
6.00
4.00
2.00
0
0
.33
.67
1
$p(S^{-R}|R)$
1
.67
.33
0
1
$p(S^{-R}|\cancel{R})$
$p(S^{-R}|\cancel{R})=0$
$p(S^{-R}|R)=0$
$p(S^{-R}|R)=0$
GROUP 2
A-58
A-54
B-6
A-44
GROUP 3
B-10
A-56
B-14
B-16
0
.33
.67
1
0
$p(S^{-R}|R)$
1
67
33
0
1
$p(S^{-R}|\cancel{R})$

B. Group 2: $p(S^{-R}|R)$ increasing, $p(S^{-R}|\not{R}) = 0$

1. Responding in t^D

Unlike the previous data stemming from phases in which $p(S^{-R}|R)$ was the first parameter to be changed, phases with the $p(S^{-R}|\not{R})$ constant at zero had been preceded by 60 sessions in which $p(S^{-R}|\not{R})$ decreased.

As under constant $p(S^{-R}|R) = 1.0$ values, the response rate decreased as the probability of shocks for responses increased (Fig. 2). The variability among animals was somewhat greater than for Group 1, but the response rates of all but one animal (B-6) decreased continuously throughout the successive increases in $p(S^{-R}|R)$. At the $p(S^{-R}|R) = 0.67$ point, three animals yielded near-zero values and almost no responding was observed for any of the animals under the p(1.0, 0) condition (Fig. 3). A comparison of the mean rates of the first and last 6 days (Fig. 4) in each phase shows a similar picture as for Group 1: increased response rates in t^D were observed when shocks first became contingent upon responses in t^D (i.e., when $p(S^{-R}|R) > 0$). As $p(S^{-R}|R)$ increased, the differences between the first and last 6 days disappeared.

Response distribution in t^D changed from an increasing function during p(0, 0) to a decreasing function during the p(0.67, 0) and p(1.0, 0) conditions (Fig. 5). One animal (A-58) stopped responding altogether when shocks for responses were introduced (Fig. 6), and for two other animals (A-54 and B-6) the relative frequency distribution

Figure 10. Number of t^D periods in which no responses occurred for the first and last 6 days of each phase, averaged over 4 animals for each group. Recovery points are presented on the right.

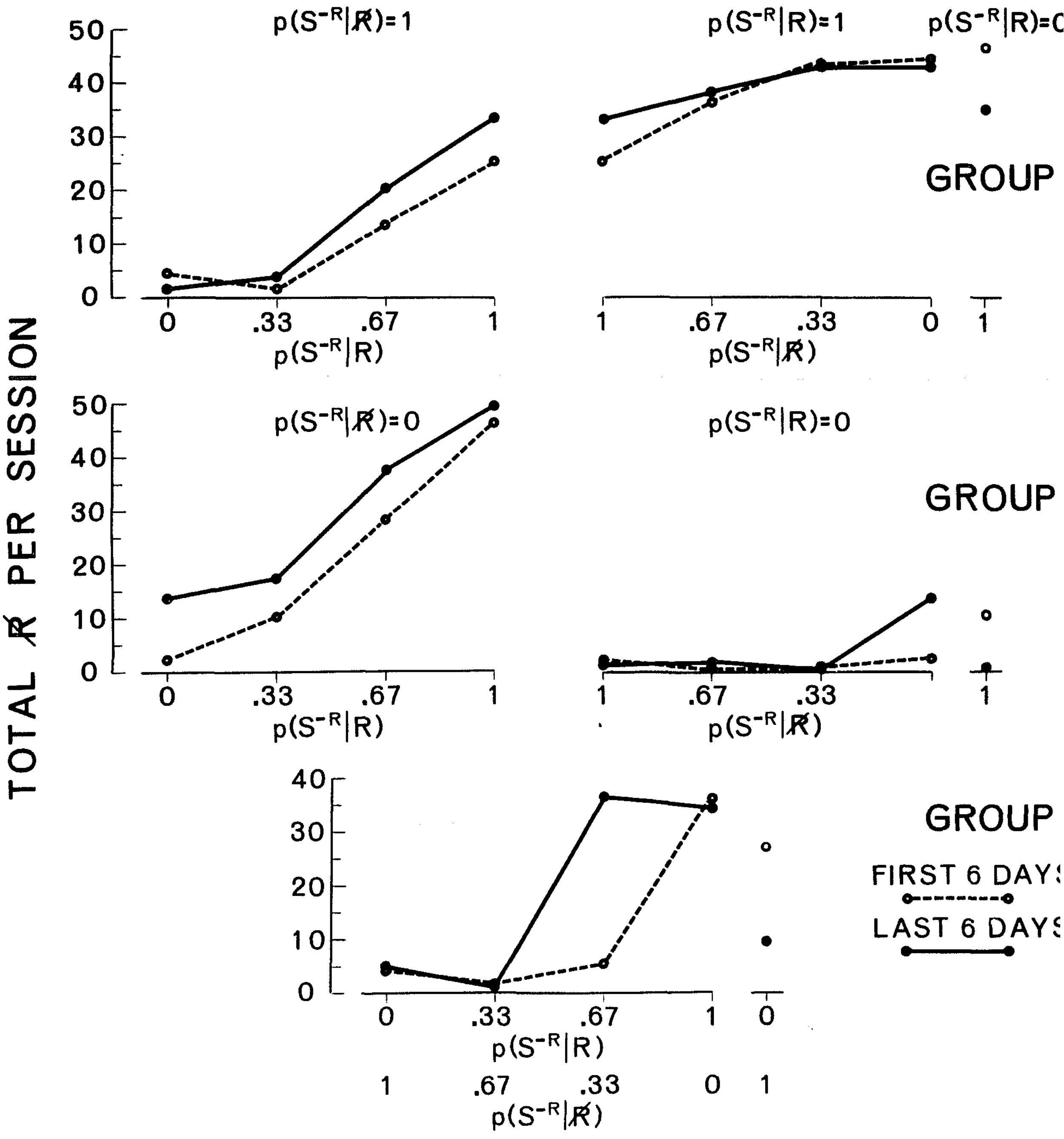
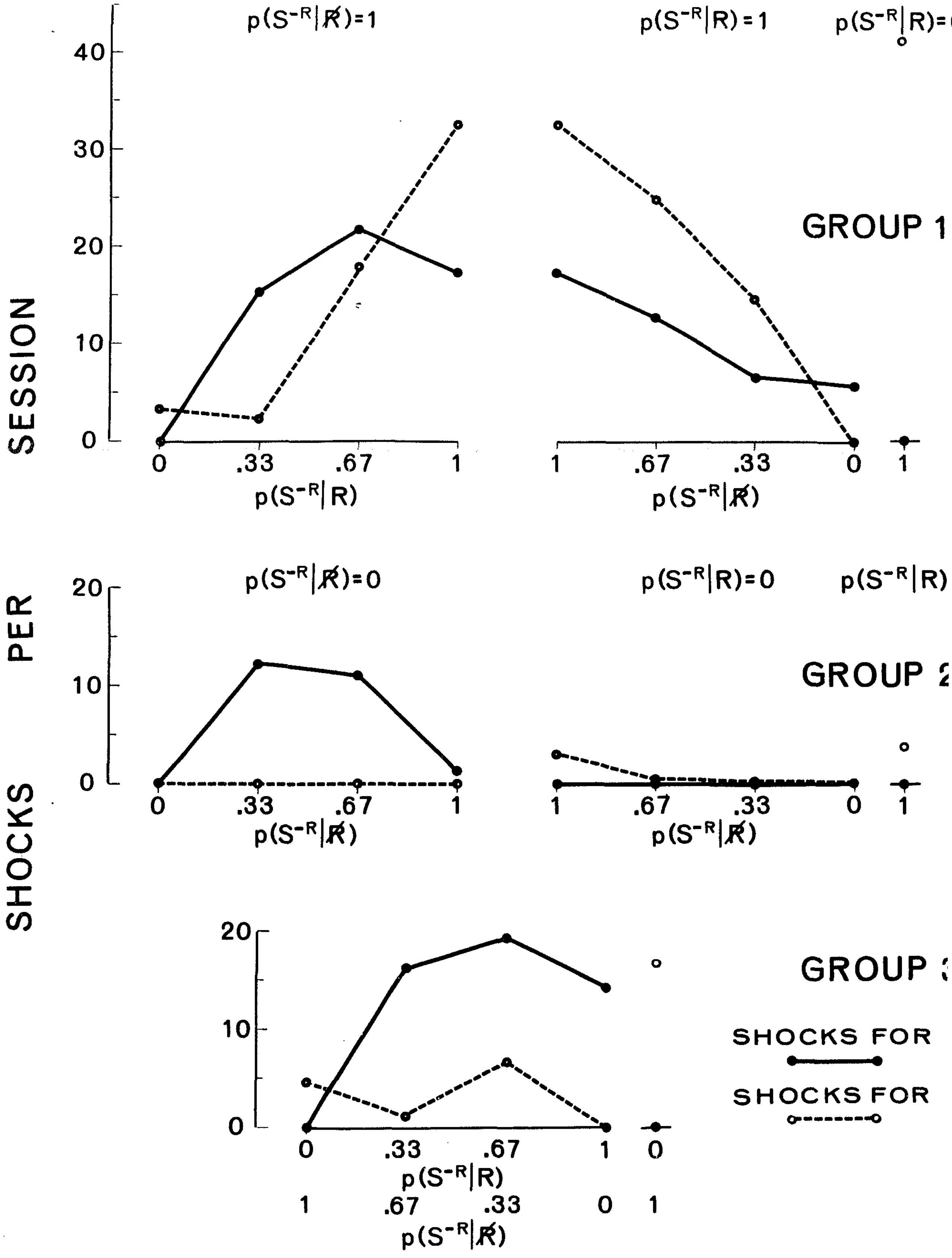

TOTAL $\cancel{R}$ PER SESSION
p(S^{-R}|$\cancel{R}$)=1
p(S^{-R}|R)=1
p(S^{-R}|R)=C
p(S^{-R}|$\cancel{R}$)=0
p(S^{-R}|R)=0
50
40
30
20
10
0
0
.33
.67
1
p(S^{-R}|R)
1
.67
.33
0
1
p(S^{-R}|$\cancel{R}$)
GROUP
GROUP
GROUP
FIRST 6 DAY
LAST 6 DAY
1
.67
.33
0
1
p(S^{-R}|$\cancel{R}$)

Figure 11. Shocks per session, averaged for 4 animals in each group, are separated into shocks for responses and shocks for failures to respond in t^D. The open circle at the right of each group's graph represents the shocks for $\not{R}$ during re-exposure to p(1.0, 0). Data are taken from the last 6 days of each phase.



SHOCKS PER SESSION
p(S-R|R̸)=1
p(S-R|R)=1
p(S-R|R)=
GROUP 1
40
30
20
10
0
0 .33 .67 1
p(S-R|R)
1 .67 .33 0 1
p(S-R|R̸)
p(S-R|R̸)=0
p(S-R|R)=0
p(S-R|R)
GROUP 2
20
10
0
0 .33 .67 1
p(S-R|R̸)
1 .67 .33 0 1
p(S-R|R̸)
GROUP 3
20
10
0
0 .33 .67 1 0
p(S-R|R)
1 .67 .33 0 1
p(S-R|R̸)
SHOCKS FOR
SHOCKS FOR

shows that most responses were still emitted near the end of t^D. Under the last two parametric values of $p(S^{-R}|R)$, however, response rate during the last 2 sec period was reduced to zero. Curvature index values (Fig. 7) decreased throughout parametric variations until p(0.67, 0). As in Group 1, curvature indices for the first 6 days on each phase were higher during the last two phases of increasing $p(S^{-R}|R)$.

Except for a decrease at p(0.33, 0), no systematic change in latencies (Fig. 8) was observed. As in the first group, latencies for the first response in t^D were shorter for the first 6 days when $p(S^{-R}|R) = 0.33$ was initially introduced. Latency data for individual animals (Fig. 9) reveal that one animal (B-6) responded almost exclusively at the end of the t^D period, whereas the other animals generally showed shorter latencies as $p(S^{-R}|R)$ assumed greater values. Both animals that kept responding after p(0,67, 0) showed decreased latencies at p(1.0, 0). The variability among animals in Group 2 was considerably greater than for the animals in Group 1 under the same changing variable, and response rate data show that fewer responses were emitted at $p(S^{-R}|R) = 1.0$ parameter value.

The number of $\not{R}$ trials increased gradually during each 20 day phase and with successive phases when $p(S^{-R}|R)$ increased from 0 to 1 with $p(S^{-R}|R) = 0$ (Fig. 10). The total number of shocks increased initially, but returned to the original level at p(1.0, 0)(Fig. 11).

Figure 12. Median response rate during t^{Δ}. Each point represents the median response rate averaged over the four animals in each group. Interquartile ranges (Q_3-Q_1) are presented by vertical lines through each data point. Data from the re-exposure phase are presented by the unconnected point at the right on each graph.

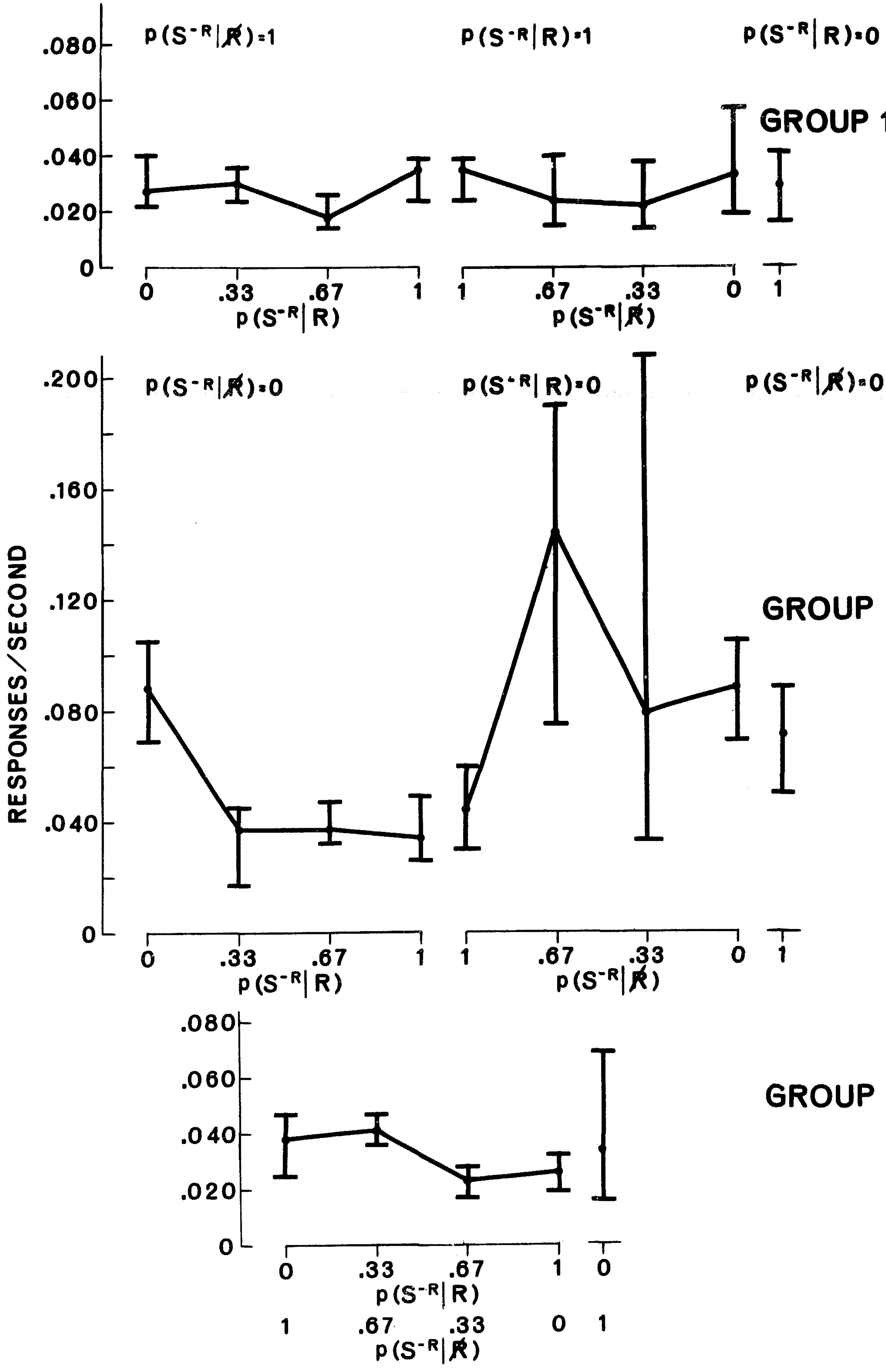
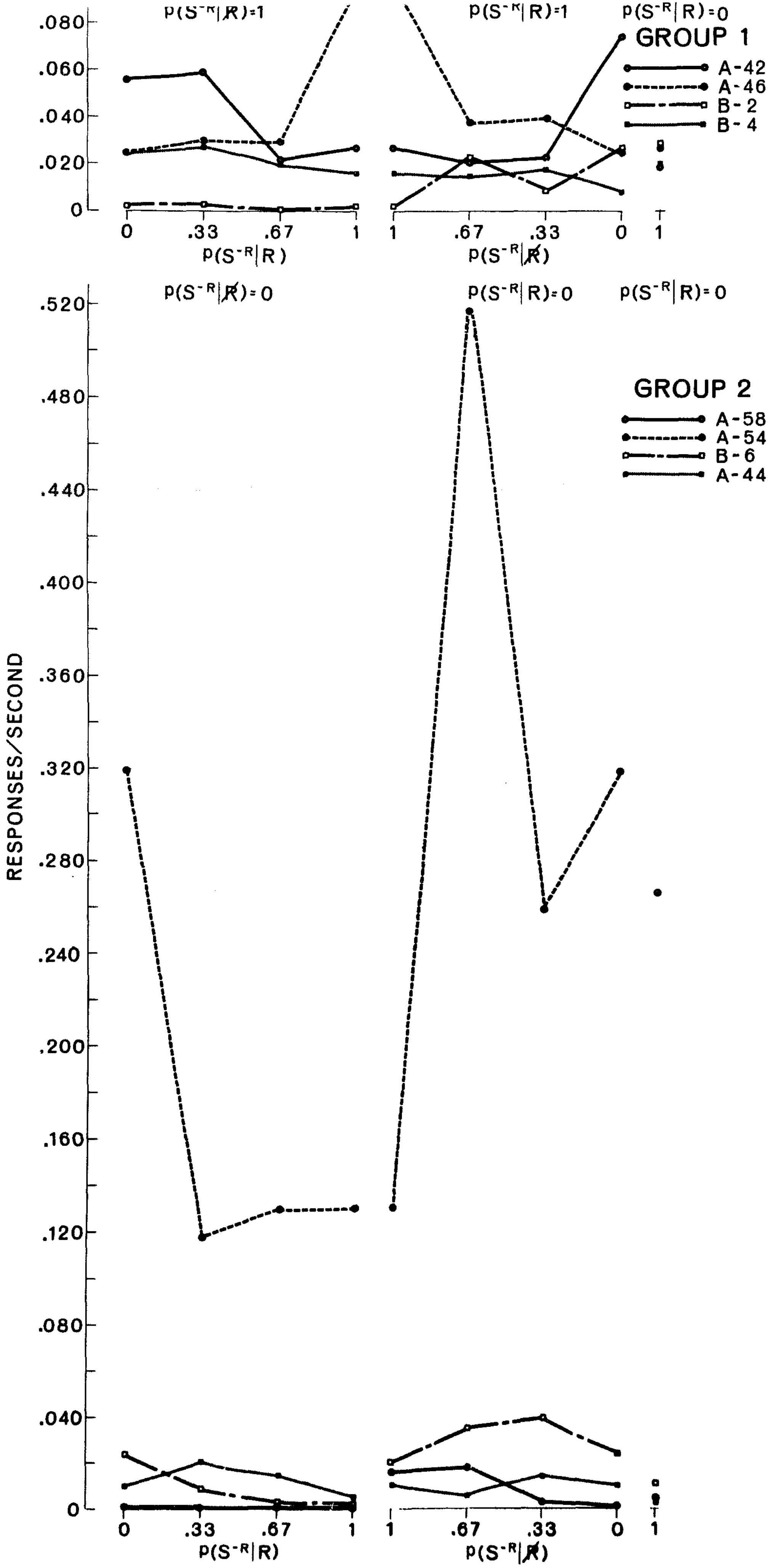
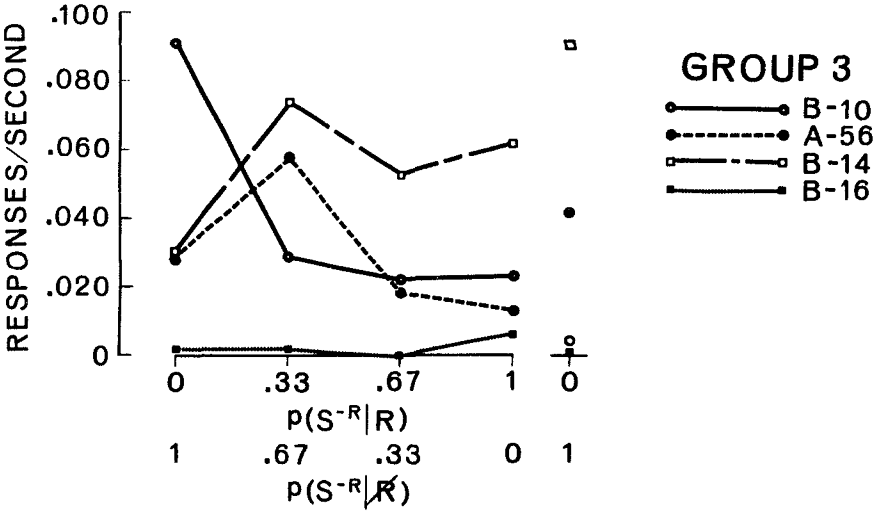

RESPONSES/SECOND
p(S⁻ᴿ|R̸)=1
p(S⁻ᴿ|R)=1
p(S⁻ᴿ|R)=0
GROUP 1
.080
.060
.040
.020
0
0
.33
.67
1
p(S⁻ᴿ|R)
1
.67
.33
0
p(S⁻ᴿ|R̸)
1
p(S⁻ᴿ|R̸)=0
p(S⁻ᴿ|R)=0
p(S⁻ᴿ|R̸)=0
GROUP
.200
.160
.120
.080
.040
0
0
.33
.67
1
p(S⁻ᴿ|R)
1
.67
.33
0
p(S⁻ᴿ|R̸)
1
GROUP
.080
.060
.040
.020
0
0
.33
.67
1
0
p(S⁻ᴿ|R)
1
.67
.33
0
1
p(S⁻ᴿ|R̸)

Figure 13. Median t^{Δ} rates for each animal of three groups for all combinations of parameter values. The p(1.0, 1.0) and p(0, 0) combinations have been plotted twice. Recovery data appear at the right on each group's function.


p(S⁻ᴿ|R̸)=1
p(S⁻ᴿ|R)=1
p(S⁻ᴿ|R)=0
GROUP 1
A-42
A-46
B-2
B-4
.080
.060
.040
.020
0
0
.33
.67
1
1
.67
.33
0
T
1
p(S⁻ᴿ|R)
p(S⁻ᴿ|R̸)
p(S⁻ᴿ|R̸)=0
p(S⁻ᴿ|R)=0
p(S⁻ᴿ|R)=0
GROUP 2
A-58
A-54
B-6
A-44
RESPONSES/SECOND
.520
.480
.440
.400
.360
.320
.280
.240
.200
.160
.120
.080
.040
0
0
.33
.67
1
1
.67
.33
0
T
1
p(S⁻ᴿ|R)
p(S⁻ᴿ|R̸)


GROUP 3
B-10
A-56
B-14
B-16
RESPONSES/SECOND
.100
.080
.060
.040
.020
0
0
.33
.67
1
0
p(S^-R|R)
1
.67
.33
0
1
p(S^-R|R̸)

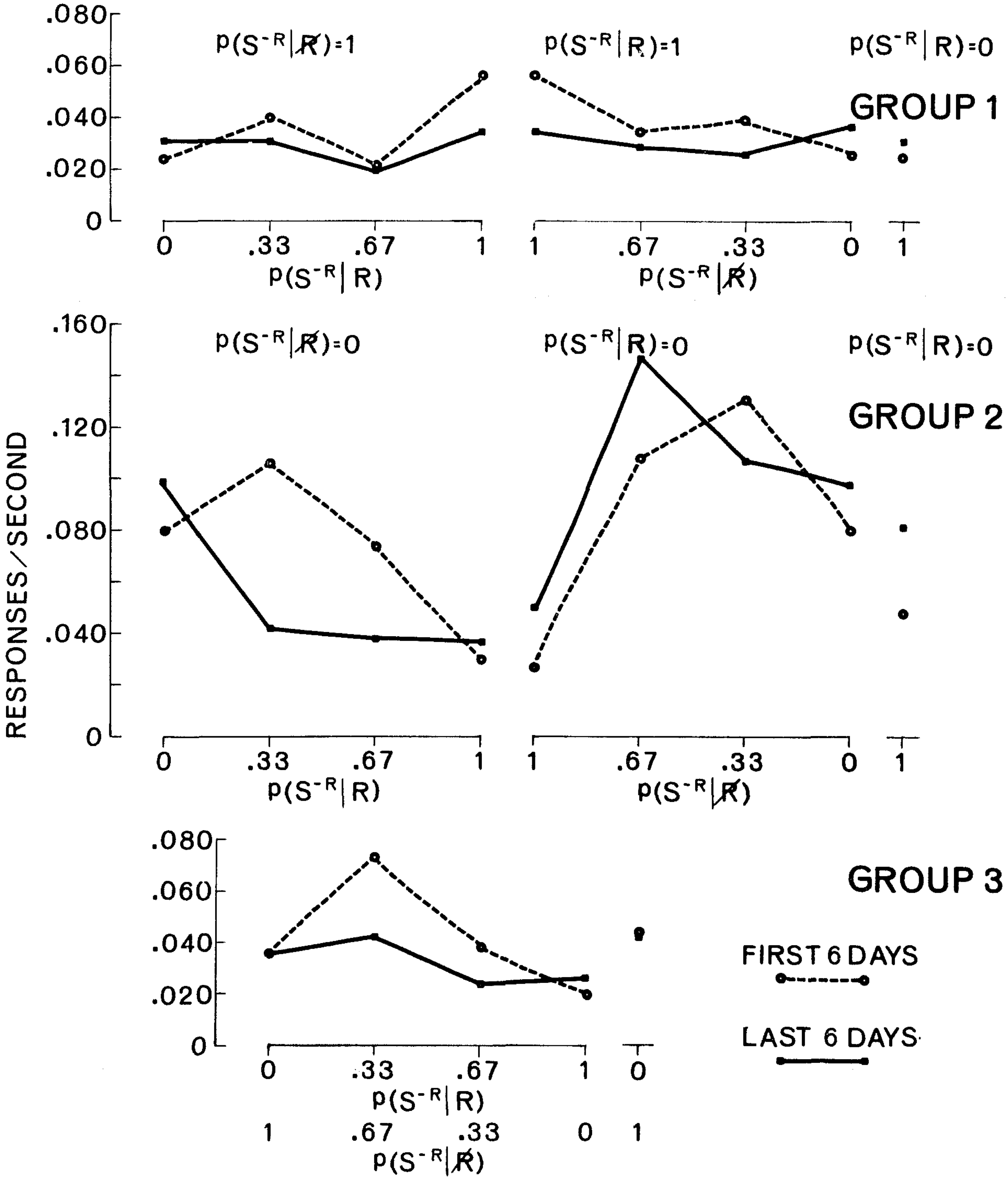
2. Responding in t^{Δ}

Rates in t^{Δ} (Fig. 12) decreased as $p(S^{-R}|R)$ rose above zero. Figure 13 shows that the greatest change was due to one animal (A-54), whose response rate was about 10 times higher than that of the other animals. The remaining subjects' rates decreased slightly as the $p(S^{-R}|R)$ values were changing. As in t^{D}, the response rates in t^{Δ} for the first 6 days of each phase (Fig. 14) increased initially at p(0.33, 0) and remained higher until and during the "punishment" condition p(1.0, 0), with steadily decreasing differences between rates for the first and last 6 days.

Response distributions in t^{Δ} (Fig. 15) show that responding near the end of t^{Δ} increased during p(0.33,0) and p(0.67, 0), although not all animals (Fig. 16) showed the increased rates at the same time or under the same conditions. When the "discriminated punishment" condition of p(1.0, 0) was reached three of four animals displayed a decelerating function as response distribution in t^{Δ}.

Cumulative records (Fig. 18) of Day 14 for one animal of each group under $p(S^{-R}|R) = 0.33$, show the increased responding before the onset of t^{D}, which was not evident from the records of animals under the same $p(S^{-R}|R)$ condition when $p(S^{-R}|\not{R})$ was constant at 1.0. The curvature indices for t^{Δ} responding rose above zero for p(0.33, 0) and p(0.67, 0) (Fig. 17). The data from the first 6 days reveal that initially, when a new $p(S^{-R}|R)$ value was introduced, responses tended to occur slightly earlier in the t^{Δ} period.

Figure 14. Mean response rates in t^{Δ}, for four animals in each group, for the first and last 6 days in each phase. Recovery data are presented at the right.


RESPONSES/SECOND
GROUP 1
p(S^-R|R̸)=1
p(S^-R|R)=1
p(S^-R|R)=0
.080
.060
.040
.020
0
0
.33
.67
1
p(S^-R|R)
1
.67
.33
0
1
p(S^-R|R̸)
GROUP 2
p(S^-R|R̸)=0
p(S^-R|R)=0
p(S^-R|R)=0
.160
.120
.080
.040
0
0
.33
.67
1
p(S^-R|R)
1
.67
.33
0
1
p(S^-R|R̸)
GROUP 3
.080
.060
.040
.020
0
0
.33
.67
1
0
p(S^-R|R)
1
.67
.33
0
1
p(S^-R|R̸)
FIRST 6 DAYS
LAST 6 DAYS

C. Group 1: $p(S^{-R}|\not{R})$ decreasing, $p(S^{-R}|R) = 1.0$

1. Responding in t^D

As $p(S^{-R}|\not{R})$ decreased for Group 1 animals, the already low rates in t^D showed a further decline (Fig. 2), until zero response rates were obtained (Fig. 3) for all but one animal at the p(1.0, 0) condition. Differences between first and last 6 days (Fig. 4) were very small or non-existent.

The reversal of the relative frequency distribution that had begun earlier for some animals, (Fig. 6), generally progressed until, at the p(1.0, 0) condition, most responding occurred in the beginning of t^D (Fig. 5). This confirms the observations for Group 2 with increasing $p(S^{-R}|R)$ and $p(S^{-R}|\not{R}) = 0$ where responding also increased with the shock frequency. Curvature indices (Fig. 7) decreased with the $p(S^{-R}|\not{R})$ parameter. Under the "discriminated punishment" condition, the curvature index values were higher during the first 6 days on that phase than during later sessions.

Latencies decreased with the $p(S^{-R}|\not{R})$ parameter (Fig. 8), and the variability of the latency data between animals became greater, as shocks for failure to respond diminished and as more t^D periods passed without a response (Fig. 9).

When no responses in t^D occurred fewer shocks were presented, as the number of shocks for R went down (Fig. 11), resulting in a low shock frequency at p(1.0, 0).

Figure 15. Relative response ratios during t^{Δ} averaged over four subjects in each group. Data are taken from the last 6 days on each phase. They are presented in the order in which the phases followed each other during experimentation. The relative ratios were computed for each day by taking the number of responses in each t^{Δ} subdivision and dividing it by the product of the ratio of t^{Δ} subdivision and total t^{Δ} and the total number of responses in t^{Δ} :

$$\frac{r}{\frac{t}{T} \times R}$$

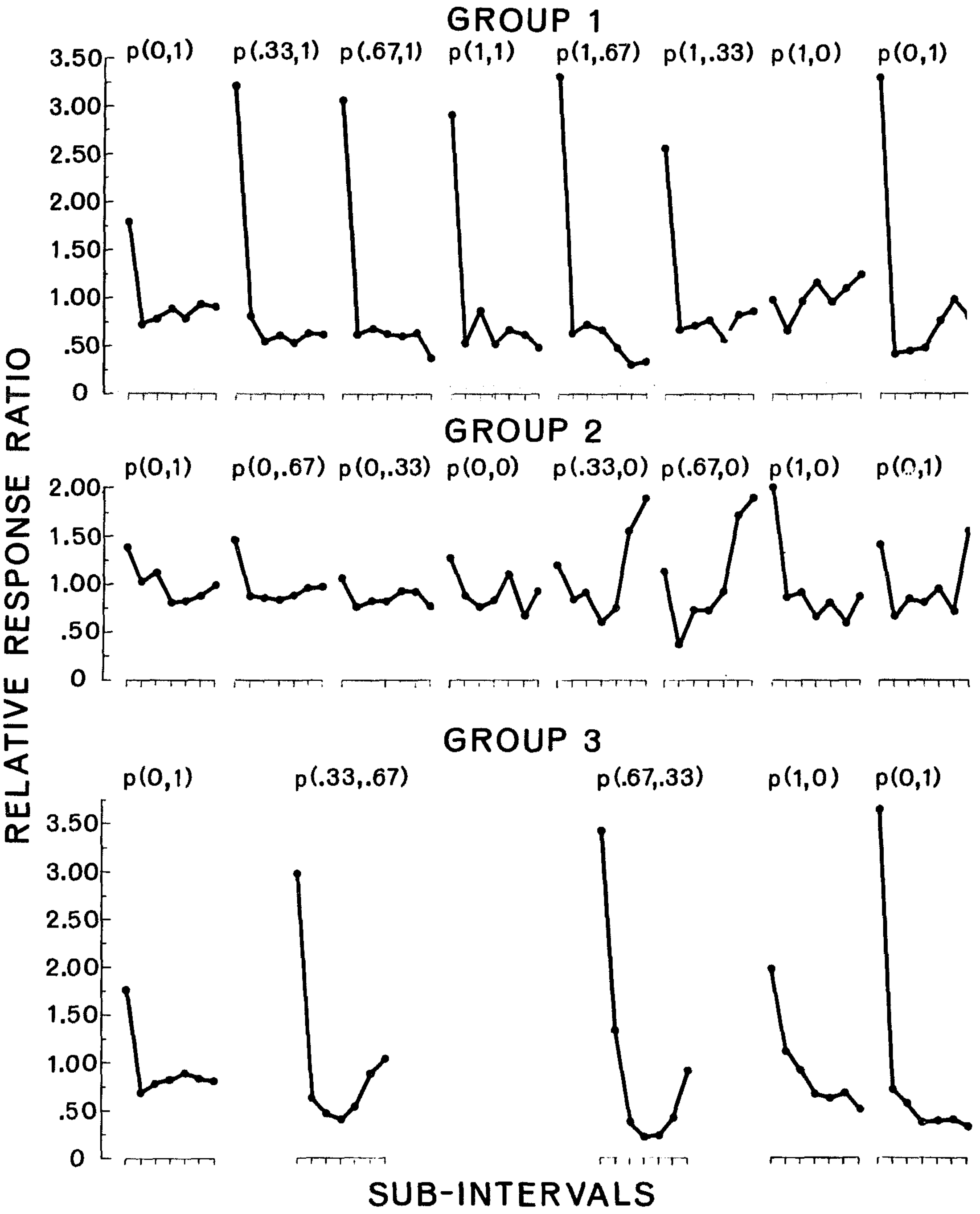
where r: total number of responses in the t^{Δ} sub-period

t: t^{Δ} sub-division (bin)

T: t^{Δ} period

R: total responses in t^{Δ}

The first 6 points of each graph are based on 30 sec bins, the last point on the last 10 sec preceding t^{Δ}. The combination of probabilities for R and $\not{R}$ is indicated above the function for each phase.


GROUP 1
p(0,1)
p(.33,1)
p(.67,1)
p(1,1)
p(1,.67)
p(1,.33)
p(1,0)
p(0,1)
3.50
3.00
2.50
2.00
1.50
1.00
.50
0
GROUP 2
p(0,1)
p(0,.67)
p(0,.33)
p(0,0)
p(.33,0)
p(.67,0)
p(1,0)
p(0,1)
2.00
1.50
1.00
.50
0
GROUP 3
p(0,1)
p(.33,.67)
p(.67,.33)
p(1,0)
p(0,1)
3.50
3.00
2.50
2.00
1.50
1.00
.50
0
RELATIVE RESPONSE RATIO
SUB-INTERVALS

2. Responding in t^{Δ}

The mean median response rates in t^{Δ} (Fig. 12) decreased with the decline in the value of $p(S^{-R}|\not{R})$, until the "punishment" condition was reached. At that point more responding in t^{Δ} was observed for two animals (A-42 and B-2) as shown in Figure 13. The latter change in response rate developed slowly, as seen in Figure 14 where the data for the first six days show higher rates for the first three parametric changes, but lower rates under the punishment condition.

The decelerating response distribution in t^{Δ} (Fig. 15) disappeared during the p(1.0, 0) condition. For all but one animal (B-2), the relatively high rates during the first 30 sec in t^{Δ} diminished until responding was about equally spread over the entire 190 sec period, as shown in Figure 16. Curvature values, revealing the same picture, rose above zero when $p(S^{-R}|\not{R}) = 0$. Functions for the first and last six days of each phase showed an increasing trend toward the last parameter point.

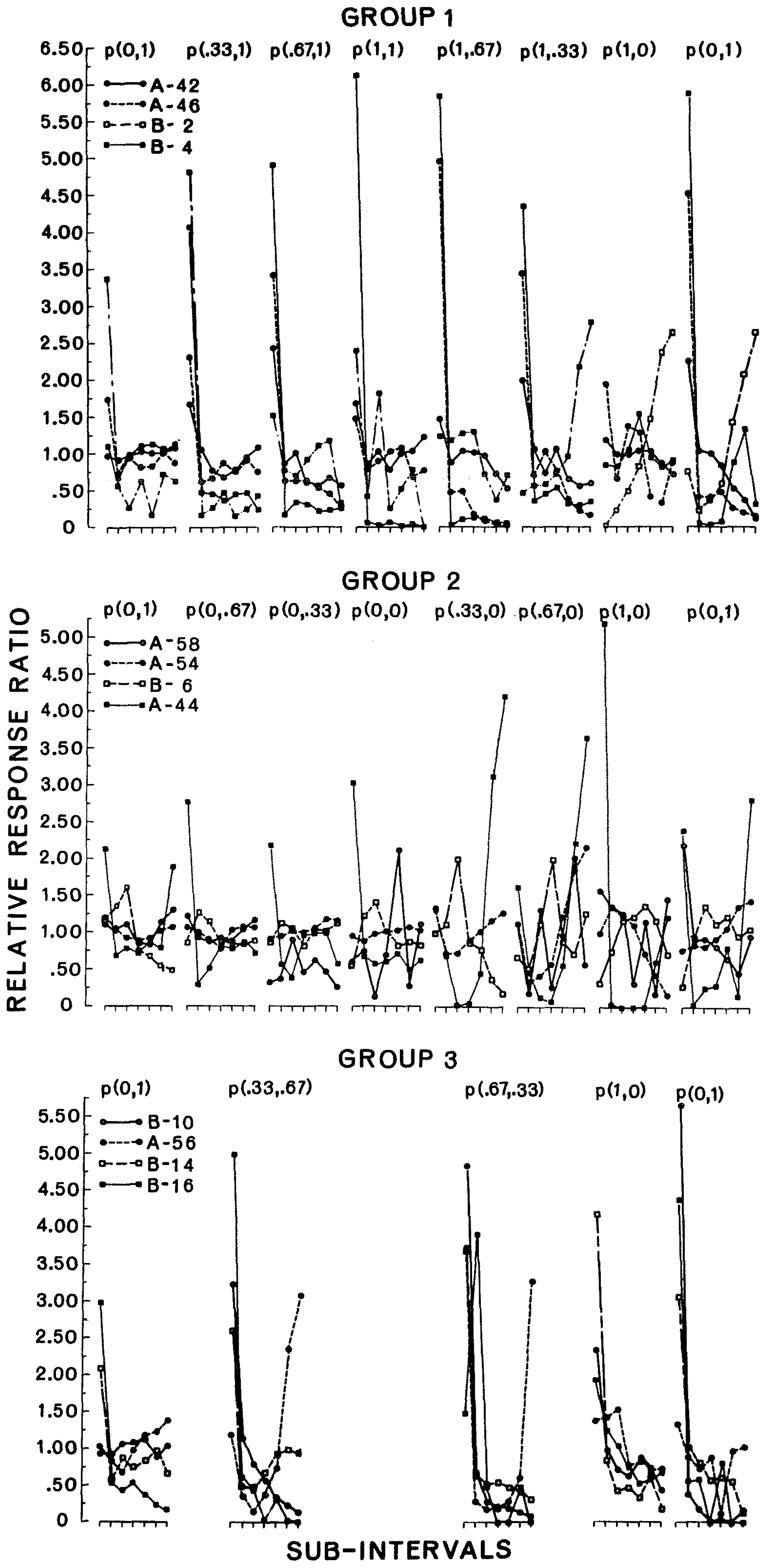
D. Group 2: $p(S^{-R}|\not{R})$ decreasing, $p(S^{-R}|R) = 0$

1. Responding in t^{D}

For Group 2, the decreasing $p(S^{-R}|\not{R})$ variable was the first parameter to be changed in the series of experimental phases.

Response rates during the stimulus did not decrease substantially as failure to respond produced fewer shocks, until the

Figure 16. Relative response ratios during t^{Δ} for the last 6 days of each phase, for each animal. The ratios are computed as in Figure 15.


GROUP 1
p(0,1)
p(.33,1)
p(.67,1)
p(1,1)
p(1,.67)
p(1,.33)
p(1,0)
p(0,1)
A-42
A-46
B- 2
B- 4
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.50
0
GROUP 2
p(0,1)
p(0,.67)
p(0,.33)
p(0,0)
p(.33,0)
p(.67,0)
p(1,0)
p(0,1)
A-58
A-54
B- 6
A-44
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.50
0
RELATIVE RESPONSE RATIO
GROUP 3
p(0,1)
p(.33,.67)
p(.67,.33)
p(1,0)
p(0,1)
B-10
A-56
B-14
B-16
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.50
0
SUB-INTERVALS

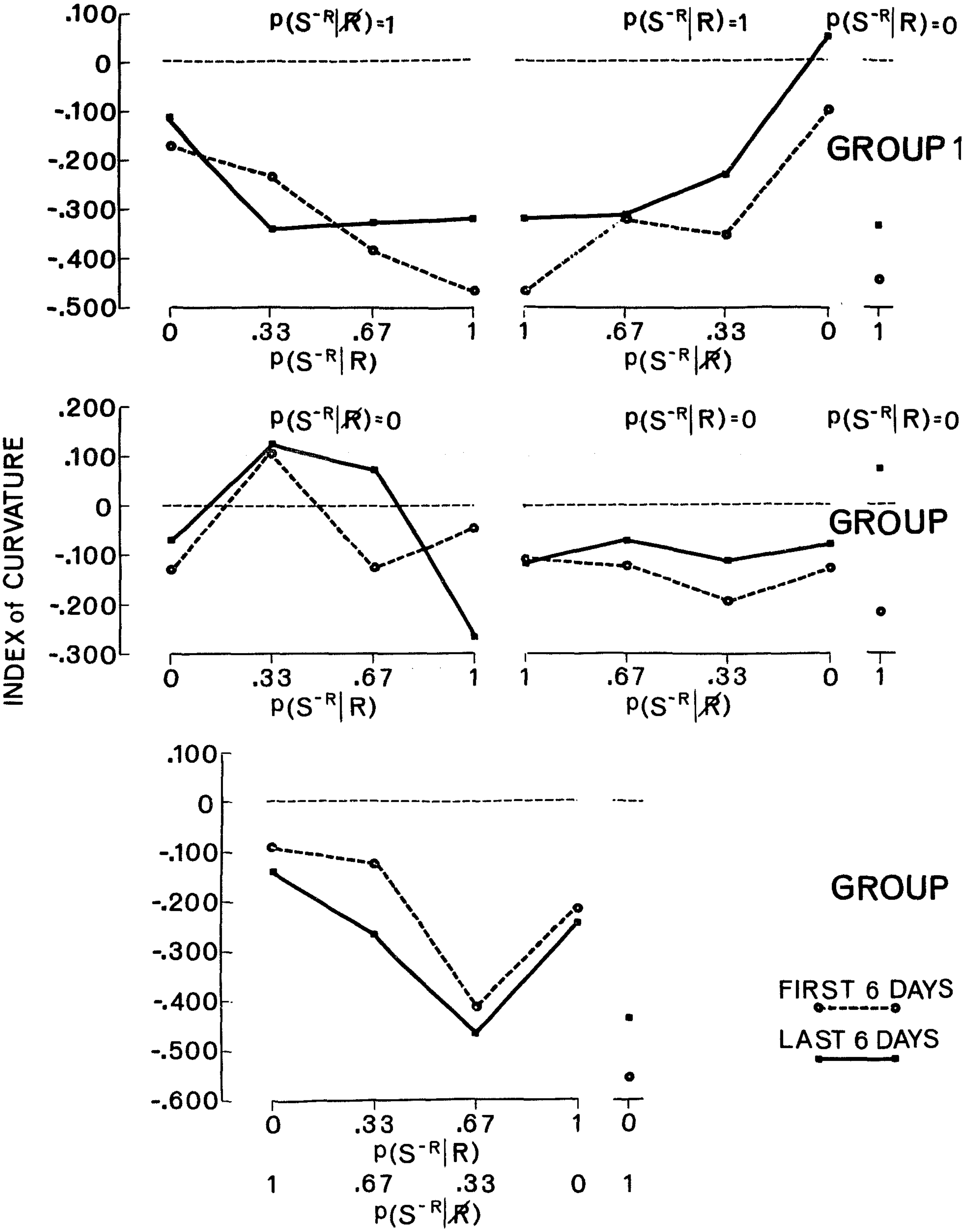
p(0, 0) condition was reached (Fig. 3). Although one animal (A-54) that already responded at a very high rate increased its responding when $p(S^{-R}|\not{R})$ dropped from 1.0 to 0.67, its rate also dropped under the "extinction" condition. Responding decreased slowly under the p(0, 0) condition, as may be seen from a comparison of the t^D response rate data of the first and last 6 days (Fig. 4), and from the data of A-58 whose response rate at p(0, 0.33) was as high as the rates of two other animals in its group but approached zero rates at the end of the "extinction" phase.

Response distribution data indicate that responding tended to increase near the end of t^D (Fig. 5). The response distribution during t^D diverged between animals (Fig. 6) only at the p(0, 0) condition. Curvature indices increased towards p(0, 0), and response patterns were similar during the last 6 days and the first days of each phase.

As suggested by the response distribution data (Fig. 5), increasing latencies were seen at the "extinction" condition for all but one animal (Fig. 9), whose response rate was so high as to prevent long latencies from occurring. Latencies were shorter for the first 6 days in the p(0, 0) condition.

The frequency of t^D periods in which no response occurred, increased (Fig. 10), when no shocks were programmed, p(0, 0) (Fig. 11).

Figure 17. Curvature indices of t^{Δ} responding averaged over four animals in each group, for the first and last 6 days in each phase. Combinations of parameter values that could belong on either abcissa are repeated. Recovery data are presented at the right of the functions of each group.


INDEX of CURVATURE
GROUP 1
p(S⁻ᴿ|R̸)=1
p(S⁻ᴿ|R)=1
p(S⁻ᴿ|R)=0
.100
0
-.100
-.200
-.300
-.400
-.500
0
.33
.67
1
p(S⁻ᴿ|R)
1
.67
.33
0
p(S⁻ᴿ|R̸)
1
GROUP
p(S⁻ᴿ|R̸)=0
p(S⁻ᴿ|R)=0
p(S⁻ᴿ|R)=0
.200
.100
0
-.100
-.200
-.300
0
.33
.67
1
p(S⁻ᴿ|R)
1
.67
.33
0
p(S⁻ᴿ|R̸)
1
GROUP
.100
0
-.100
-.200
-.300
-.400
-.500
-.600
0
.33
.67
1
0
p(S⁻ᴿ|R)
1
.67
.33
0
1
p(S⁻ᴿ|R̸)
FIRST 6 DAYS
LAST 6 DAYS

2. Responding in t^{Δ}

Median response rates in t^{Δ} (Fig. 13) for three of four animals did not show great variations except for some tendency to decrease after the initial increase at p(0, 0.67). One animal (A-54) increased its response rate even more at p(0, 0.67), but slowly decreased its rate as $p(S^{-R}|\not{R})$ became smaller. The peculiar behavior of this animal may be related to an infection of the tail during that phase. Figures 12 and 14 show that most animals decreased their responding in t^{Δ} near the p(0, 0) point.

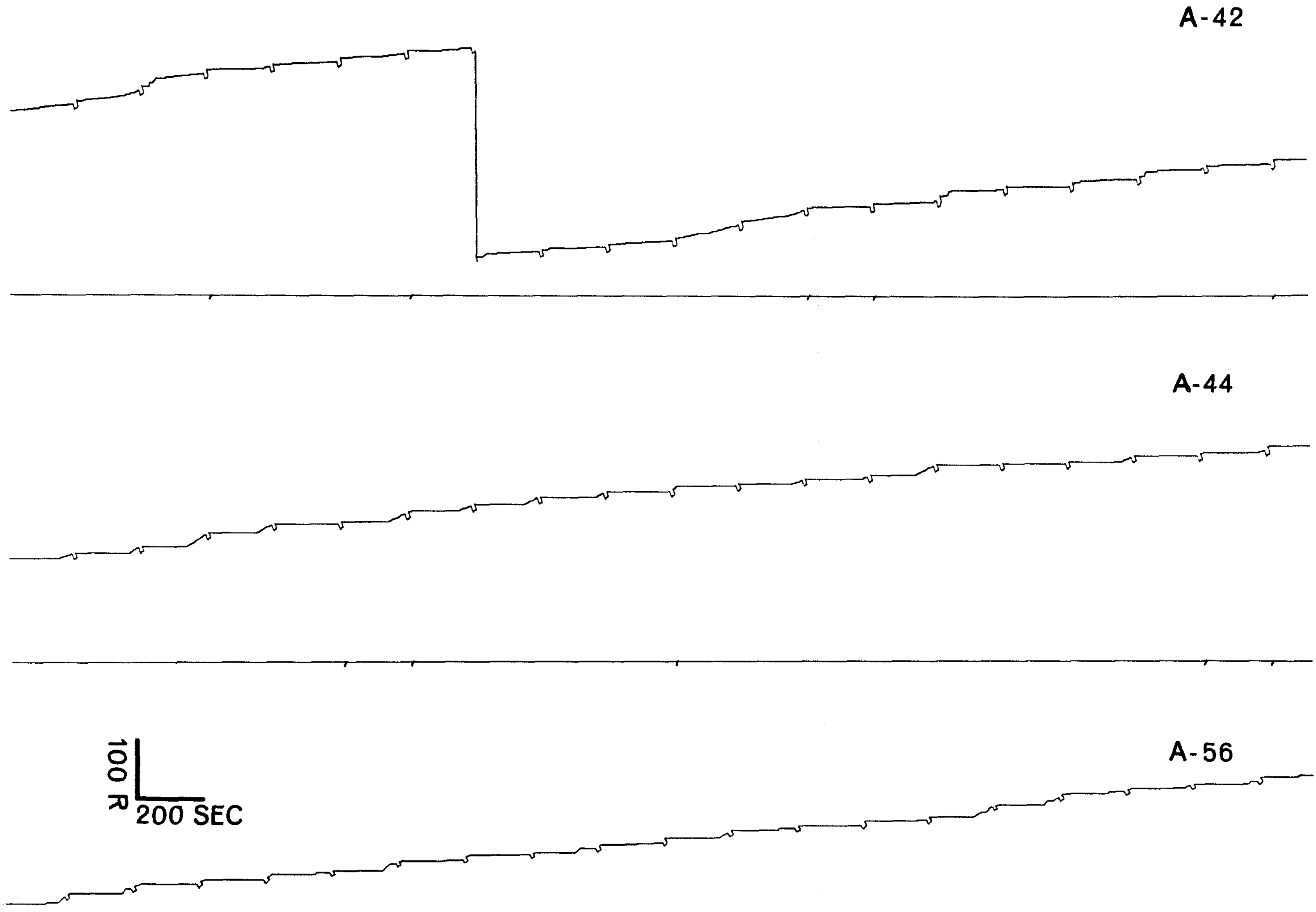
Response distributions were almost flat after the first 30 sec period (Fig. 15), but one animal (A-44) consistently showed higher rates in the first 30 sec of t^{Δ} (Fig. 16). Curvature indices were a little below zero and did not differ between first and last 6 days in each phase.

E. Group 3: Simultaneous, inverse variation of $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$

1. Responding in t^{D}

When $p(S^{-R}|R)$ increased from 0 to 1 while $p(S^{-R}|\not{R})$ decreased in equal steps but in opposite direction, response rates in t^{D} decreased (Fig. 2). Three of four animals reached near zero response rates when $p(S^{-R}|R)$ reached 1 and $p(S^{-R}|\not{R})$ reached 0 (Fig. 3). The rates of two subjects (B-14 and B-16) increased

Figure 18. Cumulative records for Subject A-42 of Group 1 during $p(S^{-R}|R) = 0.33$ and $p(S^{-R}|\not{R}) = 1.0$ for A-44 of Group 2 during $p(S^{-R}|R) = 0.33$ and $p(S^{-R}|\not{R}) = 0$ for A-56 of Group 3 during $p(S^{-R}|R) = 0.33$ and $p(S^{-R}|\not{R}) = 0.67$. Downward excursions of the response pen indicate the duration of the t^D period. Shocks are indicated on the baseline. Data are taken from day 14, and represent the 11th - 30th T-cycle.


A-42
A-44
A-56
100 R
200 SEC

when shocks for responding in t^D were first introduced, as did those of one animal in the first group and of one in the second when $p(S^{-R}|R)$ increased. Response rates during the first 6 days (Fig. 4) were higher than during the last 6 days only for the last two phases.

Responding was equally spread over the entire t^D period during the "discriminated avoidance" p(0, 1.0) condition (Fig. 5) except for one animal which maintained a higher rate in the first 2 sec period in t^D than during the rest of t^D, throughout the entire experiment (Fig. 6). When $p(S^{-R}|R)$ increased to 0.33, two animals showed positively accelerated response distributions, and one animal's response distribution was flat. When $p(S^{-R}|R)$ reached 0.67, three subjects showed a decelerating curve with least frequent responding at the end of t^D. At the "discriminated punishment" point p(1.0, 0) all animals responded most frequently in the beginning of the signaled t^D. Figure 7 shows that the curvature index measure reflects these previous observations; curvature indices are highest at the p(0.33, 0.67) point and decrease as $p(S^{-R}|R)$ approaches 1. Response distributions for the first 6 days were initially less accelerated, but in the last 2 phases curvature index values of the first 6 days remained above the values for the last 6 days. Latency values (Fig. 8) increased until p(0.67, 0.33). Lower latency values were observed during "discriminated punishment" p(1.0, 0). The latencies of two animals did not change during the

4 phases of the experiment (Fig. 9). The increased latencies were not apparent during the first 6 days, except for the p(1.0, 0) condition where latencies for the last days were lower than for the first days.

The number of $\not{R}$ trials was highest at p(0.67, 0.33) and p(1.0, 0) (Fig. 10). Shock frequency stayed at about the same level after p(0.33, 0.67) (Fig. 11). The shock frequency did in fact decrease sharply for 3 of 4 animals; one subject (B-14) maintained a high response rate during t^D throughout the "discriminated punishment" condition.

2. Responding in t^{Δ}

The mean of the median t^{Δ} response rate for the four animals generally declined towards p(1.0, 0) (Fig. 12). When shocks for responses were first introduced rates increased (Fig. 14). Response rates in t^{Δ} were higher on the first 6 days of each phase, except for the p(1.0, 0) condition, where, as in Group 1, t^{Δ} rates increased during the last sessions.

Relative response ratios of t^{Δ} responding (Fig. 15) showed a decreasing function throughout. Examination of individual data (Fig. 16) reveals that some animals did show a rise in response rates near the end of t^{Δ} as $p(S^{-R}|R)$ increased above zero, and that only during the p(1.0, 0) condition were the lowest rates in t^{Δ}

observed near the end of the 190 sec period. Curvature index values decreased gradually, but were lowest during p(0.67, 0.33). Cumulative records (Fig. 18) show instances of increased response rates preceding the onset of t^D.

F. Cardiac data

The pulse rate data presented in Figures 19 and 20 were collected during 2 days of days 15 through 18 of each phase. Cardiac data in Figure 19 are expressed as percent change from the last 2 sec period in t^Δ.

As $p(S^{-R}|R)$ increased, all animals showed an elevated heart rate (HR) near the end of t^D (there is one exception to this, B-4 maintained a decreasing HR function throughout all but the first of the experimental phases). For Group 1, as the number of shocks for responding increased, all animals reached the maximum change from baseline HR at the end of t^D, and the greatest differences from baseline HR rates were observed at p(1.0, 1.0). For Group 2, maximum change from baseline rate was obtained earliest in the course of the changing $p(S^{-R}|R)$ parameter, either at p(0.33, 0) or at p(0.67, 0), again near the end of the t^D period. As the animals in this group reached the p(1.0, 0) condition, HR functions were flat for three of four animals.

Figure 19. Cardiac rate of individual subjects during consecutive 2 sec periods in t^D, expressed as percentage of baseline heartrate during the last 2 sec period of t^{Δ}. Phases are presented in the order in which they occurred during the experiment. Data are taken from days 15 and 16 for B-2, B-4, B-6 and A-44, and from days 17 and 18 for the remaining _S_s.

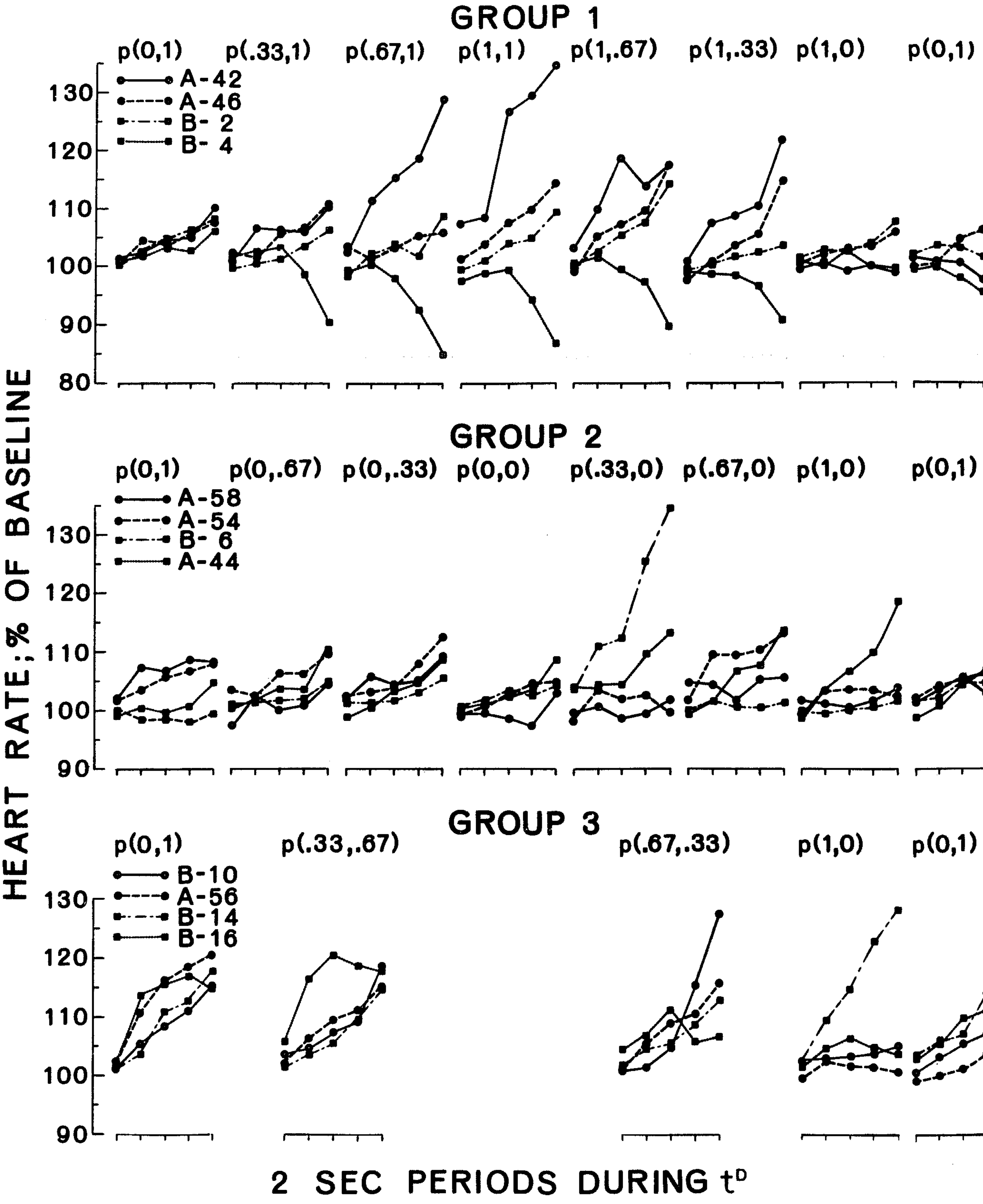
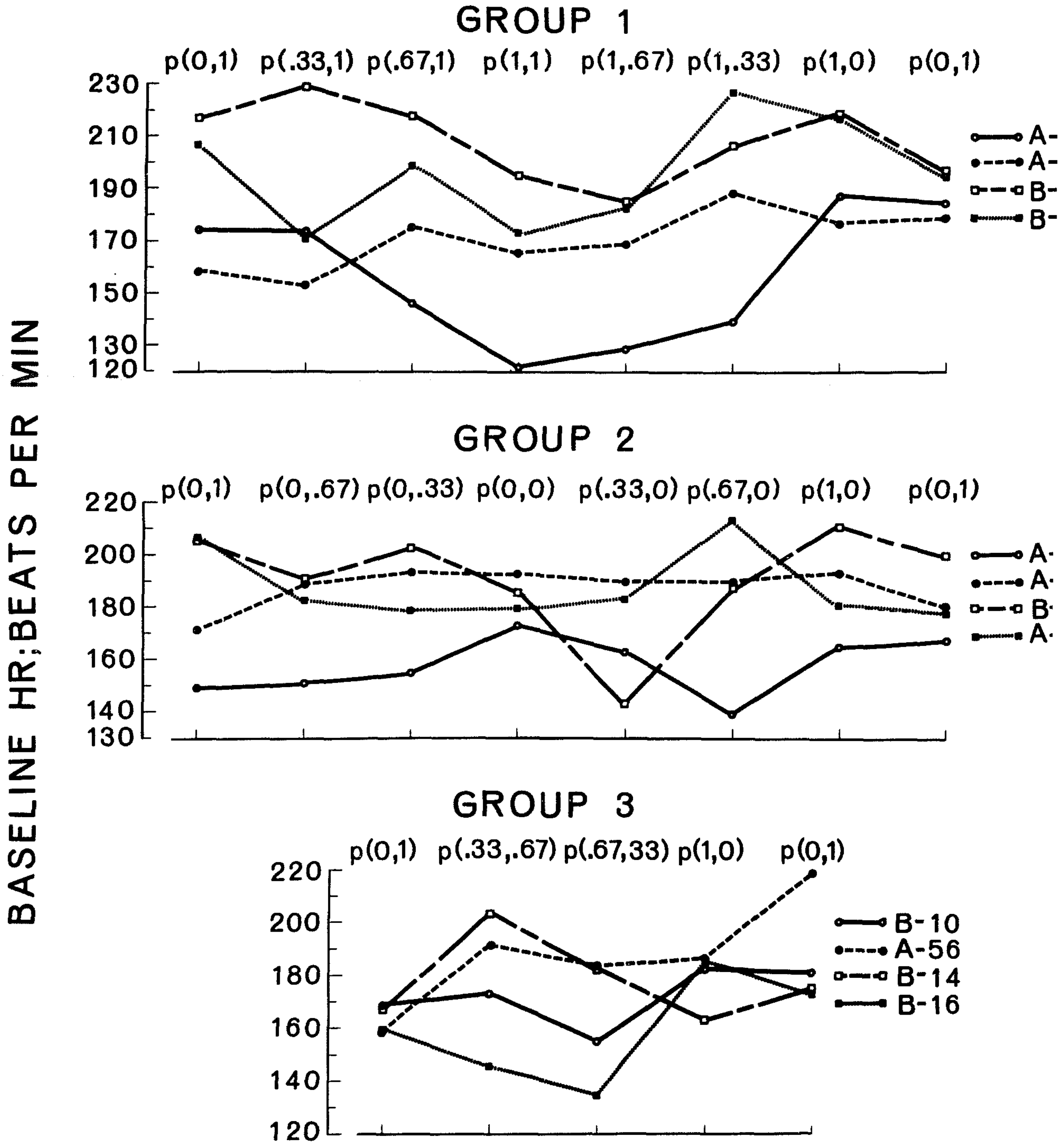

GROUP 1
p(0,1)
p(.33,1)
p(.67,1)
p(1,1)
p(1,.67)
p(1,.33)
p(1,0)
p(0,1)
A-42
A-46
B- 2
B- 4
130
120
110
100
90
80
GROUP 2
p(0,1)
p(0,.67)
p(0,.33)
p(0,0)
p(.33,0)
p(.67,0)
p(1,0)
p(0,1)
A-58
A-54
B- 6
A-44
130
120
110
100
90
GROUP 3
p(0,1)
p(.33,.67)
p(.67,.33)
p(1,0)
p(0,1)
B-10
A-56
B-14
B-16
130
120
110
100
90
HEART RATE; % OF BASELINE
2 SEC PERIODS DURING t^D

Figure 20. Changes in HR baseline (last 2 sec of t^{Δ}) for all animals during successive phases.


BASELINE HR;BEATS PER MIN
GROUP 1
p(0,1)
p(.33,1)
p(.67,1)
p(1,1)
p(1,.67)
p(1,.33)
p(1,0)
p(0,1)
230
210
190
170
150
130
120
A-
A-
B-
B-
GROUP 2
p(0,1)
p(0,.67)
p(0,.33)
p(0,0)
p(.33,0)
p(.67,0)
p(1,0)
p(0,1)
220
200
180
160
140
130
A·
A·
B·
A·
GROUP 3
p(0,1)
p(.33,.67)
p(.67,33)
p(1,0)
p(0,1)
220
200
180
160
140
120
B-10
A-56
B-14
B-16

Decreasing the $p(S^{-R}|\not{R})$ value resulted in progressively smaller diversions from the baseline HR for animals in Group 1. HR functions under the p(1.0, 0) condition were again flat. No major changes were observed when $p(S^{-R}|\not{R})$ decreased with $p(S^{-R}|R)$ constant at zero (Group 2) as compared with the original "discriminated avoidance" (p(0, 1.0)) condition. The one animal that did maintain near-zero response rates during p(0, 0) showed the smallest increase over the baseline.

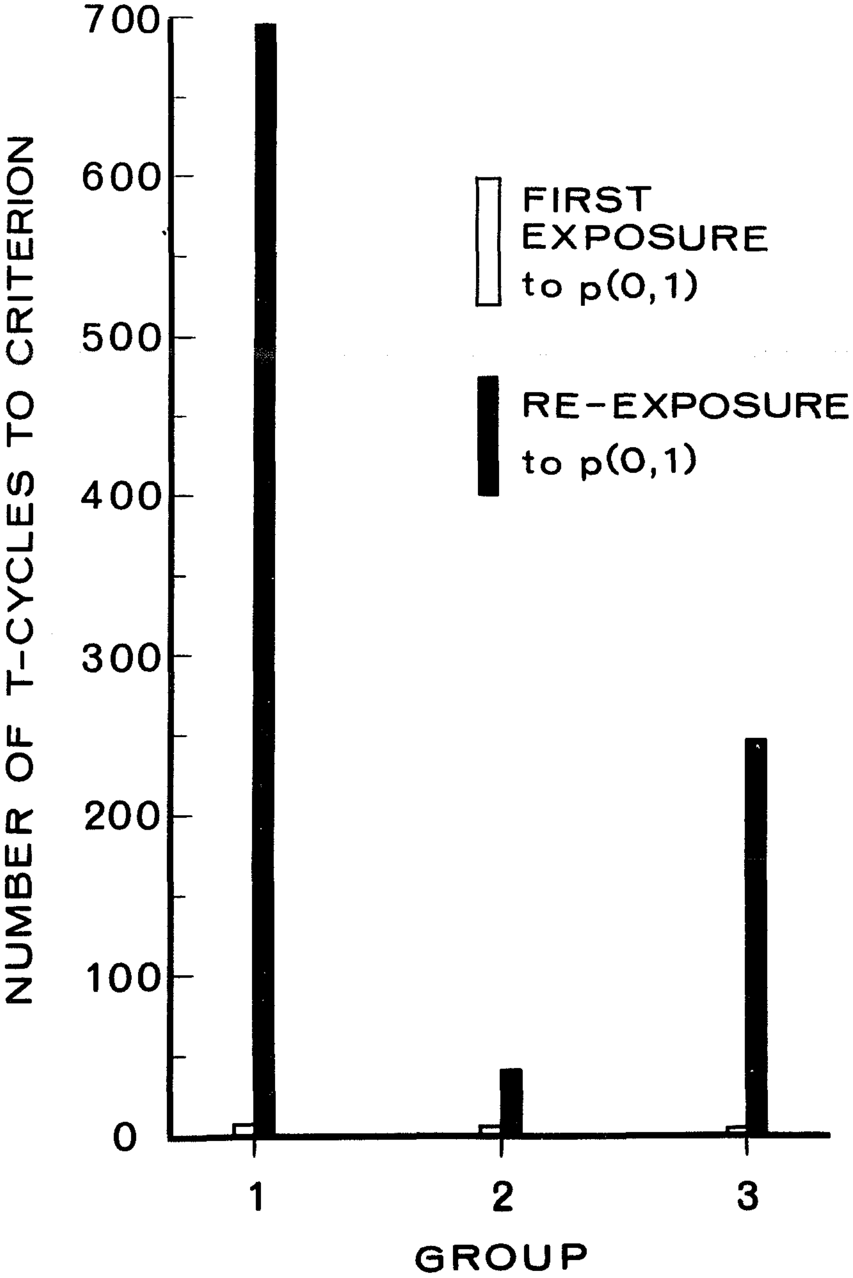
HR functions for Group 3, in which both parameters changed simultaneously did not change substantially during the first three phases (Fig. 19). At the p(1.0, 0) condition, HR functions for three animals were flat while one animal (B-14) who maintained responding and, consequently, at maximum shock frequency, showed a great rise in cardiac rate near the end of t^D. One animal (B-16) generally showed a bimodal HR function throughout the experiment.

Baseline HR, upon which the percentages in Figure 19 are based, tended to be highest at the p(1.0, 0) condition for all groups than at any other condition. Low baseline HR's were observed at, or just after the "non-contingent" point: p(1.0, 1.0) for Group 1, p(0, 0) for Group 2 and between p(0.33, 0.67) and p(0.67, 0.33) for Group 3. Often coincident with this, baseline HR tended to be lowest at the points of highest shock frequency: p(1.0, 1.0) for Group 1, p(0.33, 0) for Group 2, and p(0.67, 0.33) for Group 3.

G. Re-exposure to "Discriminated Avoidance"

The last phase for all groups after the p(1.0, 0) condition, consisted of re-exposure to the same p(0, 1.0) condition with which the experiment was started. If a criterion is applied of five consecutive T-cycles in which a response durint t^D prevents the occurrence of a shock, it may be seen from Figure 21 that the animals in Group 1 did not show any recovery at all, or at best very late in the series of sessions, whereas Group 2 reacquired the original behavior during the first two sessions, and that the Group 3 fell somewhere between the first and second group. A criterion of 10 consecutive T-cycles in which a response occurs yields similar results. Response rates in t^D (Figs. 2 and 3) show that only one animal in Group 1 approximated its initial t^D rate during the last 6 days of the recovery phase. Response distribution during t^D for Group 1, however, was quite similar for re-exposure data to the initial p(0, 1.0) distribution (Figs. 5, 6 and 7), and curvature index values between first and last days did not differ, although latencies (Figs. 8 and 9) of the first response in t^D were substantially longer on recovery. Response distributions for Groups 2 and 3 differed somewhat from the original p(0, 1.0) condition, as evidenced by the curvature index values (Fig. 7). Latencies were shorter than originally for Group 2, but longer for Group 3.

Figure 21. Number of T-cycles needed to reach a criterion of 5 consecutive t^D periods in which a response occurred, during the first exposure (open bars) to the p(0, 1.0) schedule and during re-exposure (solid bars). The data are the average of four animals in each group.


NUMBER OF T-CYCLES TO CRITERION
700
600
500
400
300
200
100
0
1
2
3
GROUP
FIRST EXPOSURE to p(0,1)
RE-EXPOSURE to p(0,1)

Response rates during t^{Δ} were quite similar during original training and re-exposure to p(0, 1.0) for 11 of 12 animals: A-54 of Group 2 displayed low response rates during original p(0, 1.0) and when $p(S^{-R}|R)$ increased above zero (Figs. 12, 13 and 14). Response distributions of t^{Δ} responding were characterized by more frequent responding at the beginning of the t^{Δ} period (Figs. 15 and 16), while curvature indices for Group 2 were somewhat higher than during original training (Fig. 17). Data from the first 6 days of re-exposure show that initially more responses were emitted at the beginning of t^{Δ} by all groups.

The number of t^{D} periods in which no responses occurred (Fig. 10) was higher for all groups during the first 6 days than during the last 6 days of re-exposure to the p(0, 1.0) schedule. Final $\not{R}$ rates remained high for Group 1, recovered its original value for Group 2 and stayed slightly higher for Group 3. A similar statement can be made about the shock frequency for those groups (Fig. 11).

Cardiac rates for two animals of Group 1 (Fig. 19) decreased near the end of t^{D}. The animal showing best recovery did not show substantial HR changes during t^{D}. The fourth animal of this group displayed an increasing HR during t^{D}. The HR functions of Group 2 were not substantially different from the HR functions during first exposure to the p(0, 1.0) schedule. In Group 3, cardiac rate tended to rise less steeply during re-exposure and baseline HR differed noticeably in only one animal of this group.

Discussion

The current study set out to explore two independently specifiable parameters of reinforcement probability: $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$; it provided for localized and general response rate measures, and for recording of heart rate during successive phases of the experiment and re-exposure to the original parameter values. The results of the study are discussed around the findings concerning response rate and response distribution during t^D, responding during t^Δ, data obtained during the recovery phase and heart rate data from the last days of each phase.

Response rate in t^D

As the $p(S^{-R}|R)$ value increased, response rates declined for all animals.

The generality that punishment procedures decrease response rates, cannot be entirely supported by the current data. For example the initial reaction at the introduction of $p(S^{-R}|R) = 0.33$ for the animals in Groups 1 and 2, was an increase in response rates, that was maintained, for at least one animal in each group, throughout the entire phase. Whereas, for the first two groups, changes of parameter values at the transition from one phase to the next, occurred in only one parameter, the other parameter remaining at either one or zero, the changes for Group 3 concerned both $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ values simultaneously. The data from Group 3 indicate for the first days of $p(S^{-R}|R) = 0.33$ and $p(S^{-R}|\not{R}) = 0.67$ an immediate decrease of responding during t^D. Decreased response rates were initially not accompanied by a change in the number of t^D periods per session in which no response was made.

Response facilitation through response-dependent shock delivery is not an uncommon phenomenon. Azrin and Holz (1966) have reported increased response rates for pigeons that received shocks for every response on several intermittent food-reinforcement schedules, as well as during extinction of such schedules. They argue that the shock had become a discriminative stimulus for food presentation. Similar results were reported by Appel (1960b) who initially trained monkeys on a Sidman avoidance schedule and then presented them with a multiple schedule of avoidance and punishment. In the presence of one stimulus responses were punished on a VI 1' schedule, while the original avoidance schedule was in effect during a second stimulus. The multiple schedule produced higher overall rates, and response rate in the punishment component exceeded the avoidance rate. Other studies have reported response facilitation under schedules of shock presentation as well (e.g., Appel, 1960a; Byrd, 1969; McKearny, 1968, 1969; Sidman, *et al*, 1957; Sidman, Mason, Brady & Thach, 1962; Sidman, 1966; Stretch, Orloff & Dalrymple, 1968). In general these studies demonstrate that an occasional shock may serve to increase or maintain responding.

The design of the present study makes comparison possible with other studies in which intermittent response-independent stimuli were delivered. For example, Lachter (1971) found that behavior resulting from exposure to a positive schedule could be maintained temporarily when switched to several different schedules of response-independent reinforcement. Kadden (1971) investigated response dependence of shock presentation and found that as the proportion of response-dependent shocks increased response rates declined. In both studies response-independent stimuli may have contributed to the level of responding.

Punishment as a procedure has been defined by the contingency of a presumed aversive stimulus upon a response (e.g., Azrin, 1966). The independent variables which have been explored have included intensity, duration, the temporal relation between the response and shock, the scheduled frequency of occurrence, and the temporal variability of shock presentation. Punishment as a behavioral effect has been defined as the outcome of stimulus presentation schedules that produce decreased rates of responding upon which the stimulus presentation is presumed to be contingent. In the procedural definition, the aversiveness of the stimulus is inferred from the results of experiments using similar procedures. This definition of punishment acquires broad applicability from the many parameters that have been varied, and is restricted by the presumption that the stimulus is aversive. The behavioral definition acquires its usefulness from the many observations where a stimulus has suppressed behavior. In these cases, it has been assumed that it is the response-contingency that determines the behavioral effects of punishment.

The increase in response rate when $p(S^{-R}|R)$ was raised above zero, indicates that the shock itself served as a discriminative stimulus after avoidance conditioning, but its function could be changed. When $p(S^{-R}|\not R)$ values were held constant throughout changes of $p(S^{-R}|R)$, such response increases occurred mainly at the transition from $p(S^{-R}|R) = 0$ to $p(S^{-R}|R) = 0.33$, and in Group 1 and 2 rate differences between first and last six days of each phase became less as the $p(S^{-R}|R)$ value increased. When both parameters changed simultaneously, as is the case for Group 3, a shock did not become a discriminative stimulus for an avoidance or punishment schedule as easily.

Experiments by Muenzinger (1934) and Muenzinger and Wood (1935) reveal some of the problems as applied to "annoyers". Punishment of the correct response and punishment of the wrong response served equally well to enhance the learning of a visual discrimination. They also found that shocks on both right and wrong responses served equally well to aid discrimination learning. Even when corrections for shock frequency and duration were made, this finding was upheld (Fowler and Wischner, 1969). If one were to accept a "general alerting" theory as an explanation for the increased response rates during the first days of each new $p(S^{-R}|R)$ value, one would also have to explain why the theory would not hold for the overall findings, where response rates decreased with increased shock-frequency.

Appel (1960b) has shown that Rhesus can discriminate avoidance from extinction components in a mixed schedule. Free shocks in extinction resulted in increased response rates throughout the mixed schedule and discrimination between unavoidable and avoidable shock did not occur until the addition of external stimuli. Mixed avoidance punishment procedures produce discriminated responding, but not mixed avoidance extinction. In fact, when the punishment component was changed to an extinction procedure in a mixed punishment avoidance schedule, response rates increased rapidly during the extinction component only. In the absence of external control, the presence of a punishment contingency leads to discriminated responding. In the present experiment the external stimulus did not change with the increased or decreased parameter values. The present procedure differed from other discriminated punishment experiments in that the punishment responses were only punished at the end of the 10 second stimulus, independent of where in the t^D period the response occurred.

Response patterns in t^D

When responding resulted in more shocks than not responding, the response distribution during t^D assumed a decelerated pattern. When responding resulted in fewer shocks than not responding an increasing response distribution during t^D was found.

The present procedure, employing a non-terminable stimulus during the period in which the first response affects the aversive stimulus presentation, has few equivalents in the existing literature. Latencies of the first response during the signal in discriminated avoidance have been reported by some researchers. The common finding is that responses occur with longer latencies as training proceeds (Gilbert, 1971; Hineline & Herrnstein, 1970; Keehn, 1967; Sidman, 1962; Stretch & Skinner, 1967). One report of short latencies (Ulrich, Holz & Azrin, 1964) may well be the result of high shock intensity (5 ma on rats). Hineline and Herrnstein (1970) did not find longer latencies in extinction; patterned responding in their study was observed in conditions where responding only eliminated the shock but did not start the next R-S interval. In their study long latencies did not reduce the potential rate of shock delivery ("discrete trial" procedure). Latencies in the current study increased as $p(S^{-R}|R)$ increased with $p(S^{-R}|\not{R}) > 0$, but they changed only slightly when $p(S^{-R}|R) = 0$ and $p(S^{-R}|\not{R})$ decreased (Group 2). When responding increased shock rate, shorter latencies prevailed; under conditions where responding decreased shock rate longer latencies were observed as training progressed.

The relative frequency distribution of all responses during t^D changed in a similar fashion as the latency data. The functions obtained under p(0, 1.0) are relatively flat; these functions became accelerated when occasional shocks were delivered for responding in

t^D, with the avoidance schedule still in effect (Group 1). When all or most shocks were produced for responding, decelerating functions were obtained (Groups 1, 2 and 3). Under extinction conditions, p(0, 0), most responding occurred near the end of the signal. Traditionally, the signal in discriminated aversive control experiments has been assigned two functions: that of a conditioned aversive stimulus and that of a discriminative stimulus. Accordingly, responding during the signal may be explained by two arguments: when responding terminates the signal, a stimulus change is made contingent upon responding; and responding terminates or produces a period free of shock. Equally traditional are the arguments against such theorizing: if given an opportunity, the animals do not postpone the onset of the signal and thereby reduce the probability of shock, and, responding can be maintained even when it does not terminate the signal. Most accounts of discriminated avoidance employ in one form or another, a two-factor theory, which requires that the pairing of an aversive stimulus with a previously neutral stimulus acquires properties that make the removal of the neutral stimulus a reinforcing agent (e.g., Anger, 1963; Mowrer, 1947; Schoenfeld, 1950). Along the lines of traditional theories one would expect that in the present experiment, using a non-terminable signal, the end of the stimulus period would become more aversive than the beginning, since shocks occur at the end of t^D. As responding during the stimulus becomes less and less effective in eliminating the shock at the end of t^D, i.e. as the shock frequency increases, the end of the stimulus period would gain more and more strength as a conditioned aversive stimulus so that responses closest to the termination of the signal would be more strongly reinforced. If one were to accept a two-factor theory one could find some support in the current response distribution data where responses during the latter portion of t^D, with shortest delay of signal termination, are most frequent. However latencies should become shorter as more shocks are delivered and the CS period becomes more aversive. In fact, for Group 1, with approximately equal shock rates for p(0.67, 1.0) and p(1.0, 0.67), the latencies only became shorter when $p(S^{-R}|R)$ exceeded $p(S^{-R}|\not{R})$. Similarly, at these equal shock rates the accelerating response distribution changed to a decelerating function when the probability of shocks for responses became greater than shocks for not responding. For Group 1 the difference between p(0.67, 1.0) and p(1.0, 0.67) lies in the response rate and $\not{R}$ rate and, most remarkable, in the accelerating and decelerating response rate in t^D, and this difference cannot be explained by a shock frequency reduction theory (Herrnstein & Hineline, 1966; Sidman, 1962; Sidman, 1966).

Of the two theories, shock reduction and two-factor theory, the more general, two-factor theory, can most easily be applied to the current data: Responding becomes more reinforcing near the end of the stimulus period if it eliminates the shock with $p(S^{-R}|\not{R}) > p(S^{-R}|R)$, and responding becomes least reinforcing near the end of t^D with $p(S^{-R}|R) > p(S^{-R}|\not{R})$.

The present results do not, however, provide "proof" for either theory. There are findings in the literature on avoidance latencies that are quite similar to the present results. Gilbert (1971) reports that the probability of lever pressing increases near the end of the signal in a discriminated avoidance situation. Both Boren (1960) and Anderson and Nakamura (1964) have found that responding drifts away from the signal onset in a discriminated avoidance procedure even though this resulted in increased shock frequencies. Anderson and Nakamura (1964) labeled the phenomenon "avoidance decrement". Stretch and Skinner (1967) report very few short latencies during discriminated avoidance and Keehn (1967) reports a direct relation between stimulus duration and latency.

Hineline and Herrnstein's (1970) "discrete trial" procedure consisted of successive periods during which a response terminated a signal and caused the lever to be withdrawn quickly; when no response occurred, a shock was delivered at the end of the trial. If a response had occurred during a trial, the signal and lever returned at the end of the trial but no shock was presented. This differs from the regular discriminated avoidance procedure (Sidman, 1955) since a response does not initiate a new response-stimulus period, but produces a safe period in which no shocks are delivered and no responses can be made. The distribution of latencies during the stimulus period is essentially random, although the investigators observed some drifting towards longer response latencies; when they disconnected the shocker for some animals, they found that the response latency distribution was hardly affected. In view of these observations, drift in timing of responses could not be explained through extinction-like procedures, caused by successful avoidance.

Gilbert (1971) has analyzed responding from a discriminated avoidance experiment, and has observed that during the warning stimulus period responses became more likely as time passed. Although responses late in the warning stimulus may lead to a reduced shock frequency, he observed an increased shock frequency. In both experiments, we see that timing cannot reduce shock frequency (Hineline and Herrnstein, 1970) or does not reduce shock rate (Gilbert, 1971). In both experiments, the termination of a conditioned aversive stimulus (withdrawing the lever, and offset of the warning signal, respectively) results from responding. In the present experiment, responding itself did not produce an immediate change in the external stimulus situation. Although under these conditions very little timing was observed at the end of the discriminated avoidance phase, response patterning did occur when the $p(S^{-R}|R)$ values were increased above zero. Similarly, response patterns changed when $p(S^{-R}|\not{R})$ was reduced below 1.0. Therefore, the data of this experiment suggest that response patterns are mainly affected by the reinforcement schedule, and probably less so by overall shock frequency or signal termination.

Church, Wooten and Matthews (1969) compared behavior under CER-like conditions and under discriminated punishment schedules.

The CER rats, on a food reinforcement baseline, received shocks during a signal at random intervals averaging 1 per minute. The discriminated punishment animals, received shocks during a signal which could be initiated by a response on a VI 1 min schedule. The discriminated punishment animals showed greater response suppression than the CER animals. A third group which received non-contingent shocks in the absence of the signal and punishment during the signal, showed considerably less response suppression during the signal than either of the other groups. In an earlier study, Gibbon (1967) found that rats on a food-reinforced baseline suppressed less in the presence of a signal of variable duration, when the first response would result in a shock and signal termination, and not responding would result in a shock at signal termination (unavoidable shocks), than rats which could avoid shock by not responding and waiting for the end of the signal period (avoidable shock).

Since at p(1.0, 1.0) both parameter values were at maximum, the animals under this condition always received a shock. This procedure closely resembles the classical conditioning paradigm, but it also resembles a CER procedure if the t^D and t^Δ periods are viewed as periods in which ongoing behavior is maintained by a not experimentally identified schedule. At p (1.0, 0) responses during t^D produce a shock at the end of the stimulus period. The finding that punishment-like procedures result in greater response suppression than response-independent shocks is confirmed by the data from the present experiment, without any baseline schedule other than the parameter values during t^D, to maintain behavior during t^Δ.

Responding in t^{Δ}

When $p(S^{-R}|\not{R}) < 1.0$ increasing response distribution functions during t^{Δ} could be observed for some groups.

Response rates during t^{Δ} were less influenced by the changing parameter values than response rates during the stimulus period. Differences of t^{Δ} rates between the first and last six days of a phase were also less pronounced. The initial increase in response rates when $p(S^{-R}|R) > 0$ occurred mainly after the shock-offset and seemed to be correlated with shock frequency. Increased shock rates appeared to result in lower overall response rates particularly when $p(S^{-R}|R) = 0$.

Curvature index values of t^{Δ} responding indicated that most responding occurred during the first subinterval of the t^{Δ} period. A noticeable exception was the animals of Group 2 in the p(0.33, 0) and p(0.67, 0) conditions. Cumulative records and relative frequency measures showed that animals under these conditions tended to show increased response rates near the end of the t^{Δ} period. At the same time, the animals which showed a response increase just before the signal showed a decreasing response pattern during the signal.

Lately, the literature reporting increasing response distributions during FI shock schedules has been extended. Sidman *et al*, (1957) showed that behavior could be maintained with response independent shocks. Later experiments (Byrd, 1969; McKearny, 1968, 1969; Stretch, Orloff & Dalrymple, 1968) showed that FI schedules of electric shock-presentation resulted in response patterns similar to FI scallops usually seen under such schedules of FI food-presentation. Investigations of response-independent shock produced either scallops infrequently (Byrd, 1969) or response patterns that yielded lower values of curvature index measures than those obtained under response-dependent schedules of shock presentation (Kop and Snapper, 1970). Kadden (1971) investigated response-dependence of shock presentation as a variable and found that response-independent shocks resulted in higher response rates when the shocks were presented on a periodic schedule. Kop and Snapper (1970) did find positive accelerated response rates preceding a signal terminated with an unavoidable shock, but response rates during the signal were considerably lower than those preceding the signal. Response patterning improved with omission of the baseline avoidance schedule and shortening or elimination of the signal.

In the present study, the patterning emerged under p(0.33, 0) or p(0.67, 0), for all animals in Group 2, but only occasionally for animals in Groups 1 and 3. As in other studies, the presence of an avoidance contingency worked against establishing FI-like response patterns. In the present study, shocks were response-produced during the t^D period. The curvature index values showed that most responding for the animals showing response-patterning occurred in the beginning of t^D. Since latencies for the first response in t^D did not change appreciably, one cannot conclude that the response pattern in t^D was only the result of an "overshoot" of the responding in t^Δ. Response patterns during t^D and t^Δ differed considerably: the two parameters $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ appeared to control increasing and decreasing response patterns during t^D and t^Δ differentially and independently.

Two features of the above studies seem important in establishing favorable conditions for scalloping to emerge: first, shocks, whether response-produced or response-independent, have to be presented on a periodic basis, and second, the animals must have some history of avoidance conditioning.

Kelleher, Riddle & Cook (1963) beginning with a multiple schedule having VI for food and shock avoidance components were able to maintain behavior and observe some accelerated responding during a pre-shock stimulus; when no shocks were presented very low response rates resulted. In other studies (e.g., Kadden, 1971; Kop and Snapper, 1970; McKearny, 1968, 1969), animals were trained on avoidance schedules and occasionally returned to such schedules. In the present study, scalloping was observed after 80 sessions in which $p(S^{-R}|\not{R})$ had decreased from 1.0 to 0, with very low shock rates during the first 60 sessions and no shocks at all in the last 20 sessions. The present procedure resulted in response patterning after a long gradual extinction procedure. A next step might be to investigate what procedures constitute a sufficient pre-training to produce scalloping under response-dependent shocks without an avoidance history.

Re-exposure to p(0, 1.0)

The animals that had reached discriminated punishment, p(1.0, 0), through procedures in which both parameters $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ were simultaneously above zero value, did show very little or no recovery during re-exposure to discriminated avoidance. Immediate recovery was observed for animals of Group 2, while animals of Group 3 recovered slowly although earlier than Group 1 animals.

If an animal of Group 1 were to give a response in all 7000 trials of the experiment preceding the recovery phase, it would receive a mean of 5000 shocks. If an animal of Group 1 were to withhold all responding it would also receive 5000 shocks. The highest number of shocks possible for animals in Group 1 was 7000 and the lowest number of shocks possible was 3000. For the animals of Group 2, always responding and never responding would each result in 2000 shocks. The highest number of shocks these animals could receive was 4000 and the lowest number was zero. For Group 3 animals that always responded or never responded would receive 2000 shocks; the highest possible number was 4000 shocks and the lowest number of shocks possible was 667. In Group 1, 46% of the shocks given were response-produced,in Group 2, 83% and in Group 3, 77%. These percentages of shocks delivered for responding in t^D correlate highly with the total number of t^D periods during recovery of p(0, 1.0) in which a response occurred, and a difference in shock frequency between groups may have contributed to the results of the re-exposure phase. Group 1 animals received, preceding the recovery phase, about 1600 shocks for R and 1900 for $\not{R}$, Group 2 about 500 for R and 100 for $\not{R}$ and Group 3 about 1000 for R and 300 for $\not{R}$. During the recovery phase shocks were delivered for $\not{R}$: 860 for Group 1, 80 for Group 2 and 340 for Group 3. Comparisons between groups show that the number of shocks for R as well as the number of shocks for $\not{R}$ is inversely related to the number of t^D trials in which a response occurred.

The literature on "learned helplessness" (e.g., Seligman, Maier & Solomon, 1971) maintains that animals learn that aversive stimulus presentation and responding are independent. In the present experimental design for Groups 1 and 3 there were trials in which both probabilities $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ were simultaneously above zero value, such that the animals might receive a shock regardless of their responding or not responding. For Group 1 these trials number 3000, for Group 2 zero and for Group 3 there are 667 of such trials. The numerical relation between the number of such trials and the number of trials needed before a criterion of 5 successive avoidance responses was reached during the recovery phase is clear. This relation, however, only holds for Rs and shocks; there is no indication in these data that such a relation would exist between "irrelevant" R's (Seligman, <u>et al</u>, 1971) and no-shock delivery.

The results of the present experiment indicate that "learned helplessness" may occur with procedures in which no escape contingency is involved. Moreover, prior avoidance training appeared not to be a sufficient condition to produce recovery after procedures in which responding did not affect the shock presentation.

The effectiveness of the animal's strategy is not in a straightforward way related to the number of trials needed to reach criterion: Group 1 animals earned 500 more shocks than necessary, Group 2 animals 600 and Group 3 animals 1400.

The effect of the independence of responses and shocks appears to last through a "punishment procedure" during which there is a very straightforward relation between response and shock. Re-establishing the relation between R and shock, as in the p(1.0, 0) procedure does not enhance the recovery of behavior during an avoidance procedure, where a direct relation between R and shock exists.

Cardiac Data

Heart rate during t^D was generally accelerated, regardless the slope of the response distribution curve during t^D.

Upon the discovery that simple physiological principles were not enough to explain the changes in cardiac rate commonly observed during physiological experiments, psychologists have been invited into physiology laboratories. The heart appears to be governed by principles beyond the physiological scope, and some of the rules that the heart tends to follow have been uncovered by employing conditioning techniques. There is now ample evidence that experimental procedures such as Pavlovian conditioning and avoidance conditioning do affect heart rate; exactly what such an effect will be is a more complex question, and very diverse results adhere to such a statement. Not only may the problems of cardiovascular physiology be furthered by applying conditioning techniques to the cardiovascular system, but theories within the discipline of Psychology have been made dependent upon the outcome of heart rate experiments. Two-factor theorists have stated that avoidance conditioning may not occur without prior classical conditioning, and the classical conditioning paradigm has been said to affect mainly the autonomic system (e.g., Mowrer, 1947). Smith (1954) has argued that heart rate changes during conditioning are only secondary to skeletal movements and that heart rate changes induced through classical conditioning represent only the fortuitous effect of motor activity upon heart rate. A similar explanation would hold for the operant conditioning of skeletal responses, concomitant with heart rate changes.

Recent studies (e.g., Stern and Word, 1962; Brady, Henton & Ehle, 1970) of heart rate during classical conditioning and avoidance conditioning reported differences in cardiac rate between inter-trial periods and in the presence of the CS. Webb and Obrist (1967) have presented data from an experiment in which an animal was required to initiate and then to inhibit activity. They found under these conditions a strong relationship between heart rate and motor activity. This does not necessarily mean that heart rate always depends on motor activity, since heart rate may be controlled centrally and also be movement correlated. Curare studies only indicate that heart rate changes are not controlled via feedback from the peripheral response (cf Black, 1971).

The present study provides examples of both increasing and decreasing heart rate, during both accelerating and decelerating response distributions. Although heart rate generally increased during t^D the acceleration varied somewhat in the rate of increase during the different phases of the experiment. Fastest heart rate increases were obtained under conditions of high shock frequency, while the least effect was observed under p(0, 1.0) and p(1.0, 0) conditions.

Several experiments in the literature on discriminated avoidance and Pavlovian conditioning have reported cardiac changes during exteroceptive signals. Notterman, Schoenfeld and Bersh (1952a) showed that heart rate in humans decreased during the signal of a Pavlovian procedure; when the subjects were later instructed to forestall the occurrence of the shock by tapping a key, the cardiac effect disappeared rapidly (Notterman, Schoenfeld & Bersh, 1952b). Bersh, Notterman and Schoenfeld (1956) investigated the effect of avoidance conditioning upon the conditioned cardiac response.

They found that autonomic responses observed during Pavlovian conditioning tend to disappear during avoidance training. The data from the present experiment show that the cardiac effect obtained under avoidance training was enhanced by the presentation of occasional shocks. Experiments on the development of autonomic responding under Pavlovian and avoidance procedures usually involve Pavlovian training followed by avoidance (e.g., Snapper, Pomerleau & Schoenfeld, 1969; Zeiner, Nathan & Smith, 1969). In such reports (e.g., Snapper, et al, 1969) greater diversions from baseline cardiac rate are seen under classical conditioning procedures than under either avoidance or yoked-control procedures. The present study, in which avoidance preceded the Pavlovian procedure, also yielded a greater cardiac effect during classical conditioning. Since cardiac effects are usually quite small, the effect of decreasing $p(S^{-R}|\not{R})$ is difficult to ascertain when such procedures result in low shock rates. The increase in heart rate was highest for those animals that received the greatest number of shocks during the transition from $p(S^{-R}|\not{R}) = 1.0$ to $p(S^{-R}|\not{R}) = 0$.

An interesting experiment with regard to the form of the cardiac response is reported by Niemela (1969). In human cardiac conditioning employing a Pavlovian conditioning procedure, when the CS is of fixed duration, a decreasing heart rate function may be observed. Under variable US probability increased cardiac rates were observed during the CS. Niemela has concluded from his data that cardiac rates decrease once the subject has decided a shock will positively occur or not occur. Before such a decision has been made the cardiac rate changes are in the tachycardiac direction.

The influence of central processes on heart rate has been of interest in the recent literature. Caul and Miller (1968) performed an experiment in which rats were given 10 days of classical conditioning (CS: 6 sec buzzer; US: 0.5 sec shock of 0.6 ma). One group was trained on 100% reinforcement, i.e. each of 20 daily trials ended with US presentation; a second group received a US during 50% of the trials; a third group received no US at all (0%). Heart rate increased for all but the 0% group during the CS. The pre-CS heart rate measures indicate a marked decrease for the 50% group, while pre-CS heart rate was stable for the consistently reinforced groups (100% or 0%) over the 10 conditioning days. After 10 days the 100% and 0% conditions were reversed, i.e., the former group did not receive any US presentations during five days and the latter was now reinforced 100% of the time. CS and pre-CS heart rate decreased over days for both groups. When the 50% group was put on extinction (0%) the pre-CS rate did not change in 100 trials; the CS rates were again higher than the pre-CS rates. Partial reinforcement had its effects on pre-CS rates as well: when changed from 50% to 0% no pre-CS changes were observed. The conclusion drawn from this experiment is that partial reinforcement ("uncertainty" in the authors' terms) causes bradycardia in rats. Earlier research on partial reinforcement during heart rate conditioning in humans (Notterman, Schoenfeld & Bersh, 1952a) reports no difference between regular and partial reinforcement.

In a subsequent experiment, Miller and Caul (1969) found that partial reinforcement in classical conditioning may yield the same cardiac effects as regular Pavlovian conditioning. Rhesus monkeys received 10 CS^+ trials of which either ten or three trials were followed by a shock. Increased heart rate functions were observed for both groups, but better discrimination in heart rate to a CS^- occurred when fewer shocks were received. When the CS^+ and the CS^- were preceded by the same warning signal, the conditioned cardiac response changed from tachycardia to a bradycardiac pattern. These data suggest that the cardiac response is not limited to the CS duration alone and that the cardiac response may be bimodal.

Others (e.g., Geer, 1964; Ramsay, 1970) have argued that changes in cardiac rate may have a biphasic form which does not show when heart rate measures of long signal periods are averaged, and the temporal pattern of the cardiac response is disregarded. The current data, obtained over five successive periods of 2 sec show mainly monotonic changes. The functions appear to be independent of the response distribution during the t^D period.

In the present experiment, pre-CS heart rate decreased considerably with increased shock rates for those animals in Group 1 (A-42 and B-2) that also displayed the greatest percent absolute change from baseline heart rate during t^D. Similarly, two animals in Group 2 (B-6 and A-44) displayed a decrease in pre-CS cardiac rate at the point of highest diversion from baseline heart rate during t^D; for two animals in Group 3 (B-10 and B-14) a similar statement can be made. The duration of the signal (10 sec) may have been too short to show a biphasic response form. From the data of these animals some support for the Law of Initial Value (Wilder, 1957) may be derived, as it states that the magnitude of the change is inversely related to the pre-stimulus values. Not all animals, however, displayed such cardiac behavior, and pre-CS cardiac rates may not be the most appropriate baseline for the measurement of cardiac effects, when short CSs are presented at fixed intervals.

Summary

The present experiment investigated the effect of two parameters $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$, upon responding before and during a neutral stimulus, that could terminate with a 0.3 sec shock presentation, depending on the shock probabilities and behavior during the stimulus. Heart rate measures were taken during the stimulus.

Although responding initially increased upon increased shock frequency, overall responding decreased as $p(S^{-R}|R)$ increased. Further decreasing rates were observed when $p(S^{-R}|\not{R})$ was decreased from 1.0 to 0. Shocks for R appeared to have a greater effect on response rates than shocks for $\not{R}$.

Response distribution functions during t^D were positively accelerated when $p(S^{-R}|R) > p(S^{-R}|\not{R})$ and decelerating when $p(S^{-R}|R) < p(S^{-R}|\not{R})$. A two-factor theory point of view would suggest that since shocks are delivered at the end of the signal, itself, the end of t^D would become more aversive. If signal termination were reinforcing, the responses at the end of the signal would have the shortest delay of reinforcement. This would explain the accelerating response rate. On the other hand, as more shocks are delivered, the entire signal period becomes more aversive and latencies of the first response in the signal should become shorter. This was not observed in this experiment. It was observed that response-dependent shocks cause greater response suppression than response-independent shocks.

At intermediate values of $p(S^{-R}|R)$, "scalloping" was observed during t^{Δ}. Especially under procedures in which the accompanying parameter value of $p(S^{-R}|\not{R})$ was smaller than 1.0 animals tended to increase responding near the end of t^{Δ}, followed by a decreasing response rate during the signalled t^D period. The observation that scalloping occurs more often when no baseline schedule is applied ($p(S^{-R}|\not{R}) = 0$) and when shocks are presented on a periodic basis, was confirmed. Moreover, response-dependent shocks led to "scalloping" before response-independent shocks did. The finding that "scalloping" occurred after prolonged extinction of avoidance conditioning or numerous sessions without shock presentation, indicates that an avoidance baseline history may be a necessary condition, but the avoidance baseline need not be concurrent with the schedule upon which the response-dependent or response-independent shocks are presented.

When the animals were returned to the original avoidance procedure, after a punishment procedure, almost no recovery was observed for the group that had reached the punishment procedure through a Pavlovian conditioning procedure; immediate recovery could be seen for the group that reached punishment through an extinction phase, and intermediate recovery for the group for which both parameters $p(S^{-R}|R)$ and $p(S^{-R}|\not{R})$ varied simultaneously. The literature on "learned helplessness" maintains that the number of trials in which both R and $\not{R}$ may result in a shock is directly related to the number of trials needed to reach criterion in a subsequent avoidance procedure. The current data provide support for such a statement, although there was an equally strong relation between the number of shocks received in preceding phases of the experiment and the number of trials needed to reach criterion. Furthermore, none of the procedures affected the performance during p(1.0, 0) differentially.

Generally increasing HR functions were observed during t^D. From the current data it appears that response distribution and cardiac wave form could take negatively correlated forms, i.e., when response distribution during t^D was decelerating, accelerating HR functions could be observed. Greatest cardiac effects were obtained under conditions which yielded highest shock frequencies.

No substantial differences were observed between the Pavlovian procedure and procedures which employed other than regular reinforcement for R or $\not R$. For some of the animals largest cardiac effects were observed when the baseline HR was lowest, providing some support for the Law of Initial Value. The short duration of the signal period may have prevented the observation of biphasic waveforms of the cardiac conditioned response.

The experiment shows that the two probability variables, that a response results in a shock, $p(S^{-R}|R)$, and that not responding results in shock presentation, $p(S^{-R}|\not R)$, control response rate and latencies during t^D. The use of a non-terminable signal allowed for response distribution measures which reflect the parametric combinations of $p(S^{-R}|R)$ and $p(S^{-R}|\not R)$. The parameters also controlled response rate and response distributions between signal presentations. HR functions during the signal were observed to be independent of response distributions.

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Curriculum Vitae

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