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by

Jeffrey M. Shamow

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

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ABSTRACT

THE EFFECTS OF CYCLE LENGTH, LIMITED HOLD DURATION, AND PROBABILITY OF REINFORCEMENT ON BEHAVIOR MAINTAINED BY INTERVAL SCHEDULES OF POSITIVE REINFORCEMENT

by

Jeffrey M. Shamow

Adviser: Professor Thom Verhave

Five pigeons were exposed to schedules of reinforcement in which the interval length (T), the probability of reinforcement for the first response in each interval (p), and the proportion of the T-cycle in which the first response was eligible for reinforcement ($\overline{T}$) were systematically manipulated. Four T-cycle lengths (T=1, 4, 16, and 64 sec) were used in a multiple schedule. Values of p from 0.125 to 1.000 were presented in a geometric progression for five days at each value, yielding schedules that ranged from random interval 512 sec (T=64 sec, p=0.125) to fixed interval 1 sec (T=1 sec, p=1.000). The procedure was replicated four times, once at each $\overline{T}$ value of 1.00, 0.75, 0.50, and 0.25. The values of p and $\overline{T}$ applied equally to all T-cycle lengths.

Data consisted of corrected and running response rates, post-reinforcement pause lengths, and the rates and proportion of rates in each of the components of the T-cycle (t^D and t^{Δ}). Both corrected and running response rates were decreasing functions of T length. The T-rate relation was described with a hyperbolic equation derived from the proportion of responses at each T value that was in excess of the necessary minimum for all reinforcers. The values of the constants of the equation were similar across animals, and were not systematically affected by p or $\overline{T}$. While p had no systematic effects on response rates, it had clear effects on the pattern of responses between reinforcers when $\overline{T}=1.00$. At $\overline{T}=1.00$, $p=1.000$, the response pattern was primarily break-run at all T values. As p decreased, responding became less periodic. At lower $\overline{T}$ values, there was no detectable effect of decreasing p. $\overline{T}$ also had minimal effects on corrected or running response rates, but clear effects on the pattern of responses within T-cycles. At $\overline{T}$ values lower than 1.00, animals either responded primarily in t^D, or primarily in t^{Δ}, with rates in t^D and t^{Δ} changing in an orderly manner across T values. The particular pattern was not related to either running or corrected rates, with animals showing dissimilar patterns producing similar overall response rates. Each animal's pattern was characteristic and stable. Post-reinforcement pause values were a linear function of T, and as in the rate data, there was no systematic effect of p. The slope constants of the post-reinforcement pause-T function tended to increase with decreasing $\overline{T}$, although the relation did not appear monotonic.

The lack of a systematic effect of p on response rate or post-reinforcement pause raises questions about the advisability of treating the mean expected interreinforcer time as the independent variable in interval schedules, and then describing rate as a function of that mean. The values of the constants describing rate and post-reinforcement pause as functions of T are quite similar to those found when previously published data are fitted to the equations, suggesting that rate data from interval schedules may be plotted along a single curve. The data are discussed in terms of a servomechanism model, with the temporal distribution of responses and reinforcers seen as interacting in such a way that interreinforcer times are driven to their minimum possible values. That minimum is determined by one parameter of the reinforcement schedule, T.

DEDICATION

This dissertation is dedicated to my wife, Nancy, for the years of devotion, unselfish generosity, and determined encouragement that made this study possible. She is, in a multitude of ways, as responsible for it as I am.

ACKNOWLEDGEMENTS

I wish to gratefully acknowledge Professors Thom Verhave, William N. Schoenfeld, and Brett K. Cole for their continuous support, advice, and encouragement during the course of this research and the years that preceded it. Their friendship and intellectual guidance are deeply valued.

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INTRODUCTION

> The biological system presented by an individual ... is obviously not a "thing," a single event, but a system of <u>relations</u>. It is these relations which must be defined through investigation (Crozier, 1929, p. 45).

INTRODUCTION

I

Background

A contingent schedule of reinforcement may be described as a set of rules for selecting and reinforcing responses (Schoenfeld & Cole, 1975) under which the temporal distribution of reinforcers is determined by the temporal distribution of responses (Schoenfeld, Cole, Lang, & Mankoff, 1973). It is also true, given an animal whose behavior is "under the control of the schedule," that the temporal distribution of responses is determined by the temporal distribution of reinforcers. The former statement may be expressed as $S=g(R)$, while the latter is an elaboration of the reflex, or, $R=f(S)$. Taken together, the two statements describe a dynamic interaction between responding and reinforcement under contingent schedules.

This interaction is implicit in Skinner's definition of the operant (1938, p. 19-21). Much of the work in schedules of reinforcement, however, has concentrated primarily on the effects of reinforcement on responding and has ignored the dependency of reinforcement on responding. This has made the identification of the relevant independent variables difficult, and has impeded the search for a rational quantitative analysis of the behavior-schedule relation. The present paper examines some of this work in schedules of reinforcement, and proposes an alternative to current analytical approaches which is based on the interaction of reinforcement and responding, and which uses the parameters of the reinforcement schedule as independent variables.

Reinforcement schedules may base the identification of the response to be reinforced either on response count (ratio schedules), or on time (interval schedules). Because ratio schedules may be approached along a continuum of interval length (see Schoenfeld, Cole, Blaustein, Lachter, Martin, & Vickery, 1972), reinforcement schedules based on the passage of time may be seen as primary. Since the publication of *The Behavior of Organisms* (Skinner, 1938), two aspects of behavior controlled by interval schedules have occupied investigators. The first is the character of responding during the interval (including the characteristic post-reinforcement pause, or P_Sr). The second is the relationship between the schedule parameters and overall response rate. In neither of these has the interactive character of the response-reinforcer relation been considered in the analysis, and in neither case has a rational, quantitative analysis emerged. Attempts to quantify relationships have been almost entirely empirical and *post hoc*.

A. Response Pattern

Skinner (1938) originally saw the interreinforcer response pattern as linear. After the P_Sr, responses were emitted at a regular rate, with the now-familiar scallop seen as a deviation, although there were hints of dissatisfaction with the scallop as early as 1936 (Skinner, 1936). Since 1953 (Skinner, 1953), the scallop has generally been considered to be the final steady-state response pattern (Dews, 1978). In 1957, Herrnstein and Morse published a paper on the effects of a barbiturate on fixed interval behavior and introduced the quarter-life as a measure of the interreinforcer response pattern. This was followed by Fry, Kelleher, and Cook's (1960) "index of curvature," in which the general shape of the scallop was calculated by determining the area under the cumulative response curve drawn between reinforcers. A positive index indicated an upward curve (scallop); a negative index indicated a negatively accelerated pattern.

In 1964, Gollub published a comparison of the quarter-life, index of curvature, and a modification of a statistic called the "first-half ratio" (Gleitman & Bernheim, 1963). The first-half ratio is the ratio of the responses in the first half of the interval to the total responses in the interval. In Gollub's case, since he had divided his intervals in fifths, responses occupying the first two-fifths of the interval were divided by the total responses in the interval. The quarter-life and index of curvature were highly correlated, and both were only moderately correlated with response rate. The poor correlation with response rate may have been due either to the considerable degree of variability of both of the other measures, or, as Fry, et al., (1960) had suggested earlier, the curvature may in fact be independent of overall response rate. This latter alternative was supported by Weiss and Moore (1956) who fitted straight lines to the interreinforcer response patterns in a fixed interval 3 minute schedule. The slopes of the lines were approximately equal for two groups of rats at different levels of deprivation (5 and 22 hours), with the 22 hour group showing significantly higher response rates. The measure of response pattern (slope) and overall response rate (intercept) were independent of each other. Azrin and Holz (1961) demonstrated a similar independence by punishing FI responding. While the added punishment decreased the overall rate, it had no effect on the quarter-life or index of curvature.

Gollub (1964) concluded that the choice of a descriptive statistic was largely a pragmatic one, since all seemed to more or less accurately reflect the visual appearance of the cumulative records. They also yielded similar predictions. He suggested that with all of the complexities involved in the computation of the index of curvature and the quarter-life, "...empirical curve fitting ... may provide rational procedures for comparing performances" (Gollub, 1964, p. 343).

The "ontological" status of the fixed interval scallop has maintained a tenacious hold despite the accumulating evidence to the contrary. Ferster and Skinner had shown in

Schedules of Reinforcement (1957) that there were indeed many instances in which the final steady-state pattern of responding was not a scallop, but rather a pattern resembling the break-run more often associated with ratio schedules. In such a pattern, the animal either responds or does not, and the transition from no responding to responding at a high rate is abrupt. This occurred in one case after sustained responding on a fixed interval schedule:

> By the 50th session after CRF ... the pause after reinforcement is extended, and it usually gives way to an abrupt shift to a higher rate (Ferster & Skinner, 1957, p. 150).

In fact, there were a number of patterns discernable in Ferster and Skinner's records, and: "... the curvature ranges all the way from arcs of circles ... to a sharp acceleration immediately after reinforcement" (p. 163).

In 1958, Cumming and Schoenfeld demonstrated that break-run was a fourth stage in the transition from continuous reinforcement to stable FI responding (the scallop was the third): "... while the overall rate is remaining fairly constant, the terminal rate is reached almost immediately after reinforcement" (p. 248). The finding was confirmed three years later by the same authors (Cumming & Schoenfeld, 1961). It should be noted that in both of the preceding papers, the length of the interval was rather long (30 minutes). This might have contributed to the eventual demise of the scallop, although that remains an empirical question.

The two-state pattern of responding was also observed by Sherman (1959) and Schneider (1969). Sherman exposed five pairs of rats to five fixed interval schedules of from 10 seconds to 5 minutes. Break-run was the predominant response pattern. The running rate was high and stable, and the P_Sr occupied a constant portion of the interval. Schneider exposed six pigeons to six fixed interval values of from 16 to 512 seconds. By fitting two straight lines to the averaged cumulative responses for each subject at each schedule value (one line from the reinforcer to something Schneider called a "breakpoint," the other line from the breakpoint to the next reinforcer), he was able to determine the point at which the acceleration to a higher rate began. A statistical analysis of the data fitted to the new equations indicated that the two-state model (a period of low, constant rate following reinforcement, succeeded by a period of high, stable responding) was supportable, with most of the variability occurring in the first state. The "second state rate" showed substantial regularity both within and across subjects, a finding that Schneider attributed to the variability of interreinforcement (I_Sr) times in FI; since the I_Srs varied slightly, he thought the behavior was similar to behavior under the control of variable interval schedules. An equation was derived to predict the overall rate of responding from the obtained rates in both states and the locus of the breakpoint. Not surprisingly, since most of the variance in the data was accounted for by the two fitted lines, the equation predicted response rates rather accurately, despite the rather irregular function that Schneider obtained (see his Fig. 9). It should be noted that the breakpoint was not the end of the P_Sr, but rather was computed by an iterative least-squares equivalent of determining the period of rapid acceleration "by eye."

Dukich and Lee (1973) compared a number of response measures under fixed interval schedules: average response rate (similar to the corrected rate of Cumming & Schoenfeld, 1960), running rate (response rate calculated after the subtraction of the P_Sr from the interval; see also Clark, 1959, and Cumming & Schoenfeld, 1960), the length of the P_Sr, the quarter-life, and the time taken for the first four responses in the interval to be emitted (T4). In general, the measures of curvature (quarter-life and T4) were highly correlated with each other for three of the four rats in the study. In comparing their findings with those of Gollub (1964), Mechner, Guevrekian, and Mechner (1963), and Schneider (1969), the authors demonstrated little difference between functions derived for quarter-life, Schneider's breakpoint, their T4, or the time to the sixth response in the interval (Shull & Brownstein, 1970).

There is clearly a profusion of measures, all more or less making the same predictions from the data, and none rational. Reiterating Gollub (1964), it would appear that until a rational formulation does appear, the quantitative aspects of the interreinforcer response pattern are probably best left at the descriptive level, with measures chosen for convenience or ease of computation. Lund (1976), for example, fit the interreinforcer response distributions to power functions on both fixed and variable interval schedules in order to assess the effects of reducing the periodicity of reinforcement. While orderly decreases in the exponents occurred with decreases in the periodicity of reinforcement, the power functions had no independent meaning beyond their descriptive value.

Dews (1970), in summarizing his own extensive program of research as well as that of other researchers, concluded that fixed interval schedules produce four main classes of effect on the distribution of responses between reinforcers: direct, indirect, higher order, and consequent. Direct effects were those that resulted in the scallop, despite interuptions, changes in stimuli, and intrusions of stimuli (reinforcing, neutral, or discriminative) into the interval. Regardless of the nature of the stimulus intrusion, Dews' earlier data indicated that the scallop seemed to survive in both an absolute sense (response rate increased through the interreinforcer interval), and in a relative sense (the proportion of responses throughout the interval was independent of the interval length). He argued (Dews, 1962) as had Hull (1932, 1943), that the reinforcer exerted a powerful retroactive effect that showed itself as a kind of "temporal goal gradient." While the whole pattern of responses seemed strengthened by reinforcement (cf. Ferster & Skinner, 1957; Mowrer & Jones, 1946), those responses earlier in the interval were remote from reinforcement, and were therefore not strengthened. This led Dews to conclude:

> Behavioral time, like Einstein's physical time is relative. The faster the intervals succeed one another, the faster time passes within the interval and the more a fixed, absolute delay between responding and the reinforcer reduces the reinforcing effect (Dews, 1970, p. 47).

Interrupting the interval with intruded stimuli signalling non-reinforcement (S^{Δ}s) did not interrupt that "temporal relativity," and the scallop seemed immune to them. Dews' explanations for the seeming durability of the scallop, however, present some problems.

In explaining the scallop, Dews (1970) rejects the notion that "mediating behavior" is responsible for the increasing rate through the interval, where that does indeed occur. However, the key peck is one segment of a continuous "behavior stream" (Schoenfeld & Farmer, 1970), and detected by the manipulandum or not, the organism is behaving between pecks at the key. If the interreinforcer response pattern is regular, then it is reasonable to assume that the behaviors not detected by the key must be also. Killeen's (1975), Skinner's (1948a), and Staddon and Simmelhag's (1971) data demonstrated that no matter where relative to reinforcement one chose to look in FI schedules, the behavior appeared regular. It is not clear if Dews means that those behaviors are not regular, or that even if they are, they do not contribute to the scalloped pattern. Intruding S^{Δ}s and timeouts introduces stimuli that control behavior other than key pecking. When stimuli that control key pecking are reintroduced, pecking resumes at its expected rate in that portion of the interval. That would seem to suggest that the behavior not detected by the manipulandum is not only important in the development of the pattern of responding, but that it too is (or may be brought) under stimulus control. In addition, it seems not to matter what the nature of the stimulation is. Shocks delivered on fixed interval schedules produce FI behavior (see Morse & Kelleher, 1966, 1970, 1977; Schoenfeld, Cole, et al., 1972, p. 107 et seq.; Stretch, 1972), whether or not those shocks are response dependent (Herrnstein & Sidman, 1958; Kelleher, Riddle, & Cook, 1963; Sidman, Herrnstein, & Conrad, 1957; Waller & Waller, 1963). Periodic stimulation produces periodic behavior, or "... the schedule of reinforcement is more important than the nature of the reinforcer" (Morse & Kelleher, 1966; p. 286). The explanations for these effects must lie in the independent variables; if the "temporal goal gradient" responsible for the scallop is not independently determined, then its invocation as an explanatory construct is unnecessary and non-parsimonious.

The second class of effects of the fixed interval described by Dews (1970) were those that resulted in a lower probability of reinforcement for short (as opposed to longer)

IRTs. These "indirect effects" produce negatively skewed IRT distributions (most of the IRTs in fixed interval controlled behavior are long). In an experiment performed to determine whether decreasing the emission of long IRTs would have an effect on the pattern of interreinforcer responses, Dews (1969) inserted a fixed ratio requirement after the completion of a fixed interval. While the general effect of the imposed FR was to increase the overall response rate (and therefore, reduce the number of long IRTs), the scalloped pattern remained:

> In conclusion, indirect effects of the fixed interval in favoring longer IRTs for reinforcement may affect local rates and patterns of responding without affecting the most characteristic feature of FI responding, namely the scalloped pattern through the interval (Dews, 1970, p. 52).

The "higher order" effects of the fixed interval were described by Dews (1970) as the sequential dependencies that arise when responding is maintained by FI schedules, and resemble (in many respects) Skinner's (1938) four "orders of deviation." For example, one type of higher-order effect resembles Skinner's "deviation of the second order" (oscillations in rate that occur over several reinforcers). These oscillations in overall rate do not affect the pattern of responding within individual intervals, and while the pattern of responses remains constant between reinforcers, the overall rate may decrease and then decay over successive FI cycles. Dews (1970) then suggested that responding in any given interval in a series of fixed intervals might be determined not only by the schedule parameter, but by the pattern and rate of responding in the interval immediately preceding as well. This raised the question of whether or not prediction of response rate in one interval of the schedule was possible from performance on the preceding interval.

In an attempt to answer that question, Dews examined 200 successive intervals in a FI 180 sec schedule to determine if there was any discernable pattern in the number of responses in successive intervals, or if any statistical pattern could be culled from the data. While either an autocorrelation or a Fourier analysis might have revealed more, the kind of visual "running average" technique he devised revealed no clear pattern. If a pattern existed at all, it consisted of a tendency for intervals with many responses to follow intervals with many responses, and intervals with few responses to follow intervals with few responses, but even that effect was weak and unreliable. Dews concluded that the occurrence of both intervals with few responses and intervals with many responses in some kind of alternation "... betoken(ed) a remarkable ability of the subject to average over many intervals over a long period of time" (1970, p. 59). It is more likely that the roughly alternating increases and decreases in the number of responses in successive intervals do not compensate for each other (as Dews suggested), but rather reflect the operation of variables not accounted for. The resulting pattern of responses per interval is roughly random. Ferster and Skinner (1957) had explained this relatively random change in the extinction ratio from one interval to another as due to the point during the interval at which the P_Sr terminated, which, in turn, depended on some unknown "trigger":

> In a quite stable FI performance, in which the rate is low or zero after reinforcement but increases in standard fashion as the interval elapses, the number of responses emitted at the reinforcement should be fairly constant. Since this condition depends in a sensitive way upon the "triggering" of acceleration to a higher rate, the number of responses at reinforcement will vary considerably (Ferster & Skinner, 1957, p. 134).

The nature of the event responsible for "triggering" the acceleration to a higher rate has neither been specified nor ever determined, but Schneider's (1969) "breakpoint" comes close to determining its temporal location.

"Consequent effects" of the fixed interval lie, according to Dews, in the extent to which specific response characteristics are reinforceable. For example, since FI schedules produce rates that are relatively high at the moment of reinforcement, the effect of the reinforcer is to increase the future probability of later reinforcement intercepting a high rate:

> When a subject is exposed repeatedly to a consistent schedule, patterns of responding may become sufficiently consistent to be related reliably to the schedule. The very reliability of the relation may lead to

> the further strengthening of those particular aspects of the pattern (1970, p. 59).

The nature of the scallop as a reinforceable aspect of behavior (suggested as a consequent effect of the schedule) raised questions as to whether it was possible to take control of the process, and "shape" a scallop. In 1975, Hawkes and Shimp did just that, by requiring birds to produce cumulative records in which responding increased at a constant rate in a FI 5 sec schedule. A constant rate of increase, of course, produces a gradually increasing rate, and the subjects produced the required pattern in most cases. Sussman (1975), in an attempt to determine whether an increasing probability of reinforcement during the interval would produce an increased rate of responding through the interval, increased the probability of reinforcement for a response from 0.0 to 1.0 through a FI 160 sec schedule. The interval was divided into eight 20-second segments, or "bins." Initially, the probability of reinforcement for the first response in the first 7 bins was 0.000, while the probability of reinforcement for the first response in the last bin was 1.000 (a "FI limited hold" in Ferster and Skinner's terminology). Following 30 days at those values, the probability of reinforcement for the first response in the first bin was raised to 0.125. Bins 2 through 7 still programmed probabilities of 0.000. In successive 30-day blocks, the probability of reinforcement for the first response in each of the bins progressively closer to the first was raised by 0.125. For the first 30 sessions, then, bin 1 programmed a probability of reinforcement of 0.000; bin 2, 0.000;...(7) 0.000; (8) 1.000. Sessions 31-60: (1) 0.125; (2) 0.000;...(7) 0.000; (8) 1.000. Sessions 61-90: (1) 0.125; (2) 0.250; ...(7) 0.000; (8) 1.000. Sessions 91-120: (1) 0.125; (2) 0.250; (3) 0.375; ...(7) 0.000; (8) 1.000, and so on until the schedule programmed successive 20-second periods of increasing probability of reinforcement of from 0.125 to 1.000. Rather than produce a scalloped pattern, the subjects responded at a constant rate throughout the interval so long as the probability of reinforcement was greater than zero in any of the first 7 segments. Catania and Reynolds (1968) earlier had examined the effects of differing probabilities of reinforcement within a fixed interval schedule by varying the placement and probability of an intruded short interval. The major effect was to produce an increase in the local rate of responding at the point in the interval at which the short interval was intruded.

While the meaning of "probability" differed for Sussman and for Catania and Reynolds, the effects of occasionally intruding a reinforcer between reinforcers in FI schedules were largely the same. In their exhaustive study of interval schedules, Catania and Reynolds (1968) demonstrated considerable agreement between animals on the distribution of responses through fixed interval values ranging from 30 sec to 200 sec. Their "local rate" functions showed consistent increases through the interval when rates were plotted as a function of relative time since reinforcement. When response rates were plotted as a function of absolute time since reinforcement, there was an ordered effect of interval length (suggesting once again that the rate and pattern are not necessarily related). The pattern of responding only occasionally suggested a scallop, however (see their Fig 16). In addition, they noted that FI schedules produce lower rates than VI schedules with the same mean scheduled I_Sr, but the local rate patterns were similar, despite the "classic" appearance of the behavior under each schedule.

It is safe to conclude, in light of these studies, that the scallop may be treated as any other complex aspect of behavior. If reinforcement depends on a scalloped pattern, scalloped patterns will predominate. Response rates do not "track" reinforcement probability, nor does the ability to "shape" scallops imply that some feature of the shaping procedure is operating in standard FI schedules. In fact, there seems to be some disagreement on the pattern of responding between reinforcers in fixed interval schedules. While some consistency may be found in the verbal description of the interreinforcer response pattern as a scallop, attempts to describe this pattern quantitatively have produced difficulties not obvious when the description was literary and restricted to the visual appearance of the cumulative record. First, comparisons of measures from the simple (Weiss & Moore, 1956) to the complex (Gollub, 1964) have yielded similar predictions, leading the authors of two of these comparisons (Dukich & Lee, 1973; Gollub, 1964) to conclude that the choice of descriptive metric is a pragmatic (or arbitrary) one. Second, Schneider's two-state analysis seems to describe the data remarkably well, and is in agreement with Cumming and Schoenfeld's (1958, 1961) findings. Additionally, the difference between a "sudden" and a "gradual" transition from low or moderate rates to high terminal rates may reflect more the speed of the cumulative recorder (or the size of the subdivisions of the interval throughout which responses are distributed) than the behavior of the subject. It seems that the scallop is but one class of transition patterns from one schedule value (CRF, for instance) to another (FI) that seems (by eye) orderly, lasts for a long time, and corresponds to some popular notions about behavior control (i.e., temporal discrimination -- see Morse, 1966). The preponderance of the evidence, however, indicates that the final steady-state pattern in FI is one in which responding either occurs or does not (Cumming & Schoenfeld, 1958, 1961; Schneider, 1969; Schoenfeld, et al., 1972; Sherman, 1959).

The periodicity inherent in FI is, of course, disrupted when the interreinforcer intervals are varied, and the pattern of responding reflects this disruption of temporal regularity. The first report of behavior under the control of an aperiodic interval schedule of reinforcement was published by Skinner (1948b). Two years later, Skinner (1950) described experiments which varied the interreinforcer intervals according to either an arithmetic or geometric series. In both cases, the behavior under the control of the schedules lost its periodicity and became smoother and more regular than behavior under fixed interval schedules. Cumulative records showed extended periods of sustained responding at a stable rate, punctuated by reinforcers, and there seemed to be little or no post-reinforcement pausing. Jenkins, McFann, and Clayton (1951) also showed "smooth" cumulative records from behavior under aperiodic schedules, and this absence of "third order deviations" (Skinner, 1938) continued during extinction, producing smoother, longer extinction curves than ones generated under regular reinforcement (see also Jenkins & Rigby, 1950; Skinner, 1948b, 1950). VI schedules were later explored in depth, first by Skinner (1953), and then by Ferster and Skinner (1957), and the earlier findings were confirmed: the less periodic the schedule, the less periodic the response pattern.

In summary, the pattern of interreinforcer responses in interval schedules is determined to a large extent by the periodicity of the schedule. When interreinforcer intervals are scheduled irregularly, the response pattern is aperiodic. When the schedule is periodic, so is the pattern of responding. While the behavioral transition visible on the cumulative record when the schedule of reinforcement is changed from CRF to FI is so standard that this has, since 1949 (Keller & Schoenfeld, 1949), been used as a demonstration, the final steady-state pattern is in some dispute, and seems to vary across similar experiments. The quantitative measures introduced are all purely descriptive. The variables that control the interreinforcer response pattern have not been sufficiently identified to make adequate rational equations possible. While some authors report gradual transitions from low rates early in the interval to high terminal rates (scallops), and others report more rapid transitions (break-run), evidence is accumulating that the final steady state pattern is one in which responding either occurs or does not, with the point of acceleration to the final rate predictable. What remains is to first identify and then to gain some measure of experimental control over the variables that determine the rate at which response rate changes between reinforcers. At that point, equations are possible, and we may dispense with hypothetical "temporal goal gradients" and non-measurable temporal discriminations.

B. Rate of Responding.

Historically, response rate has been the primary datum in operant conditioning experiments, and overall rate is quite sensitive to the parameters of interval schedules. The attempts to quantify the relationship between schedule parameters and overall response rate, however, have not been substantially more successful than the treatment of the interreinforcer response patterns.

The overall response rate was first described by Skinner in 1933 as:

> ... a function of the interval between successive reconditionings. The shorter the interval, the steeper the slope of the cumulative graph (Skinner, 1933, p. 11).

In a later replication (1938, p. 27), Skinner noted that the rate-interval relation appeared linear. This led to the hypothetical "reflex reserve" in which responses were emitted in direct proportion to the number of reinforcers delivered. Despite some objection (e.g., Ellson, 1939), there was no arguing with the data. In the range of interval lengths that Skinner explored, the curve seemed linear. That was not to last, however, and Skinner tentatively began to modify the notion in the light of later research (Skinner, 1940).

The linearity of the rate-interval relation, however, was generally assumed as late as the publication of Keller and Schoenfeld's Principles of Psychology in 1950. In that same year, Jenkins and Stanley (1950) published an extensive survey of partial reinforcement studies and reported the data from Skinner's 1933 paper (in which the function was first reported as linear) as current, although some of their own unpublished data suggested that the function might be curved. It is interesting to note that the most important implication of the linearity of that function -- the reflex reserve -- was not even mentioned in that paper. The first published paper demonstrating the curvilinearity of the relationship was Michael Kaplan's (1952a) doctoral dissertation, done under Keller and

Schoenfeld at Columbia University. A shortened version of this study was published in The Journal of Comparative and Physiological Psychology (Kaplan, 1952b). While Kaplan's experiment dealt with escape (the first response after the onset of a light terminated the light for 66 sec), rather than food reinforced behavior, the data indicated that with fixed intervals ranging from 12 seconds to five minutes, the function relating response rate to interval length was a decreasing, monotonic curve:

> The data ... reveal that, as the duration of aversive light increases in this situation, the white rat's rate of escape responding tends to decrease sharply and rapidly approaches a constant value (Kaplan, 1952b, p. 544).

Wilson (1954), also working under Schoenfeld and Keller, but using food as a reinforcer, investigated the effect of the length of the interval and the number of reinforcements on both the response rate and the resistance to extinction. Rats, in groups, were assigned to fixed interval lengths of from 0 sec to 360 sec. Replicating Kaplan (1952a, 1952b), response rate was a negatively accelerated decreasing monotonic function for the range of interval values beyond 10 seconds. As in the case of both Skinner's early results and Kaplan's, the response rate function for the longer intervals was nearly linear:

> It may be seen that the curve is changing slowly for intervals beyond 3 min. Since Skinner reported a linear function between 3 and 9 min., it is felt that the present data are not in disagreement with his finding. Obviously, a linear function will not de-

> scribe the curve over its entire range (Wilson, 1954, p. 53).

The curvilinearity of the function was now clear. The effect of Skinner's failure to explore a sufficient range of parameter values to see the curvature was not likely to have been foreseen, especially when the effect was to lend support to the reflex reserve, a theoretical notion basic to Skinner's new system.

Since the early 1950s, a number of descriptive equations for the rate-interval relation have appeared, but stripped of the rational basis supplied by the reflex reserve. These have ranged from a hyperbolic relation between the response rate and the square root of the interval length (Bush & Mosteller, 1951, who treated unpublished data reported by Jenkins & Stanley, 1950) to a sigmoid curve derived from an equation containing constants which represent sources of reinforcement other than those intended by the experimenter (Herrnstein, 1970). Most have been short-lived, and in Kaplan's (1952b) case, he simply reported (with regard to Bush and Mosteller's function) that "the present data do not fit their equation" (p. 546). He attributed the disparity to the difference between a terminated noxious stimulus and the food reinforcement more usually used in interval studies, but the attempts to quantify the rate-interval relation have in general proven remarkably non-durable, and almost entirely empirical.

The absence of a rational basis upon which to construct a quantitative model for the rate-interval relation is less of a problem in FI than in VI, since the major independent variable in FI (the interval length) is easily specified. Given a sample of rates at a few fixed interval lengths, a fairly accurate approximation may be made to the rates generated over a large range of interval values. The specific form of the equation does not matter, provided that it conforms to a decreasing monotonic curve, and most fits to the FI data have been good. Similar attempts using data from variable interval schedules, however, have produced a considerably more complicated picture.

While they never addressed the problem directly in Schedules of Reinforcement, Ferster and Skinner published data that suggested that rates of responding were influenced by the mean interreinforcer interval in VI schedules (compare cumulative records on their page 327 with those on 330). Catania and Reynolds (1968) also found response rates to be lower under VI schedules with longer mean interval values when responding was averaged over lengthy periods of time. They described the relation between average response rate and average reinforcement rate as a power function:

$$R=kr^n \qquad (1)$$

where R was response rate, r was the reinforcement rate, and k and n were constants derived from the data. Catania and Reynolds (1968) indicated that one of the considerations in the choice of a power function was that it predicted that there would be no responding in the absence of reinforcement (if $r=0$, then $R=0$). This was unfortunate, since responding, even after prolonged extinction, only approaches a zero rate. In addition, the equation predicts no asymptotic response rate with increasing reinforcement rate. Since both the organism and manipulandum have upper limits, the conclusion is forced that the rate-interval relation is discontinuous. It would appear that while the mid-range of interval values may be adequately fitted to the equation, the predictions made at extreme values of the range of the function are not confirmed. The major difficulty with Catania and Reynolds' function, however, lies in its treatment of reinforcement rate as an independent variable, which it clearly is not in contingent reinforcement schedules. This is a major problem common to almost all of the attempts to quantify the data from interval schedules, and will repeatedly reappear throughout the analysis that follows.

Most of the work in the mathematical description of the interval-rate relationships in VI schedules has been done with schedules arranged to occur either simultaneously (Ferster and Skinner's "concurrent schedules") or sequentially (mixed, tandem, chain, and multiple schedules). In concurrent schedules:

> Two or more schedules (are) independently arranged, but (are) operating at the same

> time, reinforcements (are) set up by both (Ferster & Skinner, 1957, p. 724).

There are a number of rather thorough summaries of the work with concurrent schedules (for example, see Catania, 1966; de Villiers, 1977), but the quantitative aspects of the procedures are of primary interest here.

In the typical concurrent procedure, pigeons are presented with two simultaneously available response keys, with each key producing reinforcement through a different and independent schedule of reinforcement. The birds can peck either key at any time. Since the keys are spatially separated, it is not possible to respond on both simultaneously. Responding on the two keys is therefore analyzed separately. While the two-key concurrent procedure prevents simultaneous responding on both keys, it encourages another phenomenon -- rapid alternation between the two keys (Skinner, 1950). If the birds alternate rapidly between the two response alternatives, then the rate of responding on either one of them is governed by the "switching rate." The switching rate is also under the control of the prevailing reinforcement schedules, but it is generally not the operant of interest (however, see Findley, 1958 and Verhave, 1963), and steps are usually taken to prevent rapid alternation. An almost universally accepted solution has been Herrnstein's (1961) "change-over delay" or COD (the "anti-superstition contingency" for Verhave, 1963). It consists of a few seconds during which reinforcement is unavailable after a switch from one key to another.

In addition to introducing the COD, Herrnstein (1961) adopted a measure, the relative response rate, that has become a nearly standard metric for the analysis of behavior maintained by concurrent schedules. It appeared from Herrnstein's (1961) data that over a relatively wide range of concurrent VI,VI schedules (90, 108, 135, 180, 270, and 540 sec), the relative frequency of responding on one key was a linear function of the relative frequency of reinforcement on that key. That led to the equation:

$$\frac{p_1}{p_1+p_2} = \frac{ke_1}{k(e_1+e_2)}, \qquad (2)$$

in which "p" and "e" represented the absolute rates of pecking and eating. The constant "k" was related to the extinction ratio (the ratio of reinforced to unreinforced responses; Skinner, 1938). Skinner saw the extinction ratio as constant for any single organism, and the function relating pecking to eating was therefore assumed to be linear:

$$p=ke. \qquad (3)$$

Herrnstein's final version of equation (2) dropped the constant "k" and changed the symbols:

$$\frac{p_1}{p_1+p_2} = \frac{R_1}{R_1+R_2}, \qquad (4)$$

Where "p" and "R" stood for pecks and reinforcers, respectively. Equation (4) has proven quite accurate in predicting (or describing) response rates under concurrent schedules (see de Villiers, 1977), but difficulties arise when attempts are made to draw any more than descriptive conclusions from the function.

Rachlin (1973) for example, suggested that the time base used for the rate computation in these procedures forces the equality. He argued that the response rate on each key when the animal was actually responding (corresponding with a running rate of sorts) was constant. What was affected by changes in the schedule parameters was the time spent pecking at any one key before a switch to the other one. If the time base for the rate computation is the time spent responding on the key in question, then the rates of responding on both keys are approximately equal, regardless of the schedules in effect at the time (recall the relative invariance of Schneider's "second state rate"). If the entire session length, or any other time base that is the same across both keys is used, the relation holds. The conventional procedures compute response rates using the same time base for both keys.

In addition to the time base problem, there are two additional limitations on the generality of equation (4). The first is that the schedules are VI schedules programmed in such a way that reinforcers are "held" once available until "earned." This has the effect of making reinforcement following a switch between keys inevitable if the switch has been preceded by a long period of responding on the other key. While the animal is responding on one key, reinforcers are setting up on the other. The COD reduces the immediacy of reinforcement, but its duration has ramifications. If the COD is too short relative to the intervals on both VI tapes, it is ineffective in preventing alternation. If the COD is too long, then the likelihood of reinforcement following a switch from one key to another is never greater than for continuing to respond, and the animal will remain on one key:

> The effective duration of a COD probably is limited by the interreinforcement intervals making up a given pair of concurrent interval schedules.... If any of the interreinforcement intervals in a given schedule are shorter than the COD ... reinforcement is likely sooner after a (switch) to the other schedule. Under these conditions, responding will probably become restricted to only one schedule. This is seldom a practical problem, however, because CODs longer than 2 or 3 sec are rarely programmed with interval schedules (Catania, 1966, p. 229).

The COD, then, must be chosen with an eye toward the scheduled interreinforcement intervals on each of the two concurrent VI schedules, and therefore becomes part of the schedule. It is, in fact, another "component" of the schedule on each key. Outside of a narrow range of COD values, there is no longer a direct proportion between relative response and reinforcement rates. The value of the COD, however, appears nowhere in the equation. Even so, de Villiers asserted that:

> ... matching is found for all values of

> the COD greater than (a necessary) minimum.... The matching relation is therefore not an artifact of any particular COD duration (1977, p. 243).

This, of course, is somewhat at odds with Catania's (1966) argument, although both authors argue for the validity of the matching relation.

De Villiers provided a detailed denfense of the generality of the matching relation, but the point he addressed differs from the one under consideration here. It is certainly true, as de Villiers argued, that the matching law holds across a wide range of conditions, given that all of the special restrictions necessary to program concurrent VI,VI schedules are in effect. Given these restrictions, it is replicable across species, qualitatively different reinforcers, and any number of conditions that typically affect the reinforcing effects of various stimuli (e.g., delay of reinforcement, Chung, 1965). The problem lies in the failure to account for even the minimal conditions necessary to generate the data for which the equation is appropriate. If those conditions are not met, the relation does not hold. Since neither the COD value nor any of the other numerous peculiarities of tape-programmed VI schedules enters into the equation, there is no way to quantify their effects. This is not to suggest that the equation is somehow "wrong." It does suggest that the equation's generality is considerably more limited than its proponents indicate, and hardly qualifies the underlying relation it purports to represent as a law.

The second major restriction on the generality of the matching relation lies in the degree to which the parameters of variable interval schedules may be treated as independent variables, a recurrent problem in the quantitative treatment of these schedules. VI schedules are constructed with intervals and sequences of intervals designed to produce specific effects (short or zero intervals are usually included to prevent the post-reinforcement pause; see Ferster & Skinner, 1957, p. 326), confounding the independent variables with behavior. In addition, the matching equation describes the relation between <u>delivered</u> reinforcers and response rates. Had the equation been based on <u>scheduled</u> reinforcers and response rates, the built-in confounding in VI sequences might have been dismissed as trivial, and not likely to differentially affect the outcome. In this case, since delivered reinforcers are a function of responding, the equation describes the contingencies of reinforcement. While this may not be necessarily clear between extreme values of the range of the function, one need only examine such extreme values. If the organism restricts all of its responses to one choice (which can happen, for example, if the COD is too long) then regardless of the schedule values, the relative frequency of reinforcement will be 1.0 for that choice. Again, the equation cannot be wrong.

It is just simply not analytic.

In 1970, Herrnstein extended the matching relation from its original application in concurrent schedules to the case in which schedules of reinforcement occur in sequence, particularly multiple schedules. A multiple schedule may be defined as a schedule of reinforcement in which two or more independent schedules alternate according to some rule, each in the presence of its own distinctive cue. While Ferster and Skinner (1957) had earlier demonstrated that the pattern of responding in any given component of a multiple schedule is appropriate to the schedule in effect in that component (periodic responding, for example, in the FI component of a Mult FI,VI schedule with non-periodic responding in the VI component), the absolute response rates differ from what they would normally be under similar schedules in isolation (Morse, 1966). This difference was attributed (by Herrnstein & Brady, 1958) to an "interaction" across components of the schedule of which Reynolds (1961; after Skinner, 1938) identified two possible types: contrast and induction. If the change in response rate in an unchanging (from a baseline condition) component of a two-component multiple schedule is in the same direction as that in the changing component, then the effect is called "induction." If the rates change in opposite directions, the effect is called "contrast." For example, if a multiple VI 15, VI 15 sec schedule were changed to a Mult VI 15, VI 30 sec schedule, and the rates in both the VI 30 sec and VI 15 sec components were to decrease from baseline, the effect would be induction. If the rate in the VI 15 sec component increased, while the rate in the VI 30 sec component decreased, the effect would be called contrast. Both contrast and induction may be either positive or negative, depending on whether the change is in an upward or downward direction.

Since in both concurrent and multiple schedules, the animal alternates between schedules, both types of compound schedule may be seen as somehow similar. In the concurrent case, the switch between the schedules is not explicitly controlled by the experimenter, but is an effect of the schedules on both choices and on the COD. In multiple schedules, the component change is under the direct control of the experimenter. Assuming such a similarity, Herrnstein (1970) attempted to apply the same general matching equation to multiple schedules, but the interaction effects in multiple schedules made the relation non-linear. In order to account for these nonlinearities, Herrnstein assumed an implicit concurrent operant (1970, p. 254-255). The implicit choice was to do something other than to peck the response key. When the animal was responding on the key, all of the reinforcers were derived from the programmed reinforcement schedule. When the animal was not pecking the key, it was engaging in "other" behavior. Such other behavior was assumed to have associated with it its own reinforcers whose aggregate value was assumed equal to the relative time spent earning them. The result of these assumptions was the following variant of equation (4):

$$P_1 = \frac{kR_1}{R_1+mR_2+R_o}. \tag{5}$$

"P" and "R" stand for "pecks" and "reinforcers," respectively. The constant "k" is a proportionality constant intended to represent the maximum (asymptotic) response rate of the particular pigeon. This value is not empirically determined, although it is conceivably amenable to empirical approximation. Both "m" and "R_o" are "free parameters to be extracted from the data" (Herrnstein, 1970, p. 255).
The degree of interaction across components is represented by "m," and in the case of concurrent operant procedures, where responding is assumed to be maximally influenced on each key by responding on the other, the value of "m" is unity. In a single key with only a single schedule, since there is no other schedule with which to interact, there is no interaction, and the value of "m" is zero. Multiple schedules, which allow a range of interactions will generate values for "m" between zero and one. "R_o" is intended to account for reinforcers for other than key-pecking behaviors (hence the subscripted "o"), on the assumption that if other behaviors are competing with key-pecking, they must be producing reinforcers of their own. The degree to which birds do not peck the key is then deter-

mined by the "reinforcement value" of the reinforcers responsible for those other behaviors (see Rachlin, 1971). The resulting curve (Herrnstein, 1970, p. 261, 262) describes a negatively accelerated increasing function relating relative response rate to relative reinforcement rate from values of both of 0.00 to 0.50. The curve is symmetrical about the 0.50 point for both axes, so the remainder of the function predicts a positive increase in the relative frequency of reinforcement from the 0.50 point to 1.00.

The equation was an attempt to quantify the relation between response and reinforcement rates on what Herrnstein obviously saw as rational grounds, but as before, there are serious flaws. To begin with, the function is valid only for interval schedules (although there was an application of equation (4) to ratio schedules published by Pear in 1975, followed by a rebuttal of sorts by Timberlake, 1977), and all of the critical comments applicable to the concurrent case (except the COD problem) apply here as well. As before, the separation of independent and dependent variables necessary for a meaningful quantitative analysis is, at best, difficult when behavior is plotted as a function of a frequency of reinforcement, which in turn, is dependent upon behavior.

The more serious difficulties, however, lie in the conception of the behavior-schedule interaction that underlies the invention of the constants "m" and "R_o," both of which were treated by Herrnstein as independent variables. The interaction across components of a multiple schedule, and therefore the value of "m," is not an independent variable, but rather a behavioral effect (if it is in fact to be granted empirical validity) of some of the characteristics of schedules programmed in multiple (e.g., component length). Nowhere in the "matching literature" is there a procedure for transforming the component length, for example, into a numerical value of "m," although that certainly should be possible. "R_o," the aggregate "value" of reinforcers for "other" behavior, appears to assume a large range of values (see de Villiers, 1977, appendices A-D). Its status is similar to Hull's sOr (the "oscillatory" constant), in that it accounts for all behavior not accounted for by the rest of the equation. If behavior is to be divided into two classes (responding and not responding), then some satisfactory a priori definition of "not responding" must precede its measurement. Schoenfeld and Farmer (1970), for example, defined not responding, $\not{R}$, temporally, as a fixed period of time during which no measured response occurred. If the response class represented (or reinforced?) by R_o is infinitely elastic, as it is for Herrnstein, it can expand and contract as needed to fill any gaps in predictions. In Herrnstein's case, it appears that the "o" associated with R_o is the sum of all of the IRTs -- the "rate" of not responding. However, since the rate of responding (and presumably, therefore, the rate of not responding, if it makes any sense to compute the rate of occurrance of a non-event) is under the control of the schedule of reinforcement, the behaviors that encompass both response classes would appear integrally related, and there would seem to be little logical reason for separately computing rates or attempting to determine the "value" of the reinforcers responsible for their maintenance.

In summary, when applied to concurrent VI,VI schedules, the "matching function" seems to be descriptively adequate, providing one is willing to forego the inclusion of the schedule parameters and the COD in the analysis. When applied to multiple schedules, it reduces to curve-fitting that produces an equation with three free parameters (k, m, R_o):

> It is a mathematical rule of thumb that almost every curve can be approximated if three or more free parameters are permitted -- i.e., if an equation contains three or more so-called constants that cannot be verified otherwise. This is true quite irrespective of the particular form of the equation chosen.... Such calculation is a mere mathematical exercise (von Bertalanffy, 1968, p. 172).

Even if the empirical validity of the quantities represented by those three constants is to be taken seriously, they represent behaviors, not independent operations. They must therefore be products of the schedule parameters, and are dependent variables. Rather than providing quantitative support to the law of effect, the "matching law" seems to be little more than a curve-fitting exercise not dissimilar to Hull's, and despite its current popularity, is not analytic. Rather, it is, at best, a descriptive tool of problematic utility.

There is, of course, nothing inherently wrong with curve-fitting, provided that no a priori meaning is assigned to the derived constants. In the absence of a truly quantitative system of independent variables, curve-fitting may provide a reasonable approach to determining the systematic effects of those variables to the extent to which they can be quantified.

Using such an approach, Lander and Irwin (1968) built on Catania's (1963) equation relating response and reinforcement rates for concurrent schedules:

$$R=kr^{1/6} \tag{6}$$

where R and r were responses and reinforcers, respectively. They fit their own data (as well as Catania's) to a power function of the form:

$$(N_1+N_2) = K(n_1+n_2)^{1/6}. \tag{7}$$

N and n were responses and reinforcers, respectively, in both components of a two-component multiple schedule. K was selected so that the curve passed through the same point as had a similar function derived during an earlier portion of their experiment. The value of the exponent (1/6) was derived from the data. Plotting the relative frequencies of responding and reinforcement in each of the components of their eight multiple schedules, the authors then fit the data to another power function:

$$\frac{N_1}{N_1+N_2} = \frac{n_1^{\,a}}{n_1^{\,a}+n_2^{\,a}} \qquad (8)$$

where "a" was derived from the data. Solving equations (7) and (8) simultaneously to determine the rate in component 1 of the two-component multiple schedule (N_1) produced:

$$N_1 = \frac{n_1^{\,a}}{n_1^{\,a}+n_2^{\,a}} K(n_1+n_2)^{1/6}. \qquad (9)$$

The correction introduced by the use of the relative reinforcement rate in component 1 as a constant multiplier was intended by Lander and Irwin to correct equations (7) and (8) for interaction effects. The authors suggested an alternative to equation (8) which described the ratio of response rates in the two components as a power function of the reinforcement rates:

$$\frac{N_1}{N_2} = \left(\frac{n_1}{n_2}\right)^a \qquad (10)$$

(Lander & Irwin, 1968, p. 522). The value of "a" reflected the degree of interaction across the schedule components. Single schedules in isolation (and hence, no interaction) would produce a value of "a" of about 1/6. In concurrent schedules, where contrast is assumed maximal, "a" should equal 1.0, while multiple schedules, which allow a range of interactions, should produce a value of "a" of about

1/3. While the data the authors chose to develop their analysis seem to support these conclusions, there is no continuum along which multiple, concurrent, and isolated schedules may be conveniently ordered.

While Lander and Irwin's equations are rather cumbersome, they at least make no assumptions about unseen responses and "occult" reinforcers, and describe changes in interaction effects in terms of a single parameter (a). Baum (1974) later suggested a more general form of equation (10):

$$\frac{B_1}{B_2} = k\left(\frac{r_1}{r_2}\right)^a, \tag{11}$$

where B and r stand for behaviors and reinforcers, and the constants k and a describe the degree of "bias" and "interaction," respectively. Again, as in Lander and Irwin's equations, there is no provision for unseen reinforcers, although behavioral effects are still treated as independent variables, somehow separate from the direct effects of the schedule parameters.

As had Herrnstein's (1970) "matching function," Lander and Irwin's (1968) equations (and Baum's 1974 modification) treated the reinforcement rate, which depended on response rate, as the independent variable. There is no true independent variable in any of these attempts, and they simply describe (eith varying degrees of accuracy) the reinforcement contingencies. One attempt to predict the relation between reinforcement and responding that took into account their mutual causality was published by Baum in 1973. In that paper, the reinforcement rate was predicted from response rate (on tape-programmed VI schedules with, however, unspecified underlying mathematical series). Buam's equation 1 (1973, p. 138) rested on the assumption that the organism was integrating reinforcement and its effects over time, with the resulting steady-state values of responding and reinforcement rates subject to only rather gross (or as Baum terms them, "molar") changes in reinforcement parameters:

> Performance of the (response-reinforcer) system can be assessed only as it extends through time. This means that no particular momentary event should be seen in isolation, but rather, as part of an aggregate, a flow through time (Baum, 1973, p. 139).

The closest approximation to an independent variable in Baum's equation was a term that represented the "averaged scheduled interval" between reinforcers. As Ferster and Skinner (1957) had quite clearly indicated, however, when different VI sequences were programmed, "different distribution of intervals may produce the same mean interval ... but still have diverse effects" (p. 326). Catania and Reynolds (1968), for example, had demonstrated that intruding a "short" interval into a VI sequence increased the rate of responding markedly. While the "averaged scheduled interval" between reinforcers may be a convenient way to describe the schedule, it does not necessarily specify the relevant independent variable.

Baum (1973) recognized the need to include the interactive nature of the schedule-organism system in the analysis of that system, but his choice of averaged data and averaged independent variables obscured the underlying relationships. Organisms respond to stimuli impinging on them. While the effects of an instance of stimulation will certainly persist in time, and perhaps interact with the effects of previous instances of stimulation that have not as yet decayed, there is no evidence that organisms "integrate" anything (see Schoenfeld, 1972, p. 59-60). Baum's model, while describing the effects of responding on the $I_S r$ distribution, still does not provide a useful quantitative model for predicting behavior controlled by interval schedules. It is not possible, using Baum's equation, to predict response rate given just the schedule parameters.

A substatially more elegant analysis of the schedule behavior interaction than Baum's (1973) was published by Rachlin (1978). Rachlin, resting on the assumption that an organism responding on a schedule of reinforcement divides its time between responding, eating, and neither, derived a set of equations that described the data from diverse experiments quite well. As had Baum, Rachlin described the reinforcement rate as a function of response rate in the development of his analysis. Unfortunately, Rachlin also expressed the interval schedules he used in terms of mean expected reinforcement rate. Again, there is no consideration for the effects of the actual series underlying the mean VI values used, and while he fitted the data he chose to develop the analysis quite well, the effects of the internal parameters of the schedules were ignored. Rachlin's procedure did, however, generate equations with constants that seemed invariant over a wide range of experimental conditions. This should allow a somewhat more orderly description of the effects of changing reinforcement parameters than had earlier attempts, but still does not permit the prediction of response rate functions given only the schedule parameters.

It would appear, in fact, that while adequate descriptive equations are clearly possible, the search for meaningful quantitative laws of behavior is stalled in the face of an absence of a rational basis for such laws. The causal variables in the analyses above are confounded and confused with the dependent variables. The description of the interreinforcer response patterns has been entirely empirical, with the result a profusion of equations, all adequate to a degree, and all different. The best that can be said is that periodic stimulation produces periodic behavior, but the specifics of that behavioral periodicity are, as yet, only describable *post hoc*. The response rate-interreinforcer time relation has produced more fitted curves, and a major quantitative attempt (Herrnstein, 1970), that is, in large measure, fanciful.

A recent paper by Staddon (1977) treats the equations generated by workers in the Herrnstein tradition as analogous to those found in chemistry:

> The equation proposed by Herrnstein (1970) to describe response functions on interval schedules has a solid empirical basis, but an uncertain theoretical foundation (Staddon, 1977, p. 169).

While he constructs convincing examples of cases in which responding under interval schedules resembles chemical equilibrium states, the fact remains that his equations are power functions selected for their "goodness of fit" to the data. There is no reason to believe, based on any sound foundation in learning theory, or on any inherent properties of the schedules of reinforcement, that the behavior and schedule conditions must make the ratio of responses in two conditions proportional to the ratio of reinforcers in the two conditions. As was the case in the analysis of the interreinforcer response patterns, there are no rational bases for these equations, and the best that can be hoped for is good correspondence with the data.

If a true quantitative analysis of behavior that would yield an orderly set of interrelationships is to be forthcoming, some measure of both experimental and analytical control over the relevant variables is necessary. The schedule system invented by Ferster and Skinner in 1957 has produced enough convincing demonstrations of the orderliness and regularity of behavior to make such an undertaking seem reasonable. Their system, while obviously useful, was never intended to form the basis of a quantitative analysis, however, and focused on the explorations of visible (on the cumulative record) changes in behavior.

II

The t-tau Systems

An alternative to the classic system of reinforcement schedules that could support a real quantitative anaysis is provided by the t-tau systems. The first paper in the series that developed the system antedated publication of Schedules of Reinforcement by one year (Schoenfeld, Cumming, & Hearst, 1956), and defined a system of reinforcement schedules based on the passage of time. Time, rather than response count, was chosen because:

> ... time is a physical variable that can be defined, measured, and experimentally applied independently of any particular behavior (Schoenfeld & Cole, 1972, p. 148).
>
> We chose the time variable because, unlike response count, it reduced the involvement of the experimental subject as a partner in the experiment. It tended to free the independent variable operation (here, reinforcement schedule) from contamination by the dependent variable (the organism's responses) (Schoenfeld, et al., 1972, p. 5).

In the t-system, a repeating time cycle, T, is established independently of the animal's responding. By convention, only the first response in T is eligible for reinforcement. With no other specification than the length of T, it is possible to construct schedules ranging from CRF to extinction. For example, if T is shorter than the reinforcer time, or shorter than the animal's shortest interresponse time, then each response will be the first in a T-cycle, and each will be eligible for reinforcement. Lengthening T so that it functionally resembles infinity (for example, setting T at a value longer than the session length) permits no response beyond the first to be reinforced, and the resulting schedule resembles extinction. By dividing the T-cycle into two portions, one (t^D) in which the first response is eligible for reinforcement, and the other (t^Δ), in which no response is eligible, Ferster and Skinner's FI "limited hold" is produced.

The effect of introducing the t^D and t^Δ periods during the T-cycle is to make the probability that the first response in T will produce reinforcement dependent upon whether it occurs during t^D. If T is shorter than the shortest IRT, then the likelihood that a response will occur during t^D is equal to the relative length of t^D, or t^D/T. That ratio is called $\overline{T}$. Since reinforcement in this case depends on whether a t^D period is intercepted by a response, the number of reinforcers delivered in any period of time will depend on the number of t^D periods intercepted by a response. In other words, reinforcement rate under these conditions is linearly dependent on response rate. The schedule is indistinguishable in its effects from a ratio schedule in which responses are counted, and is called "random ratio," or RR. The expected value of the RR schedule is the inverse of $\overline{T}$.

Lengthening T from its shortest values through lengths that permit more than one response per interval and finally to infinity defines the continuum of schedules from FI to extinction. Reducing the probability that an eligible response (the first in t^D) will produce reinforcement to less than unity makes the expected interreinforcer time distribution random, and a type of variable interval schedule -- random interval, or RI emerges. RI schedules may be specified with only two variables: T and the probability that the first response in T will produce reinforcement (assuming that $\overline{T}=1.0$), p.

Multiple schedules may be reproduced within these systems by adding a cue change to the alternation of t^D and t^Δ. The alternation of t^D and t^Δ in the absence of a change in stimuli results in a schedule equivalent to Ferster and Skinner's "mixed schedule." In both cases, one of the "components" of the resulting compound schedule is extinction, but it need not be so. The convention has been to reinforce no responses in t^Δ, but by assigning different probabilities of reinforcement for the first responses in both t^D and t^Δ, compound random interval, random interval schedules may be produced.

Ratio schedules are not directly defined in these systems, but are approached as limiting cases at limiting values of parameters. For example, shortening T to less than the shortest IRT produces random ratio schedules. Random ratio schedules are the basis of the <u>tau</u> system.

In the *tau* system, two random ratio schedules alternate, with higher $\bar{T}$ values in one of the schedules the rule. The period with the higher $\bar{T}$ value is called *tau*^{D}, while the period of lower $\bar{T}$ value is called *tau*$^\Delta$. Analogous to the t-system, *tau*^{D}+*tau*$^\Delta$=*Tau*, with the ratio of *tau*^{D} to *Tau* called $\overline{\text{Tau}}$ (*Tau*-bar). If *tau*^{D} and *tau*$^\Delta$ are accompanied by different cues, then multiple random ratio, random ratio schedules result; if uncued, the schedules might be called Mix RR,RR. While random ratio schedules, like conventionally programmed ratio schedules, allow response rate to directly determine reinforcement rate, RR schedules are produced without the need for "counting" responses beyond the count of one (the first response in T). Ratio and interval schedules, then, differ parametrically, not qualitatively, and the task of organizing the data is vastly simplified. In either system (t or *tau*), all that is necessary for reinforcement is the coincidence of a response and a t^D period. Except for the stimuli themselves, all of the variables in the t-*tau* systems are temporally defined, and are true independent variables.

The studies in the t-*tau* systems to date have largely concentrated on the systematic exploration of the system parameters, and the data that have emerged are relatively straightforward. First, lengthening T decreases response rate. The T-rate relation is largely decreasing and monotonic beyond some short T values (Cole, 1968; Schoenfeld

& Cumming, 1957; Schoenfeld, Cumming, & Hearst, 1956). Second, the effects of $\overline{T}$ are dependent on T length. At short T values (for example, 40 msec), $\overline{T}$ has virtually no effect on response rate (Brandauer, 1958; Gilbert, 1976; Sidley & Schoenfeld, 1964), although Brandauer found non-monotonic functions for both the $P_S r$ and corrected rate. Subtracting the $P_S r$ from the time base used for the response rate computation produces a measure that Clark (1959) called "running rate." Farmer and Schoenfeld (1967) found running rate insensitive to $\overline{T}$, with the post-reinforcement pause and p ($\overline{T}$=p) showing an inverse relation. If the $P_S r$ is seen as a crude measure of response pattern, then the independence of rate and pattern again seems confirmed.

At intermediate T lengths (30 seconds or so), decreases in $\overline{T}$ produce increases in response rate (Hearst, 1956, 1958; Schoenfeld & Cumming, 1957; Schoenfeld, Cumming, & Hearst, 1956) and response patterns that change from classic FI patterns to break-run as $\overline{T}$ decreases:

> Individual cumulative response curves ... showed distinct changes as $\overline{T}$ decreased in value. For some birds, the scalloping typical of FI reinforcement was apparent for $\overline{T}$s of 1.00 and 0.35 .... At $\overline{T}$ values 0.03 and lower the records were marked by periods of responding at a very high and steady rate, usually until reinforcement was delivered. Immediately after a reinforcement, there characteristically was a pause ... followed by an abrupt transition to rapid responding.... (Hearst, 1958, p. 51).

Using slightly longer T lengths (T=2 min and 10 min), Clark (1959) examined the effects of $\bar{T}$ values of from 1.00 to 0.002 (T=2 min), and from $\bar{T}$=1.00 to $\bar{T}$=0.0016 (T=10 min). Corrected rate was found to be a decreasing, monotonic function of $\bar{T}$ at both T lengths.

Finally, at extremely long T-lengths (1800 seconds), $\bar{T}$ was shown to have little or no effect on response rates (Schoenfeld & Cumming, 1960). In addition, the response pattern generated at these extremely long interval values most clearly resembled ratio responding. There was little or no scalloping, extremely long pauses (ratio strain?), and high, stable response rates continued once responding had begun.

The ordered interaction between T and $\bar{T}$ in their effects on response rate is amenable to a quantitative analysis. By fitting power functions to the response rate data found in Schoenfeld and Cumming (1960), which describe response rate as a function of $\bar{T}$ values (_a la_ Clark, 1959), it is possible to observe changes in the constants as T changes. The equation is:

$$R=a\bar{T}^{b}, \tag{12}$$

where R is the corrected rate, and a and b are derived from the data. Fitting Brandauer's (1958), Clark's (1959), Hearst's (1956, 1958) and Schoenfeld and Cumming's (1960) data to equation (12) produced the following:

Brandauer (1958)	T=0.001 sec,	$R=0.79\bar{T}^{-0.28}$;
Hearst (1956, 1958)	T=30 sec,	$R=0.66\bar{T}^{-0.19}$;

Clark (1959)	T=120 sec	$R=0.45\overline{T}^{-0.16}$;
" "	T=600 sec	$R=0.35\overline{T}^{-0.11}$;
Schoenfeld & Cumming (1960)	T=1800 sec,	$R=0.34\overline{T}^{+0.09}$.

In other words, as T lengthened, the a parameter (the intercept of the least-squares regression line fitted to a log-log transformation of the original data, and therefore a general index of overall rate) decreased, while the b parameter (the slope of the line) became less negative, until at T=1800 sec, the exponent was slightly positive. Equation (12) accounted for over 90% of the variance in the data, indicating that Clark's choice of a power function, if not rationally determined, did at least provide a good approximation to the data.

Weissman (1958, 1961, 1963) examined the effects of differentially cuing t^D. In all three of his experiments, a stimulus (S^D) terminated with the first response in t^D, and the procedures resembled Skinner's (1938) original operant discrimination procedure. For the most part, Weissman's data replicated earlier t-system studies in which T was held constant and $\overline{T}$ was reduced. The presence of the discriminative stimulus had mixed effects, producing a generally lower rate of responding than had obtained in the absence of S^D in two (1961, 1963) of the studies. The rate reductions, where they occurred, resulted from decreased responding in t^{Δ}, rather than increased responding in t^D. This finding is consistent with Ferster and Skinner's (1957) data using an "FI with added clock," and with Pavlov's (1927) original notions of how discriminations were formed. At very low $\overline{T}$ values, some of Weissman's animals began to "miss" t^D periods, and hence reinforcers, and this might have further reduced response rate.

In all of the preceding studies, the T-cycle length remained unchanged for lengthy periods of time, and the schedules were all variants of fixed interval. Where different cycle lengths were used, behavior was allowed to stabilize on one value of T before changing to the next (Schoenfeld & Cumming, 1957; Schoenfeld, Cumming & Hearst, 1956). The first of two procedures for varying the expected interreinforcer times was published by Millenson (1959), who, in perhaps the most primitive of variable interval approximations possible within the t-system, varied the proportion of time that one of two possible T-cycle lengths (30 sec and 120 sec) was in effect. The two T-cycle lengths alternated, with the proportion of long cycle lengths ($\overline{P}$) varied from 0.95 to 0.05. Millenson also manipulated $\overline{T}$ (which was equal in both cycles) from 1.0 to 0.003125. While the changes in $\overline{T}$ had no necessary effect on the interreinforcer times, $\overline{P}$ did, and variable interval schedules ranging from a mean interreinforcer time of 34.5 sec ($\overline{P}$=0.05) to 115.5 sec ($\overline{P}$=0.95) were produced. The data indicated that, particularly below $\overline{T}$=0.05, decreases in $\overline{T}$ produced sharp increases in corrected rate, prompting Schoenfeld, et al.

(1972) to comment: "The additional corroboration of the function relating response rate to $\bar{T}$ seemed to put the reality of that finding beyond question" (p. 35). Rate generally decreased with increasing $\bar{P}$, although the function was rather irregular. The five $\bar{T}$ curves were roughly parallel across the range of $\bar{P}$.

A more convenient, and perhaps more direct procedure for varying the expected mean interreinforcer intervals came from Farmer (1962, 1963). Farmer varied both the length of T and the probability that the first response in T would produce reinforcement (p) from 1.0 to 0.0052, allowing what Millenson (1963) called the "interassignment intervals" to vary about a mean value. The mean $I_S r$ was equal to T/p, with differences in the properties of the distribution of interassignment intervals produced by the specific effects of varying either T or p.

Under these random interval (RI) schedules, T was produced in the same way as in the earlier t-system studies a free-running clock "timed out" at regular intervals, and the first response following the timing out of the clock was eligible for reinforcement. Whether or not an eligible response produced reinforcement was determined as follows. Coincident with T, a shorter cycle (on the order of 40 msec, or so) was programmed. Only the first response in T was allowed to enter this shorter cycle, and did or did not produce a reinforcer depending on whether it intercepted the equivalent of a t^D period in the shorter cycle. In other words, p was equal to $\overline{T}$ in the shorter cycle. Since both T and p were temporally determined, the system was internally consistent.

The distribution of interassignment intervals in this type of schedule is truly random, eliminating the confounding effects of preselecting an "eligible" response for reinforcement, and the problems inherent in a finite, repeating sequence of interassignment intervals. The distribution of interassignment (expected I_Sr) intervals is described by the equation:

$$P_{(N)} = p(1-p)^{N-1}, \tag{13}$$

where $P_{(N)}$ is the probability of N T-cycles intervening between reinforcers, and p is the *a priori* probability value ($\overline{T}$ in the shorter cycle). The variance of the distribution is equal to:

$$\frac{T^2(1-p)}{p^2} \tag{14}$$

(Millenson, 1963, p. 442).

The actual interreinforcer intervals in RI schedules, are, of course, a joint function of the schedule parameters and the animal's response rate, but the nature of the schedule parameters makes the effects predictable. Specifically, equations (13) and (14) assume a response rate sufficient to assure at least one response in each T-cycle. Decreases in rate below 1/T increase the interreinforcer time by the extent to which they differ from 1/T. For example, a response rate of 0.5/T would double the real $I_S r$, a rate equal to 0.25/T would quadruple the $I_S r$, and so on. Since RI schedules differ from FI schedules only in the value of p (p=1.0 in FI), the computation of the obtained interreinforcer times is the same for RI and FI. Baum's (1973) equation 1, Rachlin's (1978) equation 1, and Lund's (1976) assertion of a tentative (or possible) continuum relating FI to VI become trivial. The FI-RI continuum is defined by p, and the "feedback" functions in Baum's and Rachlin's papers are defined by specifying both T and p. T determines the minimum and modal interreinforcer times, while p determines the variability about the mean specified by T/p.

In general, and in contrast to the RR data, Farmer found response rates to be decreasing functions of p. The curves for corrected rate, although the same shape as the running rate curves, were somewhat flatter, with the lowest rates occurring at the longest T values. This is consistent with the earlier t-system studies in which T-cycle length was the major independent variable (Hearst, 1958; Schoenfeld & Cumming, 1957; Schoenfeld, Cumming, & Hearst, 1956), as well as the more traditional FI studies (Sherman, 1959; Skinner, 1938; Wilson, 1954) that examined the effects of FI length. As had earlier authors (e.g., Ferster & Skinner, 1957), Farmer noted that the animals exceeded both the minimum rate necessary to produce all of the reinforcers (1/T) and the minimum expected R/S^R

ratio (1/p) by a considerable margin.

Farmer's post-reinforcement pause data, perhaps the most comprehensive available in the literature to the time the study was published, showed a complex relationship between the schedule parameters and the P_Sr. At short T-values, (1, 5, 10 sec), the pause was an increasing function of p. At T=30 sec, the P_Sr function was rather flat across values of p for one bird, and passed through a maximum for the other. At T=60 sec, the P_Sr decreased with increases in p.

RI schedules were the last major addition to the t-system. Later studies extended the system into "aversive control," and further explored the effects of intruding stimuli other than food or shock, but the publication of Farmer's dissertation in 1962 completed the system. It was now possible to replicate most of the major effects generated by Ferster and Skinner, but within an internally consistent, rationally ordered set of continuous, quantitatively defined variables founded on a fundamental physical property -- time.

III

Rationale

The temporal nature of the t-system parameters allows their use as independent variables in a quantitative analysis. Because they are real, rather than derived from their effects on behavior, their use suffers from few of the difficulties associated with other attempts to specify the "independent variables" in quantitative analyses of schedule-controlled performance. Since the t-system variables are derived without reference to the responding organism, the data that have emerged from studies in that system, while products of an interaction between the organism and the schedule parameters, are true dependent variables.

More than a readily organized system of independent variables is needed, however, if an analytical system is to be more than merely descriptive. The "model" under which the experiments are conducted and the data collected should be as descriptively accurate as possible. Most of the previous attempts at quantification have assumed a tacit "reflex" model, and have treated the organism's behavior as a function of reinforcement, or $R=f(S)$. This relation is undeniably valid. The application of a stimulus within the range to which an organism's receptors are sensitive will produce a change in some aspect of its behavior, measured or not. The introduction of the "response contingency" into the relation between an organism and food (or shock) deliveries, however, introduces another relation just as valid as the first.

In a "contingent" relation, not only is $R=f(S)$, but $S=g(R)$. If reinforcers are seen as inputs to the organism, and responses as outputs, then under a contingent schedule of reinforcement, the outputs are a function of the inputs and the inputs are a function of the outputs. This kind of mutual causal process (Maruyama, 1963) describes a "feedback control system," or servomechanism (Powers, 1971; Ritow, 1963). In a servomechanism, the variable of interest (the "controlled quantity") is controlled relative to an ideal value (the "setpoint") by variations in the output of the system. Any difference between the value of the input and the setpoint ("error") is resisted by changes in the output of the system, such that the absolute value of the error is driven downward. Since the effect of the feedback is to reduce the error, such a system is usually said to contain "negative feedback," although Maruyama's (1963) "deviation minimizing mutual causal process" is somewhat more descriptively accurate. A common example of a non-biological servomechanism in which error is minimized is a thermostatically controlled heating system. If the temperature of the air in the room containing the thermostat (the controlled quantity) drops below the value set on the thermostat (the setpoint), the furnace is turned on, producing heat (output). The heat is produced until the error is reduced to zero (the temperature equals the setting on the thermostat), at which point the furnace shuts off. Once could argue in this case, that the temperature of the room is a function of the heat produced by the furnace (which, of course, it is), or that the output of the furnace is a function of the temperature of the room containing the thermostat (which it is). Both are true, and it should be noted that with regard to the system, neither the heat put out by the furnace nor the temperature of the room are independent variables. The only independent variables in the system are the setpoint and the characteristics of the heating system that determine the rate at which temperature is changed once the furnace is turned on.

Servomechanisms have a lengthy history (e.g., Mayr, 1970), as does their application to the explanation of behavior (Mc Farland, 1971). Using a servomechanism model, Powers (1971) described a method for predicting response rates in a temporal (Sidman) avoidance procedure using data published by Verhave (1959). In Verhave's experiment, a timer that produced a shock if no response occurred before it timed out (the "shock-shock" or SS timer) was set to time out at 30 second intervals (SS=30 sec). A timer that reset to zero with each response, cancelling the SS timer, and delivering a shock when it timed out (the "response-shock" or RS timer) was set at values of from 30 sec to 300 sec. In addition, the "R" that reset the RS timer consisted of from one to eight bar presses. Treating the actual shocks received as the controlled quantity, Powers assumed a setpoint of zero (the ideal condition would be no shocks), and treated the response rate as output which reduced the shock rate (or more accurately, increased the time to the next shock). Verhave's data showed few shocks actually delivered ("avoidance" was "successful"). Reasoning that shocks not received control nothing, Powers assumed that the few shocks actually received (the error) determined responding (this is virtually identical with the position taken by Schoenfeld, 1950, 1969, but Powers seems to have been unaware of Schoenfeld's work).

Having only the average response rate of the organism at each value of the RS timer with which to work, Powers treated that datum as the mean of a positively skewed probability density function of IRTs. An equation was generated in which the area under this hypothetical distribuation from the RS interval to infinity was treated as a constant. This procedure produced a rather good approximation to the rate-RS function when the response requirement was eight bar presses. Adjusting the equation for reducing the response requirement to one produced even better rate predictions.

The adequacy of the predictions produced by Powers' model, and the degree with which it agreed logically with the operant paradigm suggested that a positive reinforcement analog of Sidman avoidance might yield similar results, and the following experiment was conducted (Shamow, 1975). Three naive, White Carneaux hen pigeons were trained to peck the center key of a three-key Lehigh Valley Electronics # 1519C pigeon chamber using an autoshaping procedure (Brown & Jenkins, 1968). During the autoshaping procedure, a reinforcer was delivered every 60 seconds whether or not the subject pecked the key. The key was dark for the first 54 seconds of the 60 second cycle, illuminated white for the last 6 seconds, and dark for the 3 seconds of access to a lighted hopper filled with mixed grain that constituted reinforcement. By the end of four sessions, all subjects were pecking the key reliably only during the light. On sessions 5, 6, and 7, the light was turned on for the entire 60 seconds. The response pattern at the end of session 7 for all three birds resembled that obtained under contingent FI schedules (response "runs" and post-reinforcement pauses). From session 8 on, the key was illuminated one of four colors (white, green, red, blue) in sequence. During each of the colors, the schedule in effect was (response-contingent) FI 1, 4, 16, or 64 seconds, respectively. The 60 second timer continued to run, reset with each reinforcer, whether earned in one of the FI schedules or delivered at the end of the 60 seconds. The subjects, in other words, could earn reinforcers on any of the four FI schedules (each in effect for three peck-produced reinforcers), or wait the 60 seconds and receive a reinforcer for not pecking the key. The schedule resembled a DRO-FI(T) (differential reinforcement for other behavior; Reynolds, 1961), with one of the four T-values in effect at all times.

In Sidman avoidance, the SS timer determines the intershock time given no response. If the animal does not respond, its intershock time is the SS value. If the response-shock timer is set equal to or longer than

The SS timer, the organism may drive the intershock time up by responding. In the concurrent DRO-FI(T) schedule described above, the animal could either receive a reinforcer every 60 seconds or drive the interreinforcer time to the FI value in effect at the time. Only one of the four values (T=64 sec) was longer than the 60 second DRO clock. Powers' analysis of Verhave's data required that the animals "miss" a few cycles and get shocked. The analogous situation in the positive reinforcement case described above would be for a subject to "miss" a string of FIs and get a DRO reinforcer. In 20 sessions, this never happened in any of the FI values. Since none of the IRTs were longer than the DRO timer, the area under the IRT distribution beyond the DRO value of 60 seconds was zero, and the interreinforcer times generated under the procedure equalled the T-values.

The four FI values were produced by four T-cycle lengths, with p=1.000. Since at this p value, none of the rates was low enough to permit the DRO timer to elapse, it appeared that reducing p to less than one might sufficiently lower response rate to allow at least an occasional DRO reinforcer. The value of p was then reduced to 0.125 for 10 sessions, making the schedule a DRO-RI(8XT). Despite the eight-fold increase in the expected mean I_Sr, there were still no DRO reinforcers earned. From these data, it appeared that despite the longer mean I_Srs (and the occasional extremely long interreinforcer times) that occur under random interval schedules, the animals were responding in such a way as to drive the $I_S$rs to their minimum possible values -- the T-cycle lengths.

In this experiment, the setpoint might be assumed to have been zero with respect to the interreinforcer time -- the pigeons were starved to 80% of their free-feeding weights, and the "best of all possible worlds" might safely be assumed to be continuous access to food. Powers chose a setpoint of zero with shock as a stimulus, using stimulation rate as a measure. Using the same metric as above (interstimulus time), Powers' setpoint is infinity. In both the avoidance and the positive reinforcement cases, the interstimulus time was adjustable by the organism within the bounds set by the schedule. The SS timer (and the DRO timer) determined the interstimulus time in the absence of responding. The RS timer (and the T-cycle length) determined the interstimulus time in the presence of responding. The data from both experiments revealed that organisms, under both conditions, responded more rapidly than was necessary to ensure that the interstimulus interval was at a minimum (for food reinforcement), or at a maximum (for shock). In both cases, the rate-interval (T for food, RS for shock) curve appeared decreasing and monotonic.

Despite the failure to replicate Powers' analysis of Verhave's data in the positive reinforcement case, there were sufficient similarities between the schedule-response rate interaction in both the avoidance and positive reinforcement cases to suggest that the schedule-behavior interaction might be treated as a servomechanism, regardless of the stimulus scheduled. This, in turn, suggests a route to a quantitative analysis of behavior different from previous attempts.

Virtually all of the previous attempts to functionally describe the schedule-behavior relation have treated the data as uniquely determined by the schedule "value" (usually interreinforcer time or reinforcement rate). The most ambitious of this latter type to data has been Herrnstein's (1970) "matching function." The "value" of a schedule, of course, is a function of both the independent operations involved in the construction of the schedule and the resulting behavior. Since the advent of the t-system, it has been possible to describe those independent operations in terms of schedule parameter values. It is those parameter values (or more accurately, the environmental events they represent) that determine the behavior of the schedule-organism system. The schedule parameters set limits on the extent to which characteristics of responding (such as the rate or pattern of responding) may determine the temporal distribution of stimuli. The behavior of the responding organism is in turn affected by the temporal distribution of stimuli. Both reinforcement and response rates are then dependent variables, and both may be described as functions of the schedule parameters. The preceding t-system data were not obtained with a systematic treatment of the data in mind, but rather to explore the domain defined by the system variables. The result was that most of the functions resulted from exposure to only one or two of the variables in the system at a time. Since an adequate understanding of the schedule-organism interaction requires that as many of the relevant variables as possible be controlled, and it appears that the effects of the t-system variables on behavior interact (for example, the interaction between the effects of T and $\overline{T}$), the present experiment manipulates all of the major system variables (T, $\overline{T}$, and p) within single organisms. This will allow for the construction of families of functions describing the effects of the schedule parameters within a single organism, and allow a further exploration of the servomechanism model and its quantitative implications.

METHOD

Subjects. Subjects were five White Carneaux hen pigeons approximately seven years old at the start of the experiment. All five had been trained (by the method of successive approximations) to peck the center key of a Lehigh Valley Electronics # 1519C three-key pigeon chamber one year prior to the start of the present procedure, but had no exposure to this or any other apparatus in the interim. All were maintained in separate cages at 80% (± 15 gm) of their free feeding weights for the duration of the experiment, with grit and water continuously available.

Apparatus. The Lehigh Valley Electronics # 1519C three-key pigeon chamber which was used for response shaping also served as the experimental space. Only the center key was used, and could be illuminated with one of four colors (white, green, red, blue) by an IEE # 696 projector located behind the key. General illumination, illumination of the keys, and illumination of the hopper light during reinforcement were provided by # 1828 28V bulbs supplied with 28 VAC from a transformer isolated from the controlling circuitry. Electromechanical programming equipment consisting of relays, counters, and BRS/LVE # PG901 Probability Gates controlled experimental contingencies. The time base for all experimental operations was provided by a Hurst 120 VAC 60 RPM synchronous motor equipped with a four-lobe cam operating a BRS/LVE # PF 903/252-03 pulse former every 0.25 sec. A continuously operating ventilating fan and white noise source (Grason Stadler # 901B noise generator driving a 6 in 8 ohm speaker mounted to the right of the grain hopper) provided masking noise during the experimental sessions. Data were recorded on Sodeco impulse counters and a Gerbrands Harvard C3 cumulative recorder modified to accept Rapidograph # 00 pens (Snapper, Verhave, & Herman, 1964).

Procedure. For the year prior to the start of the experiment, all subjects had continuous access to food, grit, and water in their home cages. Body weights were taken daily for the 15 days preceding the start of the experiment proper, with median weights for the last five of the 15 days used for computing running weights. Subjects were reduced by total food abstinence to 80% of that median, and maintained at that weight with daily feeding of small amounts of grain (where necessary).

All reinforcement schedules in this study were programmed within the t-*tau* systems, the parameters of which are described in detail in the introduction to this paper. Four T lengths were used in this experiment (T= 1, 4, 16, and 64 sec), each correlated with a different key color (white, green, red, and blue, respectively). This corresponds to a "four component multiple schedule" in Ferster and Skinner's terminology. The cycle lengths were programmed in the above order, and each remained in effect until three reinforcers had been delivered before changing to the next scheduled value. All values of p were generated by gating the pulse produced by the first response in each t^D through the probability gates. A session terminated after the 60th reinforcer (or five times through the sequence of T lengths). Reinforcement consisted of two seconds of access to a lighted hopper containing mixed grain. During reinforcement, all other timing stopped.

The values of $\overline{T}$ and p applied to all T-cycle lengths, and were programmed in the following manner. For the first ten sessions, both $\overline{T}$ and p were kept at 1.000; from the eleventh session on, any given value of $\overline{T}$ remained in effect for 25 sessions, while p was reduced from $p=1.000$ to 0.500, 0.250, 0.125, and then back to 1.000, with each value of p in effect for five days. Following the return to $p=1.000$, $\overline{T}$ was reduced to its next scheduled value ($\overline{T}=0.75$, in this case), and the range of p values again gone through systematically. This continued until $\overline{T}$ and p had reached their minimum scheduled values in this experiment ($\overline{T}=0.25$; $p=0.125$). The reduction in the values of $\overline{T}$ was accomplished by reducing the length of t^D. The t^Δ periods were cued by the termination of the key-color in effect at the time. Except for the two seconds of reinforcement, the key light remained on for the duration of t^D, whether or not a response was made. All changes from one value of T to the next occurred during the dark

t^{Δ} periods. The order in which the experimental parameters were scheduled is shown in Table 1.

Because at the $p=0.125$ value session lengths became quite long, it was not possible to use each subject each day. At this p value, subjects were run in a rotating order such that three of the five birds were in the experimental chamber on any one experimental day. For all other values of p, each subject was run at the same time each day, six days a week.

Since all birds had prior training, no shaping was necessary. On the day prior to the first experimental session, each subject was allowed to earn 15 reinforcers for pecking the center key (illuminated white) on a fixed interval 60 sec schedule (T=60 sec, p=1.000, $\bar{T}$=1.00). Sessions were timed from the first peck, and all subjects had completed this first "reacquisition" session within 17 minutes of the start. Since the length of the experimental sessions was a joint function of the schedule parameters and the subject's response rate, session lengths varied and are reported in the Results section (Table 34). The houselight was turned on when the subject was placed in the experimental chamber, remained on during the session, and terminated at the end of the last reinforcer.

RESULTS AND DISCUSSION

The numerical rate and pause data that follow reflect the last two of three reinforcers at each of five daily exposures to each T value. This eliminates data that might have been maximally influenced by transitions from prior T values. The cumulative recorder, however, ran continuously throughout each session, stopping only during the two seconds of reinforcement. Because there were no systematic changes visible in the data within the period of exposure to each value of $\overline{T}$ and p, all numerical data are pooled over all sessions at each value of $\overline{T}$ and p. All subjects received all of the variables in the same order. This eliminated the effects of randomizing the schedule presentations, and increased the likelihood that whatever order effects were present would be similar across subjects (Sidman, 1960).

Figures 1 through 5 show the corrected rate functions over all four $\overline{T}$ and p values. The data are presented in Tables 7-11 (running rates are shown in Tables 2-6). Each panel of each figure represents a different $\overline{T}$ value. Rate curves at each p value are represented as follows: filled circles, $p=1.000$; open circles, $p=0.500$; filled rectangles, $p=0.250$; open rectangles, $p=0.125$. The data are pooled for the first and second determinations (baseline recoveries) at the $p=1.000$ value at all $\overline{T}$ values. As expected, response rate was a generally decreasing function of T at all $\overline{T}$

and p values for all subjects, with occasional irregularities in the functions. S2 and S4, for example, showed high rates at $T=16$ sec (S2 at $\overline{T}=1.00$ and 0.75, $p=1.000$; S4 at $\overline{T}=1.00$, $p=1.000$; $\overline{T}=0.50$ and 0.25 for both $p=1.000$ and 0.500), yielding curves that passed through maxima.

There appeared to be little or no systematic effect of p on either corrected or running rates at most $\overline{T}$ values. Where an effect of p on rate was detectable, it took the form (in one case) of an inverse relation between p and rate (S1, $\overline{T}=1.00$), or (in a second case) a direct relation between p and rate (S4, $\overline{T}=0.50$). In both of these cases, the effect was maximal at $T=1$ sec. Figures 6-10 show corrected rate (averaged across $\overline{T}$) as a function of p. The weak effect of p would seem inconsistent with some studies in which variable, rather than fixed interval schedules were used to maintain responding, particularly Farmer's (1962, 1963) defining study of RI schedules.

One possible explanation for this inconsistency may lie in the length of time animals have to be exposed to a value of p after a change in p for that new value to have a noticeable effect on response rate. If the time course of the development of an effect of p is such that p takes a long time to affect behavior, then the five days at each value of p may have been insufficient for p to exert its maximal effect (see Sidley & Schoenfeld, 1964). In order for decreases in p to produce decreases in response rate, behavior would have to undergo a gradual, partial extinction

Figures 1 through 5: Corrected rate as a function of T.

Figures 1 through 5 show corrected response rate (responses per second with reinforcement time subtracted from the time base used for the calculations) for subjects 1 through 5, respectively. All data are means of all days at each parameter value, and include rates in both t^D and t^{Δ}. The curves for all p=1.000 data are pooled across original and recovery sessions.

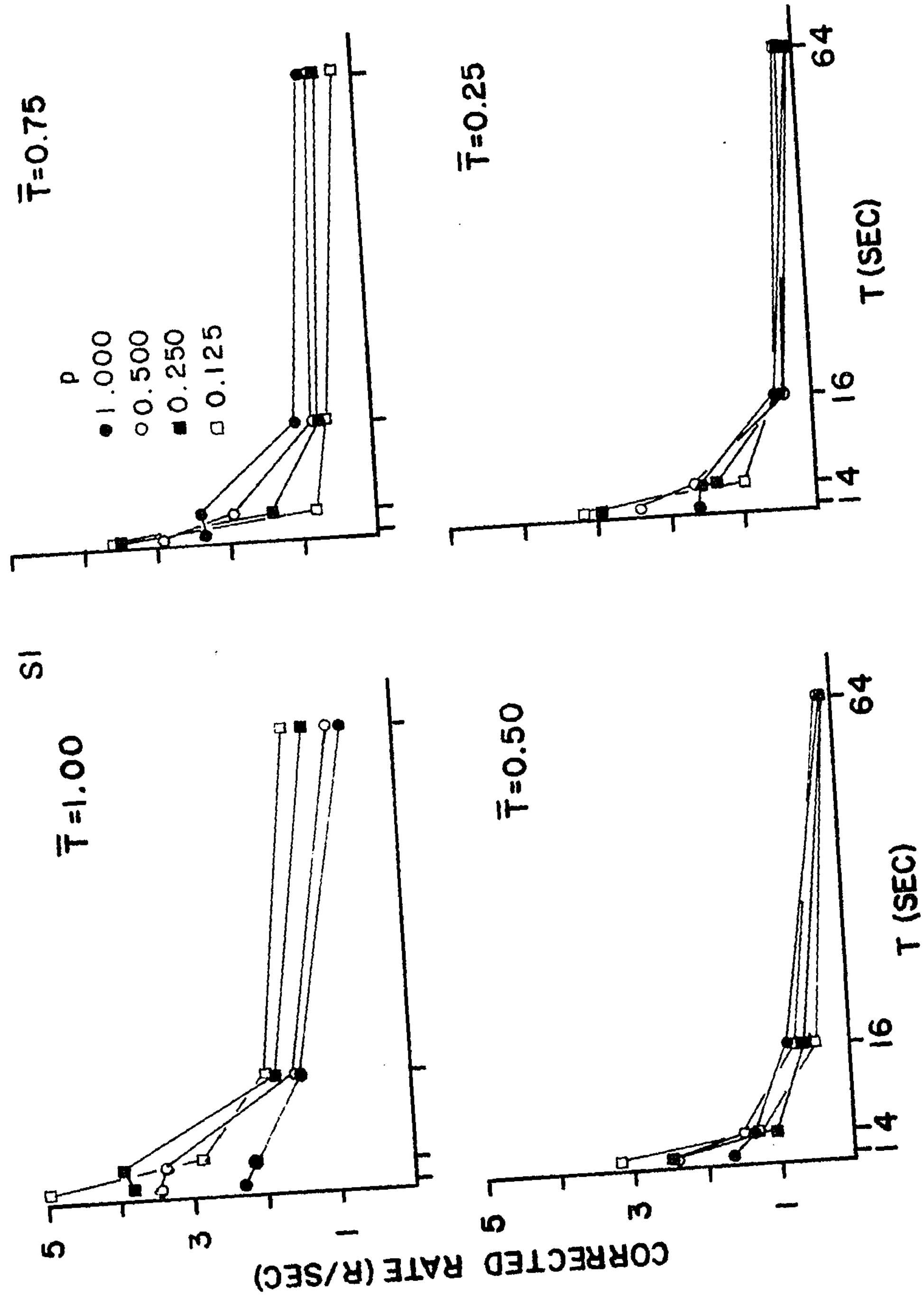

S1
T̄=1.00
T̄=0.75
T̄=0.50
T̄=0.25
p
● 1.000
○ 0.500
■ 0.250
□ 0.125
CORRECTED RATE (R/SEC)
5
3
1
T (SEC)
1
4
16
64

Figure 1

Figure 2

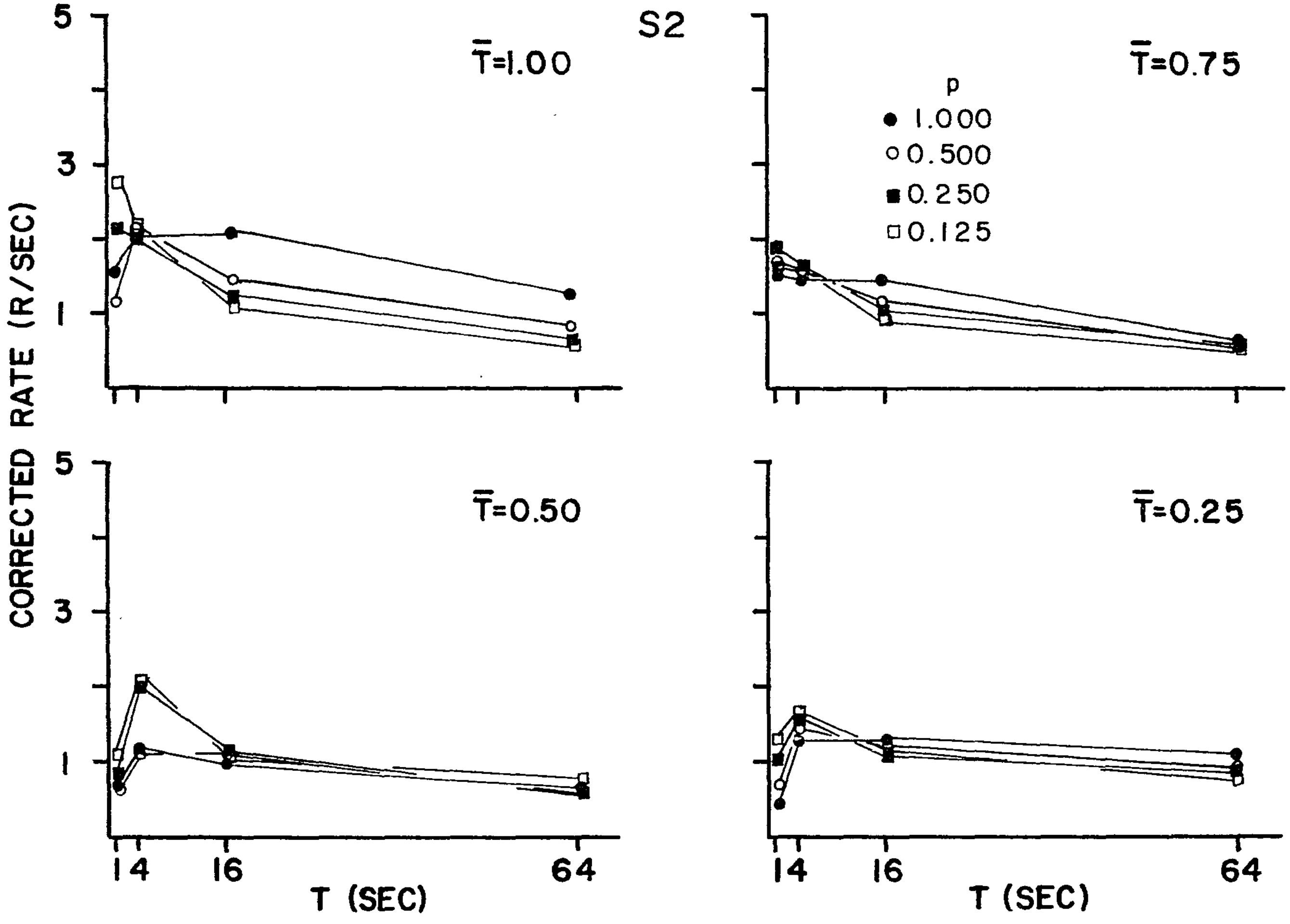

S2
CORRECTED RATE (R/SEC)
5
3
1
T̄=1.00
T̄=0.75
p
● 1.000
○ 0.500
■ 0.250
□ 0.125
T̄=0.50
T̄=0.25
14
16
64
T (SEC)
14
16
64
T (SEC)

Figure 3

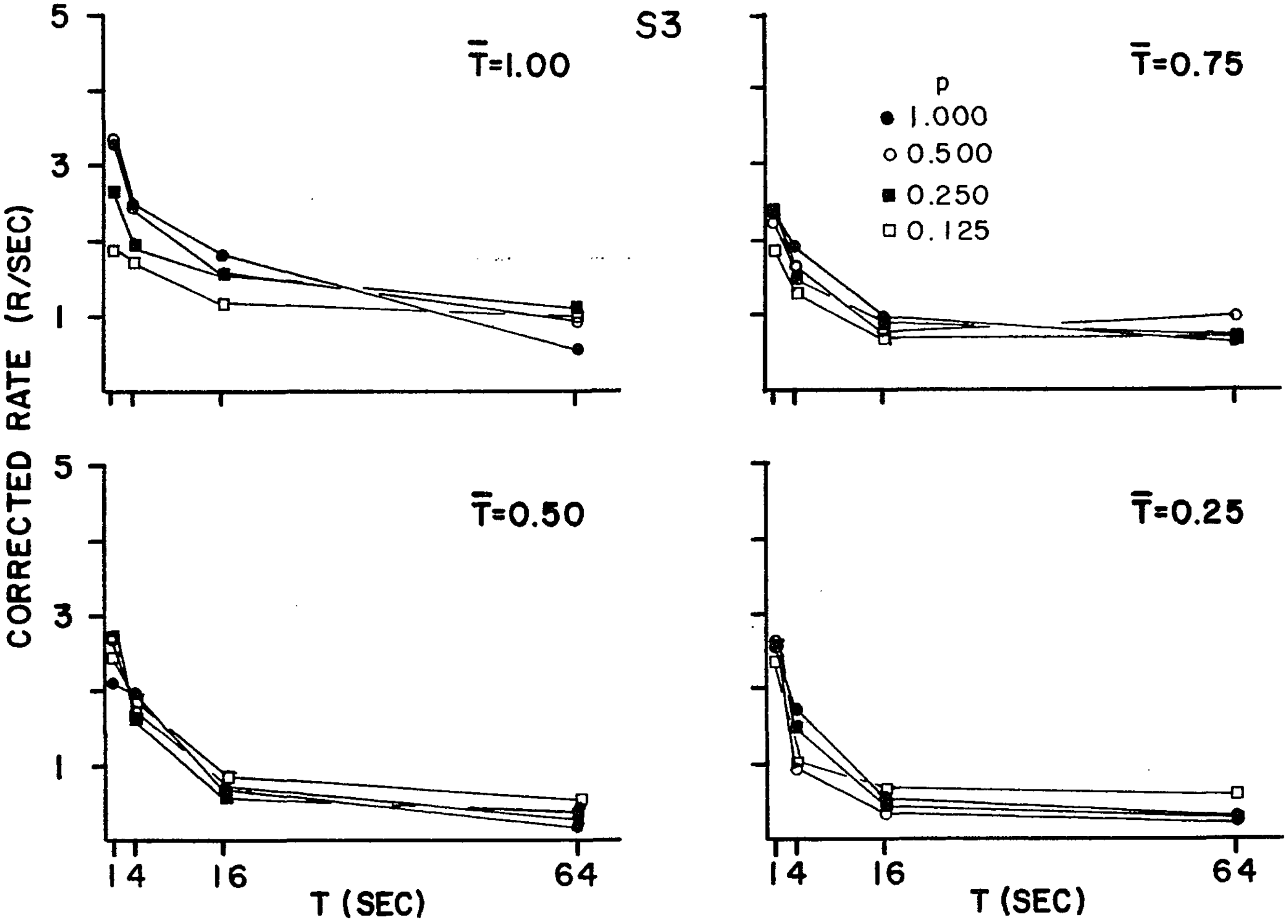

S3
$\bar{T}$=1.00
$\bar{T}$=0.75
$\bar{T}$=0.50
$\bar{T}$=0.25
p
● 1.000
○ 0.500
■ 0.250
□ 0.125
CORRECTED RATE (R/SEC)
5
3
1
5
3
1
1 4 16 64
1 4 16 64
T (SEC)
T (SEC)

Figure 4

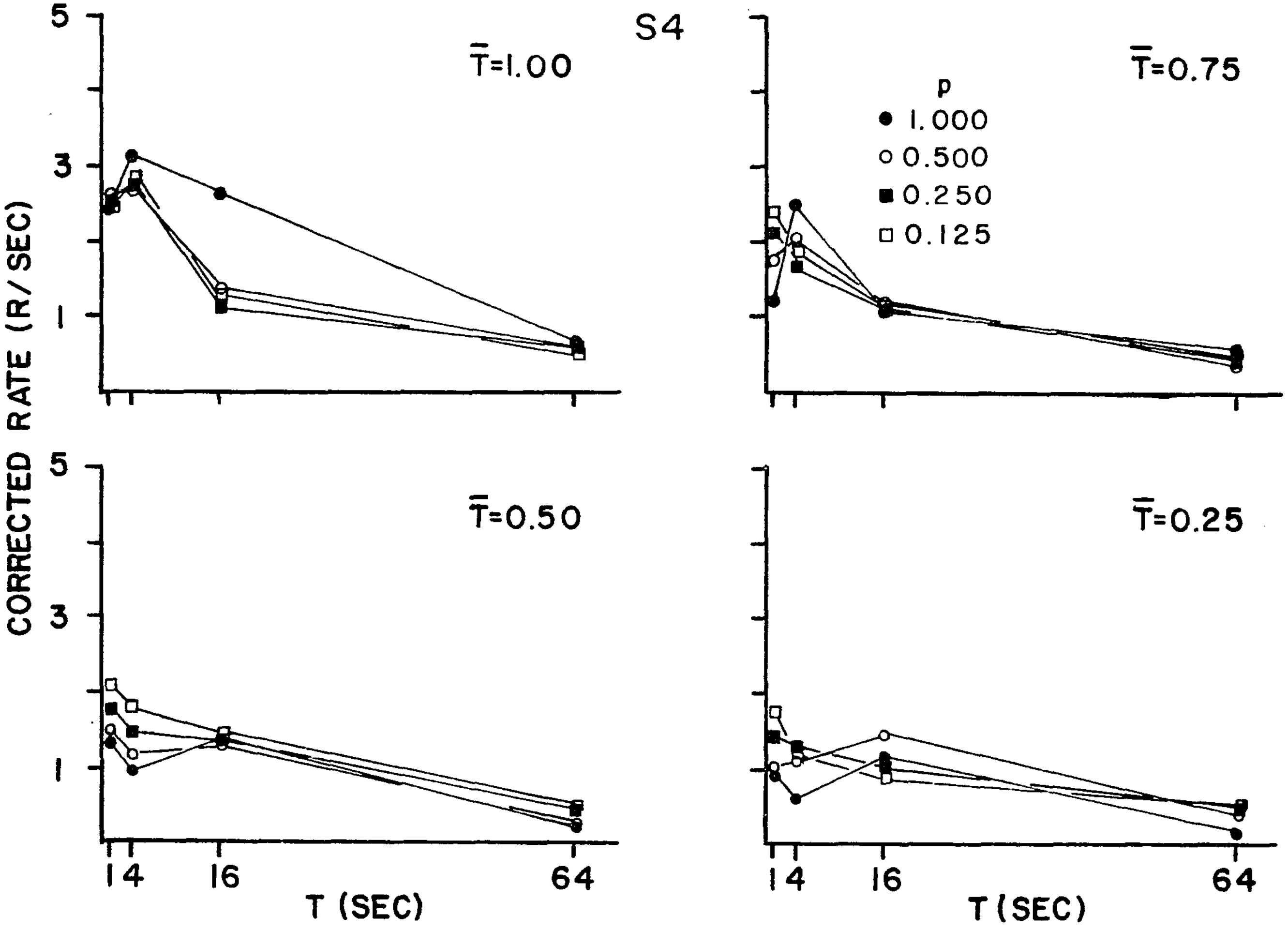
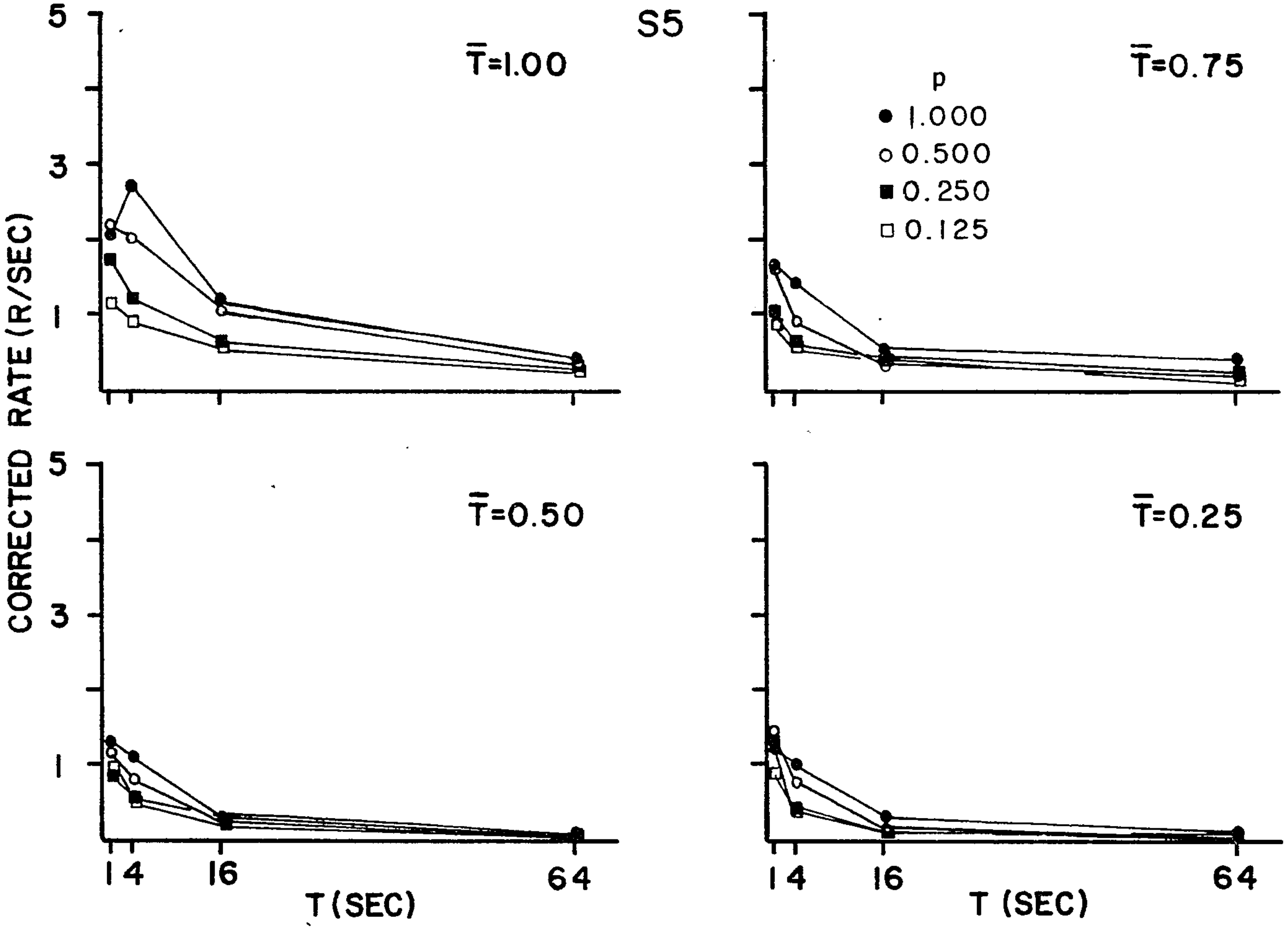

S4
CORRECTED RATE (R/SEC)
T̄=1.00
T̄=0.75
T̄=0.50
T̄=0.25
p
● 1.000
○ 0.500
■ 0.250
□ 0.125
5
3
1
1 4
16
64
T (SEC)

Figure 5


S5
$\bar{T}$=1.00
$\bar{T}$=0.75
$\bar{T}$=0.50
$\bar{T}$=0.25
p
● 1.000
○ 0.500
■ 0.250
□ 0.125
CORRECTED RATE (R/SEC)
5
3
1
T (SEC)
1
4
16
64

Figures 6 through 10: Corrected rate as a function of p.

Figures 6 through 10 show corrected response rate (responses per second with reinforcement time subtracted from the time base used for the calculations) as a function of p for subjects 1 through 5, respectively. Data are pooled across values of $\overline{T}$, include rates in both t^D and t^Δ, and represent all sessions at the indicated p values. T-cycle lengths for each curve are shown to the right of the curve.

Figure 6

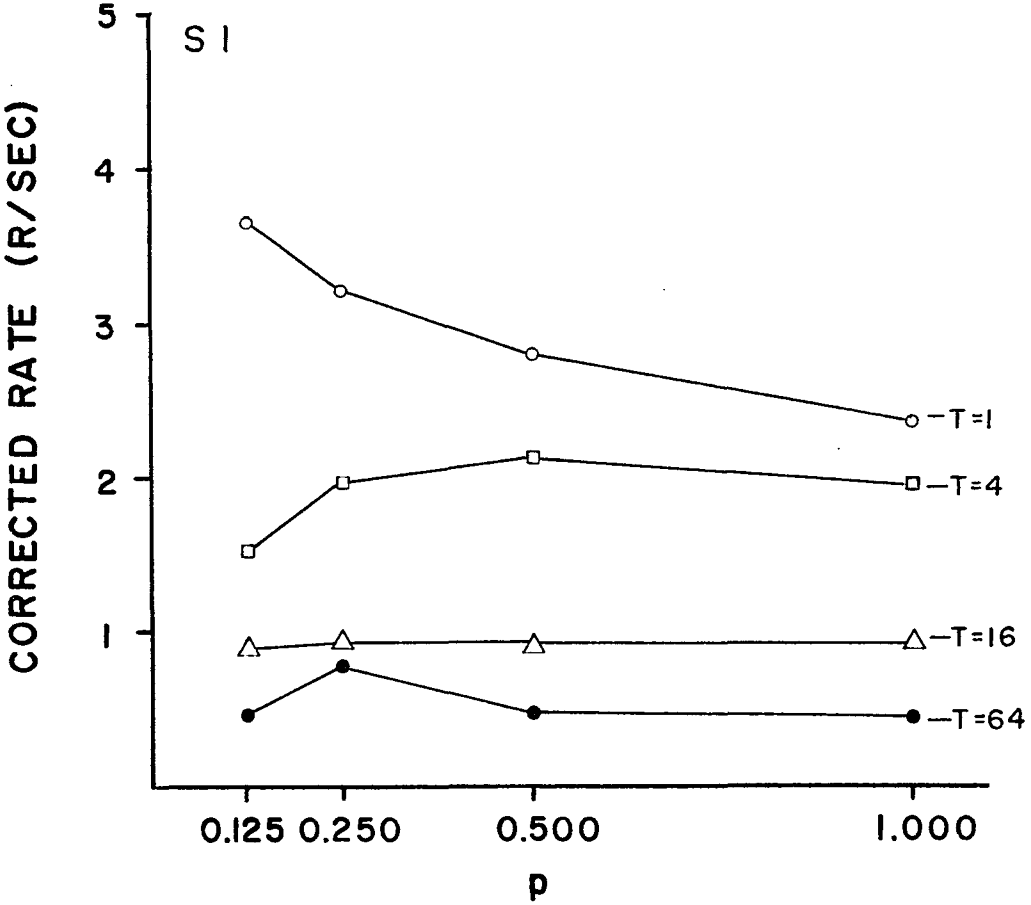

S 1
CORRECTED RATE (R/SEC)
5
4
3
2
1
0.125
0.250
0.500
1.000
p
—T=1
—T=4
—T=16
—T=64

Figure 7

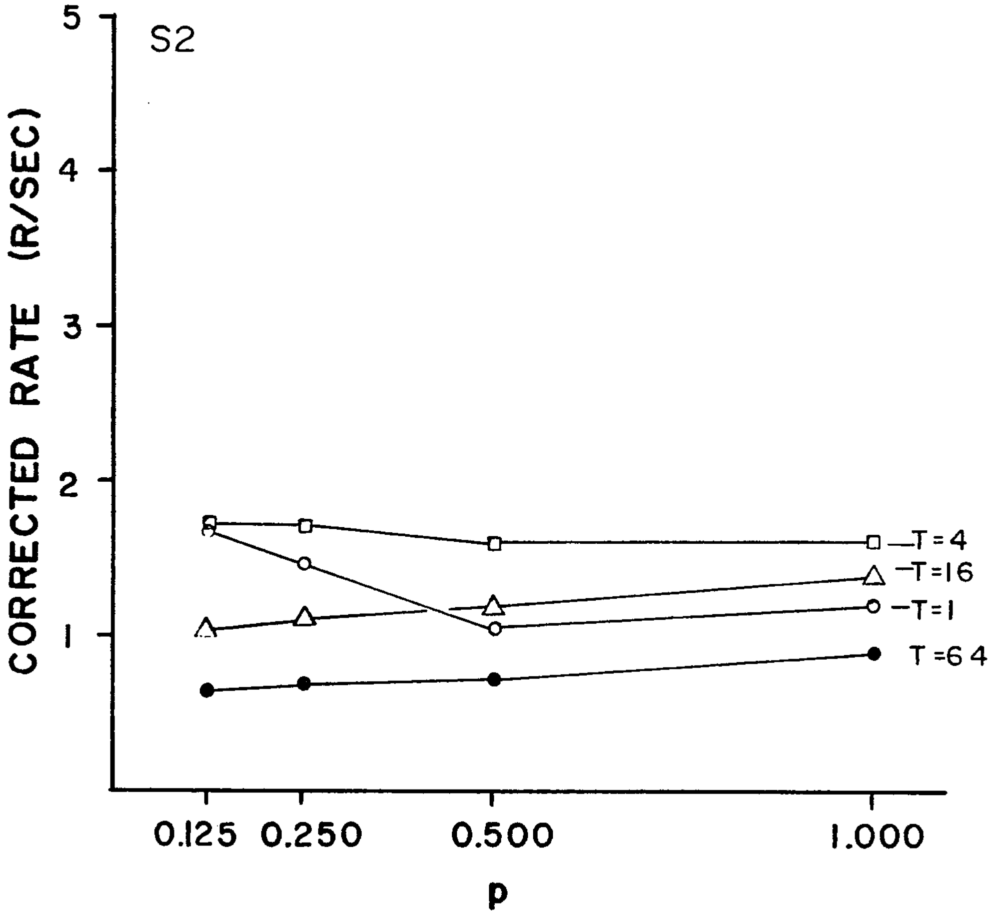

S2
CORRECTED RATE (R/SEC)
5
4
3
2
1
0.125
0.250
0.500
1.000
p
T=4
T=16
T=1
T=64

Figure 8

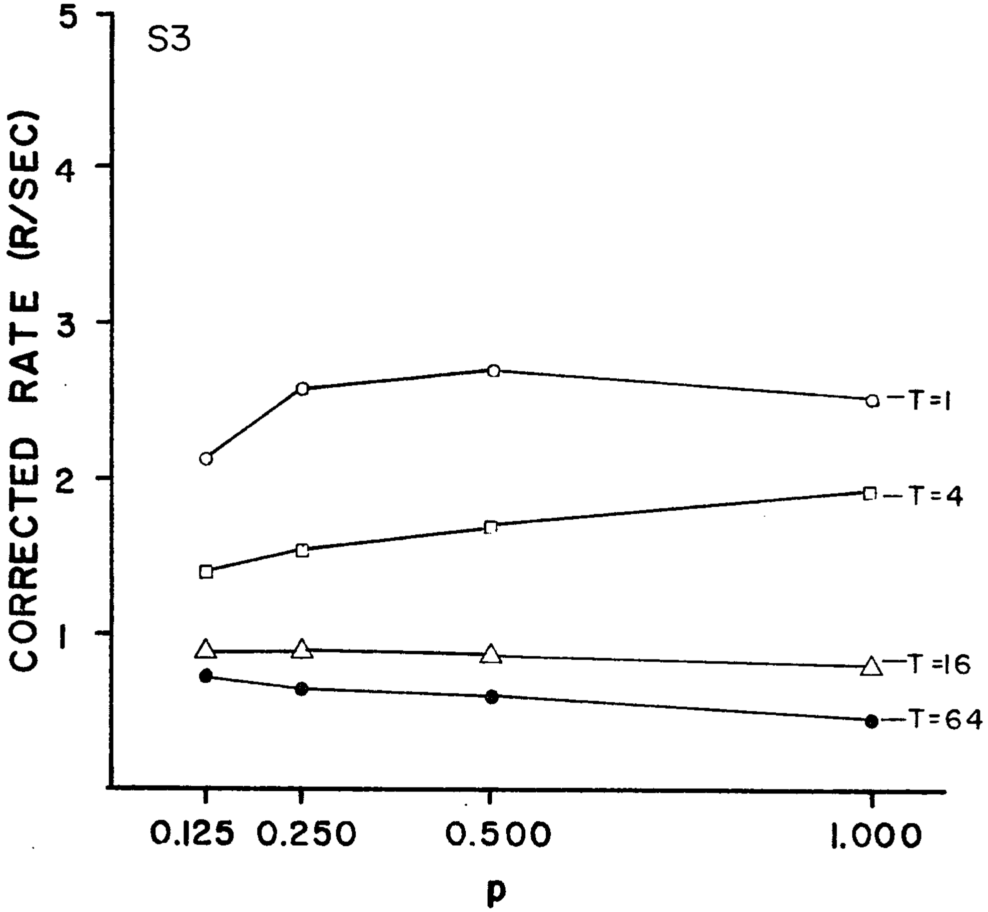

S3
CORRECTED RATE (R/SEC)
5
4
3
2
1
T=1
T=4
T=16
T=64
0.125
0.250
0.500
1.000
p

Figure 9

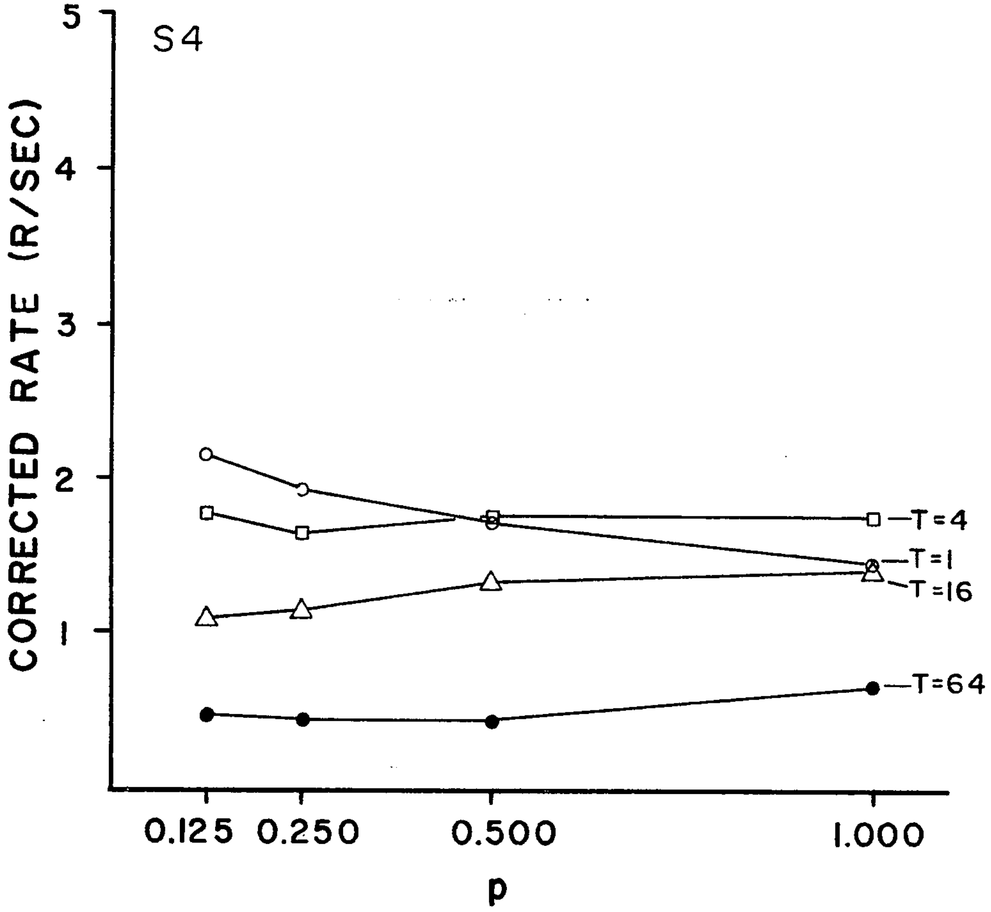
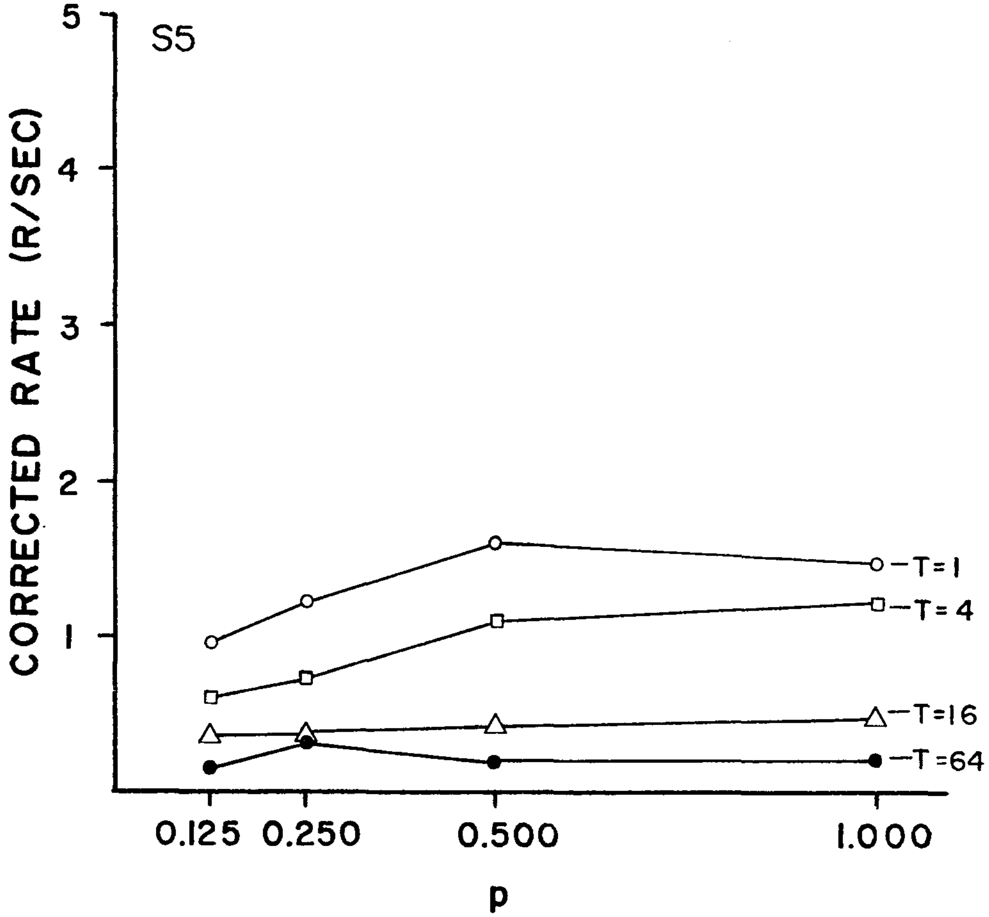

S4
CORRECTED RATE (R/SEC)
5
4
3
2
1
0.125
0.250
0.500
1.000
p
T=4
T=1
T=16
T=64

Figure 10


S5
CORRECTED RATE (R/SEC)
5
4
3
2
1
0.125
0.250
0.500
1.000
p
T=1
T=4
T=16
T=64

after a decrease in p value (and that, of course, only in those cases in which there was a direct relation between p and rate). Extinction is a relatively slow process in schedules of this type. This explanation is obviously inapplicable where the relation between p and rate was inverse (i.e., S1). It might be appealing in this case to attribute the inversion in the customary effect of p to the greater number of $P_S$rs and therefore, lower corrected rate, at higher p values. Examination of Table 2, however, shows the same effect on running rate, despite the subtraction of the P_Sr from the time base used for the rate calculation.

A second possible reason for the inconsistency between these data and previously reported RI data may lie in characteristics of the present experiment that might further mask the relatively slow-to-develop behavioral effects of p. The present procedure may be described as a multiple schedule, in which rapid changes in the cued T values might be expected to exaggerate rate differences between components of the schedule (Morse, 1966; Shimp & Wheatly, 1971; Todorov, 1972). This would embed the slowly emerging p-induced rate changes in rapid changes in response rate caused by changing T.

Whatever effects p did have on rate diminished with decreasing $\bar{T}$ values and increasing T lengths. By the time $\bar{T}=0.25$, the different curves representing rate as a function of T for the four p values were quite close together in most cases. The exception to this is S4,

$\overline{T}$=0.25 (Fig. 4), where the curves for p=0.250 and p=0.125 appear more nearly hyperbolic. Farmer, who in 1962 did show a direct effect of p on rate showed little difference between rates generated at his lower values. In addition, despite differences in the p-rate relation at some points in the present study and the clear, direct relation that Farmer found, his finding that the greatest effect of p occurred at short T-cycle lengths was generally replicated.

While changing the value of p affects the mean expected I_Sr, it has no effect on either the minimum or modal I_Sr (Farmer, 1962; Millenson, 1963; Schoenfeld, et al., 1972). The relatively weak effect of p on rate should emphasize the inadequacy of attributing behavioral effects to the expected mean interreinforcer interval. This is common practice, and the present data raise questions concerning the advisability of, for example, relating rate to "mean VI value." Both Ferster and Skinner (1957) and Catania and Reynolds (1968) were careful to point out the effects of changing the relative proportion of short intervals in a VI schedule, but naming VI schedules for their mean values, and then plotting response rate as a function of that mean is the rule.

The computation of corrected rate includes and ignores changes in the P_Sr, response patterns, and differences in rates in t^D and t^Δ (where $\overline{T}$ is less than 1.00). Each of these characteristics is examined separately below, but evaluating corrected rate quantitatively without regard for those other effects reveals orderly relations that might be lost in a less global analysis of the data.

Corrected rate as a function of T was fitted to a hyperbola of the form:

$$R = \left[T(1-B)+k\right]^{-1}. \tag{16}$$

When fitting the data to the curve, rather than entering the mean rate at each value of T over the five days' exposure to each p, each daily response rate was treated as a separate data point. The derivation and theoretical significance of the equation will be treated later, but for the present, fitting the data to equation (16) (Table 22) produced the following.

First, the equation accounted for most of the variance around the regression line (r^2) in most cases (from an aberrant worst case of approximately 2.2% of the variance around the regression line for S2 at $\bar{T}$=0.25 to 95.8% of the variance around the regression line for S5 at $\bar{T}$=0.50). In most cases, based both on the proportion of variance accounted for by the equation and the standard error values, the form of the function appears satisfactory. Second, the "B" parameter, changes in which produce changes in the height of the function, is quite close to 1.0000, ranging from a low of 0.7801 (S5, $\bar{T}$=0.50) to 0.9979 (S2, $\bar{T}$=0.25). The values reported for S5 at $\bar{T}$=0.50 and $\bar{T}$=0.25 are the only two B values lower than 0.9100. Third, "k," which determines the slope and curvature of the function, appears inversely related to $\overline{T}$, although the relation does not seem to be monotonic.

Fitting the running rate data to equation (16) produced similar results. Because the P_Sr intruded less on interreinforcement times as T lengthened, the running rate curves are smoother and steeper than the corresponding corrected rate functions, and the B and k values reflect this, as do the generally higher standard error values for the running rate functions. Beyond that, B and k seem to reflect the same processes as in the corrected rate data. Specifically, B is roughly invariant and close to 1.0000 across the range of $\overline{T}$ values in this experiment, and a substantial proportion of the variance around the regression lines is accounted for by the equation (in fact, in most cases, a greater proportion than for the corresponding corrected rate curves). While the parameter values for equation (16) were not systematically related to p, this variable had a minimal effect on overall response rate. Equation (16) appears to be adequate for describing response rates as a function of T.

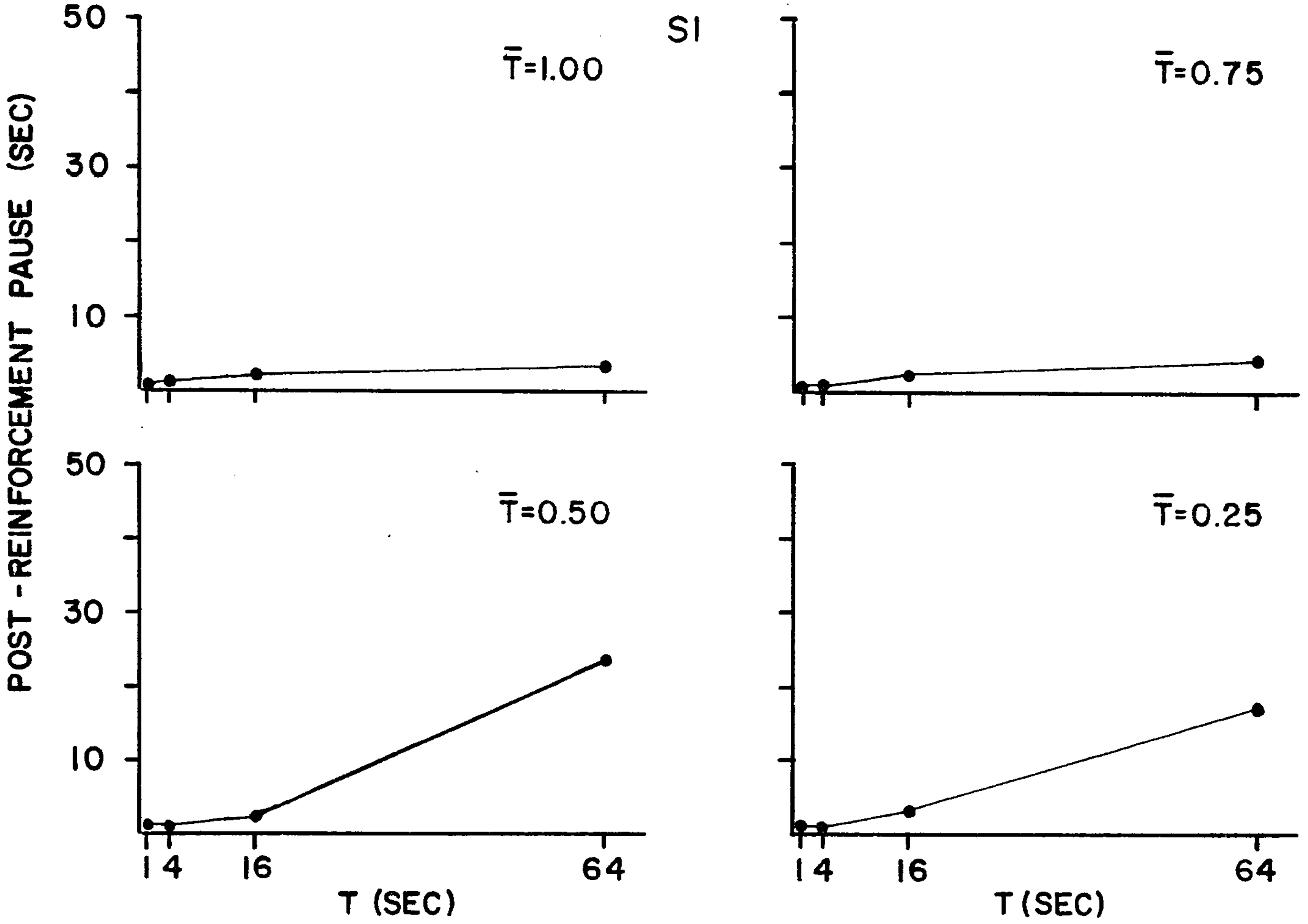
Figures 11 through 15 show the P_Sr functions averaged across p for S1 through S5, respectively. The data are tabled in Tables 12 through 16, and show no systematic change in P_Sr across p values at the various values of T. In general, the functions shown in Figures 11 through 15 may adequately be described as straight lines of the form:

$$P_Sr = aT+c, \tag{17}$$

Figures 11 through 15: Post-reinforcement pause as a function of T.

Figures 11 through 15 show post-reinforcement pause lengths (in seconds) as a function of T for subjects 1 through 5, respectively. Data are pooled across values of p and represent all sessions at each value of $\overline{T}$ (shown in each panel).

Figure 11


SI
POST - REINFORCEMENT PAUSE (SEC)
50
30
10
T̄=1.00
T̄=0.75
T̄=0.50
T̄=0.25
1 4
16
64
T (SEC)

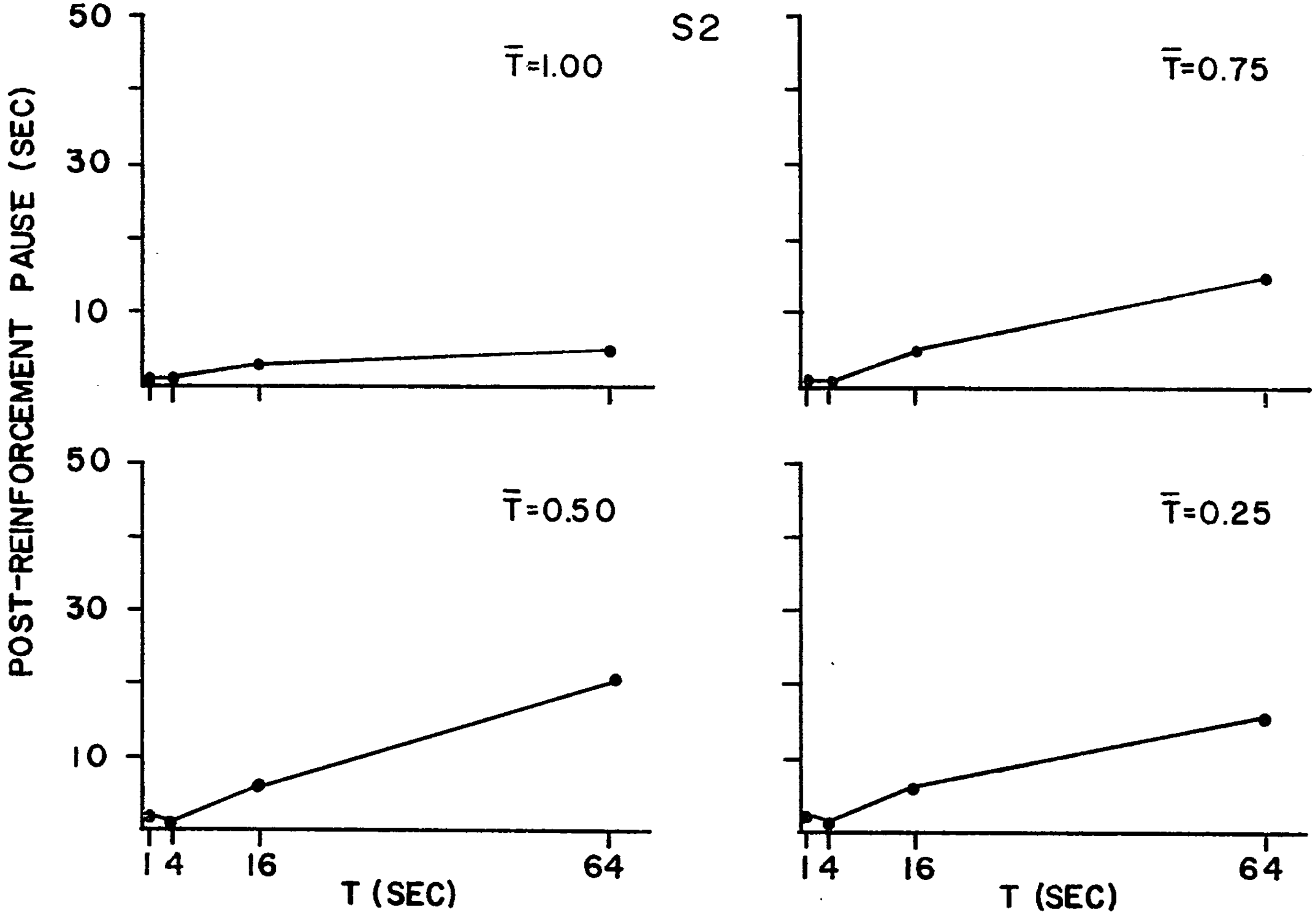
S2
POST-REINFORCEMENT PAUSE (SEC)
50
30
10
$\bar{T}$=1.00
$\bar{T}$=0.75
$\bar{T}$=0.50
$\bar{T}$=0.25
1 4
16
64
T (SEC)

Figure 12

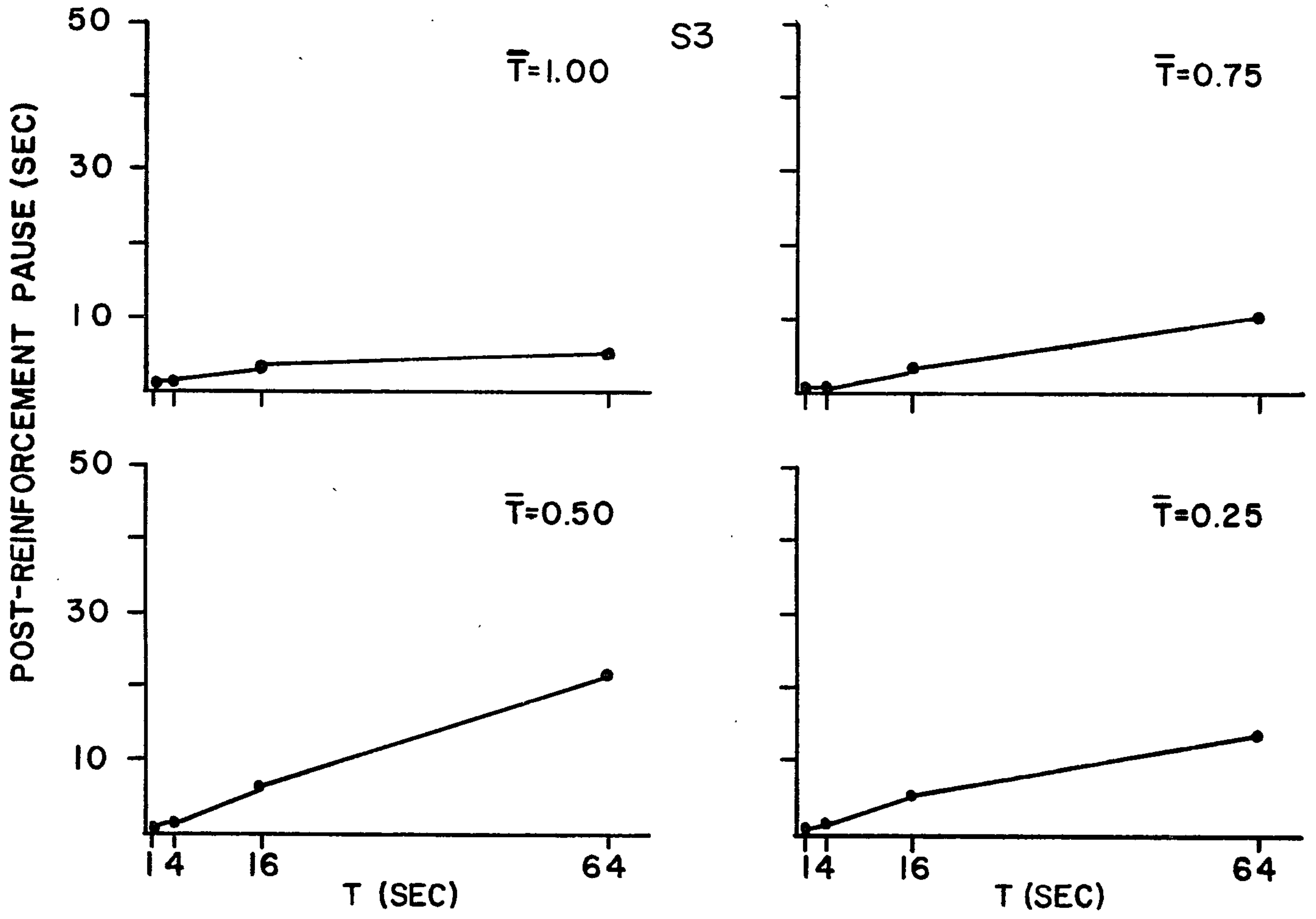

S3
$\bar{T}$=1.00
$\bar{T}$=0.75
$\bar{T}$=0.50
$\bar{T}$=0.25
POST-REINFORCEMENT PAUSE (SEC)
50
30
10
50
30
10
1
4
16
64
14
16
64
T (SEC)
T (SEC)

Figure 13

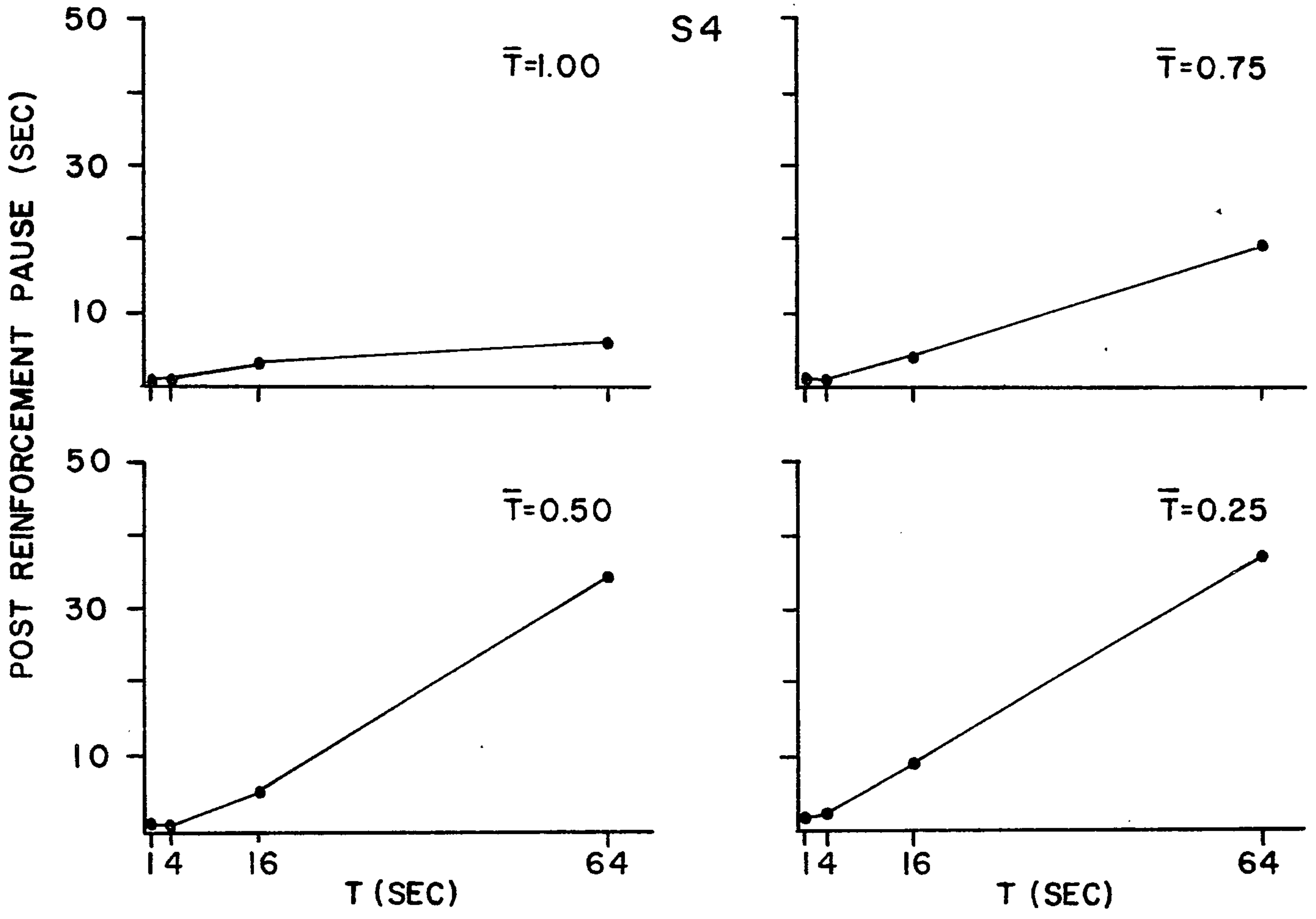
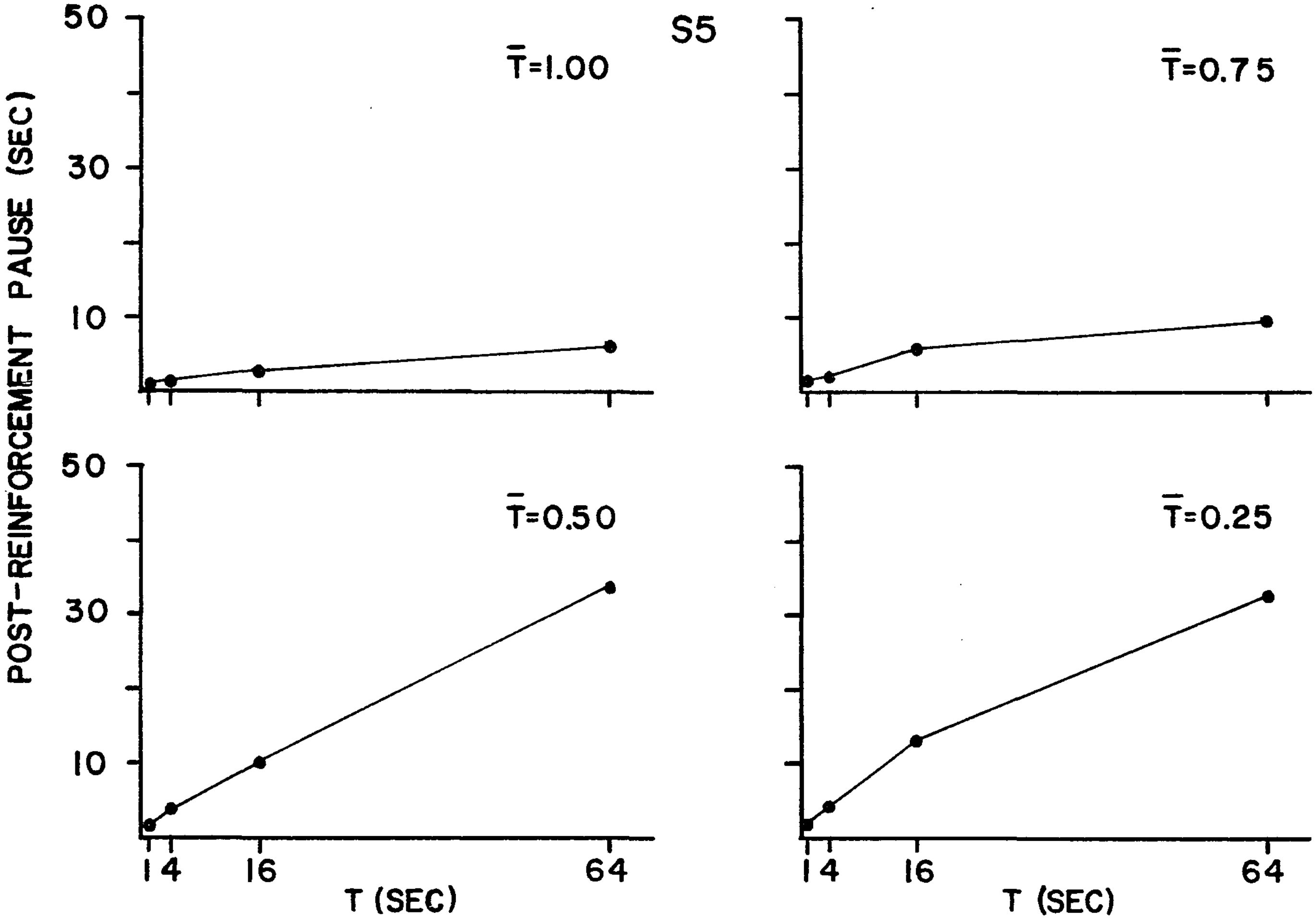

S4
T̄=1.00
T̄=0.75
T̄=0.50
T̄=0.25
POST REINFORCEMENT PAUSE (SEC)
50
30
10
50
30
10
1
4
16
64
1
4
16
64
T (SEC)
T (SEC)

Figure 14

Figure 15


S5
POST-REINFORCEMENT PAUSE (SEC)
50
30
10
T̄=1.00
T̄=0.75
T̄=0.50
T̄=0.25
1
4
16
64
T (SEC)

with the result (Table 23) that the slope constant (a) generally increased with decreases in $\overline{T}$. In most cases, the straight line equation accounted for most of the variance in the data, with the worst case being S3 at the $\overline{T}=0.75$ value where only 58.9% of the variance was accounted for by the equation. The slope constant ranged from a low of 0.0336 (S1, $\overline{T}=1.00$) to a high of 0.5185 (S4, $\overline{T}=0.50$). In four of the cases (S1, S2, S3, and S5), the slope of the P_Sr function decreased from $\overline{T}=0.50$ to $\overline{T}=0.25$, while S4 showed a slight increase in slope between $\overline{T}=0.50$ and $\overline{T}=0.25$. The intercept constant (c), which approximates the P_Sr at regular reinforcement ($T=0$) hovered around 1 (a low of -1.2095 for S4 at $\overline{T}=0.50$ to a high of +2.5696 for S5 at $\overline{T}=0.25$). Because of the combination of slope and intercept values, the equation predicts P_Sr lengths close to one second at $T=1$. Since the slope was a function in part of $\overline{T}$, the P_Sr might be expected to exceed one second at low $\overline{T}$ values, with the result that T-cycles would be "missed." This occurred (see Tables 24-28), particularly for S5. The adequacy of the linear fit to the data supports Nevin's (1973) contention that the post-reinforcement pause occupies a constant portion of the interreinforcer interval, at least at $p=1.000$. At lower p values, since the mean time between reinforcers is longer, the proportion of the interreinforcer interval occupied by the P_Sr would be expected to decrease. The extent to which similar effects might occur in the VI schedules from which Nevin drew part of his conclusion would depend on the specific parameters of the VI schedules themselves.

Farmer (1962, 1963) had found the P_Sr to be a decreasing function of T/p (and therefore an increasing function of p) at his longest T-cycle (T=60 sec). The p values Farmer used at that T value (p ranged from 1.0000 to 0.0625) included the range in the present study, but Farmer exposed each of his subjects to only one value of T and varied p. As in the case of the effects of p on response rate, the effects of p on the P_Sr may be slow to develop. Additionally, because only one value of T was assigned to each bird, it is not possible to directly assess the effects of T on the P_Sr in Farmer's study. It should be noted that the decrease in P_Sr with increasing p at short T-cycle lengths is consistent with Nevin's (1973) finding.

Cole (1968) held p constant and varied T over the range of 0 to 24 sec, providing a basis for an examination of the effects of T on the post-reinforcement pause. Fitting his data (from the condition in his experiment in which the probability of a light signalling reinforcement was 1.0) to equation (17) provided additional confirmation both for the adequacy of the straight line in describing the P_Sr as a function of T and for the values of the slope and intercepts derived from the present data. The slope values for his three subjects were 0.0135, 0.0371, and 0.0579, with intercept values of 0.9945, 0.9103, and 1.0784 for his S1, S2, and S3, respectively. Again, slope values were lower than 1 and intercept constants were close to 1 in all three cases. In both the present study and in the computation of the values derived from fitting Cole's (1968) data to equation (17), the least squares method was used. The data were entered as pooled values across p for each value of T. Cole's summary data were entered as separate data points for each value of T.

While p had a minimal effect on running rate, corrected rate, or the post-reinforcement pause, it had profound effects on the response pattern when $\bar{T}$=1.00. Figures 16 through 20 show S2's cumulative records at the $\bar{T}$=1.00 value for all four successive p values followed by the recovery at p=1.000 (all curves were taken from the fourth session at each p value). At the initial p=1.000 point (Figure 16), the response record indicates a largely break-run pattern at T=4, 16, and 64 sec. While reinforcers in the T=64 sec segments are followed by post-reinforcement pauses in the majority of cases, conditions similar both to Ferster and Skinner's "running through" and scalloping can be seen. The cumulative records for the T=1 sec component are too compact to show any real detail. Decreasing p to 0.500 (Fig. 17) produced the expected decrease in the periodicity in responding. The functions resemble the RI curves they replicate in earlier studies (i.e., Farmer, 1962), with generally smooth records predominating, little clear pausing, and an increase in grain at the longer T values. Subsequent decreases in p to 0.250 (Fig. 18) and then to 0.125 (Fig. 19) further accentuated the RI characteristics of the records. The final p=1.000 value (Fig. 20) shows good recovery of the response patterns generated under initial exposure to this p value. It should be noted that the slopes of the records in each of the four components of the multiple schedule do not change appreciably across p values. While S2 showed these characteristics most clearly, the records for this bird are typical of the remaining four animals. The primary differences between subjects at this point in the experiment lay in the differences in absolute rate and pause values; the response patterns are similar.

To summarize the data where $\overline{T}$=1.00: (1) response rates (both corrected and running) were a generally decreasing function of T and could be adequately described with a hyperbolic equation; (2) the post-reinforcement pause data could be described with straight line equations having slopes of less than one and intercept values close to one second; (3) p had little systematic effect on response rate or pause values; (4) response patterns generally replicated those found in prior studies of interval schedule maintained behavior with decreases in the periodicity of reinforcement producing decreases in the periodicity of responding, although no systematic numerical data were collected relevant to this point.

Reducing $\overline{T}$ to less than 1.00 changed the four-component multiple schedule to an eight-component multiple schedule consisting of components in which reinforcement was

Figures 16 through 20: Cumulative response records for S2.

Figures 16 through 20 show cumulative records for S2 at p=1.000, 0.500, 0.250, 0.125, and a recovery session at p=1.000, respectively. $\overline{T}$ was equal to 1.00 for all five figures. T-cycle lengths were 1, 4, 16, and 64 seconds, occurred in order, and changed from one value to the next after the delivery of the third reinforcer in each component. Reinforcers are indicated by downward "pips" in the response pen. All data were taken from the fourth session at each parameter value. Figs 16 through 20 show an entire session each, while Figs 17 through 19 show data taken from the third of five exposures to each T value. The last reset of the response pen in Fig 19 indicates completion of the T=64 sec component. All Figs begin with the T=1 sec component.

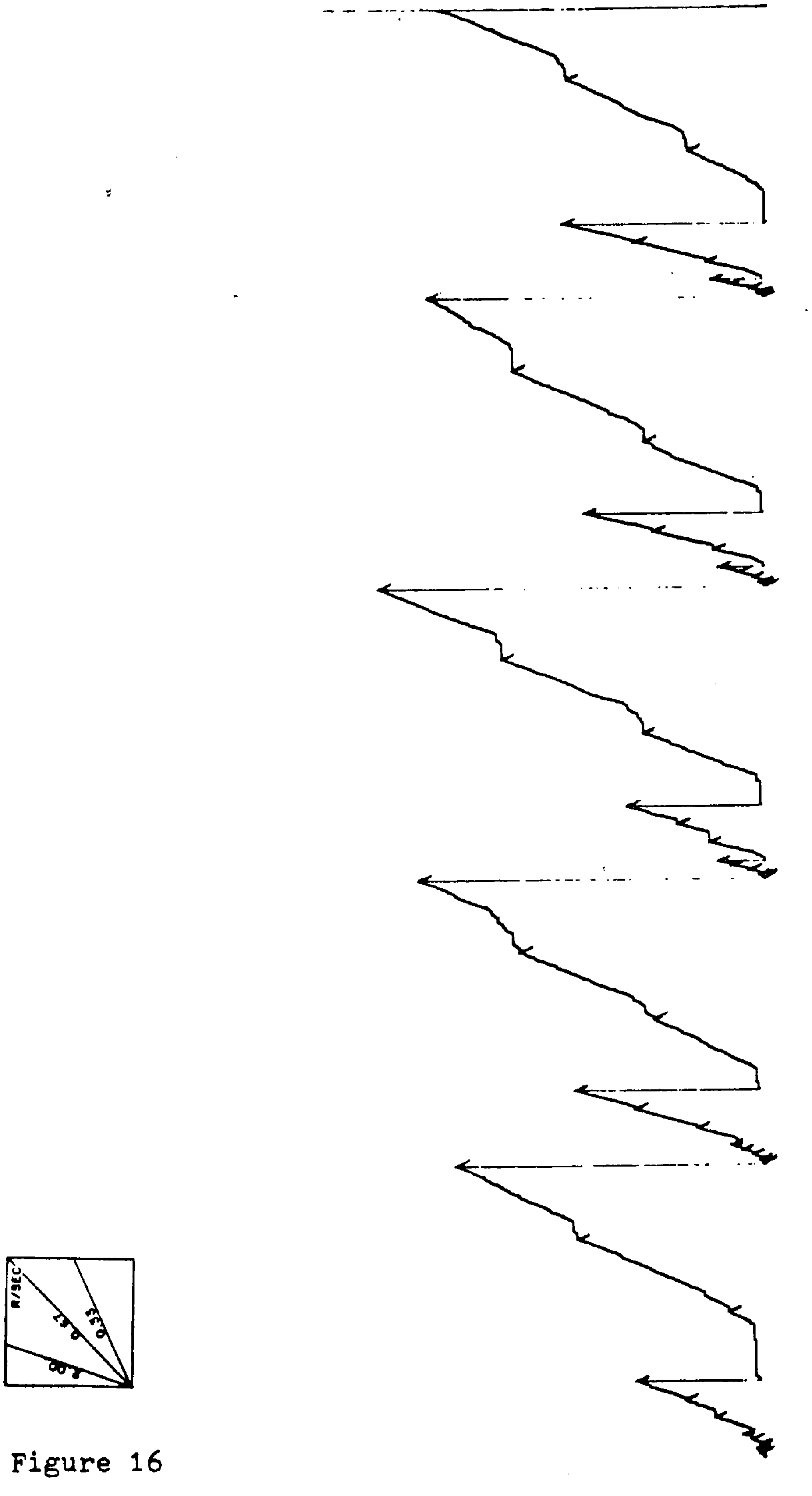


Figure 16

Figure 17

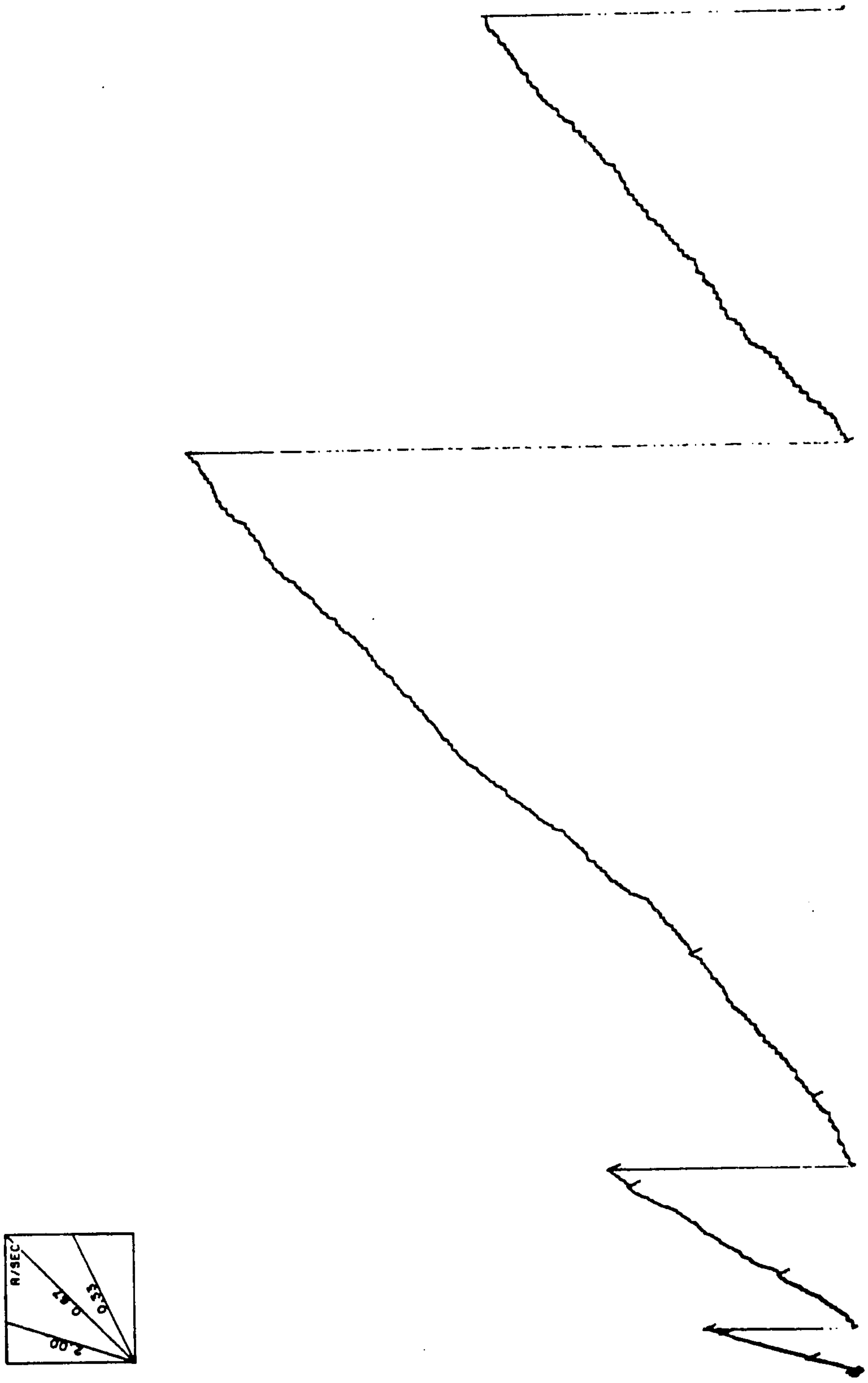


Figure 18

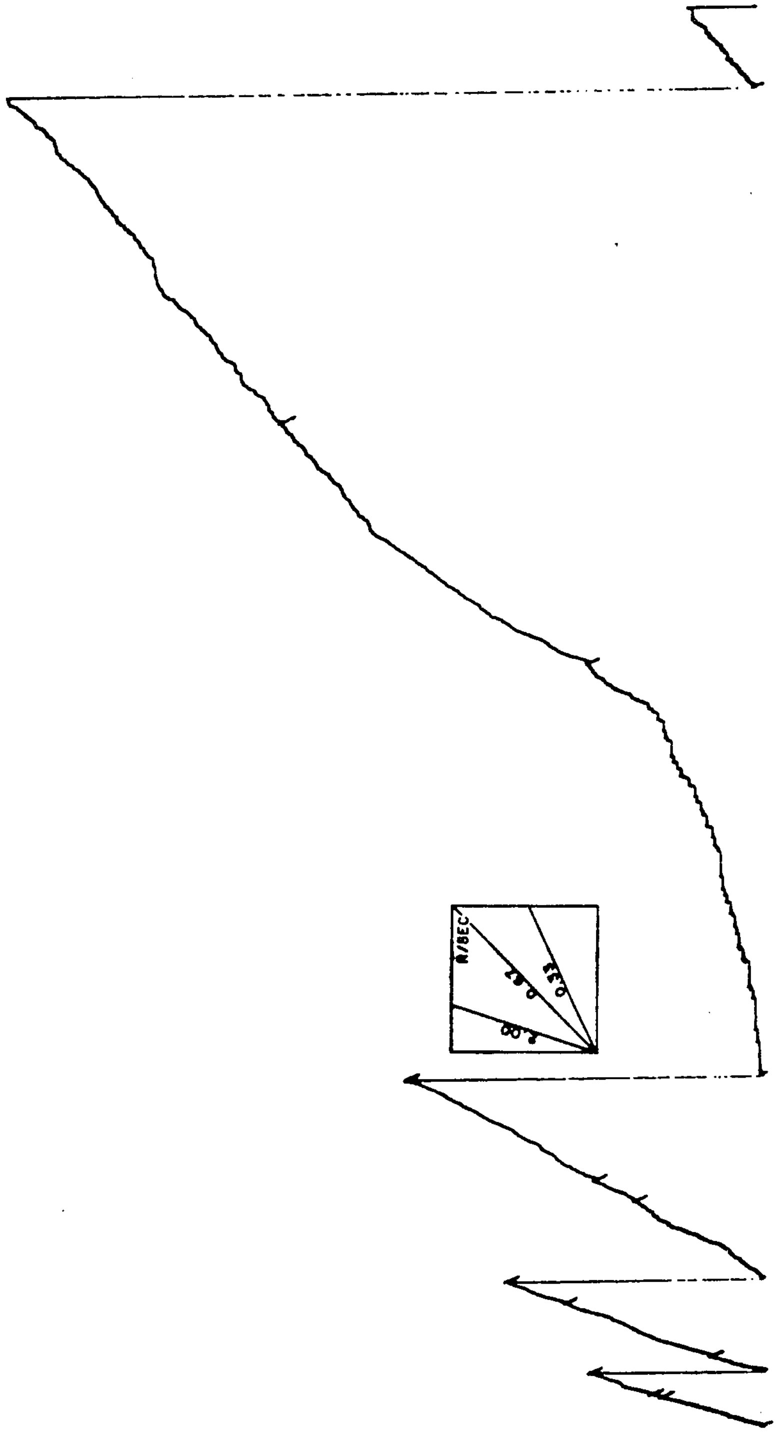


Figure 19

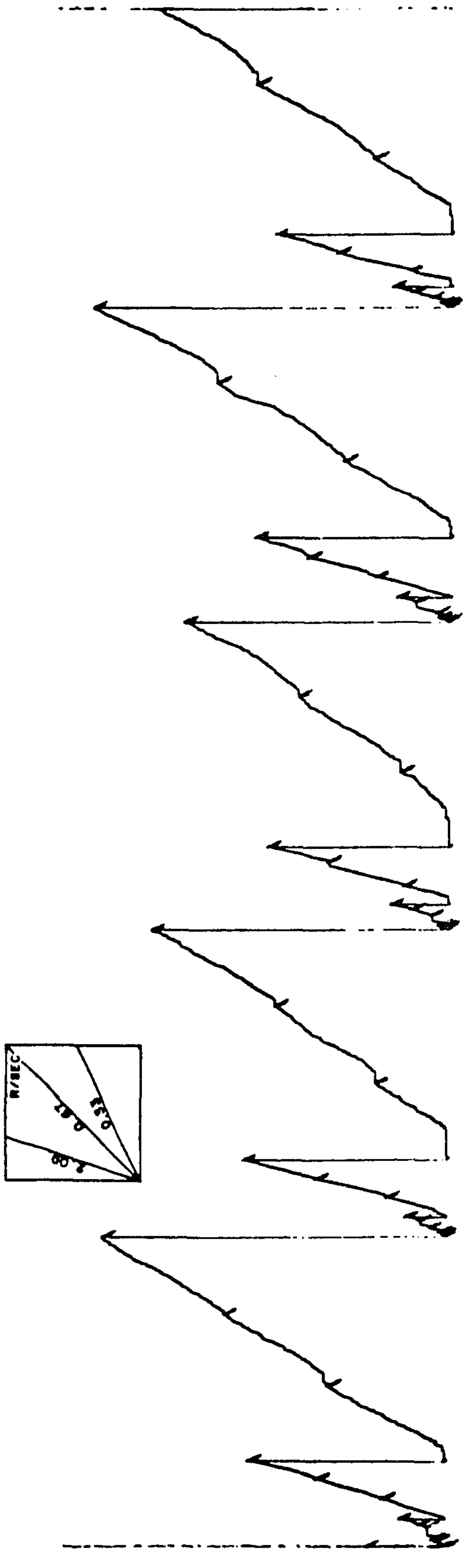


Figure 20

possible (t^D) separated by components in which it was not (t^Δ). It is easy to see how cumbersome the traditional terminology becomes when parametric manipulations are named rather than described in terms of parameter values.

Introducing t^D and its associated S^D in alternation with t^Δ (and S^Δ) partially replicated Frick's (1948) and Dinsmoor's (1952) discrimination procedures in which responses in the presence of S^D could produce reinforcement but did not terminate S^D. Reinforcement (as in the $\bar{T}=1.00$ case) was still available for only one response in the T-cycle, but now that response had to occur in t^D to qualify for reinforcement. Responses in t^Δ had no scheduled consequences.

While the t-system convention has been to begin each T-cycle with t^D, in this study, t^D occurred at the end of each T-cycle. This is of no theoretical or practical significance beyond the first T-cycle in each exposure to each T-cycle length. Each t^D period (and S^D) was preceded by a period in which the response key was dark (t^Δ and S^Δ from the cycle in effect). If the <u>temporal</u> aspects of the reinforcement schedule continued to control responding under these circumstances, rather than the presence or absence of the discriminative stimuli, the pattern of responding would not be expected to change from what it had been when $\bar{T}=1.00$. Responding, following the P_Sr, would begin somewhere after the reinforcer and continue until the next reinforcer was produced, another P_Sr would occur, and so on. If the S^D-S^Δ

alternation, rather than the temporal aspects of the reinforcement schedule controlled responding under these circumstances, a pattern of responding somewhat different from that under $\bar{T}=1.00$ might be predicted.

In that instance, there are two possibilities: either the onset of S^D controls responding or its presence does. In the first case, the organism might produce only one response at the onset of S^D, either produce a reinforcer or not (depending on the prevailing p value), pause, and not respond again until the onset of the next S^D. This is the end-point of the discrimination predicted by Skinner's equation (1938, p. 187-190; 191). The discrimination index (responses per second in S^D/ responses per second in S^D + responses per second in S^Δ) would be 1, the cumulative records would indicate a step-like one-response-per-interval pattern, and the P_Sr would occupy virtually the entire interval. There is an alternative possibility in which the onset of S^D seems to act as a conditioned reinforcer (Dinsmoor, 1951). In that case, responding might begin somewhere in S^Δ, and proceed until the first response in S^D, either produce a reinforcer or not, pause, and not begin again until somewhere in the next t^Δ period. The animals might appear to "scallop into" S^D, with the initiation of responding (the end of the P_Sr) now under the control of the temporal location of the S^D relative to the last reinforcer. The bulk of responding would occur in S^Δ, the discrimination index would be low, and the P_Sr would occupy most of t^D. The second possibility (that the presence rather than the onset of S^D controls responding), would produce response patterns in which responding would begin with the onset of S^D, either be reinforced or not, pause (in those T-cycles in which a reinforcer had been produced), and resume until the onset of the following S^Δ. In that case, responding would be maintained during S^D even in those T-cycles in which no reinforcer had been delivered. The discrimination index would be 1 or close to 1. In addition, since the presence of S^D would maintain responding, the P_Sr values would be expected to be lower than in the case where the P_Sr persisted through S^D. This is the pattern reported by Weissman (1961, 1963).

In fact, the present procedure produced all of the patterns described above, and the pattern of responding through the interval depended on a number of factors. Once established, however, a particular subject's pattern remained consistent throughout the experiment within individual T and $\bar{T}$ values. In other words, animals that showed high rates in S^D, with low rates in S^Δ, maintained those patterns through changes in p values. In some cases, the pattern of responding remained unchanged from what it had been when $\bar{T}$=1.00, producing discrimination indices lower than 1. S2 (Fig. 24-26), for example, showed higher response rates in S than in S^D for both the T=16 and T=64 sec components in all but the initial determination at p=1.000, $\bar{T}$=0.75 (where the rate was higher in S^Δ than in S^D only at T=64 sec), and even that finding changed under redetermination (Fig. 24). The same effect can be seen in the T=4 sec cycle at $\bar{T}$=0.25, p=0.250 and 0.125 (Fig.26).

S3 showed similar t^D-t^Δ rate relationships at $\bar{T}$=0.75, T=16 sec, p=0.250 and at the same $\bar{T}$ value in the T=16 and T=64 sec components at p=0.125 (Fig. 27). When $\bar{T}$ was reduced to 0.500, rate was higher in t^Δ than in t^D at the T=16 and T=64 sec values for all four p values. Below p=1.000, the effect was visible in the T=4 sec component as well (Fig. 28). When $\bar{T}$ was further reduced to 0.25, the rate in t^D exceeded the rate in t^Δ in all cases except at the T=64 sec component for all four p values, in the T=16 sec, p=0.125 condition, and in the T=4 sec, p=1.000 redetermination (Fig. 29). S4 showed higher response rates in S^Δ than in S^D at the following schedule values: $\bar{T}$=0.75, p=1.000, T=16 and T=64 sec redeterminations (Fig. 30), and for all other p values at T=16 and T=64 sec initial determinations. This difference was visible in the T=16 and T=64 sec components through the remaining $\bar{T}$ values at all p values (Figs. 31-32). In other words, under most conditions, this subject showed higher rates under the S^Δ condition than in S^D at the two longer T-cycle lengths. At the shorter T-cycle lengths, the reverse was true.

Two subjects (S1 and S5), on the other hand, showed virtually no instances of response rates in t^Δ exceeding those in t^D except for S1 at $\bar{T}$=0.50, T=4 and T=64 sec, p=1.000 (also in the T=64 sec, p=1.000 redetermination), and at $\bar{T}$=0.50, T=64 sec, p=0.500 (Fig. 22). S5 showed the same effect at $\overline{T}$=0.50, p=1.000, in the T=4 and T=64 sec components (Fig. 34). The data showing response rates in t^D, t^Δ, and the discrimination indices are tabled in Tables 17-21.

In summary, in no case did rates in t^Δ exceed those in t^D at the T=1 sec value. In general, where rates in t^Δ did exceed those in t^D, the effect occurred at lower p values and longer T-cycle lengths (T=16 and T=64 sec). Decreases in response periodicity with decreases in p were less visible at $\overline{T}$ values of 0.75, 0.50 and 0.25 than they were at $\overline{T}$=1.00. In addition, it appeared that while the alternation of stimuli coincident with the t^D and t^Δ periods had orderly and replicable effects, the data reflected a mixture of temporal and stimulus control. Where responding began in t^Δ, and continued until the onset of t^D, a case could be made for temporal control by the regularity of the keylight onset and termination. Where responding continued through t^D, whether or not a reinforcer had been obtained in a particular interval, the nature of the control is not as clear, but if a choice were forced, stimulus control would be indicated. Cole (1968) found that the reliability of the S^N-S^R relation largely determined the degree to which an exteroceptive stimulus (S^N) could function as an S^D, and S^Δ, or a "neutral" stimulus (one to which no differential responding could be attributed). Farmer and Schoenfeld (1966a, 1966b) showed that the location of S^N relative to reinforcement could also determine the effects of the stimulus. The data presented here suggest that the T-cycle length may modulate

Figures 21 through 35: Component rates as a function of T.

Figures 21, 22, and 23 show mean response rates in t^D and t^Δ at each p value for S1 at $\overline{T}=0.75$, 0.50, and 0.25, respectively. The same sequence of $\overline{T}$ values is presented in Figs 24-26 for S2, in Figs 27-29 for S3, in Figs 30-32 for S4, and in Figs 33-35 for S5. Unconnected points at p=1.000 are recovery data. Data are pooled over all sessions at each parameter value.

Figure 21

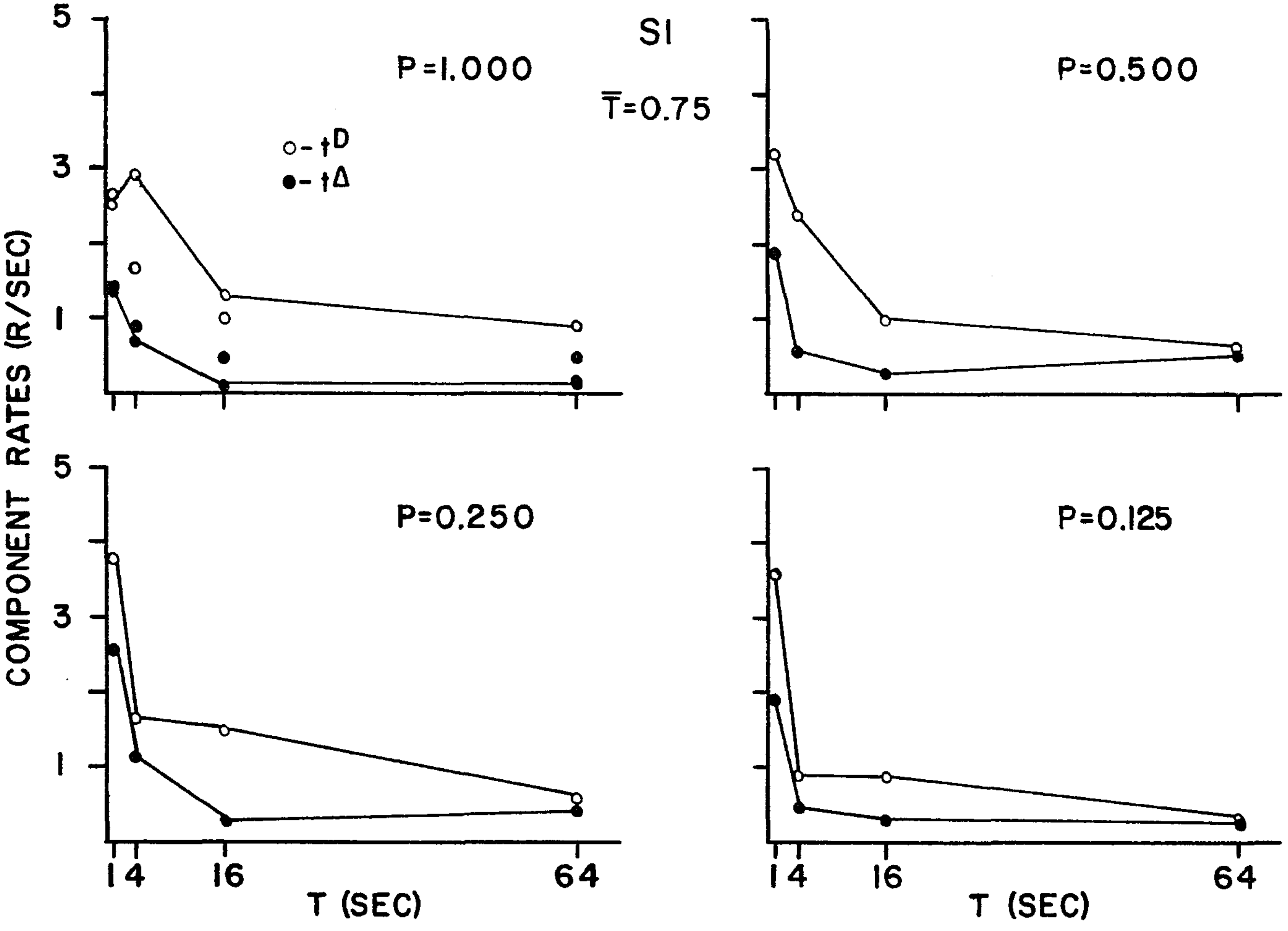
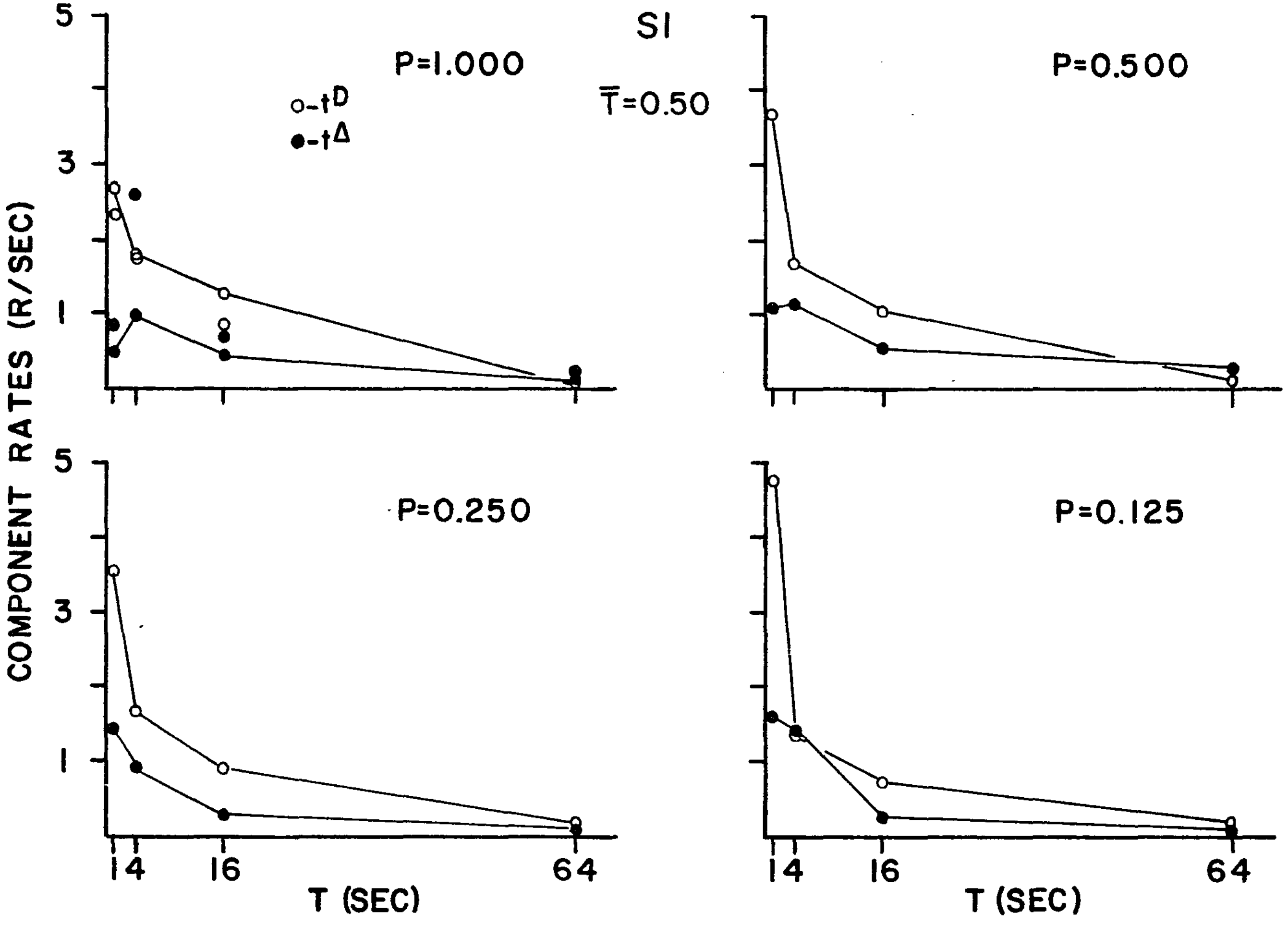

SI
$\overline{T}$=0.75
P=1.000
P=0.500
P=0.250
P=0.125
○- t^D
●- t^Δ
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
1 4
16
64
T (SEC)
1 4
16
64
T (SEC)

Figure 22


SI
$\bar{T}$=0.50
P=1.000
o-t^D
●-t^Δ
P=0.500
P=0.250
P=0.125
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
14
16
64
T (SEC)
14
16
64
T (SEC)

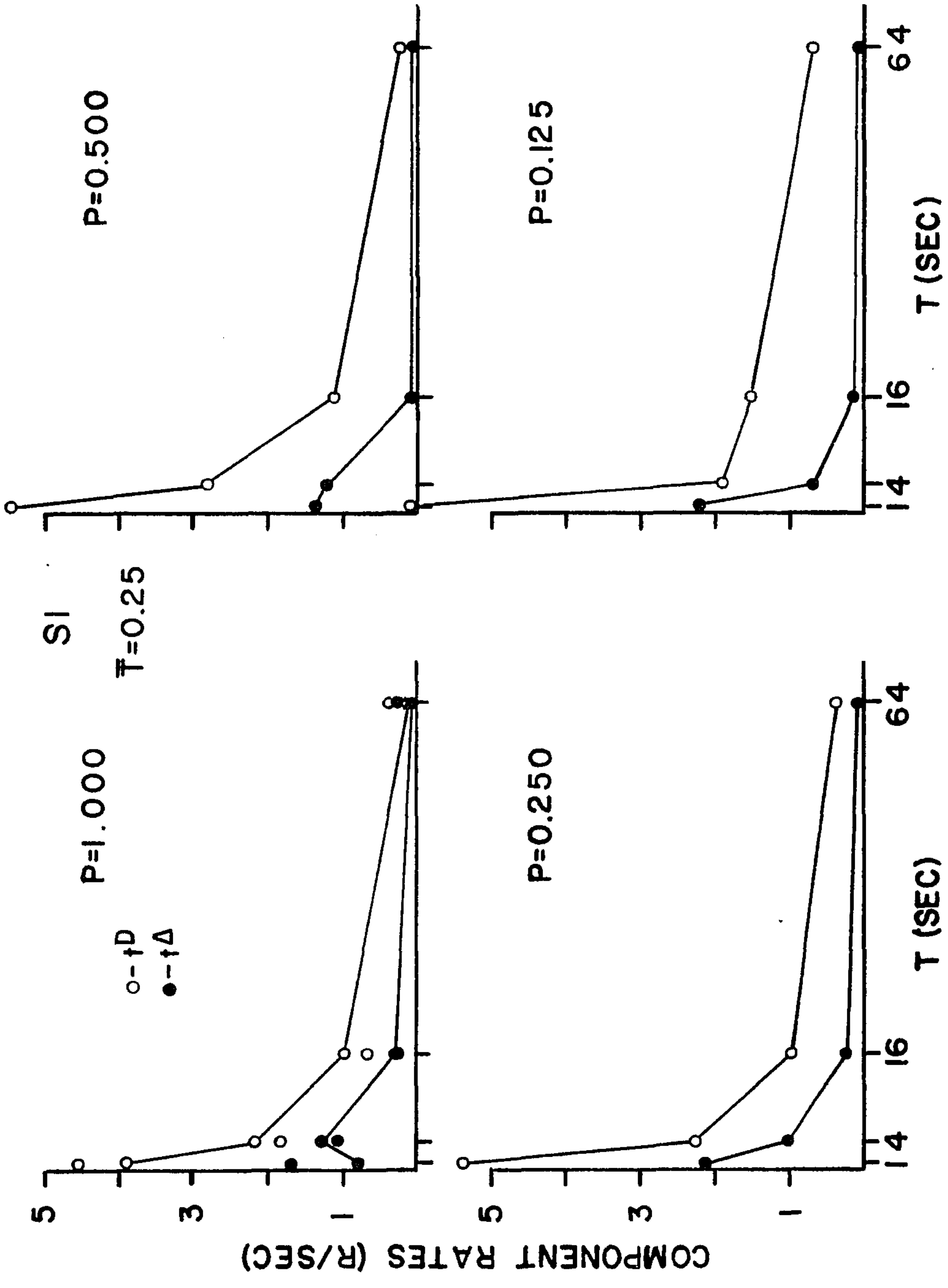
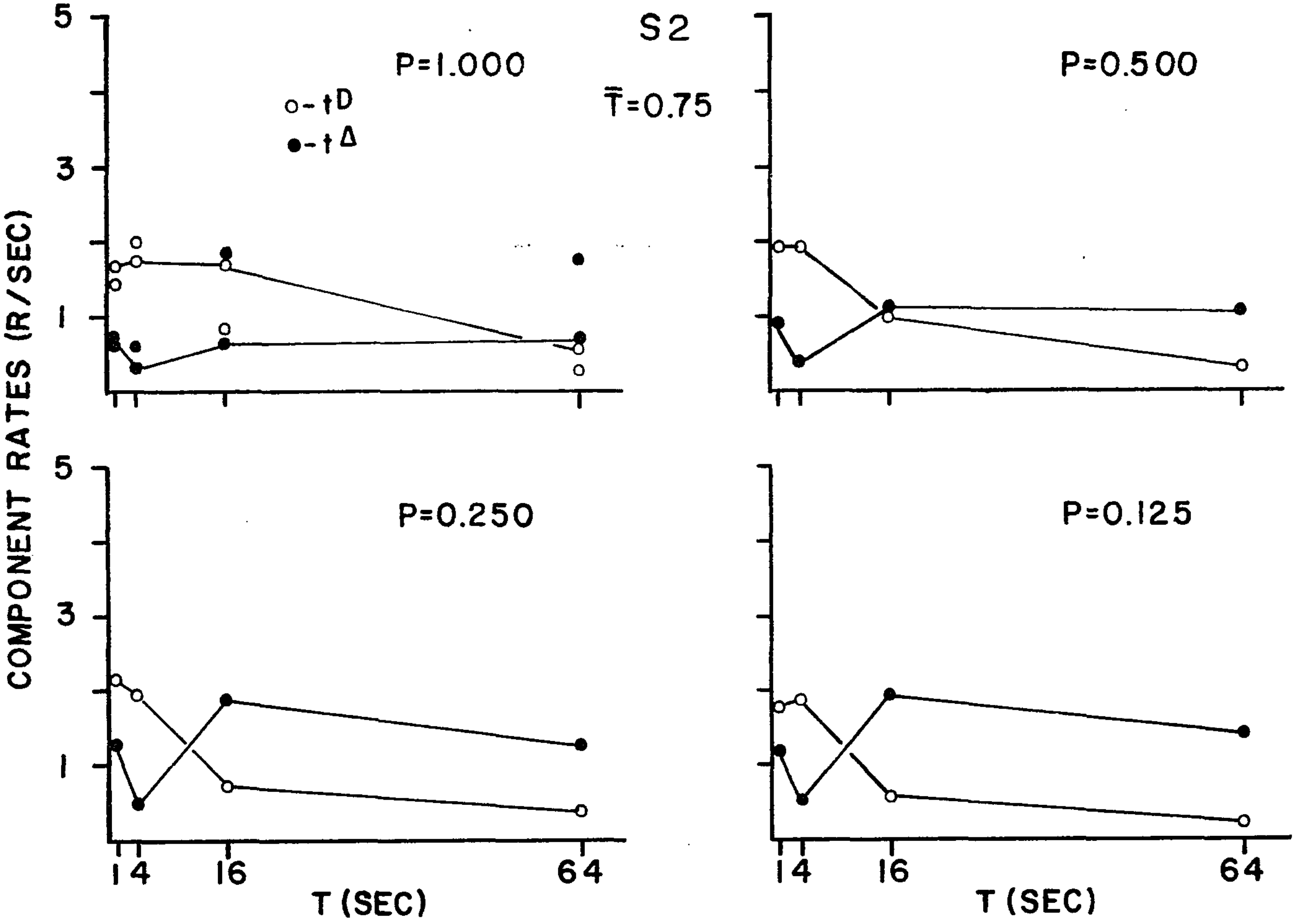

S1
$\overline{T}$=0.25
○-t_D
●-t_Δ
P=1.000
P=0.500
P=0.250
P=0.125
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
1 4
16
64
1 4
16
64
T (SEC)
T (SEC)

Figure 23

Figure 24


S2
T̄=0.75
P=1.000
P=0.500
P=0.250
P=0.125
○ - tD
● - tΔ
COMPONENT RATES (R/SEC)
5
3
1
T (SEC)
1
4
16
64

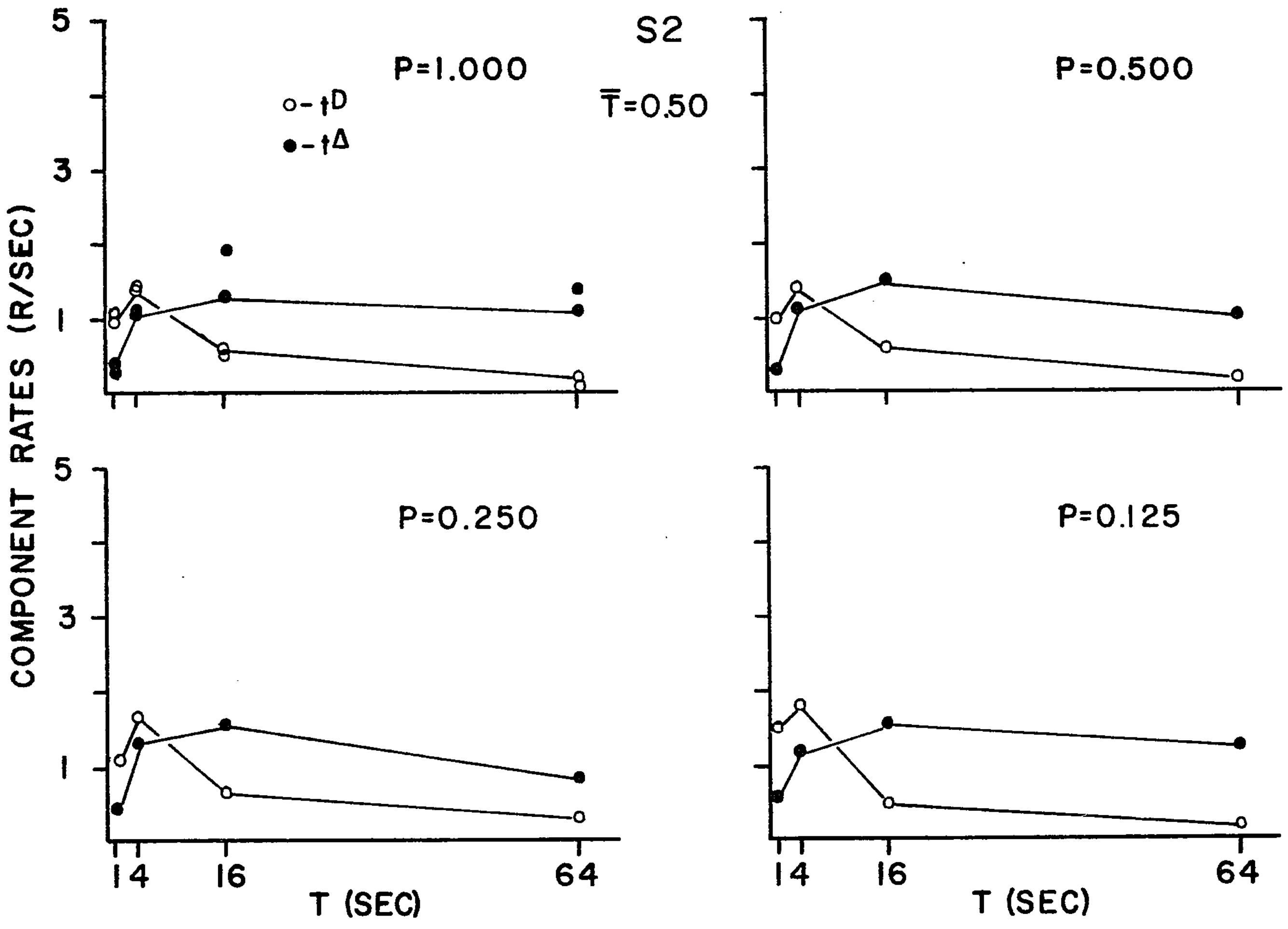

S2
$\overline{T}$=0.50
P=1.000
P=0.500
P=0.250
P=0.125
○-t^D
●-t^Δ
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
I
4
16
64
I
4
16
64
T (SEC)
T (SEC)

Figure 25

Figure 26

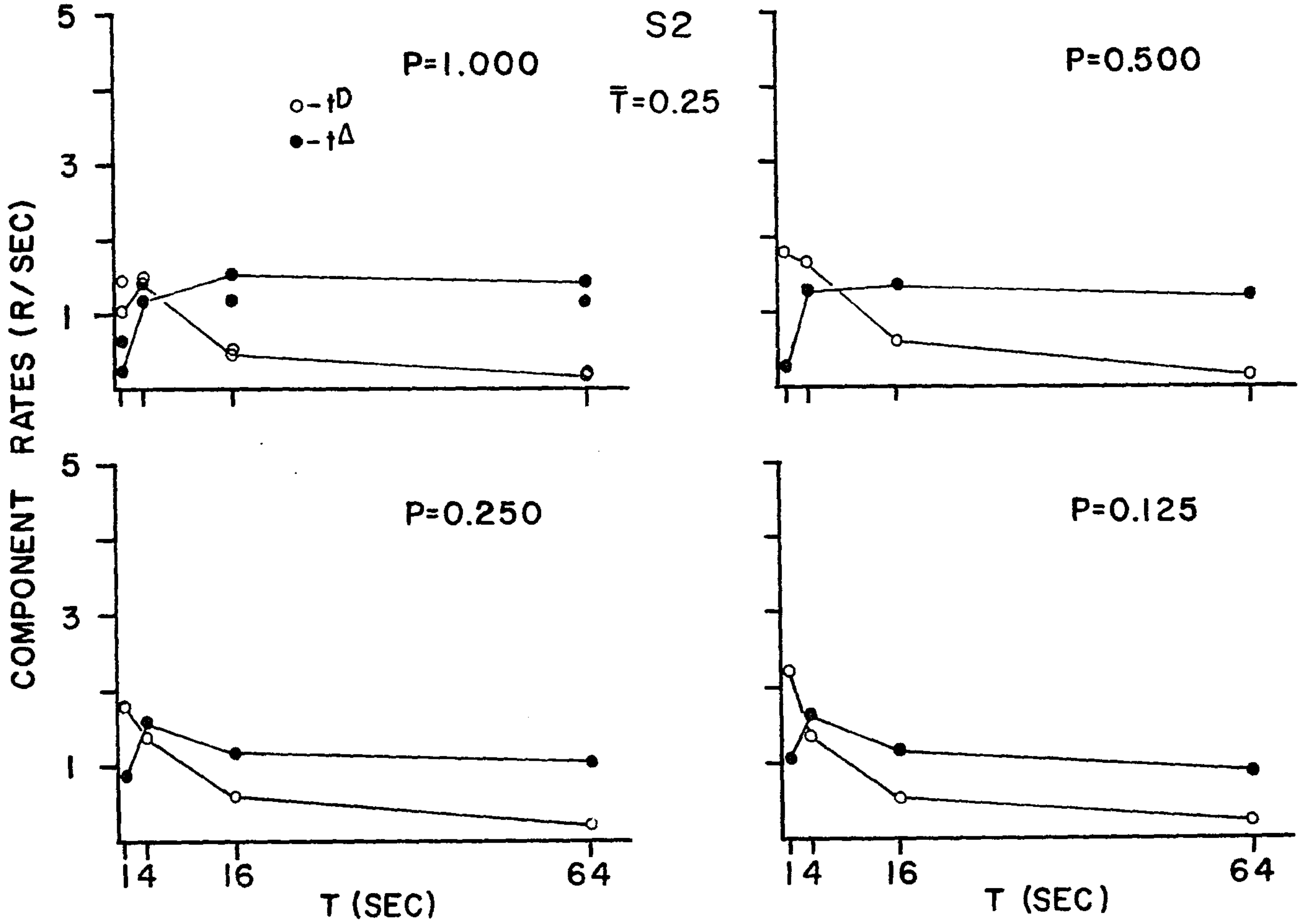

S2
$\bar{T}=0.25$
P=1.000
P=0.500
P=0.250
P=0.125
○-tD
●-tΔ
COMPONENT RATES (R/SEC)
5
3
1
14
16
64
T (SEC)

Figure 27

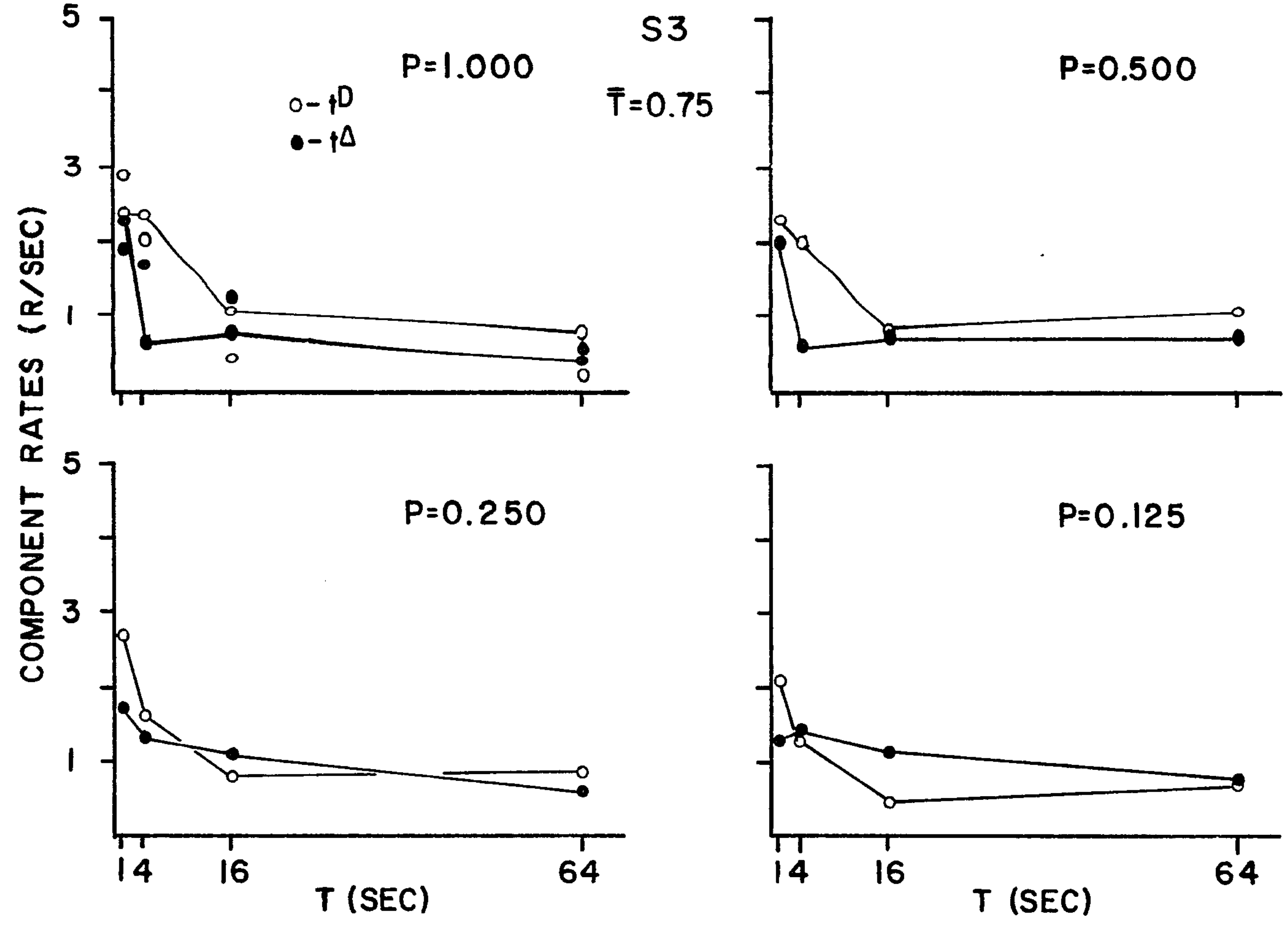

S3
$\bar{T}=0.75$
○- t^D
●- t^Δ
P=1.000
P=0.500
P=0.250
P=0.125
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
1 4
16
64
T (SEC)
1 4
16
64
T (SEC)

Figure 28

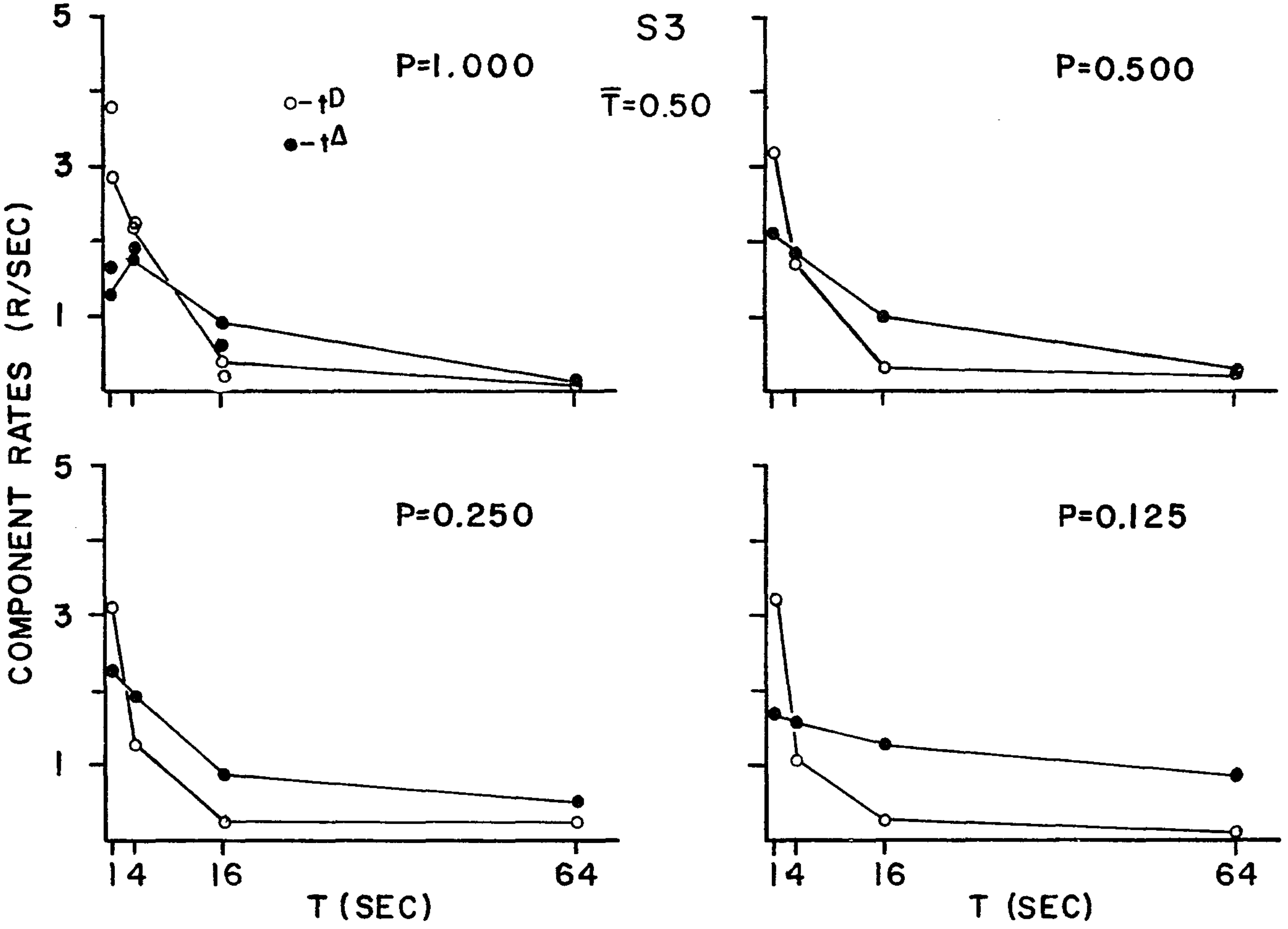

S3
$\bar{T}$=0.50
COMPONENT RATES (R/SEC)
P=1.000
P=0.500
P=0.250
P=0.125
○-t^D
●-t^Δ
5
3
1
5
3
1
14
16
64
T (SEC)
14
16
64
T (SEC)

Figure 29

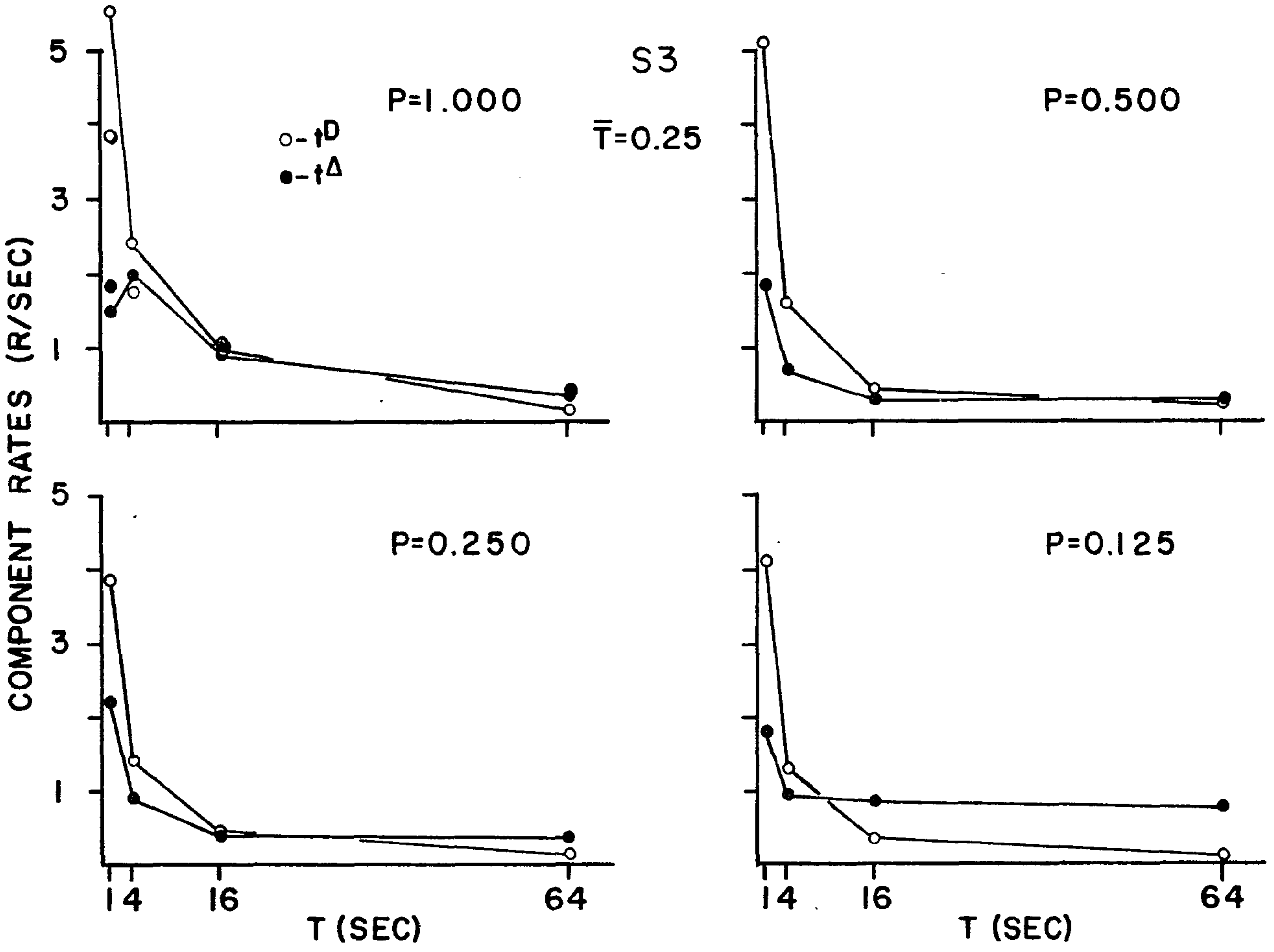

S3
T̄=0.25
P=1.000
○-t^D
●-t^Δ
P=0.500
P=0.250
P=0.125
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
14
16
64
T (SEC)
14
16
64
T (SEC)

Figure 30

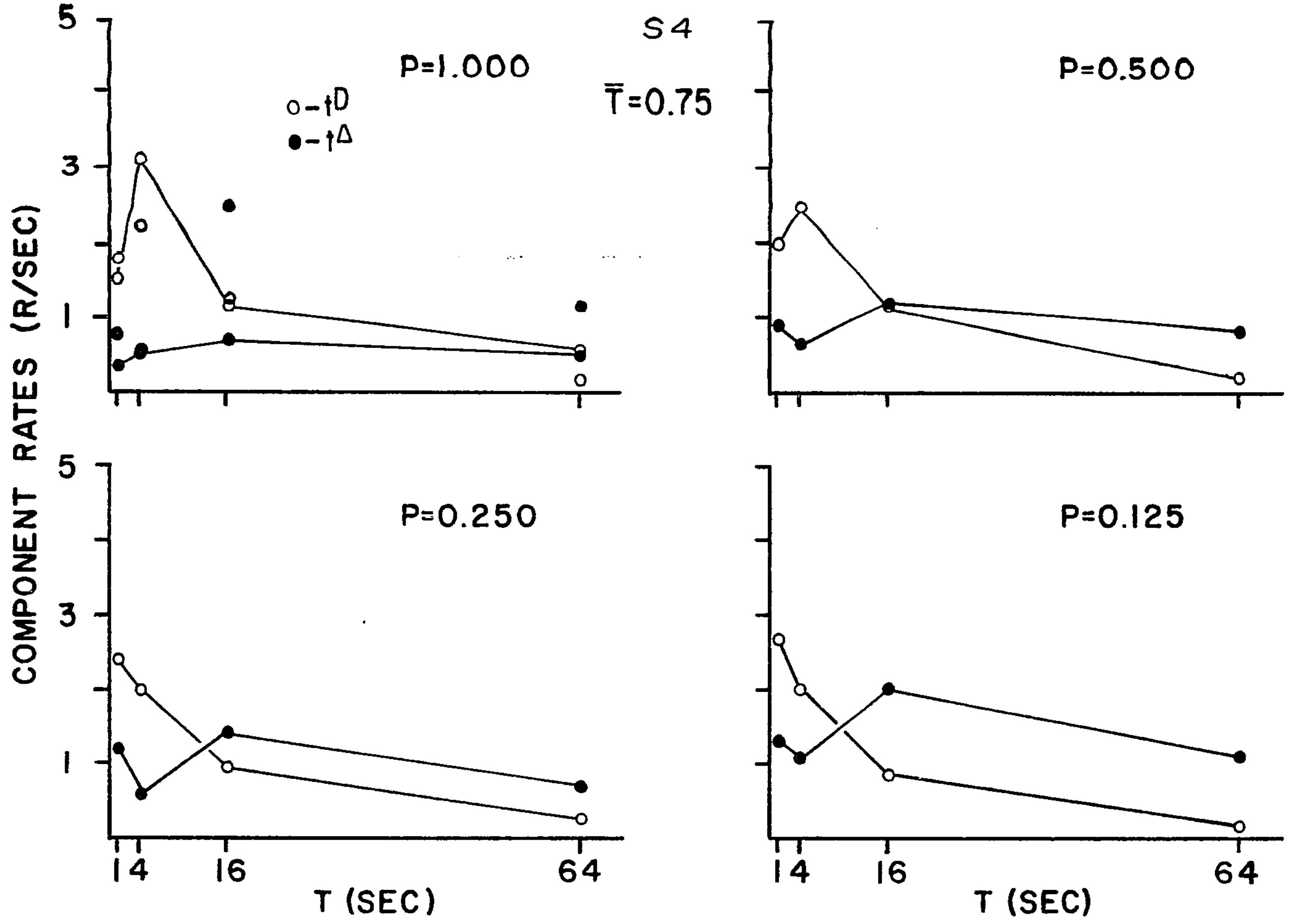

S4
T̄=0.75
COMPONENT RATES (R/SEC)
P=1.000
○ - t^D
● - t^Δ
P=0.500
P=0.250
P=0.125
5
3
1
5
3
1
14
16
64
T (SEC)
14
16
64
T (SEC)

Figure 31

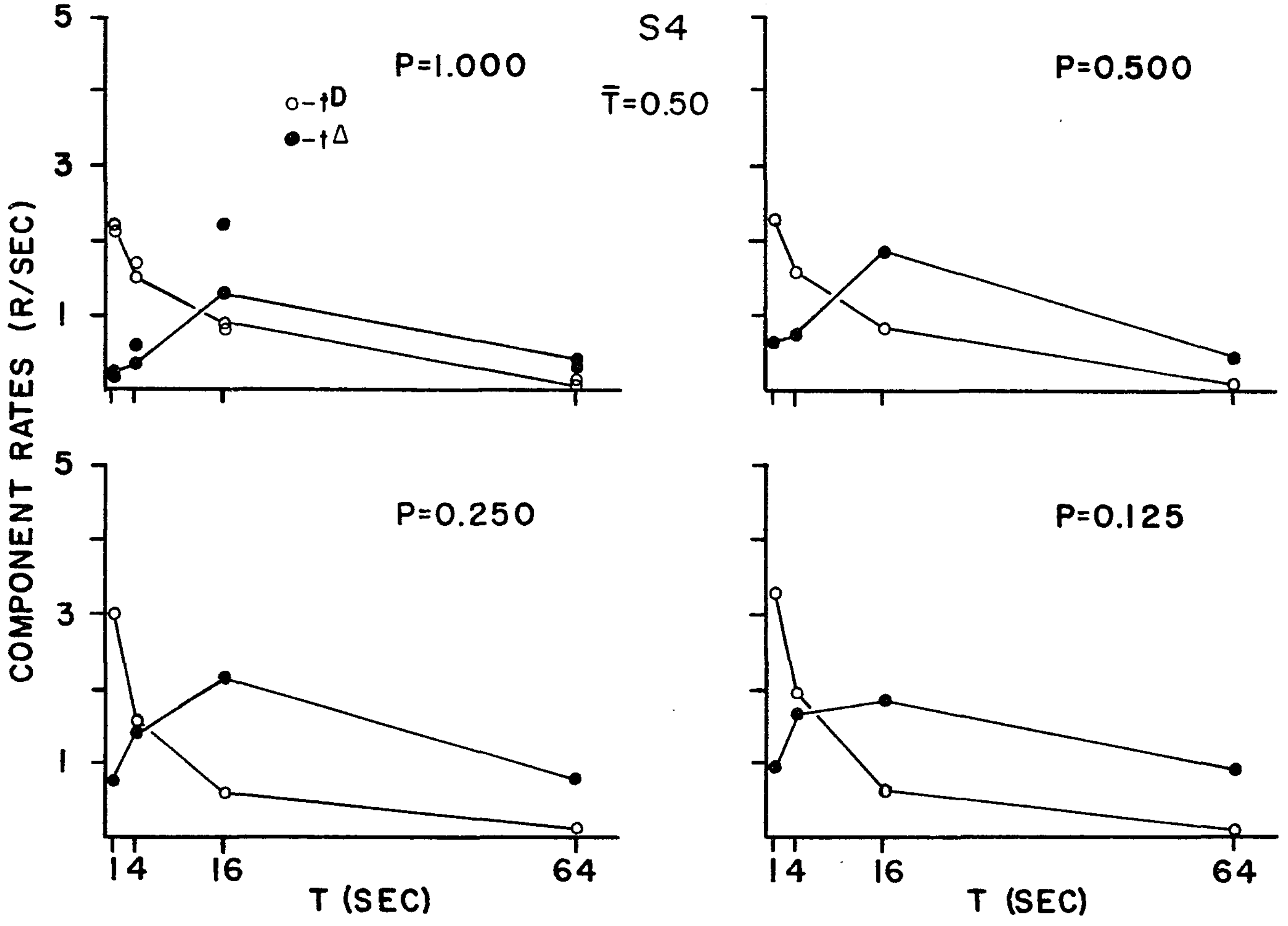
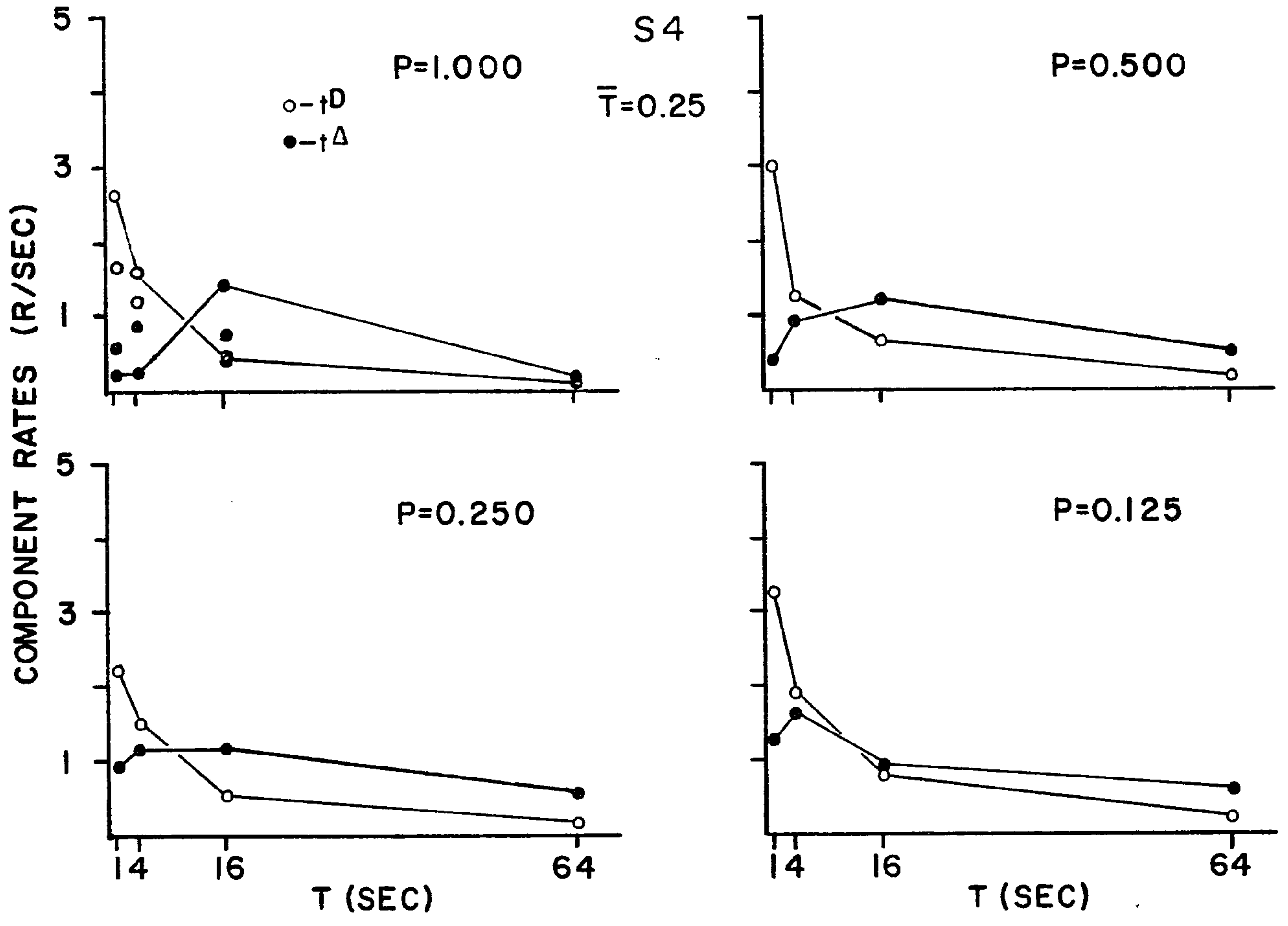

S4
$\bar{T}$=0.50
COMPONENT RATES (R/SEC)
T (SEC)
P=1.000
P=0.500
P=0.250
P=0.125
○–t^D
●–t^Δ
5
3
1
14
16
64

Figure 32


S4
$\bar{T}$=0.25
P=1.000
P=0.500
P=0.250
P=0.125
○–t^D
●–t^Δ
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
1 4
16
64
T (SEC)
1 4
16
64
T (SEC)

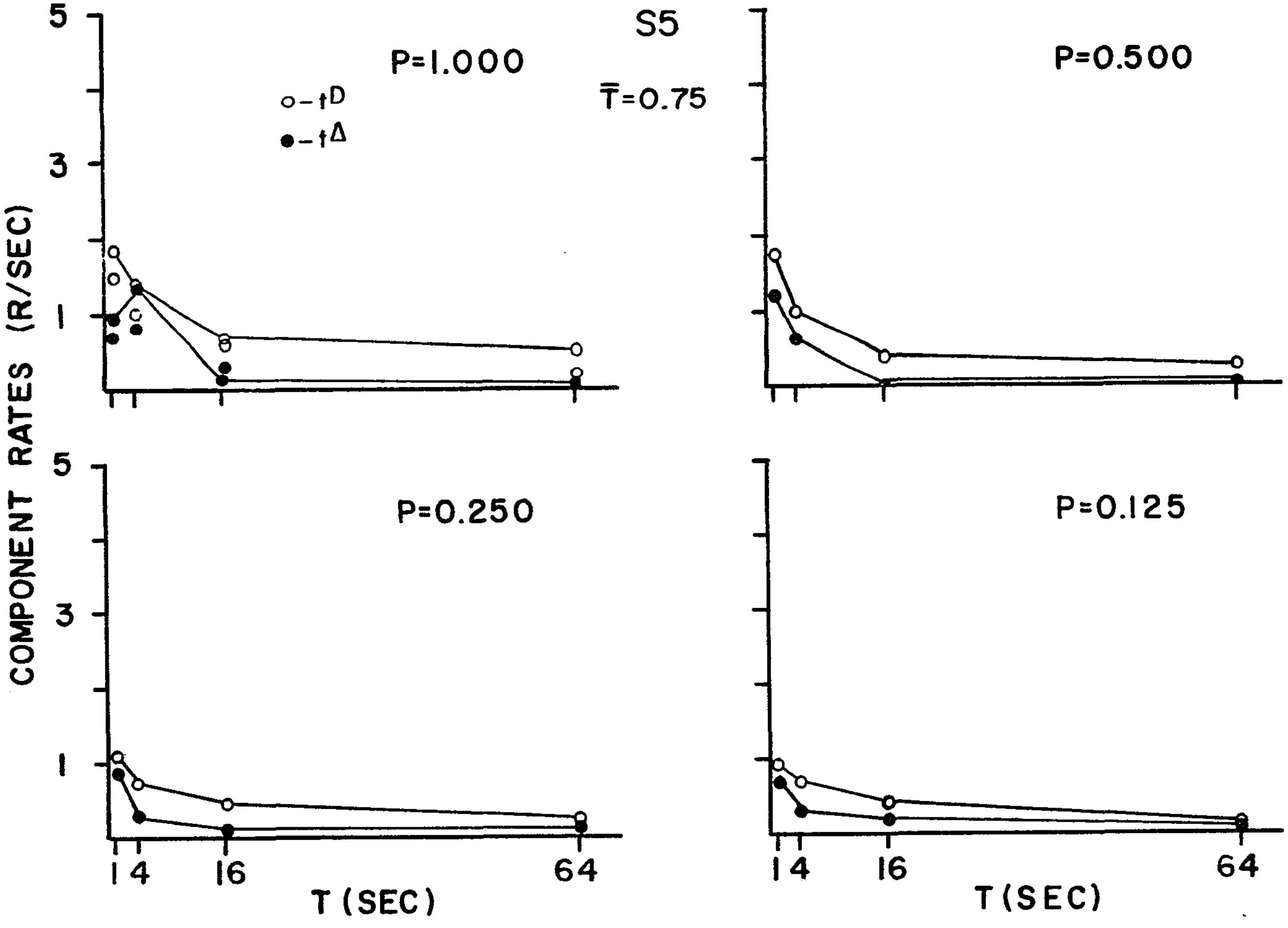

S5
$\bar{T}$=0.75
P=1.000
P=0.500
P=0.250
P=0.125
○-t^D
●-t^Δ
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
1
4
16
64
1
4
16
64
T (SEC)
T (SEC)

Figure 33

Figure 34

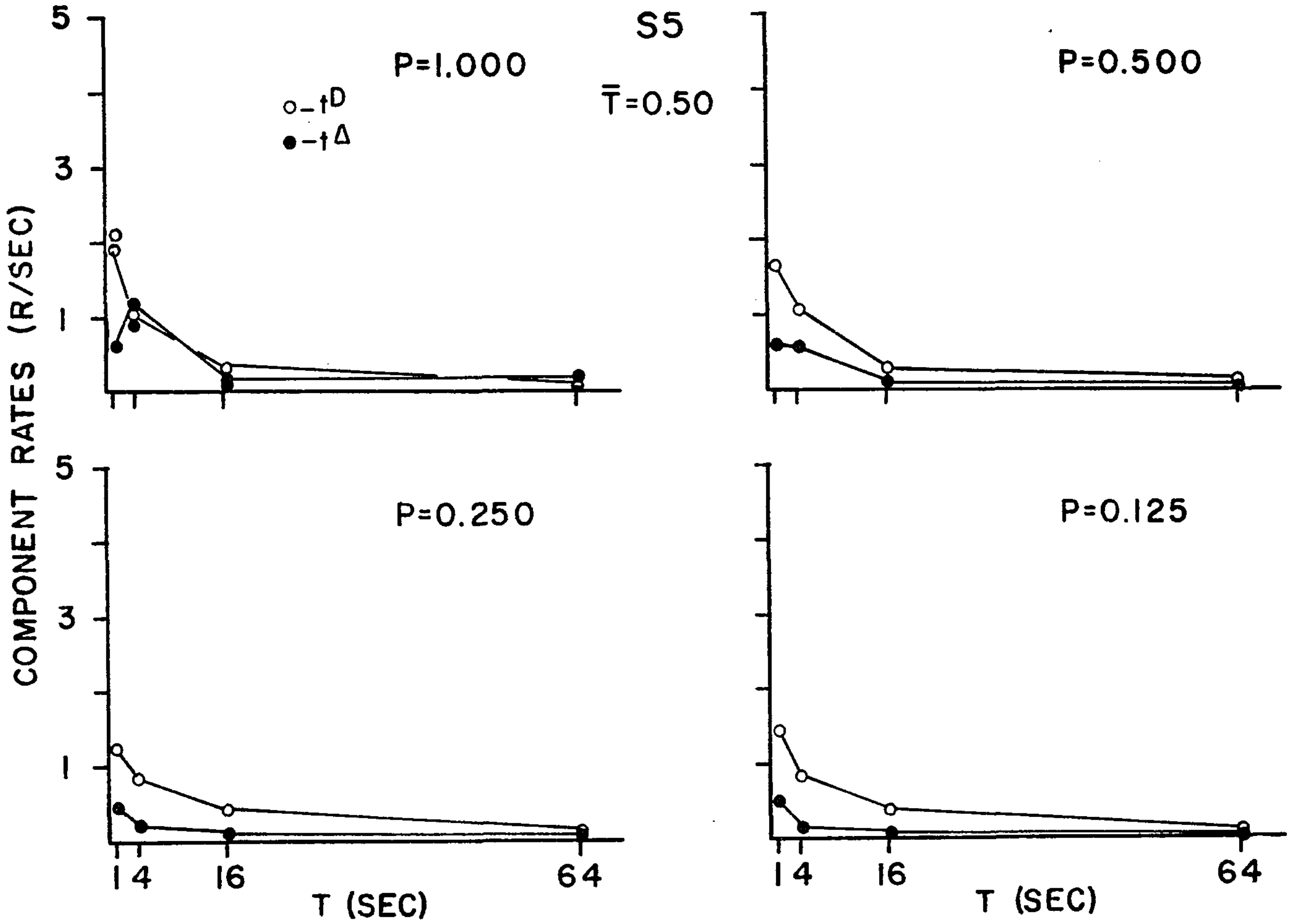
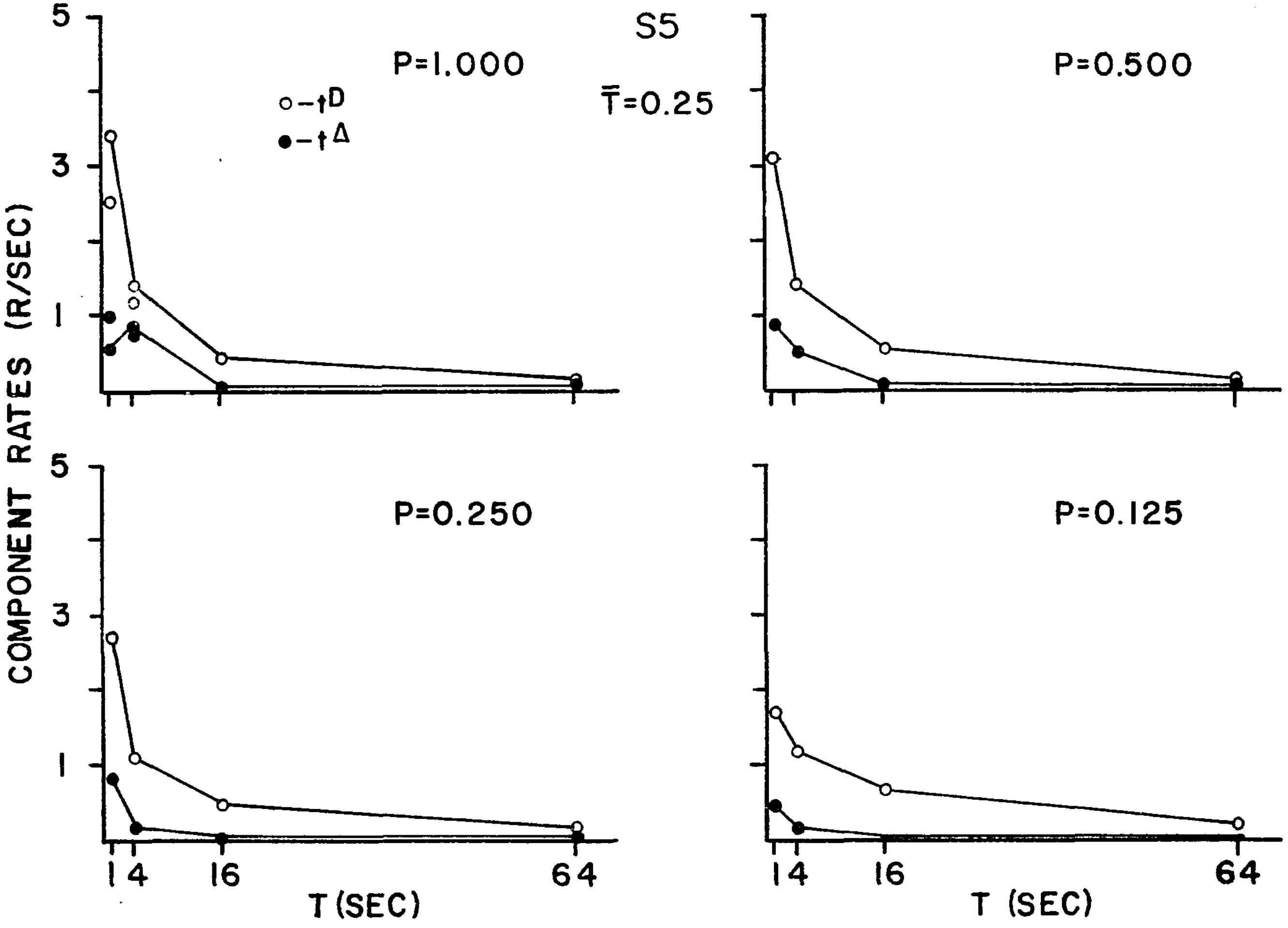

S5
T̄=0.50
P=1.000
○–t^D
●–t^Δ
P=0.500
P=0.250
P=0.125
COMPONENT RATES (R/SEC)
5
3
1
T (SEC)
1 4 16 64

Figure 35


S5
$\bar{T}$=0.25
P=1.000
○-t^D
●-t^Δ
P=0.500
P=0.250
P=0.125
COMPONENT RATES (R/SEC)
5
3
1
5
3
1
1
4
16
64
T (SEC)
1
4
16
64
T (SEC)

those effects. It is clear from the present data, as well as Cole's (1968) and Farmer and Schoenfeld's (1966a, 1966b), that the degree of control afforded by an exteroceptive stimulus is a joint function of the schedule of reinforcement, the schedule of stimulus presentation, and the parameters of the stimulus (i.e., duration), with the behavioral "function" determined by all three.

If the t^D and t^Δ periods are treated as components of a multiple schedule, then instances of "behavioral contrast" can be extracted from the rate functions under the two conditions. For example, S2 at all p values lower than 1.000, showed functions in which the rate curves for t^D and t^Δ appear to be mirror-images of each other (Figs. 24-26). As p was decreased, the curves seemed to diverge, indicating that the response rates in the two stimulus conditions were changing in opposite directions as p was reduced. A similar effect can be seen in S4's data (Fig. 30) at $\overline{T}$=0.75.

S1, S5, and to a lesser degree, S3, showed functions that were the same shape for rates in t^D and t^Δ, with rates in both portions of the T-cycles decreasing as T was lengthened. While a decreasing rate in the S^D condition might be predicted from classical reinforcement theory (as p decreased, so did average reinforcement frequency under S^D), there is no suitable explanation for the corresponding rate changes under S^Δ, except to appeal to a decreasing "secondary reinforcement value" for stimuli associated with schedules of reinforcement that were becoming progressively "leaner." Under these conditions, S1, S3, and S5 could be said to be exhibiting "induction," but that, like the "contrast" description, merely serves to label the finding. Neither pattern, it should be noted, had any necessary effect on the distribution of reinforcers in time, since responding in t^{Δ} had no scheduled consequences.

Further, even in those cases in which curves did diverge, that divergence was enhanced by decreasing p. Ever since Reynolds' (1961) paper in which behavioral contrast was attributed to schedule differences, it has been assumed that a significant contributing factor in the generation of contrast was a difference in the schedules in the contrasted conditions. In the present procedure, the reduction in p served to make the "schedules" in S^D and S^{Δ} more similar (reinforcement never occurred in the presence of S^{Δ}; as p decreased under S^D, the reinforcement rate in its presence decreased). Rather than reducing the differences in rates under the two stimulus conditions, the reverse occurred.

What is clear is that the interaction between the parameters of the schedule of reinforcement, the prevailing stimulus conditions, and the response rate is a rather complex one. The labelling of those interactions ("contrast" or "induction") obscures the search for the underlying controlling relations. In the present case, instances of behavioral change that would satisfy the necessary conditions for both contrast and induction were generated under identical experimental conditions with animals having the same conditioning histories.

Once a pattern of responding was established within a particular T value, it appeared (in some cases) that that pattern would be maintained whether or not there was a reinforcer in each interval. Fig. 36 shows the response pattern (cumulative records) for S2 at $\overline{T}=0.25$, $p=0.125$ for all four T values. It appears that the response pattern was primarily under the control of the stimuli. The bulk of responses in T=16 and T=64 sec periods occurred during S^{Δ}, with intervals containing reinforcers showing the same response pattern as those without. The same may be seen in the data for S4 at $\overline{T}=0.75$, $p=0.500$ (Fig. 37). The pattern of responding was similar to S2's (little responding in S^D, with response "runs" beginning in S^{Δ} and continuing until reinforcement in the T=64 sec component). The T=4 and T=16 sec components, while showing some irregularities, appear more "RI-like" at this value of $\overline{T}$. Fig. 38 shows the same animal at $\overline{T}=0.25$, $p=0.125$. The same pattern may be seen, and except for an increase in grain from the earlier data, the intervals with reinforcers are indistinguishable from those without. In addition, the characteristic pattern now appears in the T=16 sec component as well, with the T=1 and T=4 sec components maintaining their RI-like character. Responding (at least in the T=16 and T=64 sec components) again appears more under the control of the changes in key-color than the presence or absence of reinforcement. It might again be tempting to appeal to the "secondary reinforcement" effect of S^D, but that is another instance of labelling the effect. Unless the S^D is demonstrated to behave as a reinforcer independently of the schedule of reinforcement upon which it is superimposed, appealing to a non-demonstrated effect begs the issue. In a similar vein, might the animals not be described as "preferring" S^Δ, since most of the responding occurred there? Indeed, it appeared that the S^D suppressed responding. Figure 39 shows cumulative records for S1 at $\bar{T}$=0.25, p=0.125. Response patterns in the T=16 and T=64 sec components show just the reverse of those for S2 and S4. In this case, it appears that response "runs" begin with the first response (reinforced or not) in S^D, and stop with the end of S^D. Does this animal "prefer" S^D? Is S1 responding in such a way as to "produce" S^Δ, and does that imply that S^Δ is now to be seen as a conditioned reinforcer? The source of control must be sought in less anthropomorphic grounds.

The discrimination index functions (Figs. 40-54 and Tables 17-21) reflect differential responding under the two stimulus conditions, and allow a somewhat grosser comparison across schedule conditions and animals of the distribution of responses than do the component rate functions. In some cases (i.e., S2, $\bar{T}$=0.50 and 0.25 at all p values), the discrimination index is a decreasing negatively ac-

Figure 36: Cumulative record for S2, $\overline{T}$=0.25, p=0.125.

Figure 36 shows cumulative response curves for S2 at $\overline{T}$=0.25, p=0.125 for T=1, 4, 16, and 64 sec, respectively. The change from one value of T to the next is indicated by a reset of the response pen, and occurred after the third reinforcer in each component. Data are taken from the fourth of five exposures to the schedules on the fourth session at these parameter values. Downward deflections of the baseline pen indicate t^D periods.

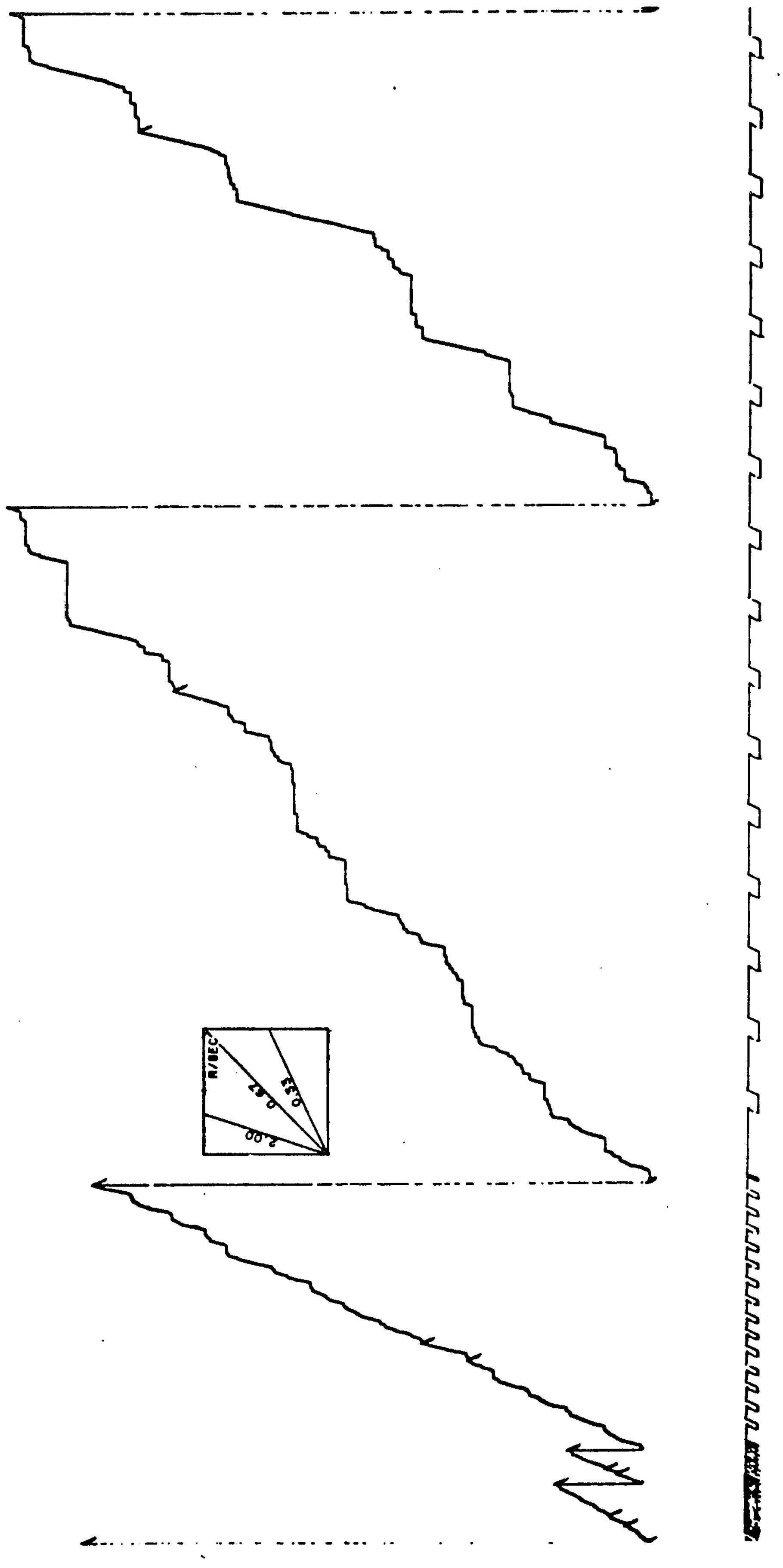


Figure 36

Figure 37: Cumulative record for S2, $\overline{T}=0.75$, $p=0.500$.

Figure 37 shows cumulative response curves for S2 at $\overline{T}=0.75$, $p=0.500$ for (from left to right) $T=1$, 4, 16, and 64 sec. The response pen reset to the baseline following the third reinforcer at each value of T, at which point T changed to its next scheduled value. Reinforcers are indicated by downward "pips" in the response pen. Downward deflections of the baseline pen indicate t^D periods. Data are taken from the fourth exposure to the schedules on the fourth session at these values of $\overline{T}$ and p.

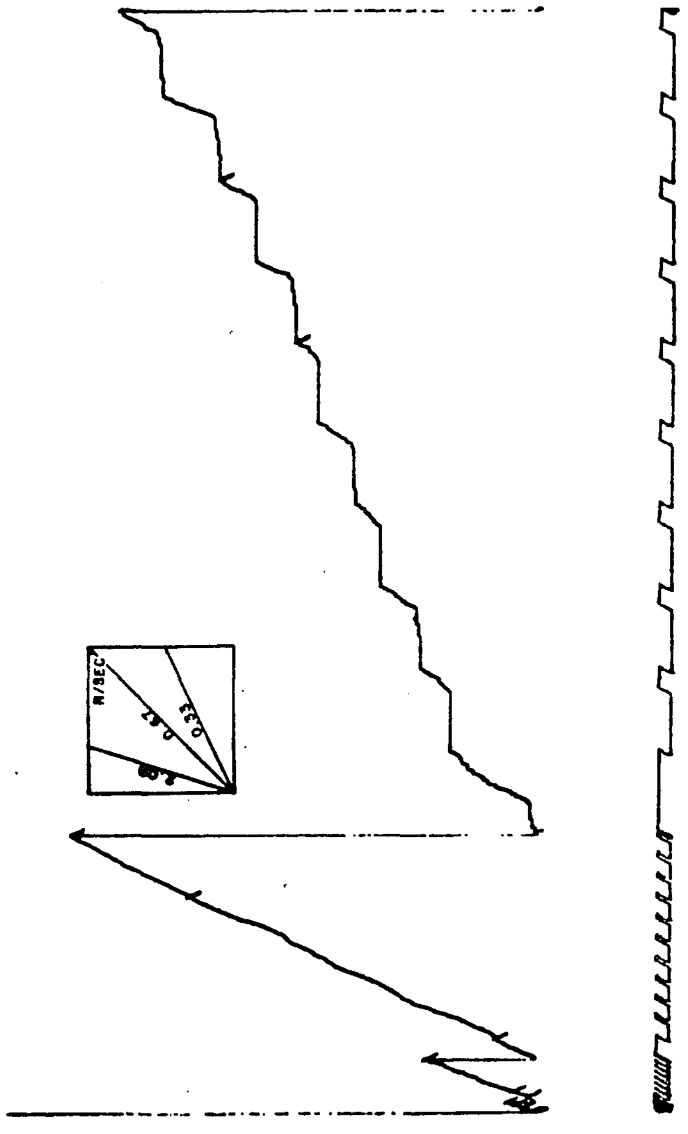


Figure 37

Figure 38: Cumulative record for S4, $\bar{T}$=0.25, p=0.125.

Figure 38 shows cumulative response curves for S4 at $\bar{T}$=0.25, p=0.125 for (from left to right) T=1, 4, 16, and 64 sec. The response pen reset to the baseline following the third reinforcer at each value of T, at which point T changed to its next scheduled value. Reinforcers are indicated by downward "pips" in the response pen. Downward deflections of the baseline pen indicate t^D periods. Data are taken from the fourth exposure to the schedules on the fourth session at these values of $\bar{T}$ and p.

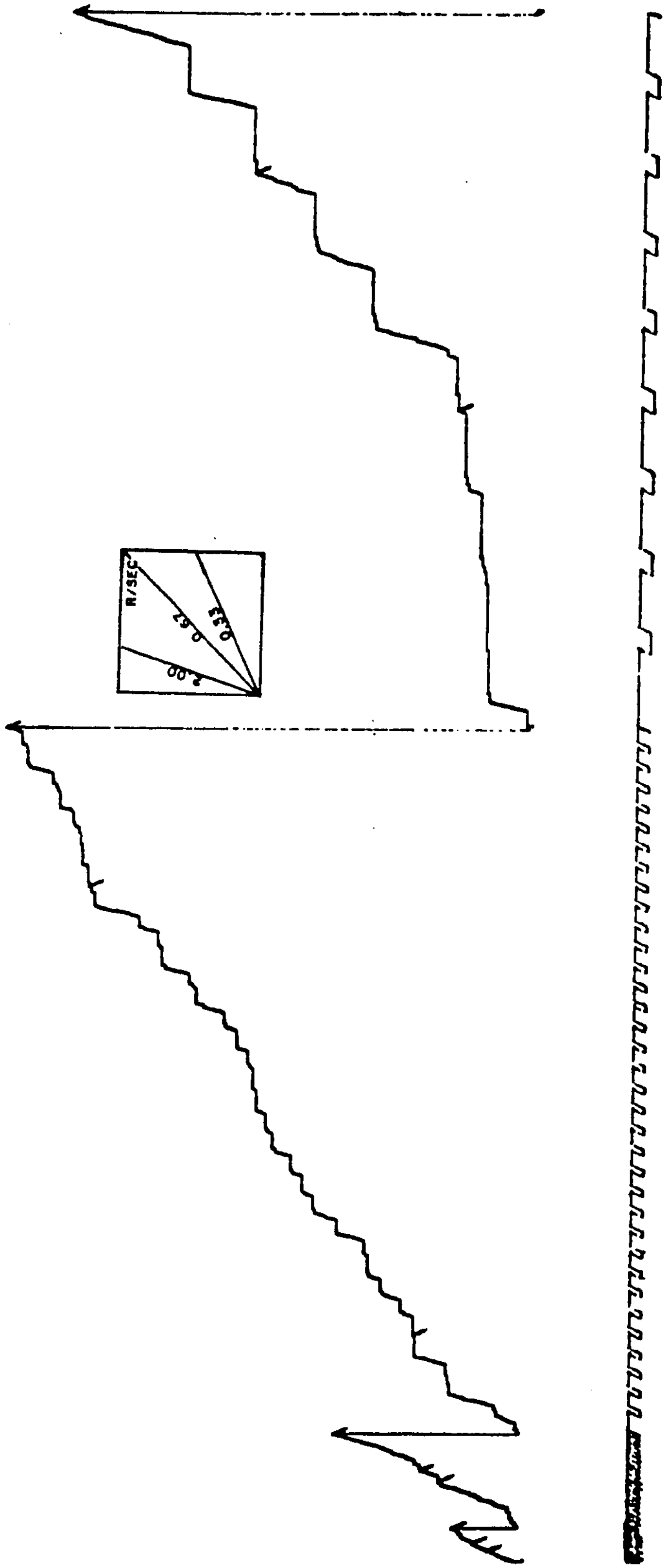


Figure 38

Figure 39: Cumulative record for S1, $\overline{T}=0.25$, $p=0.125$.

Figure 39 shows cumulative response curves for S1 at $\overline{T}=0.25$, $p=0.125$ for $T=1$, 4, 16, and 64 sec. The data for the first three values of T are shown in the upper curve, while the $T=64$ sec data are shown in the lower record. The final portion of the $T=64$ sec curve was displaced because of space limitations. Reinforcers are indicated by downward "pips" of the response pen, while downward deflections of the baseline pen indicate t^D periods. The baseline pen is deleted for the $T=1$ through $T=16$ sec components, as well as the initial portion of the $T=64$ sec segment of the curve. Data were taken from the fourth of five exposures to the schedules on the fourth session at these values of $\overline{T}$ and p.

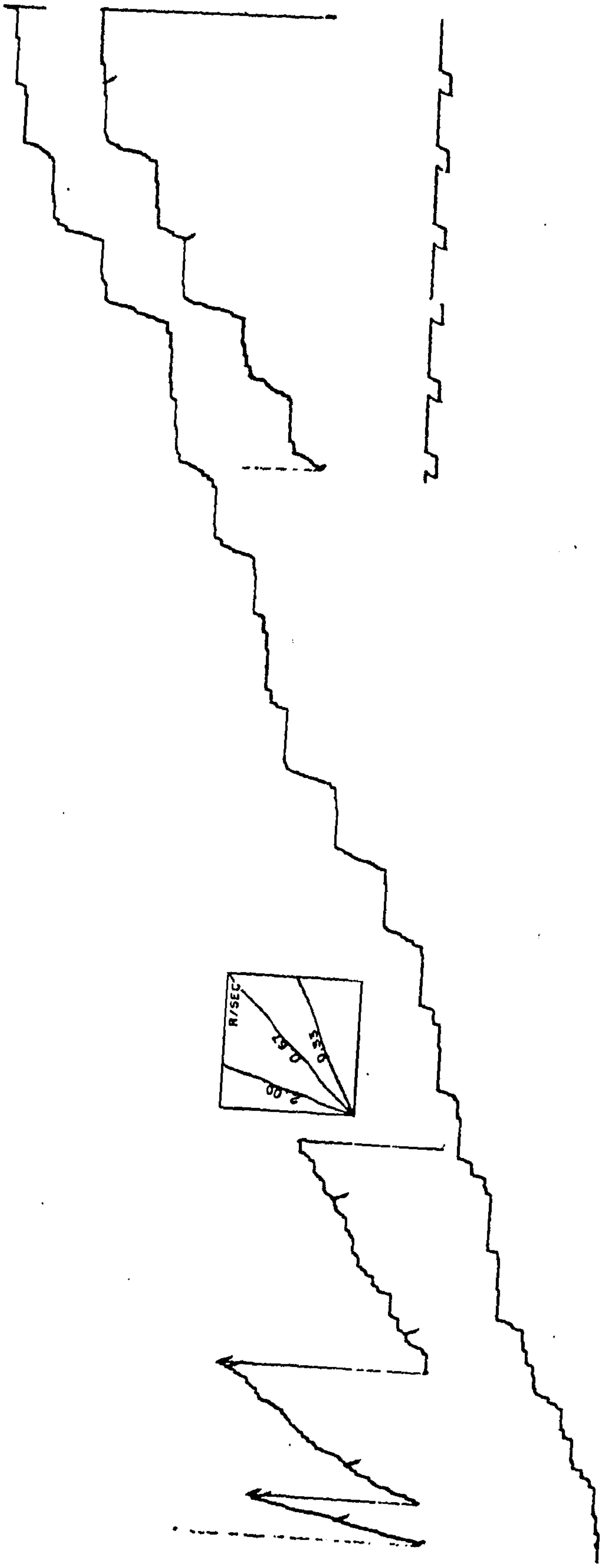
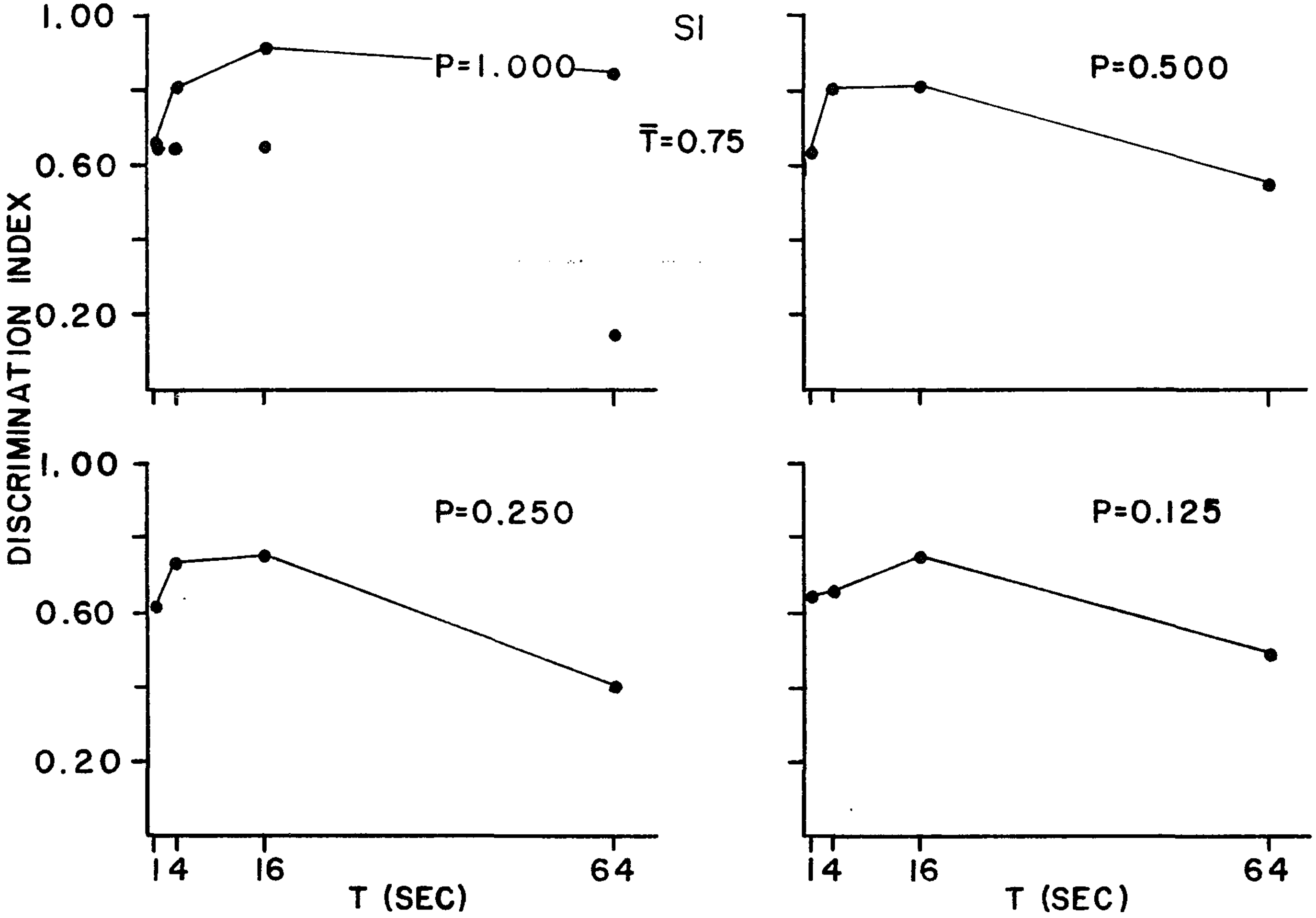


Figure 39

Figures 40 through 54: Discrimination index as a function of T.

Figures 40 through 54 show discrimination indices computed by dividing responses per second in t^D by responses per second in t^D + responses per second in t^Δ, or $R^D/(R^D+R^\Delta)$. Data for S1 at $\bar{T}=0.75$, 0.50, and 0.25 are shown in Figs 40 through 42, respectively. Figs 43 through 45 show the same sequence for S2, Figs 46-48 for S3, Figs 49-51 for S4, and Figs 52-55 for S5. Values of p are shown in each panel. Unconnected points at p=1.000 represent recovery values.

Figure 40



S1
T̄=0.75
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1.00
0.60
0.20
1
4
16
64
T (SEC)
1
4
16
64
T (SEC)

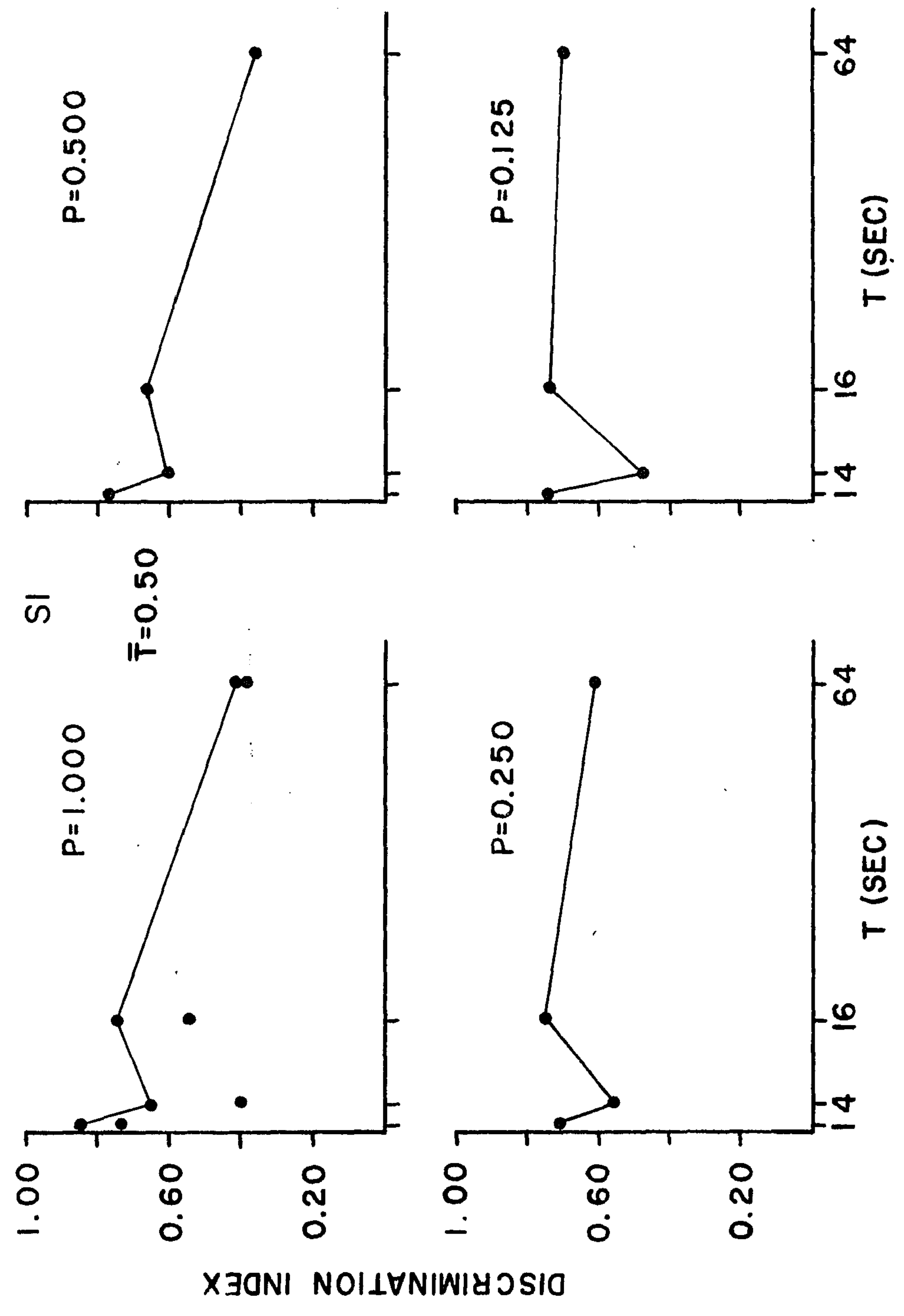

SI
T̄=0.50
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1.00
0.60
0.20
1
4
16
64
T (SEC)
1
4
16
64
T (SEC)

Figure 41

Figure 42

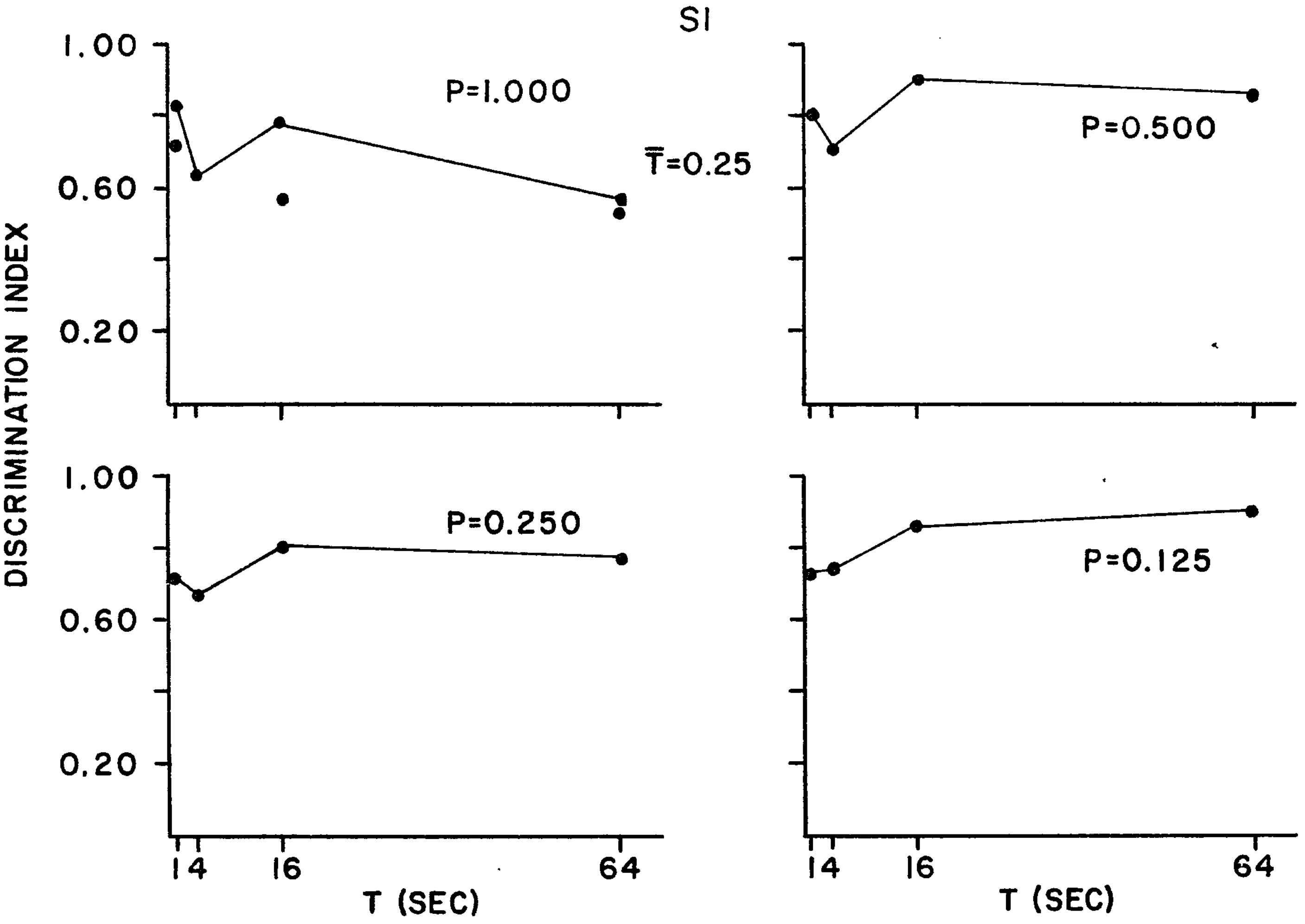

SI
T̄=0.25
DISCRIMINATION INDEX
1.00
0.60
0.20
P=1.000
P=0.500
P=0.250
P=0.125
1
4
16
64
T (SEC)

Figure 43

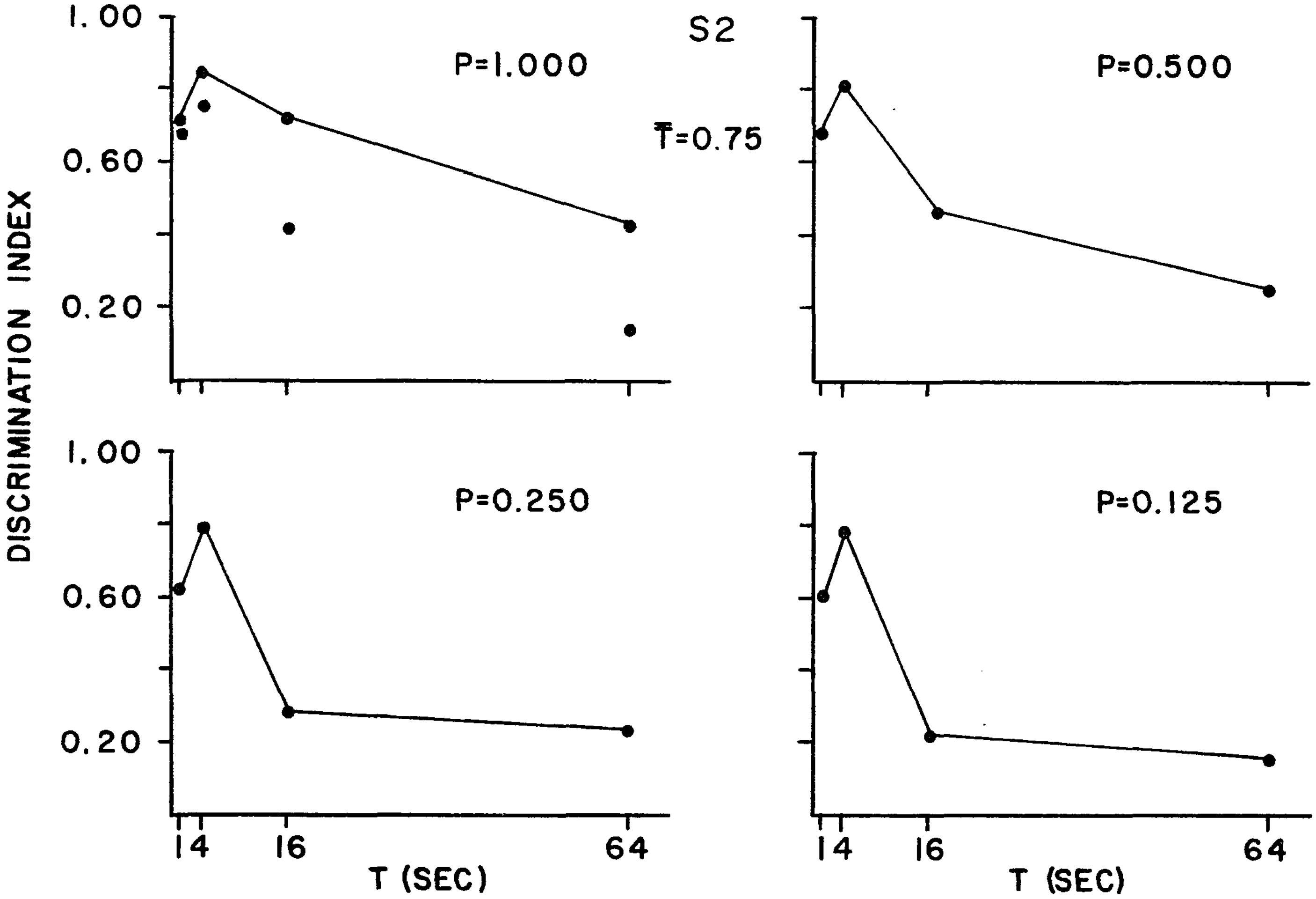
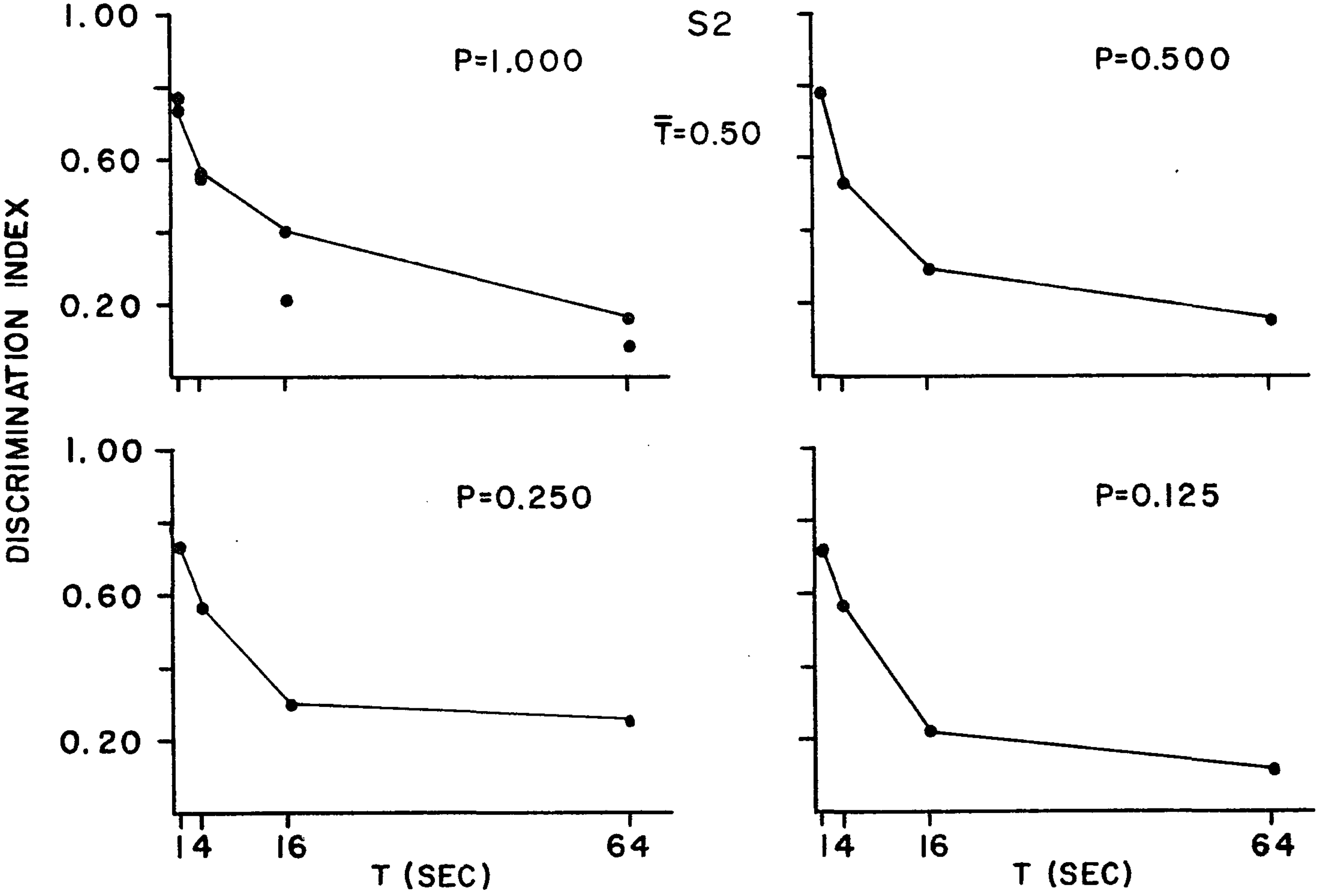

S2
T̄=0.75
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1.00
0.60
0.20
14
16
64
T (SEC)
14
16
64
T (SEC)

Figure 44


S2
T̄=0.50
DISCRIMINATION INDEX
P=1.000
P=0.500
P=0.250
P=0.125
1.00
0.60
0.20
1
4
16
64
T (SEC)

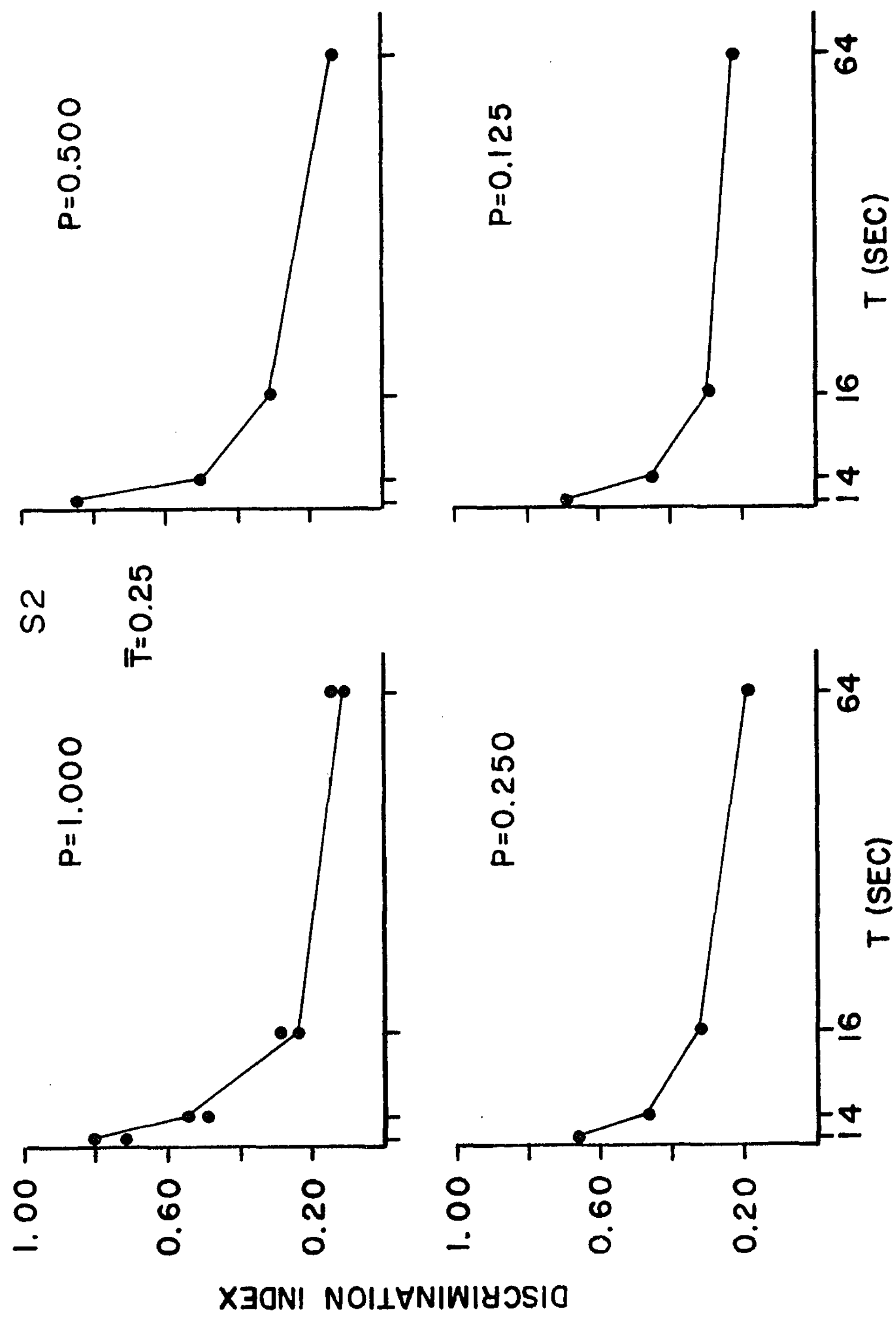

S2
$\bar{T}$=0.25
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1.00
0.60
0.20
1
4
16
64
T (SEC)
1
4
16
64
T (SEC)

Figure 45

Figure 46

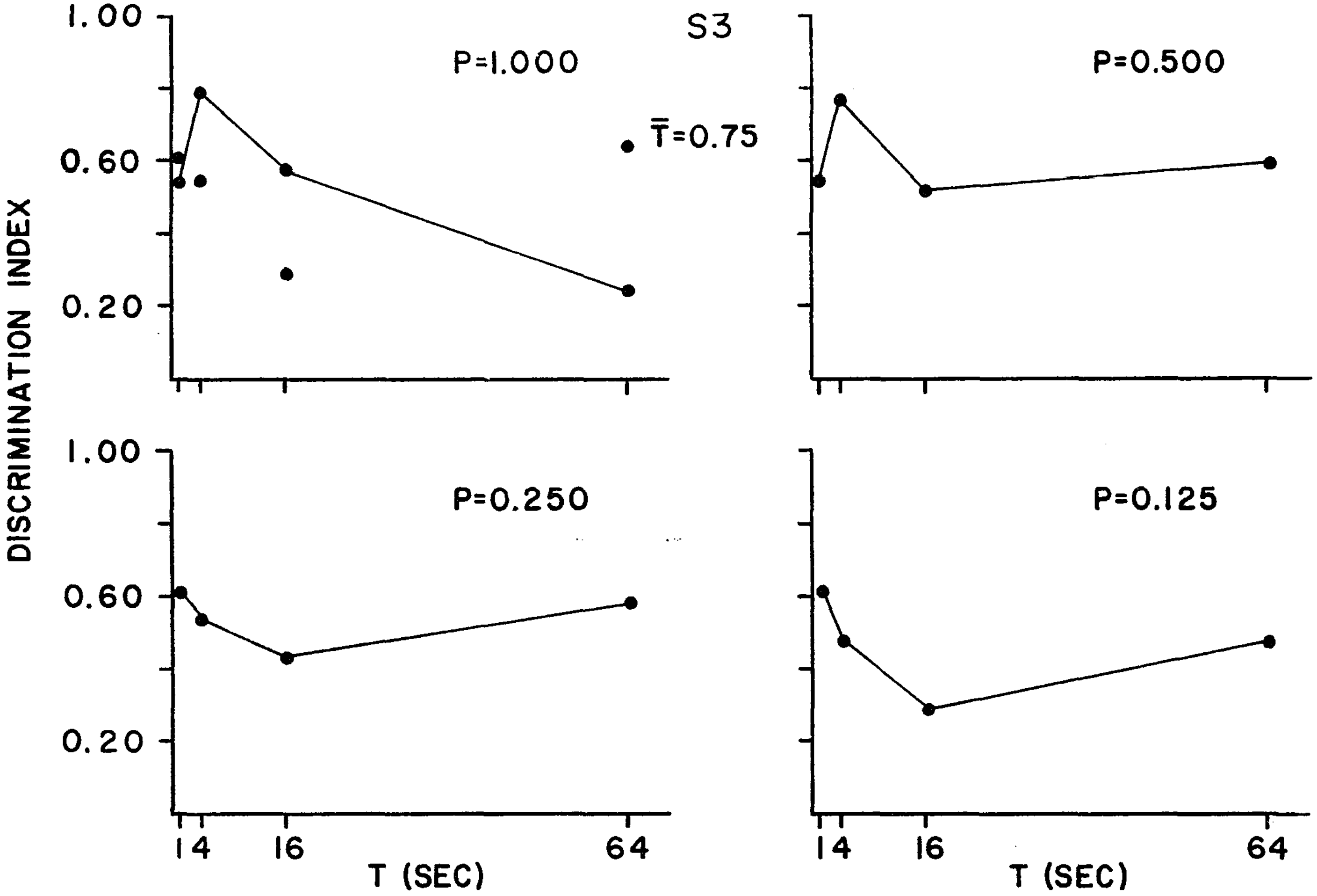

S3
P=1.000
$\bar{T}$=0.75
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1 4
16
64
T (SEC)

Figure 47

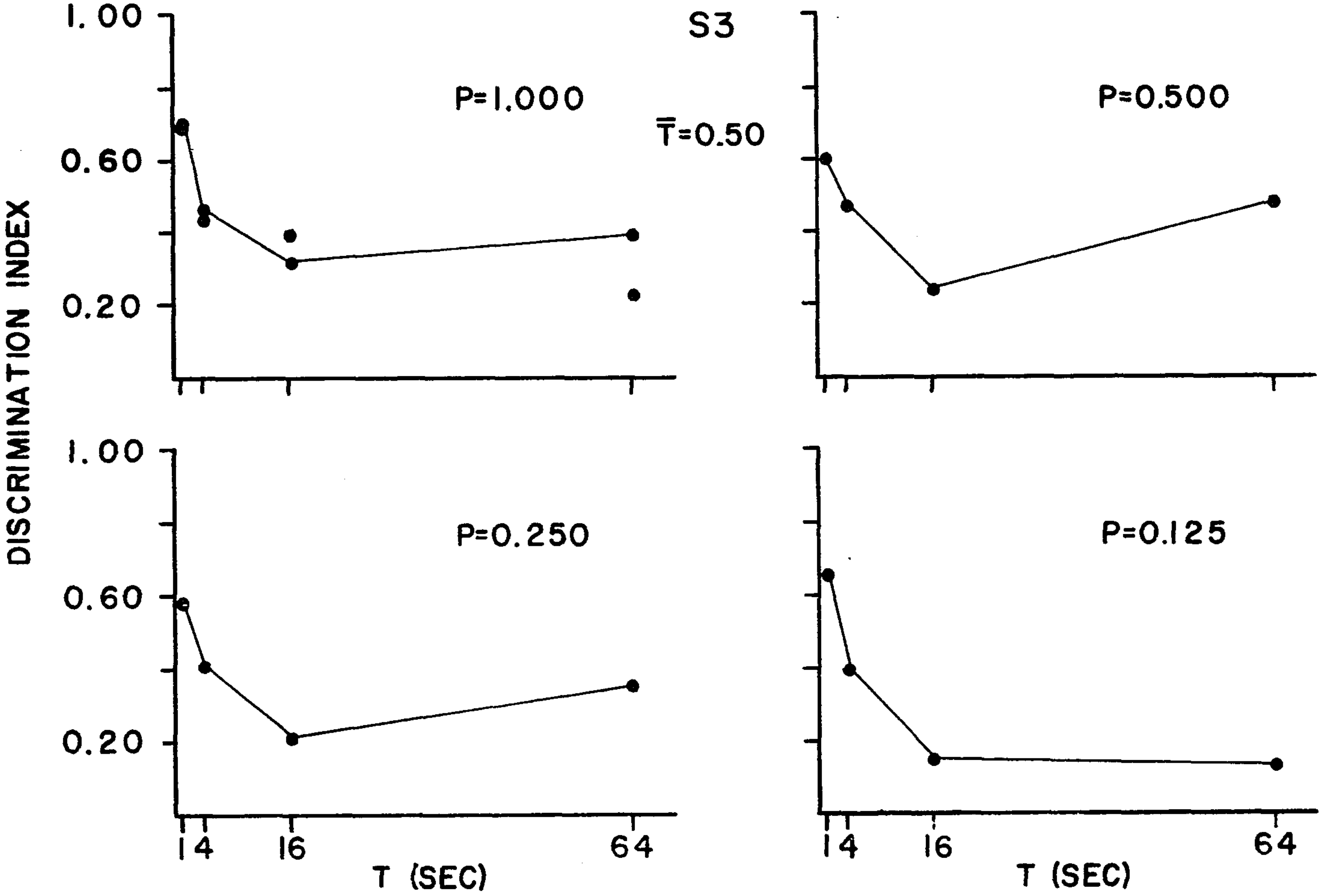

S3
T̄=0.50
DISCRIMINATION INDEX
1.00
0.60
0.20
P=1.000
P=0.500
P=0.250
P=0.125
1
4
16
64
T (SEC)

Figure 48

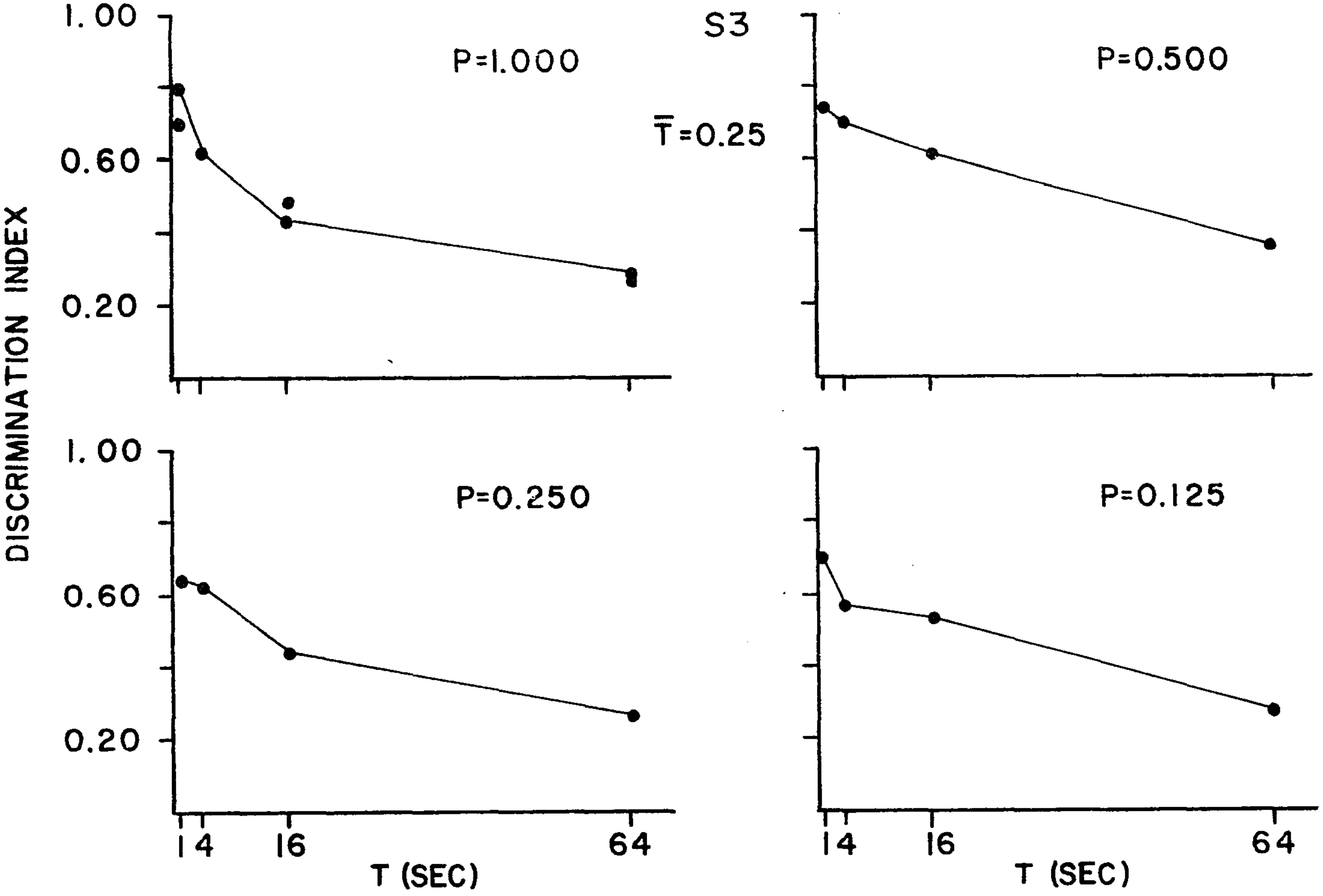

S3
$\bar{T}$=0.25
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1.00
0.60
0.20
1 4
16
64
T (SEC)
1 4
16
64
T (SEC)

Figure 49

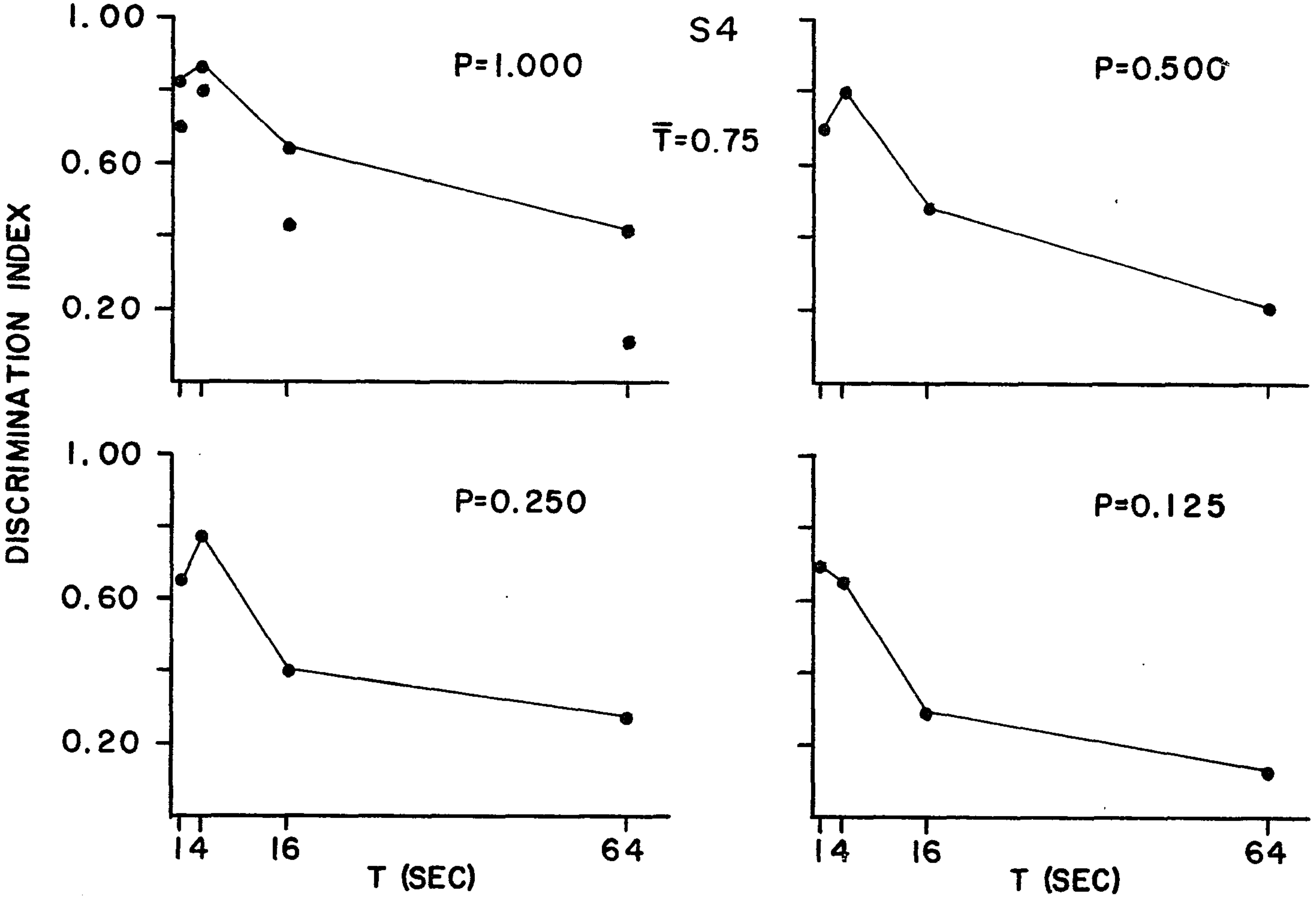

S4
T̄=0.75
DISCRIMINATION INDEX
P=1.000
P=0.500
P=0.250
P=0.125
1.00
0.60
0.20
1 4
16
64
T (SEC)

Figure 50

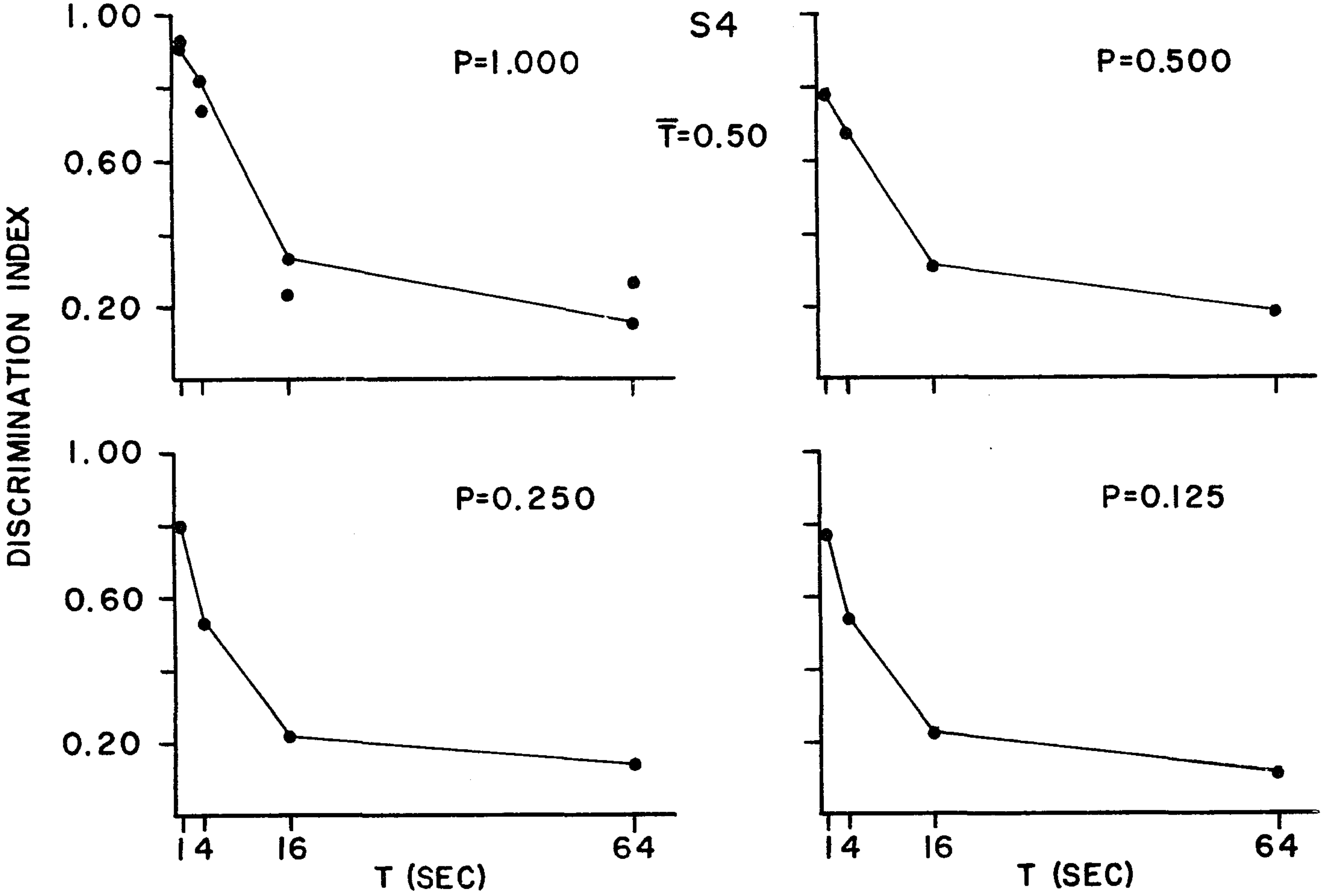

S4
$\overline{T}$=0.50
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1.00
0.60
0.20
1
4
16
64
1
4
16
64
T (SEC)
T (SEC)

Figure 51

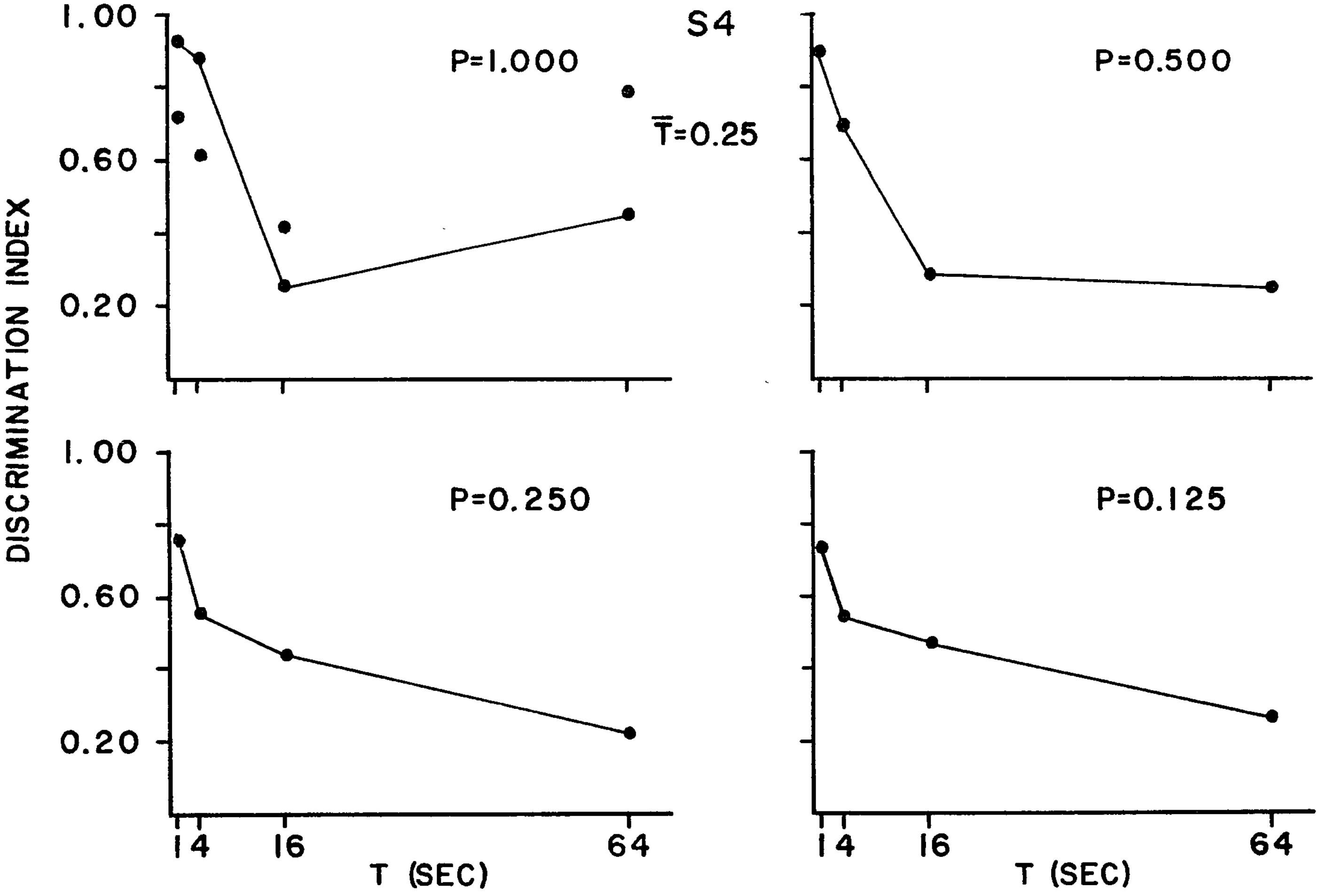
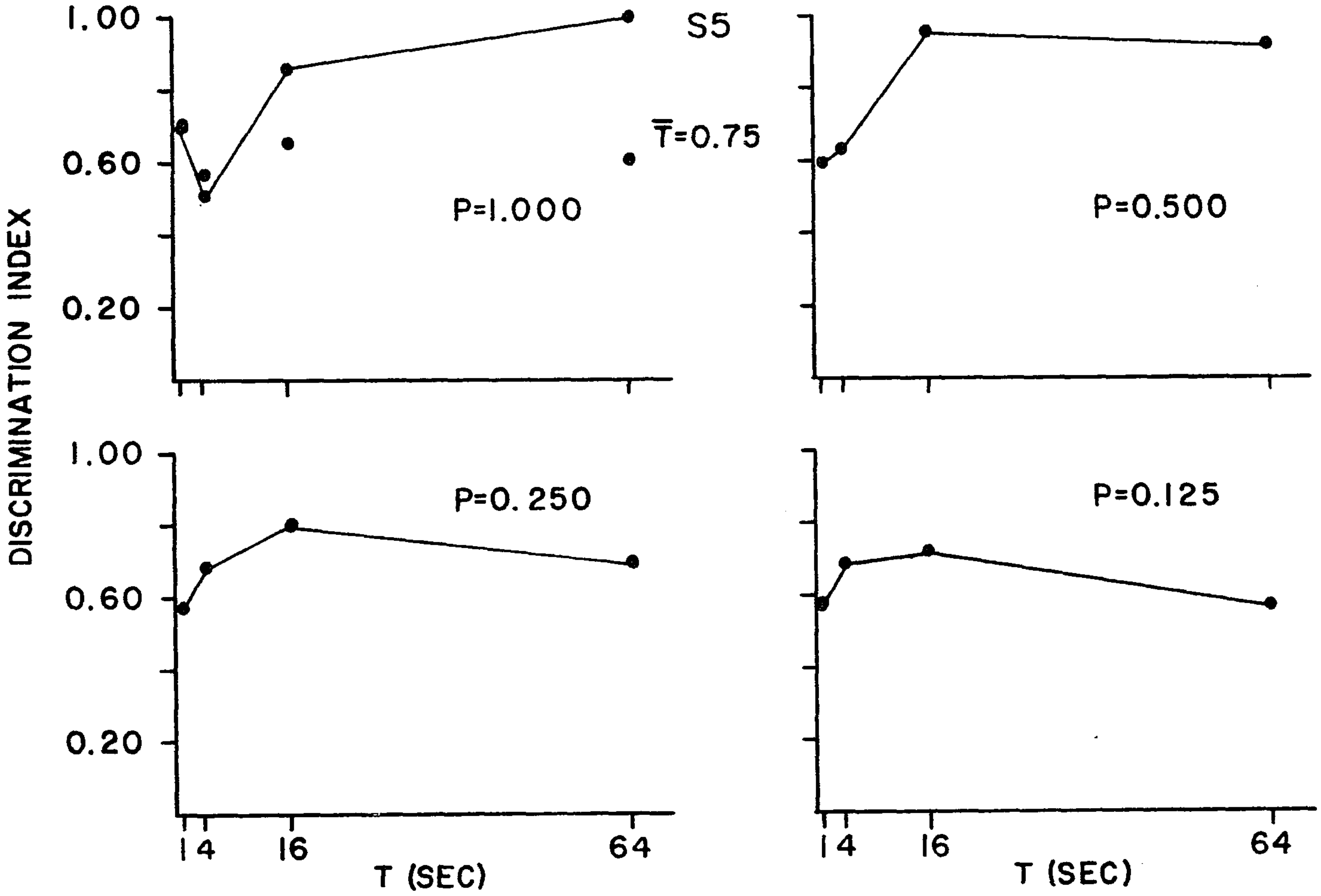

S4
T̄=0.25
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1 4
16
64
T (SEC)

Figure 52


S5
$\overline{T}$=0.75
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1
4
16
64
T (SEC)

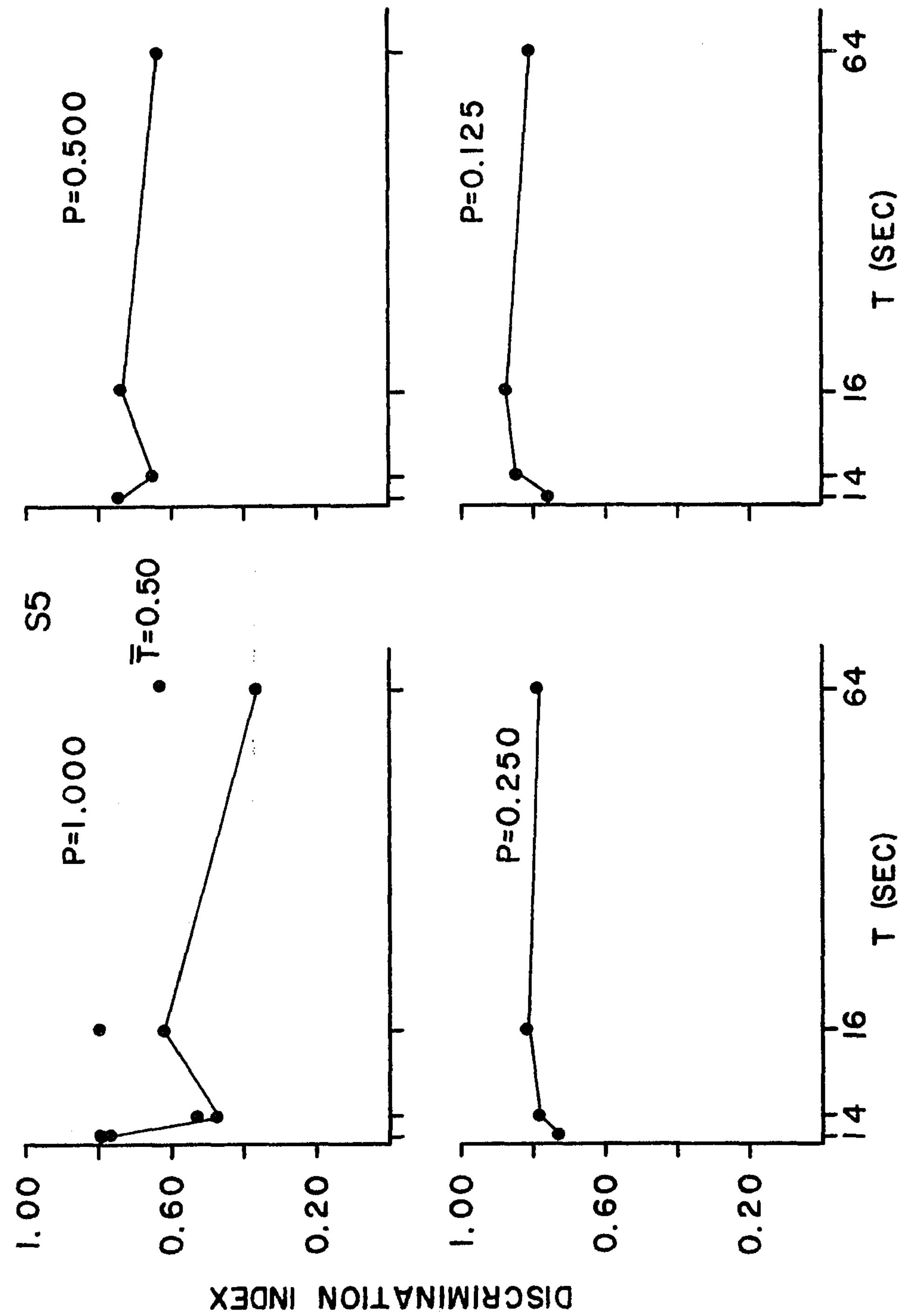
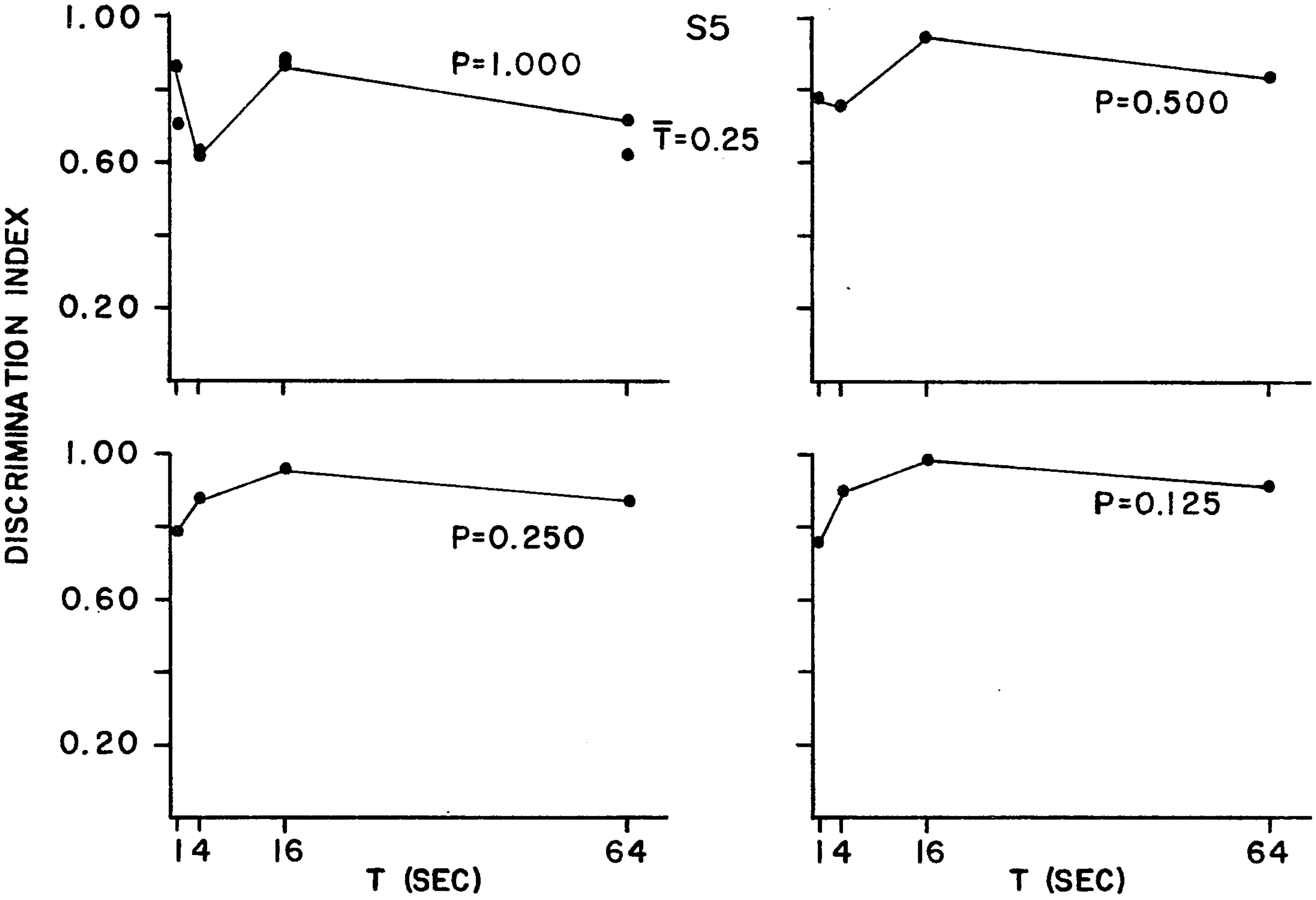

S5
$\bar{T}$=0.50
P=1.000
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1.00
0.60
0.20
1
4
16
64
T (SEC)
1
4
16
64
T (SEC)

Figure 53

Figure 54


S5
P=1.000
T̄=0.25
P=0.500
P=0.250
P=0.125
DISCRIMINATION INDEX
1.00
0.60
0.20
1
4
16
64
T (SEC)

celerated function of T (Figs. 44 and 45). Subject S5, on the other hand, produced a discrimination index that increased over T at $\overline{T}$=0.75, p=0.500 (Fig. 52). The remaining functions were non-monotonic, either passing through maxima (i.e., S1, $\overline{T}$=0.50; Fig. 41), minima (i.e., S3, $\overline{T}$=0.75, p=0.250 and p=0.125; Fig. 46), or seemingly unchanging across values of T (i.e., S5, $\overline{T}$=0.50, p=0.250; Fig. 53).

If responding were controlled by temporal cues provided by the reinforcement schedule, then the discrimination indices should approach 0.50 as p was reduced at all T-cycle lengths. That was not generally the case, and the functions do not appear systematically related to changes in p for any of the animals. As reinforcement became less "reliable," control over the response rate distribution within T-cycles shifted to the discriminative stimuli. In addition, if the response rate distribution were maintained by purely temporal cues, there would be no predicted change in the distribution as a function of T when p=1.000. Again, this was not generally the case, and there are clear, systematic effects of T on the discrimination indices in most cases.

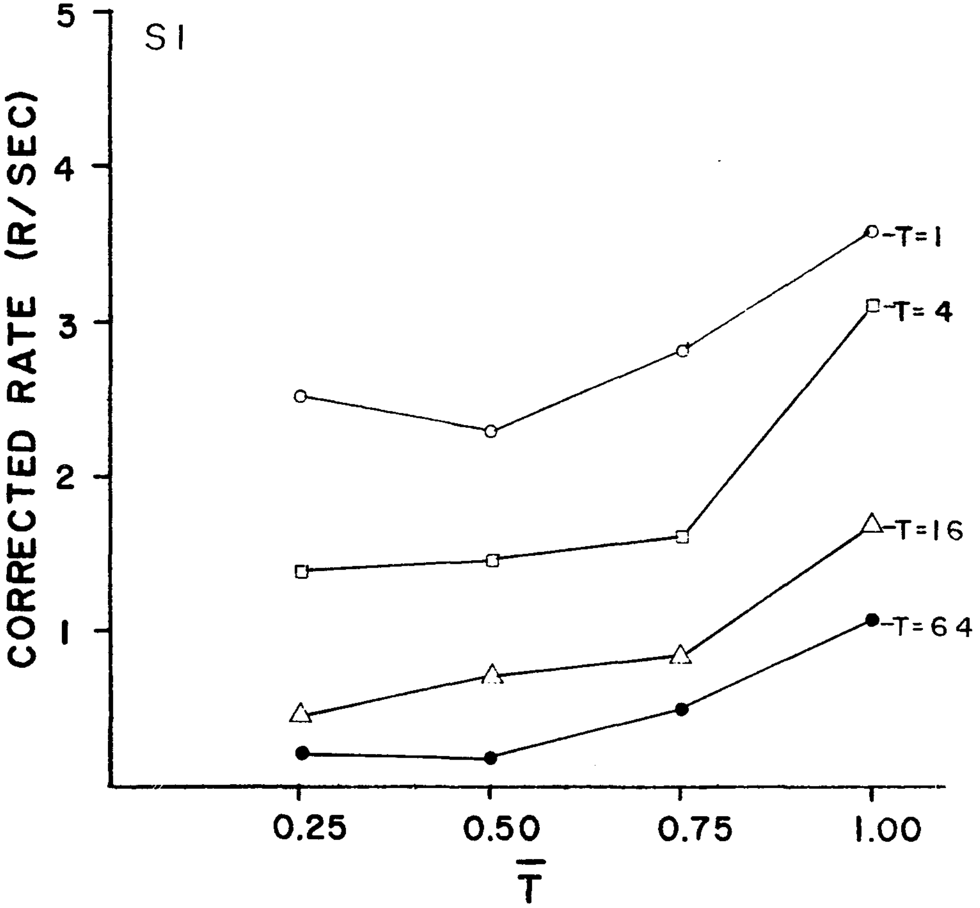
Whatever pattern developed, the animals were highly likely to intercept the start of each T-cycle with a response. A high rate of responding prior to the onset of S^D (and t^D) would ensure that a response would follow the onset of t^D shortly after its occurrence. Likewise, waiting for the discriminative stimulus to come on and then responding would also produce interception of the T-cycle with a response very shortly after its onset provided that the S^D-R latency was sufficiently low. Either "strategy" would produce reinforcement with equal frequency, and would likely continue. The major effect of the response pattern would appear in the number of T-cycles intercepted by a response. The data are shown in Tables 24-28, and except at the T=1 sec value, the overwhelming proportion of t^D periods contain at least one response. As $\overline{T}$ was reduced, a higher proportion of t^Ds were "missed," particularly at T=1 sec. Subject S3 showed this most clearly (Table 28). Missed T-cycles notwithstanding, obtained I_Sr values for all five subjects were quite close to predicted values (the predicted $I_Sr=T/p$) throughout the experiment, with the greatest variations from predicted values at the lowest p values (Tables 29-33). What is striking about the present data is the extent to which animals that began responding with the onset of S^D maintained high, stable response rates through S^D despite the fact that none but the first response in S^D was ever reinforced.

Notwithstanding the effects of the intrusion of the discriminative stimulus on the response pattern, $\overline{T}$ had a minimal effect on corrected rate. Figures 55-59 show corrected rate (averaged across values of p) as a function of $\overline{T}$. Rates across all T values tended to be slightly higher at $\overline{T}$=1.00 than at lower values for all animals, particularly at T=1 sec. Weissman (1963) also reported a minimal

Figures 55 through 59: Corrected rate as a function of $\overline{T}$.

Figures 55 through 59 show corrected response rate (responses per second with reinforcement time subtracted from the time base used for the calculations) as a function of $\overline{T}$ for subjects 1 through 5, respectively. Data are pooled across values of p, and represent all sessions at the indicated $\overline{T}$ values. T-cycle lengths for each curve are shown to the right of the curve.

Figure 55



S1
CORRECTED RATE (R/SEC)
5
4
3
2
1
0.25
0.50
0.75
1.00
$\overline{T}$
T=1
T=4
T=16
T=64

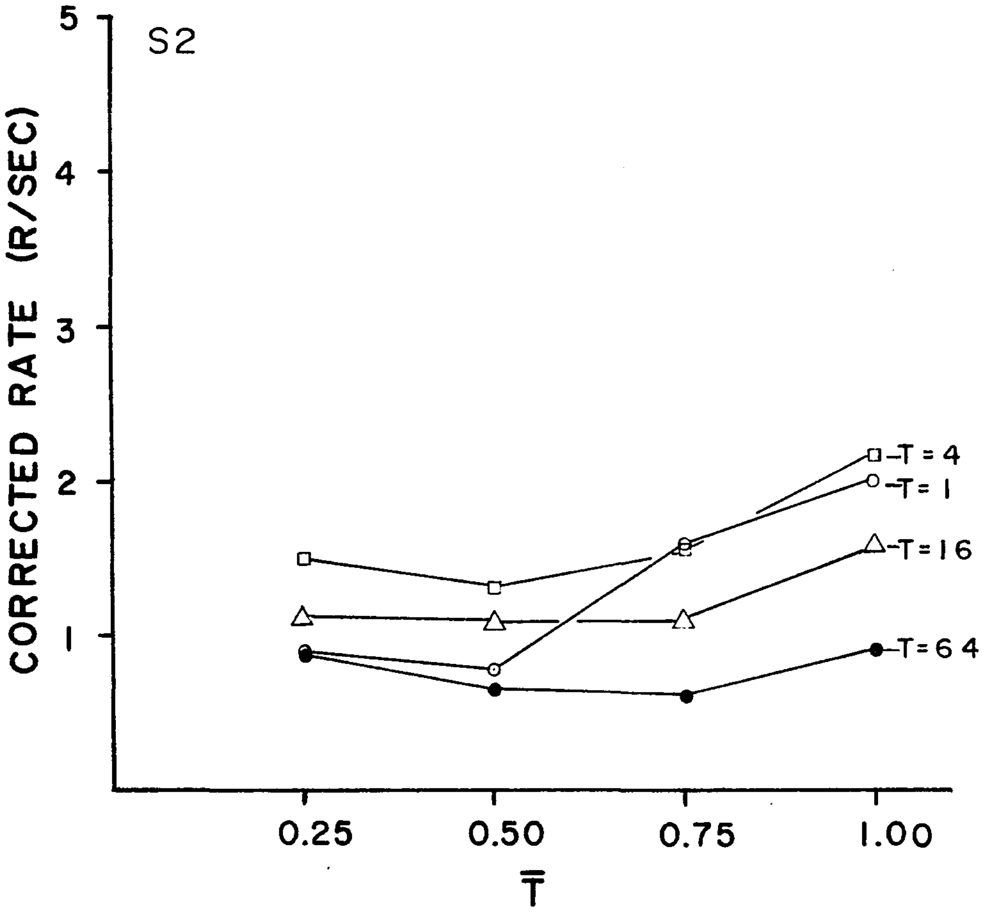

S2
CORRECTED RATE (R/SEC)
5
4
3
2
1
0.25
0.50
0.75
1.00
$\overline{T}$
-T = 4
-T = 1
-T = 16
-T = 64

Figure 56

Figure 57

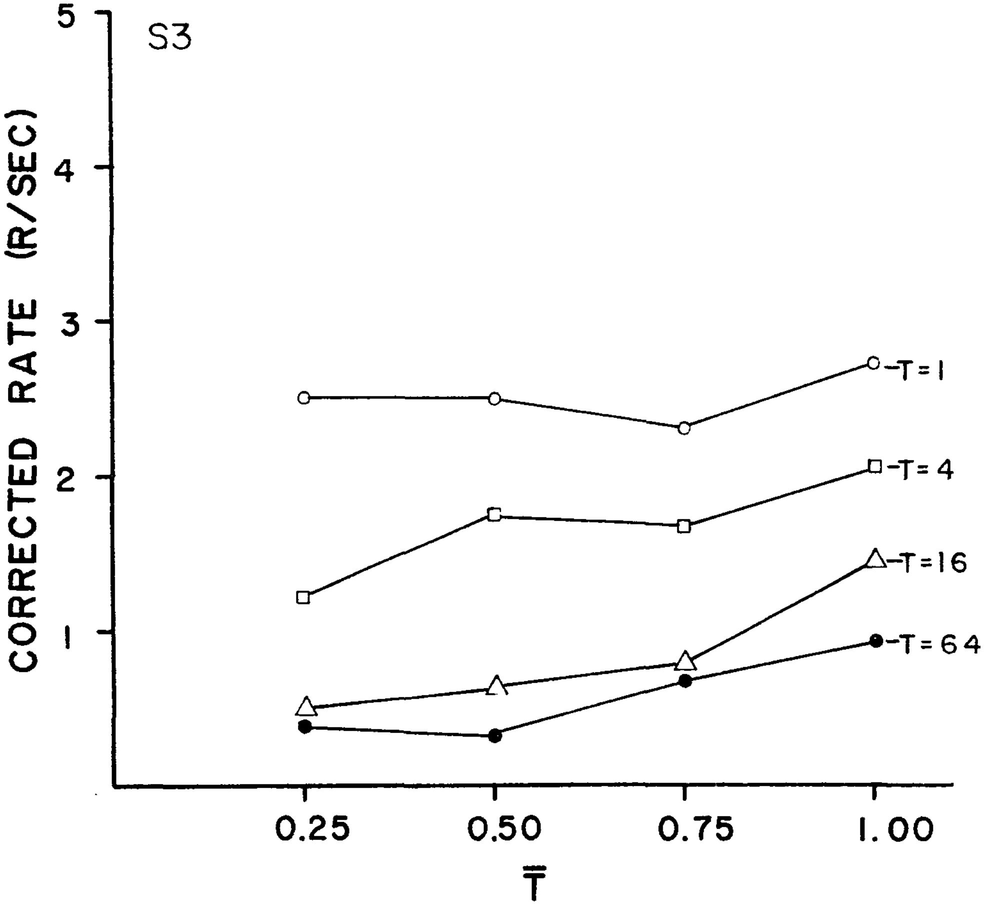

S3
CORRECTED RATE (R/SEC)
5
4
3
2
1
0.25
0.50
0.75
1.00
$\bar{\bar{T}}$
T = 1
T = 4
T = 16
T = 64

Figure 58

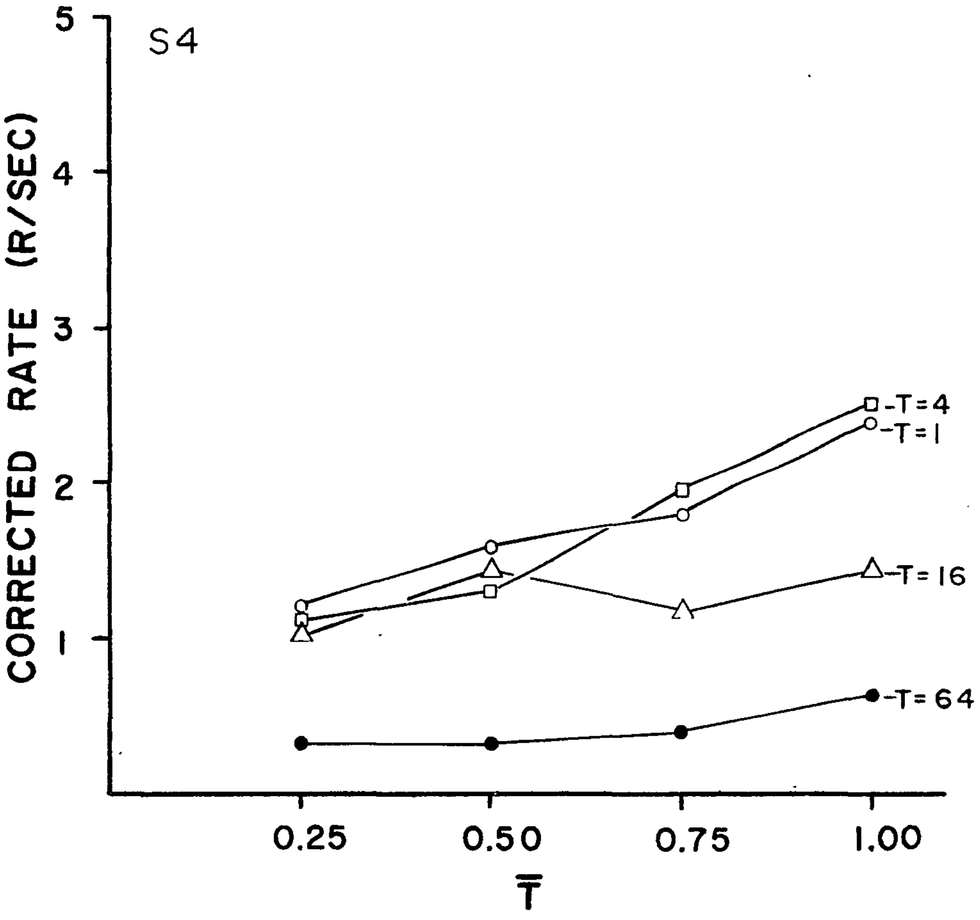
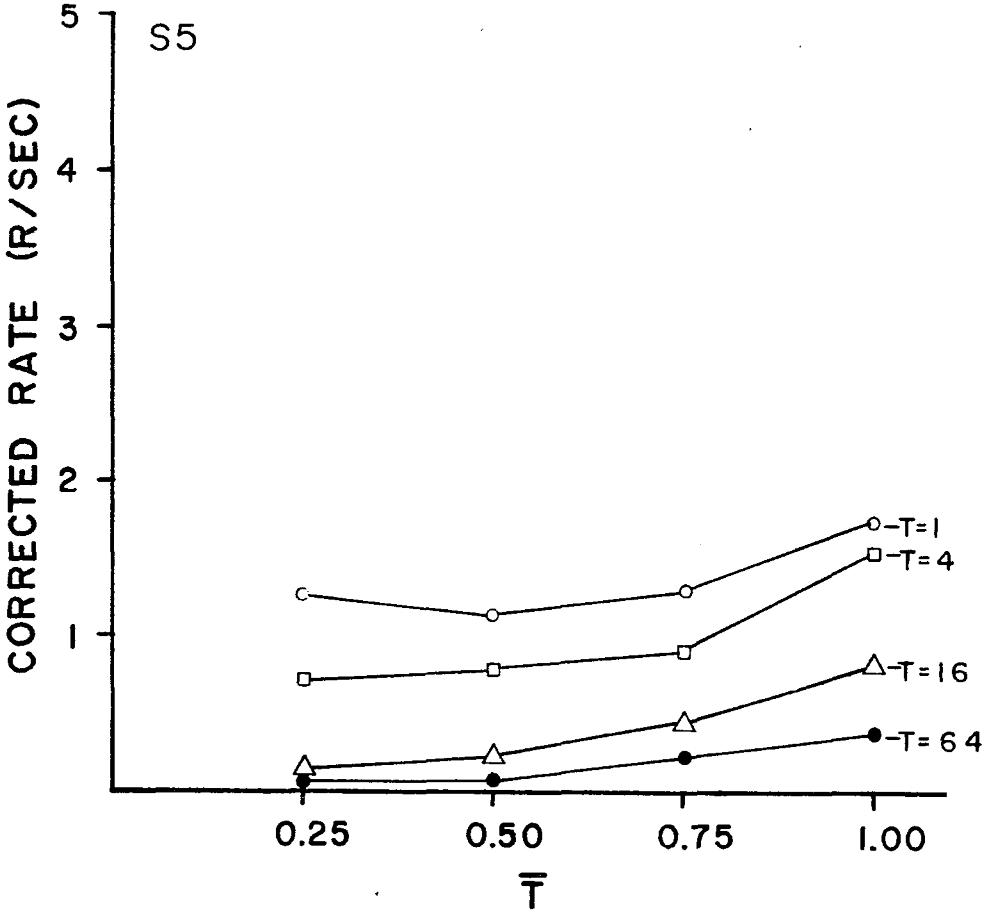

S4
CORRECTED RATE (R/SEC)
1
2
3
4
5
0.25
0.50
0.75
1.00
$\overline{T}$
-T=4
-T=1
-T=16
-T=64

Figure 59



effect of $\overline{T}$ on rate when the t^D period was longer than one second and t^D was accompanied by S^D. In the present study, all t^D periods were equal to or longer than one second except in the T=1 sec component where $\overline{T}$ was less than one, and it is there that the effects were most visible. Weissman, however, found rates increasing with decreasing $\overline{T}$, while the present data show just the reverse. While all of Weissman's procedures held p constant at 1, and the present study varied p, there was neither a systematic effect of p on corrected rate nor any obvious systematic effects of the interaction between p and $\overline{T}$. It is quite possible that reducing $\overline{T}$ to less than 0.25 would produce the more usual increases in response rate. Weissman (1963) for example, found rates increasing only below $\overline{T}$=0.33 (T=30 sec, t^D=1 sec). Millenson (1959) showed sharp rate increases below $\overline{T}$=0.05 (T=120 sec, t^D=6 sec; t^D accompanied by S^D).

Observations of the animals during the experiment revealed behavior during T=1 at $\overline{T}$ values less than one that might suggest a basis for some of the present data. At longer T-cycle lengths (4, 16, 64 sec), the birds pecked in a more or less regular manner once responding had begun. At T=1 sec, however, there was a great deal of activity, consisting of "misses" and pecks around the key correlated with S^D. The shorter the S^D, the more "frenzied" the behavior. The birds appeared to be pecking "at" the key light. Given the relative stability of the response patterns once established, it is unlikely that this effect would attenuate over time. The decrease in rate when $\overline{T}$ was changed from 1.00 to 0.50 was likely due to the restriction of the peck to the light-on period, effectively eliminating responding from the t^{Δ} portion of the T-cycle, at least for S1, S3, and S5. S2 and S4 generated their characteristic patterns (pecking at the termination of the key light) from the outset.

To review the major findings, then: (1) response rate, both corrected and running, was a decreasing function of T at all $\overline{T}$ and p values, and is adequately described as a hyperbola (Equation 16). (2) The post-reinforcement pause was a linear function of T (Equation 17), in which slope constants were less than one and intercept constants were close to one second. There was no systematic effect of p on the P_Sr. (3) While the major effect of reducing $\overline{T}$ was to increase the length of the P_Sr, the relation was not a simple one. (4) The pattern of responding within the T-cycles depended both on the length of the interval in effect at the time, p (where $\overline{T}$=1.00), and the presence or absence of stimuli cuing t^D and t^{Δ}, with each animal generating an idiosyncratic pattern at each T value. Some birds at some $\overline{T}$ and T values appeared to "scallop into" S^D from the previous S^{Δ}, while at other T values, did not respond until the onset of S^D. The result was that in some cases, rates in S^{Δ} exceeded those in S^D by a considerable margin. Where that occurred, it tended to occur at longer

T-cycle lengths and lower p values. The functions relating response rate to T in the two stimulus conditions reflected this and showed either of two characteristic patterns. In some cases, response rates in both S^D and S^Δ conditions were monotonic decreasing functions of T. In others, the S^D and S^Δ functions seemed to be almost inverses of each other, with rates in S^Δ increasing while rates in S^D decreased over T. In the latter case, the divergence increased with decreases in p. In the former case, rates in S^D were almost always higher than those in S^Δ. In all cases, regardless of the pattern of responding at longer T-cycles, the rate was always higher in S^D than in S^Δ at T=1 sec. (5) There were systematic effects of $\overline{T}$ on response rate, with rate marginally higher at $\overline{T}=1.00$ than at lower $\overline{T}$ values. (6) The discrimination index, which reflects responding in both portions of the T-cycle, differed across subjects and parameter values. There were three general patterns generated. The discrimination index was either a generally increasing, generally decreasing, or relatively flat function of T, with some functions appearing biphasic. (7) It appeared that the major controlling variable with respect to rate was T. $\overline{T}$ controlled the response distribution within each T-cycle when $\overline{T}$ was less than 1.00, as well as the length of the P_Sr. There was little effect of p at any other than at $\overline{T}=1.00$, where its major effect was to reduce the periodicity of responding as its value was reduced. (8) The independence of overall rate and response pattern characteristic of interval schedules was clearly reaffirmed in the present data. Animals showing opposite response patterns under identical schedule conditions in which S^D and S^Δ alternated maintained quite similar corrected and running rate functions. In some cases, stimulus control was virtually perfect, with practically all of the responses occurring in one of the two stimulus conditions. Whether the majority of responses occurred in S^D or in S^Δ most likely depended on which pattern was reinforced first. Animals that responded most in S^D did so from the first exposure to schedules in which $\overline{T}$ was less than 1.00, as did those with the opposite pattern. The failure to replicate earlier data showing increases in rate with decreases in $\overline{T}$ was due, in part, to the rather restricted range over which $\overline{T}$ was varied in this experiment, although hints of increased activity at short T and $\overline{T}$ values were evident in all five birds in this study.

GENERAL DISCUSSION

In t-schedules, T specifies the minimum and modal I_Sr. Since short I_Srs have noticeable and immediate effects on response rate, of the two characteristics of the I_Sr distribution determined by T, the minimum I_Sr is likely the primary determinant of response rate. To assume the alternative, that the modal I_Sr is the major determinant of rate, would require the further assumption that the organism somehow compares individual I_Sr values in the course of responding under a schedule of reinforcement.

Providing that the majority of an organism's IRTs are shorter than T, successive reinforcers will be separated by the shortest possible intervals. Since the organism's responding in time is likely to be more variable than the clock that produces T, it is possible that some IRTs will exceed T. It is these excessively long IRT values that provided the basis for Powers' (1971) function. The first effect of "missing" a T-cycle in the present experiment, is an increase in the time to the next reinforcer. That will likely be followed by an increase in rate and an I_Sr equal to T. These higher rates, since they produce reinforcers with short interreinforcer times, are likely to continue. Once responding is stable, the average response rate will likely exceed 1/T. Ferster and Skinner (1957) saw these "excess" responses as somehow indicating the inefficiency of an assumed internal clock controlling behavior under interval schedules, and failed to explore the extent to which the excess was lawfully related to the schedule parameters.

If the T-cycles are so short that no more than one response is possible in any single T-cycle, then the difference between the minimum required (in order to obtain all of the reinforcers) rate, R_R, and the obtained rate, R_o, cannot exceed zero:

$$R_o - R_R \leqq 0. \tag{18}$$

If, on the other hand, T is extremely long, then the difference between R_o and R_R can be substantial. In other words:

$$R_o - R_R = f(T). \tag{19}$$

Plotting equation (19) using data from the present experiment produced rather disorderly curves. If, however, the difference between obtained and required rates is divided by the obtained rate (a kind of "proportional excess"), and plotted as a function of T, orderly functions emerge. In other words:

$$\frac{R_o - R_R}{R_o} = f(T). \tag{20}$$

Since $R_R = 1/T$:

$$\frac{R - \frac{1}{T}}{R} = f(T), \tag{21}$$

where R is the obtained rate. Reducing equation (21):

$$1 - \frac{1}{TR} = f(T). \tag{22}$$

Response rate varies inversely with T, so equation (22) describes an increasing, monotonic function of T. As T approaches infinity, the proportional excess in responding approaches unity.

Plotting the data from the present experiment, as well as those of Cole (1968), Schoenfeld and Cumming (1957), and Skinner (1938), produced Fig. 60 (the data are tabled in Table 35). In this figure, Skinner's data were pooled across all four subjects, Schoenfeld and Cumming's data reflect the means of the corrected rates for their S7, S8, and S9 at $\overline{T}=0.75$, Cole's data are pooled across all three of his subjects at his $P_{S1}=1.0$, and the data from the present experiment are pooled across animals, p, and $\overline{T}$ values.

In order to determine f(T), it was necessary to find a transform of one of the variables that would produce a linear function. This was accomplished by inverting T. The function then becomes:

$$1-\frac{1}{TR} = \frac{-k}{T}+B. \tag{23}$$

Rearranging terms and solving for R:

$$R = \frac{1}{T(1-B)+k}. \tag{24}$$

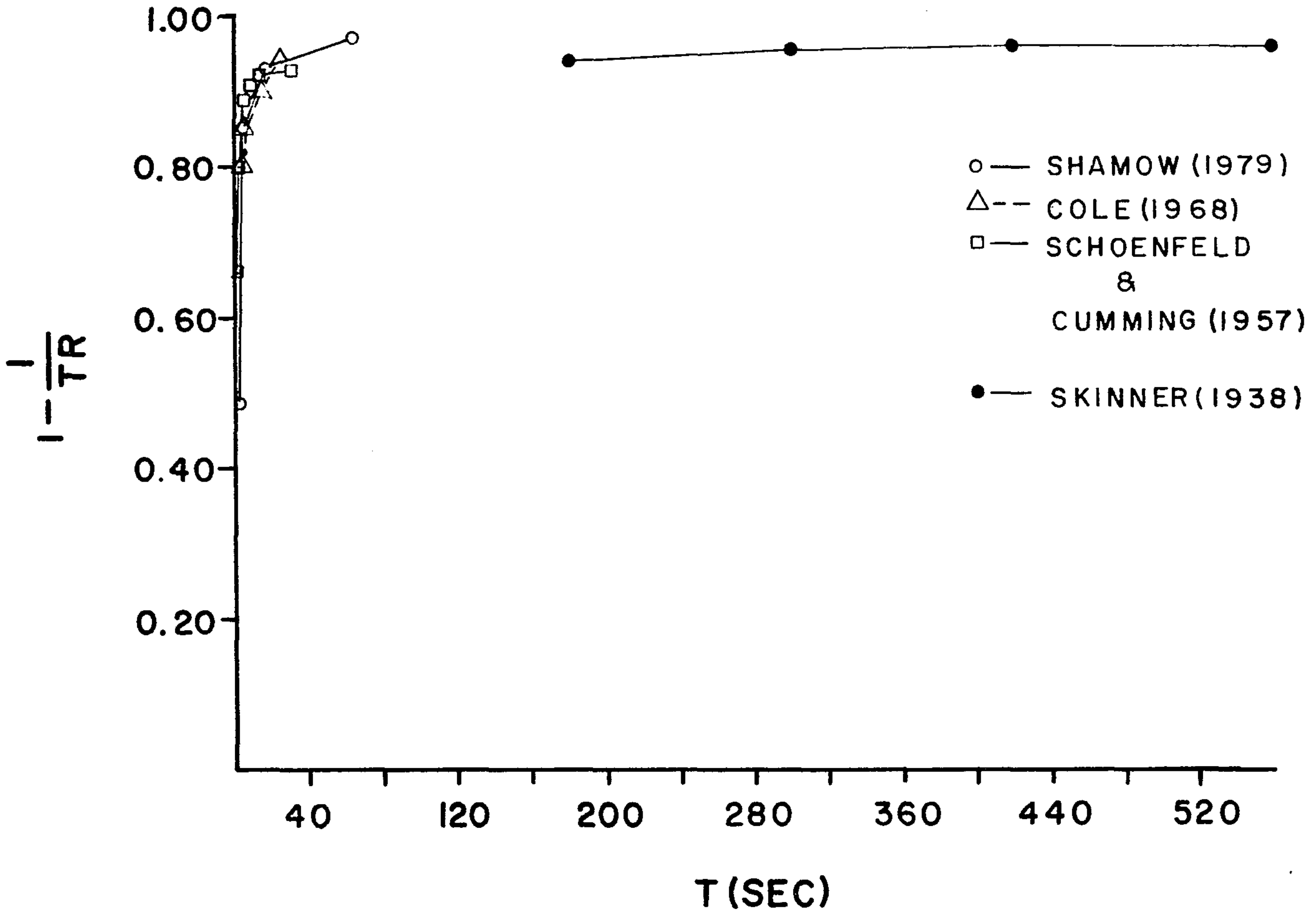
Equation (24) is, of course, equation (16).

The data from the three experiments were fitted to equation (16) by the method of least squares, with the results shown in Table 35. Since the constants (B and k) are derived from the data, the equation suffers from some of the same problems that have plagued similar attempts in

Figure 60: Proportional excess in responding as a function of T.

Figure 60 shows the proportion of responses above the necessary minimum (1/T) as a function of T in seconds. Data are taken from Cole (1968; triangles), Schoenfeld & Cumming (1957; rectangles), the present study (Shamow, 1979; open circles), and Skinner (1938; closed circles). All but Skinner's data are corrected response rates in responses per second. Skinner's data include reinforcement time. Procedures are explained in the text.

Figure 60


1.00
0.80
0.60
0.40
0.20
$1-\frac{1}{TR}$
40
120
200
280
360
440
520
T (SEC)
SHAMOW (1979)
COLE (1968)
SCHOENFELD & CUMMING (1957)
SKINNER (1938)

the past. However, unlike those in the "matching function," and in Lander and Irwin's (1968) equations, both constants represent empirically determinable events and reflect real response characteristics.

Judging from the result of fitting the data to equation (16), and the extent to which Fig. 60 shows all of the data lying on the same curve, it appears that the proportional excess in responding is a lawful function of T. Since Fig. 60 is an empirical curve (contrast with Fig. 12 in Herrnstein, 1970), and requires no "adjustments" for different subjects or unseen reinforcers, it likely represents real underlying processes.

The extent to which animals respond faster than "necessary," then, is determined by the schedule parameters, such that the I_Sr is kept close to or at the allowable minimum. Because VI tapes typically program no constant, repeating time modulus, their data do not easily lend themselves to this kind of analysis, but that the phenomenon occurs in t-schedules suggests that the same processes are at work in all cases in which the organism's response rate affects the temporal distribution of reinforcers. Powers (1971) had based his model on the same assumptions that led to the present analysis, but partially because the stimuli and schedule parameters differed considerably between the two studies, Powers' equation does not resemble equation (16). It is likely that some resolution of the differences between the two sets of quantitative predictions will emerge from further work. The differences are less in the underlying conception of behavior than in the details of the mathematics.

The present data show a relatively weak effect of p on both running and corrected rates. Since the effect of responding is to drive the interreinforcer rime to its minimum value, variability in the interreinforcer time distribution should be irrelevant. Responding should continue until a reinforcer is produced whether or not a particular reinforcer was preceded by a short or long interreinforcer interval. The two-state FI pattern, with high and invariant terminal rates and the seeming insensitivity of running rate to p in random ratio schedules support the notion that responding, once begun, continues at a stable rate until reinforcement. Sussman's (1975) data clearly show this effect, with rates of responding remaining constant through an interval during which the probability of reinforcement increased from 0.125 to 1.000.

Variability in the interreinforcer time distribution, however, translates into sequences of different individual interreinforcer times. With p values less than 1.0, the probability of an extremely long interreinforcer interval, while low, is greater than zero (equation 13). If there are sufficient extremely long interreinforcer times contiguous with each other, then it is likely that responding would begin to extinguish. At p=0.0, interreinforcer time is infinite, regardless of the value of T. Discontinuous functions are rare in nature, and it is likely that at some values of p, early declines in response rates would become visible. The present study neither explored a sufficient range of p values, nor allowed a single value of p to remain in effect long enough to examine this.

While control over the interreinforcer response pattern was clearly established with the introduction of S^D and S^Δ, there were a number of patterns evidenced. All of the patterns, however, allowed a response to occur shortly after the onset of S^D, ensuring that the interreinforcer times would be held to their minimum values. There was no restriction on the specific pattern that developed, and the final patterns that were to appear in the data were most likely maintained by their "non-contingent" reinforcement. The quantification of this effect, however, would require control over the conditions that initially determined the pattern at the time the discriminative stimuli were introduced. What is clear is that once developed, a pattern of interreinforcer responding remained quite consistent, changing in an orderly manner with changes in the parameters of both reinforcement and stimulus presentation schedules.

Since the P_Sr contributes to the response pattern, the variables that control the pattern control the pause. $\overline{T}$ affected the P_Sr, but the relation was non-monotonic. With only four values of $\overline{T}$ employed, the reason for the non-monotonic function was not clear. As in the p-rate relation, it appears, at least in the present data, that p is relatively ineffective in the control of the P_Sr, although Farmer's (1962) data would argue for a systematic effect of p and an interaction between T-cycle length and p. Resolution of this discrepancy in the data may depend on a systematic replication of the present study with extended exposure to each p value. The P_Sr is irrelevant to the servomechanism model, provided that its length does not intrude on the earliest opportunity for a reinforced response. At this stage of exploration of the P_Sr, the quantitative expression of the T-P_Sr function is best left linear, although some of the present curves might just as well be fit with power functions.

Equation (16) is not part of a set of "feedback equations." It simply describes rate as a function of a parameter of the schedule (T). A true set of feedback equations would require the quantitative description of both behavior and the reinforcers in real time. Equation (16) describes the averaged effects of many responses and stimulus intrusions, and may be thought of as preliminary. The further description of a servomechanism model would require first an exploration of the changes in the constants of equation (16) with changes in experimental conditions (deprivation, stimulus intensity, a wider range of T, $\overline{T}$, and p, longer exposure times), followed by an analysis of the behavior in real time, and perhaps some integration of the rate and P_Sr equations.

The behavior in the present analysis was in a continuous interaction with the stimuli it produced. Each individual stimulus intrusion (reinforcer) may be thought of as producing a disturbance in the continuous behavior stream such that:

> Under given conditions, the post-S1 perterbation in R subsides, not necessarily to the original level of ... R, with the time course of the damping dependent on the number and spacing of S1 repetitions (Schoenfeld, 1972, p. 59).

The analysis of the temporal course of the disturbance in the response stream and its decay are necessary for a more effective analysis of behavior under these schedules. This was the direction initially taken by Skinner, but in a descriptive, non-quantitative way. The t-system provides a convenient mechanism for the quantitative analysis of the interaction between the environment and behavior as the interaction unfolds in time.

The data presented in the tables to follow have been rounded to four decimal places to reduce cumulative errors during curve-fitting. They should not be considered meaningful beyond the second decimal.

Table 1

Session numbers are shown in the left-most column, corresponding $\bar{T}$ values in the second column, p values in the third, and under the appropriate T values (in seconds), the length of t^D and the expected interreinforcer time (T/p, shown in parentheses)

			T = 1		4		16		64	
Session #	$\bar{T}$	p	t^D	(T/p)	t^D	(T/p)	t^D	(T/p)	t^D	(T/p)
1- 10	1.00	1.000	1.00	(1.0)	4.0	(4.0)	16.0	(16.0)	64.0	(64.0)
11- 15	"	0.500	"	(2.0)	"	(8.0)	"	(32.0)	"	(128.0)
16- 20	"	0.250	"	(4.0)	"	(16.0)	"	(64.0)	"	(256.0)
21- 25	"	0.125	"	(8.0)	"	(32.0)	"	(128.0)	"	(512.0)
26- 30	"	1.000	"	(1.0)	"	(4.0)	"	(16.0)	"	(64.0)
31- 35	0.75	1.000	0.75	(1.0)	3.0	(4.0)	12.0	(16.0)	48.0	(64.0)
36- 40	"	0.500	"	(2.0)	"	(8.0)	"	(32.0)	"	(128.0)
41- 45	"	0.250	"	(4.0)	"	(16.0)	"	(64.0)	"	(256.0)
46- 50	"	0.125	"	(8.0)	"	(32.0)	"	(128.0)	"	(512.0)
51- 55	"	1.000	"	(1.0)	"	(4.0)	"	(16.0)	"	(64.0)
56- 60	0.50	1.000	0.50	(1.0)	2.0	(4.0)	8.0	(16.0)	32.0	(64.0)
61- 65	"	0.500	"	(2.0)	"	(8.0)	"	(32.0)	"	(128.0)
66- 70	"	0.250	"	(4.0)	"	(16.0)	"	(64.0)	"	(256.0)
71- 75	"	0.125	"	(8.0)	"	(32.0)	"	(128.0)	"	(512.0)
76- 80	"	1.000	"	(1.0)	"	(4.0)	"	(16.0)	"	(64.0)
81- 85	0.25	1.000	0.25	(1.0)	1.0	(4.0)	4.0	(16.0)	16.0	(64.0)
86- 90	"	0.500	"	(2.0)	"	(8.0)	"	(32.0)	"	(128.0)
91- 95	"	0.250	"	(4.0)	"	(16.0)	"	(64.0)	"	(256.0)
96-100	"	0.125	"	(8.0)	"	(32.0)	"	(128.0)	"	(512.0)
101-105	"	1.000	"	(1.0)	"	(4.0)	"	(16.0)	"	(64.0)

Table 2

Running rate for S1

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\overline{T}$=1.00				
p=1.000	6.8318	3.1346	1.8230	0.7611
	(8.9025)	(3.9818)	(1.4800)	(1.0743)
p=0.500	5.2280	3.8090	1.6727	0.9618
p=0.250	4.4004	4.1290	1.8865	1.2196
p=0.125	5.3846	2.9725	1.9977	1.5137
$\overline{X}$=	6.1495	3.6054	1.7720	1.1061
S.D.=	1.7705	0.5195	0.2011	0.2828
$\overline{T}$=0.75				
p=1.000	7.0086	3.0151	1.1280	0.7906
	(6.0346)	(1.9582)	(0.8957)	(0.3301)
p=0.500	4.2128	2.1481	0.8472	0.6596
p=0.250	3.9649	1.4996	0.8427	0.5594
p=0.125	3.3606	0.8328	0.7628	0.2918
$\overline{X}$=	4.9163	1.8908	0.8953	0.5263
S.D.=	1.5369	0.8073	0.1386	0.2134
$\overline{T}$=0.50				
p=1.000	7.0753	1.7160	0.9597	0.1800
	(5.7455)	(2.6246)	(0.9297)	(0.3161)
p=0.500	3.9709	1.5894	0.8448	0.2616
p=0.250	2.8947	1.1058	0.6203	0.1955
p=0.125	3.4891	1.4208	0.5363	0.1452
$\overline{X}$=	4.6351	1.6913	0.7836	0.2197
S.D.=	1.7300	0.5697	0.1811	0.0685
$\overline{T}$=0.25				
p=1.000	4.4405	1.9530	0.5911	0.1772
	(6.6171)	(1.7649)	(0.6388)	(0.3503)
p=0.500	3.4583	1.8246	0.4259	0.1174
p=0.250	3.6737	1.4583	0.4447	0.1938
p=0.125	3.5225	1.0395	0.4034	0.2419
$\overline{X}$=	4.3424	1.6081	0.5008	0.2161
S.D.=	1.3309	0.3661	0.1066	0.0872

Table 3

Running rate for S2

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	11.5514	2.9673	2.6177	1.4161
	(9.1548)	(2.8219)	(2.3778)	(1.1771)
p=0.500	2.3132	2.5076	1.6082	0.8689
p=0.250	2.5950	2.2235	1.2655	0.6645
p=0.125	2.9536	2.3368	1.1054	0.5999
$\bar{X}$=	5.7136	2.5714	1.7949	0.9454
S.D.=	4.3252	0.3161	0.6722	0.3463
$\bar{T}$=0.75				
p=1.000	8.3524	1.7876	1.6063	0.6939
	(3.4575)	(2.1325)	(1.4171)	(0.8232)
p=0.500	2.7982	1.7469	1.1350	0.6201
p=0.250	2.2715	1.6809	1.1159	0.6458
p=0.125	1.7946	1.6178	0.9641	0.5871
$\bar{X}$=	3.5728	1.7931	1.2477	0.6740
S.D.=	2.6523	0.2004	0.2587	0.0921
$\bar{T}$=0.50				
p=1.000	2.6191	1.3796	1.3808	0.9616
	(1.5063)	(1.6360)	(1.6272)	(1.0972)
p=0.500	1.1057	1.4648	1.2398	0.7358
p=0.250	0.9157	1.5499	1.1856	0.6051
p=0.125	1.1303	1.5720	1.1260	0.7363
$\bar{X}$=	1.4554	1.5205	1.3119	0.8272
S.D.=	0.6848	0.0998	0.1999	0.1981
$\bar{T}$=0.25				
p=1.000	0.9200	1.6193	1.7845	1.4546
	(1.5832)	(2.0901)	(1.4614)	(1.2545)
p=0.500	1.0489	1.5798	1.4309	1.0316
p=0.250	1.1783	1.5916	1.1084	0.8814
p=0.125	1.4024	1.6262	1.1560	0.7716
$\bar{X}$=	1.2266	1.7014	1.3882	1.0787
S.D.=	0.2674	0.2181	0.2722	0.2773

Table 4

Running rate for S3

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	9.2029	3.2656	2.0927	0.6450
	(6.0682)	(2.6283)	(1.2077)	(1.1730)
p=0.500	4.2968	2.7004	1.7315	0.9284
p=0.250	3.0344	2.0913	1.6001	1.1100
p=0.125	1.9868	1.9155	1.2874	0.9380
$\bar{X}$=	4.9178	2.5202	1.5839	0.9589
S.D.=	2.8377	0.5360	0.3572	0.2053
$\bar{T}$=0.75				
p=1.000	7.1186	2.4163	1.1065	0.6875
	(5.5090)	(2.3593)	(0.9365)	(0.3773)
p=0.500	3.3969	1.8598	0.8775	1.0369
p=0.250	2.8944	1.5904	0.9136	0.7916
p=0.125	2.0589	1.4261	0.6536	0.7189
$\bar{X}$=	4.1956	1.9304	0.8975	0.7224
S.D.=	2.0716	0.4458	0.1623	0.2367
$\bar{T}$=0.50				
p=1.000	5.1548	2.5149	0.8868	0.2623
	(5.2979)	(2.6103)	(0.7448)	(0.3457)
p=0.500	3.6106	1.9798	0.7949	0.2595
p=0.250	3.0517	1.6785	0.5760	0.3780
p=0.125	2.6424	1.3579	0.8266	0.5198
$\bar{X}$=	3.9515	2.0283	0.7658	0.3531
S.D.=	1.2145	0.5361	0.1180	0.1066
$\bar{T}$=0.25				
p=1.000	4.7969	2.2125	0.7929	0.3833
	(3.6377)	(2.2980)	(0.6378)	(0.3790)
p=0.500	3.2957	1.0948	0.4287	0.3235
p=0.250	2.9334	1.1435	0.4362	0.3304
p=0.125	2.5589	1.1145	0.7496	0.6266
$\bar{X}$=	3.4445	1.5721	0.6089	0.4086
S.D.=	0.8564	0.6246	0.1706	0.1249

Table 5

Running rate for S4

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	18.6473	4.1507	2.3010	0.7272
	(10.2462)	(3.6383)	(1.5780)	(1.0443)
p=0.500	3.8537	3.0249	1.4692	0.4564
p=0.250	3.0046	2.3592	1.1335	0.5722
p=0.125	2.6334	1.9134	1.2743	0.5015
$\bar{X}$=	7.6770	3.0173	1.5712	0.6603
S.D.=	6.8709	0.9113	0.4947	0.2380
$\bar{T}$=0.75				
p=1.000	8.8824	3.1375	1.2074	0.5867
	(7.6492)	(2.3441)	(1.8611)	(0.7040)
p=0.500	2.8362	2.2536	1.2776	0.4059
p=0.250	2.5177	1.7290	1.1289	0.3700
p=0.125	2.6742	1.8329	1.1877	0.4177
$\bar{X}$=	4.9119	2.2594	1.3325	0.4969
S.D.	3.0946	0.5571	0.3002	0.1428
$\bar{T}$=0.50				
p=1.000	12.6000	1.5738	2.0249	0.7107
	(11.1921)	(1.5481)	(2.2576)	(0.3695)
p=0.500	2.6430	1.2696	1.5347	0.3983
p=0.250	2.1143	1.5401	1.4587	0.4966
p=0.125	2.3644	1.8452	1.5099	0.5162
$\bar{X}$=	6.1828	1.5554	1.7572	0.4983
S.D.	5.2425	0.2039	0.3612	0.1342
$\bar{T}$=0.25				
p=1.000	4.4376	1.2891	2.1327	0.6666
	(2.0282)	(1.2925)	(1.4308)	(0.2365)
p=0.500	1.7387	1.4026	1.8215	0.5382
p=0.250	1.7243	1.4225	1.1828	0.5327
p=0.125	1.9363	1.7849	0.9349	0.4172
$\bar{X}$=	2.3730	1.4383	1.5005	0.4982
S.D.=	1.1614	0.2032	0.4818	0.1582

Table 6

Running rate for S5

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	11.1530	3.7223	1.5445	0.4561
	(4.5772)	(1.3459)	(0.7578)	(0.4437)
p=0.500	3.2866	2.3755	1.1506	0.3901
p=0.250	1.9184	1.3805	0.6458	0.3839
p=0.125	1.2066	0.9217	0.6431	0.3562
$\bar{X}$=	4.4282	1.8594	0.9504	0.4062
S.D.	3.9757	0.9536	0.3909	0.0422
$\bar{T}$=0.75				
p=1.000	6.1512	2.0633	0.6342	0.3936
	(7.7300)	(1.8192)	(0.7130)	(0.2086)
p=0.500	2.6107	1.0911	0.3726	0.2483
p=0.250	1.3067	0.7239	0.4017	0.2273
p=0.125	0.9823	0.6560	0.3897	0.1566
$\bar{X}$=	3.7562	1.2707	0.5022	0.2469
S.D.=	3.0222	0.6400	0.1592	0.0888
$\bar{T}$=0.50				
p=1.000	6.6193	2.3578	0.5251	0.2064
	(10.0396)	(2.1780)	(0.4778)	(0.1611)
p=0.500	1.8948	0.9344	0.2901	0.0589
p=0.250	1.0116	0.6234	0.2659	0.0839
p=0.125	1.0593	0.5223	0.2295	0.0813
$\bar{X}$=	4.1249	1.3232	0.3577	0.1237
S.D.=	4.0395	0.8780	0.0134	0.0571
$\bar{T}$=0.25				
p=1.000	5.1747	2.1286	0.4676	0.1342
	(2.9930)	(2.1139)	(0.5271)	(0.1601)
p=0.500	2.1700	0.9895	0.2438	0.0809
p=0.250	1.5349	0.4780	0.1618	0.0679
p=0.125	0.9204	0.4254	0.1869	0.0651
$\bar{X}$=	2.5586	1.2271	0.3174	0.1016
S.D.=	1.6519	0.8455	0.1682	0.0430

Table 7

Corrected rate for S1

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	2.3401	2.2137	1.5656	0.7179
	(3.3781)	(3.1852)	(1.3729)	(1.0380)
p=0.500	3.4813	3.4037	1.5906	0.9108
p=0.250	3.8590	3.9796	1.8426	1.2097
p=0.125	5.0122	2.9139	1.9737	1.5067
$\bar{X}$=	3.6141	3.1392	1.6991	1.0766
S.D.=	0.9632	0.6492	0.2385	0.3001
$\bar{T}$=0.75				
p=1.000	2.3579	2.4023	1.0461	0.7612
	(2.3063)	(1.5247)	(0.8178)	(0.2489)
p=0.500	2.8811	1.9625	0.8125	0.6371
p=0.250	3.4981	1.4281	0.8238	0.5479
p=0.125	3.1334	0.8106	0.7491	0.2852
$\bar{X}$=	2.8354	1.6256	0.8499	0.4961
S.D.=	0.5094	0.5979	0.1138	0.2227
$\bar{T}$=0.50				
p=1.000	1.6400	1.3883	0.8711	0.1335
	(1.6387)	(2.1664)	(0.7821)	(0.2088)
p=0.500	2.4295	1.4580	0.8047	0.2230
p=0.250	2.5056	1.0621	0.6052	0.1885
p=0.125	3.1980	1.3824	0.4762	0.1382
$\bar{X}$=	2.2824	1.4519	0.7079	0.1784
S.D.=	0.6589	0.4073	0.1626	0.0408
$\bar{T}$=0.25				
p=1.000	1.6082	1.5515	0.4911	0.1302
	(2.4311)	(1.2893)	(0.4130)	(0.2993)
p=0.500	2.4138	1.6606	0.3728	0.1001
p=0.250	2.9631	1.3750	0.4377	0.1861
p=0.125	3.2163	1.0064	0.3885	0.2372
$\bar{X}$=	2.5265	1.3766	0.4206	0.1906
S.D.	0.6188	0.2529	0.0465	0.0804

Table 8

Corrected rate for S2

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	1.5308	2.1007	2.1077	1.2631
	(2.5072)	(2.1019)	(2.1074)	(1.0977)
p=0.500	1.1324	2.2208	1.4681	0.8476
p=0.250	2.1408	2.1055	1.2262	0.6573
p=0.125	2.7414	2.2620	1.0852	0.5958
$\bar{X}$=	2.0105	2.1582	1.5989	0.8923
S.D.=	0.6706	0.0774	0.4841	0.2850
$\bar{T}$=0.75				
p=1.000	1.4882	1.4141	1.4304	0.6305
	(1.2757)	(1.6699)	(1.0692)	(0.6423)
p=0.500	1.6938	1.5847	1.0329	0.5549
p=0.250	1.9213	1.6121	1.0444	0.6168
p=0.125	1.6427	1.5797	0.9101	0.5657
$\bar{X}$=	1.6043	1.5721	1.0974	0.6020
S.D.=	0.2405	0.0953	0.1960	0.0393
$\bar{T}$=0.50				
p=1.000	0.6870	1.1472	0.9505	0.6426
	(0.6982)	(1.3052)	(1.1925)	(0.7445)
p=0.500	0.6507	1.1374	1.0512	0.5991
p=0.250	0.7702	1.4818	1.0959	0.5689
p=0.125	1.0485	1.5246	1.0599	0.7152
$\bar{X}$=	0.7709	1.3192	1.0700	0.6541
S.D.=	0.1611	0.1813	0.0872	0.0747
$\bar{T}$=0.25				
p=1.000	0.4529	1.2625	1.2678	1.1178
	(1.0573)	(1.6597)	(0.9839)	(0.9815)
p=0.500	0.6862	1.4114	1.2126	0.8945
p=0.250	1.0581	1.5324	1.0460	0.8441
p=0.125	1.3045	1.5863	1.1174	0.7537
$\bar{X}$=	0.9118	1.4905	1.1255	0. 83
S.D.=	0.3385	0.1564	0.1165	0.1387

Table 9

Corrected rate for S3

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	3.2480	2.4794	1.7511	0.5893
	(2.4281)	(1.7119)	(1.0337)	(1.1049)
p=0.500	2.3971	2.4117	1.5724	0.8982
p=0.250	2.6219	1.9492	1.5340	1.0958
p=0.125	1.8446	1.7928	1.2586	0.9317
$\bar{X}$=	2.6879	2.0690	1.4300	0.9240
S.D.=	0.6058	0.3550	0.2831	0.2092
$\bar{T}$=0.75				
p=1.000	2.3746	1.9300	0.9731	0.6529
	(2.6237)	(1.9200)	(0.6654)	(0.2835)
p=0.500	2.2481	1.6494	0.8023	1.0094
p=0.250	2.4329	1.5074	0.8755	0.7746
p=0.125	2.4329	1.5074	0.8755	0.7746
$\bar{X}$=	2.3091	1.6791	0.7912	0.6844
S.D.=	0.2821	0.2428	0.1406	0.2626
$\bar{T}$=0.50				
p=1.000	2.0837	1.9679	0.6552	0.2176
	(2.7289)	(2.0934)	(0.4427)	(0.2288)
p=0.500	2.6574	1.7290	0.6627	0.2377
p=0.250	2.6747	1.5989	0.5390	0.3632
p=0.125	2.4507	1.3139	0.7944	0.4993
$\bar{X}$=	2.5191	1.7406	0.6188	0.3093
S.D.=	0.2653	0.3076	0.1337	0.1215
$\bar{T}$=0.25				
p=1.000	2.5652	1.7287	0.5416	0.3142
	(2.3717)	(1.4356)	(0.4298)	(0.3003)
p=0.500	2.6164	0.9429	0.3500	0.2973
p=0.250	2.6044	1.0243	0.4033	0.3179
p=0.125	2.3590	1.0480	0.7344	0.6118
$\bar{X}$=	2.5033	1.2359	0.4918	0.3683
S.D.=	0.1275	0.3349	0.1526	0.1364

Table 10

Corrected rate for S4

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	2.3859	3.1289	2.0909	0.6412
	(2.1340)	(2.7573)	(1.3315)	(0.9551)
p=0.500	2.5954	2.6687	1.3605	0.6381
p=0.250	2.5083	2.2125	1.1081	0.5632
p=0.125	2.4108	1.8338	1.2389	0.4975
$\bar{X}$=	2.4069	2.5202	1.4260	0.6590
S.D.=	0.1737	0.5036	0.3845	0.1758
$\bar{T}$=0.75				
p=1.000	1.2227	2.4384	1.0477	0.5450
	(1.5604)	(1.8598)	(1.5611)	(0.4002)
p=0.500	1.7336	2.0417	1.1702	0.3571
p=0.250	2.0887	1.6501	1.0629	0.3470
p=0.125	2.3814	1.7843	1.1415	0.4000
$\bar{X}$=	1.7974	1.9639	1.1967	0.4099
S.D.=	0.4518	0.3231	0.2101	0.0794
$\bar{T}$=0.50				
p=1.000	1.3233	0.9679	1.3483	0.2259
	(1.2645)	(1.1635)	(1.7565)	(0.2115)
p=0.500	1.4991	1.1600	1.3331	0.2625
p=0.250	1.7367	1.4759	1.3633	0.4477
p=0.125	2.1188	1.8059	1.4346	0.4949
$\bar{X}$=	1.5885	1.3146	1.4472	0.3297
S.D.=	0.3487	0.3295	0.1772	0.1320
$\bar{T}$=0.25				
p=1.000	0.9105	0.6201	1.1554	0.1456
	(0.9139)	(0.9474)	(0.6596)	(0.0727)
p=0.500	1.0488	1.1102	1.4327	0.4291
p=0.250	1.4262	1.2993	1.0671	0.4686
p=0.125	1.7421	1.6877	0.8693	0.4975
$\bar{X}$=	1.2063	1.1329	1.0368	0.3227
S.D.=	0.3636	0.3979	0.2924	0.1981

Table 11

Corrected rate for S5

T-cycle lengths are in seconds. Response rates are in responses per second. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	1.0655	2.7095	2.2103	0.4194
	(1.5032)	(0.7037)	(0.6035)	(0.4175)
p=0.500	2,1782	2,0237	1.0428	0.3778
p=0.250	1.7290	1.3260	0.6462	0.3764
p=0.125	1.1437	0.8964	0.6300	0.3520
$\bar{X}$=	1.7239	1.5319	0.8266	0.3866
S.D.=	0.4208	0.8308	0.2806	0.0291
$\bar{T}$=0.75				
p=1.000	1.6294	1.4055	0.5396	0.3847
	(1.2953)	(0.9502)	(0.5404)	(0.1750)
p=0.500	1.6239	0.8953	0.3183	0.2345
p=0.250	1.0348	0.6295	0.3770	0.2223
p=0.125	0.8873	0.6149	0.3717	0.1523
$\bar{X}$=	1.2941	0.8991	0.4285	0.2338
S.D.=	0.3369	0.3211	0.1048	0.0908
$\bar{T}$=0.50				
p=1.000	1.2828	1.0815	0.2964	0.0927
	(1.3783)	(0.9930)	(0.2214)	(0.0595)
p=0.500	1.1320	0.8054	0.2092	0.0687
p=0.250	0.8644	0.5407	0.2332	0.0761
p=0.125	0.9728	0.5005	0.2152	0.0776
$\bar{X}$=	1.1261	0.7842	0.2351	0.0749
S.D.=	0.2122	0.2609	0.0354	0.0123
$\bar{T}$=0.25				
p=1.000	1.3006	0.9803	0.1644	0.0889
	(1.3996)	(0.8685)	(0.1573)	(0.0910)
p=0.500	1.4430	0.7300	0.1655	0.0656
p=0.250	1.2802	0.3856	0.1354	0.0596
p=0.125	0.8525	0.3895	0.1753	0.0614
$\bar{X}$=	1.2552	0.6708	0.1596	0.0733
S.D.=	0.2350	0.2733	0.0150	0.0154

Table 12

Post-reinforcement pause for S1

T-cycle lengths are in seconds. P_Sr values are in seconds. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	0.7600	1.2150	2.3250	3.8000
	(0.6800)	(0.8100)	(1.1800)	(2.1950)
p=0.500	0.8050	0.9300	1.9500	2.7300
p=0.250	0.7700	0.9450	2.1150	2.9800
p=0.125	0.8000	1.0150	2.0350	3.3250
$\bar{X}$=	0.7630	0.9830	1.9210	3.0060
S.D.=	0.0502	0.1492	0.4370	0.6056
$\bar{T}$=0.75				
p=1.000	0.7150	0.7850	1.1850	2.6500
	(0.7350)	(0.9450)	(1.4000)	(16.1250)
p=0.500	0.7300	0.7750	1.5050	5.5100
p=0.250	0.8600	0.9350	2.1400	8.2950
p=0.125	0.8850	1.1900	3.5000	12.2900
$\bar{X}$=	0.7850	0.9260	1.9460	8.9740
S.D.=	0.0807	0.1679	0.9387	5.3522
$\bar{T}$=0.50				
p=1.000	1.0100	0.7700	1.4550	16.2550
	(1.0500)	(0.7150)	(2.4850)	(21.9300)
p=0.500	0.8400	0.7550	1.8600	21.3500
p=0.250	1.0600	1.1400	2.1350	18.5050
p=0.125	1.1200	1.1500	3.6350	38.4750
$\bar{X}$=	1.0160	0.9060	2.3140	23.3030
S.D.=	0.1060	0.2191	0.8292	8.7833
$\bar{T}$=0.25				
p=1.000	1.2450	0.8350	3.1150	17.0050
	(0.9150)	(1.1900)	(5.4750)	(10.2450)
p=0.500	0.9600	1.0350	4.5400	28.0000
p=0.250	1.0300	1.4300	2.4450	15.1775
p=0.125	1.3150	1.7150	7.6900	15.9400
$\bar{X}$=	1.0930	1.2410	4.6530	17.2735
S.D.=	0.1773	0.3429	2.0708	6.5326

Table 13

Post-reinforcement pause for S2

T-cycle lengths are in seconds. P_Sr values are in seconds. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	1.1450	1.1800	2.8800	7.0100
	(0.7850)	(1.1100)	(1.8400)	(4.3850)
p=0.500	1.9683	1.1950	3.4950	3.8933
p=0.250	1.2400	1.2900	3.3100	3.7300
p=0.125	0.9450	1.3200	3.0400	4.9200
$\bar{X}$=	1.2167	1.2190	2.9130	4.8057
S.D.=	0.4557	0.0855	0.6452	1.3117
$\bar{T}$=0.75				
p=1.000	1.0150	0.9150	1.9350	6.2700
	(1.4750)	(0.9050)	(3.9400)	(13.9850)
p=0.500	0.9550	0.9100	3.9200	13.9300
p=0.250	0.8550	0.9850	5.8150	18.3950
p=0.125	1.0650	1.1750	8.9250	23.5200
$\bar{X}$=	1.0730	0.9780	4.9070	15.2200
S.D.=	0.2379	0.1149	2.6321	6.3691
$\bar{T}$=0.50				
p=1.000	1.8500	0.9100	5.1200	21.3150
	(1.8050)	(0.9050)	(4.4900)	(20.3800)
p=0.500	3.1800	1.0950	6.4600	23.0500
p=0.250	2.9800	1.1600	6.3900	18.9700
p=0.125	1.6500	1.1950	8.8150	19.0000
$\bar{X}$=	2.2930	1.0530	6.2550	20.5430
S.D.=	0.7257	0.1376	1.6596	1.7148
$\bar{T}$=0.25				
p=1.000	2.3550	1.2050	5.0000	15.2150
	(1.3950)	(0.9400)	(5.5050)	(13.7150)
p=0.500	2.4700	1.1850	5.5700	18.3550
p=0.250	1.8200	1.4350	7.1450	15.0250
p=0.125	1.4850	1.2300	6.6850	15.6950
$\bar{X}$=	2.0250	1.1990	5.9810	15.6010
S.D.=	0.6696	0.1760	0.8956	1.7052

Table 14

Post-reinforcement pause for S3

T-cycle lengths are in seconds. P_Sr values are in seconds. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	0.6950	0.9700	2.6300	5.5450
	(0.8250)	(1.6000)	(2.3400)	(3.7800)
p=0.500	0.6450	1.1250	3.5600	5.2000
p=0.250	0.7800	1.7250	3.2000	4.2451
p=0.125	1.0550	2.9500	4.4500	5.2500
$\bar{X}$=	0.8000	1.6740	3.2360	4.8040
S.D.=	0.1590	0.7799	0.8292	0.7526
$\bar{T}$=0.75				
p=1.000	0.7650	0.8250	1.9450	3.3200
	(0.6100)	(0.7500)	(4.7350)	(17.1850)
p=0.500	0.8150	1.0100	3.4950	5.0250
p=0.250	0.9300	1.0700	3.7550	8.1500
p=0.125	1.2250	1.2500	3.9700	19.6250
$\bar{X}$=	0.8690	0.9810	3.5800	10.6610
S.D.=	0.2298	0.1993	1.0244	7.3293
$\bar{T}$=0.50				
p=1.000	0.7533	1.2333	5.4267	9.1867
	(0.5400)	(0.8000)	(6.7200)	(22.1100)
p=0.500	0.6850	0.8600	6.2350	12.3050
p=0.250	0.6750	1.0938	7.0438	16.4000
p=0.125	0.8550	1.6050	7.5000	24.1100
$\bar{X}$=	0.7017	1.1184	6.5851	16.8223
S.D.=	0.1154	0.3235	0.7953	6.3237
$\bar{T}$=0.25				
p=1.000	0.6050	0.8950	5.0600	11.6050
	(0.5600)	(1.4700)	(5.2300)	(13.7950)
p=0.500	0.6700	1.6050	7.7150	13.4950
p=0.250	0.8050	2.4150	6.6250	14.5900
p=0.125	1.0150	2.8650	3.4600	16.7900
$\bar{X}$=	0.7310	1.8500	5.6180	14.0550
S.D.=	0.1837	0.7852	1.6225	1.8808

Table 15

Post-reinforcement pause for S4

T-cycle lengths are in seconds. P_Sr values are in seconds. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	0.8850	1.0000	2.0500	7.8900
	(0.8600)	(0.9813)	(2.5100)	(5.6700)
p=0.500	0.8650	1.0750	2.5200	4.1200
p=0.250	0.7900	1.3900	2.8200	5.3450
p=0.125	0.9000	1.9600	5.5950	7.4100
$\bar{X}$=	0.8600	1.2813	3.0990	6.0870
S.D.=	0.0423	0.4136	1.4222	1.5488
$\bar{T}$=0.75				
p=1.000	1.2050	0.8450	2.1950	4.7000
	(1.1400)	(0.8450)	(2.6400)	(25.5250)
p=0.500	1.2050	0.9050	3.6350	22.3350
p=0.250	1.0150	0.9600	5.2450	18.8350
p=0.125	1.0550	1.2250	5.9650	25.1500
$\bar{X}$=	1.1240	0.9560	3.9360	19.3126
S.D.	0.0866	0.1578	1.6303	8.5957
$\bar{T}$=0.50				
p=1.000	1.2800	0.9600	3.4300	44.8450
	(1.3750)	(1.0000)	(3.5700)	(25.8000)
p=0.500	1.2400	0.8150	4.7100	45.5550
p=0.250	1.1250	1.0050	5.9350	25.3100
p=0.125	1.0850	1.1250	7.6800	30.8000
$\bar{X}$=	1.2210	0.9810	5.0650	34.4820
S.D.=	0.1175	0.1114	1.7769	10.0167
$\bar{T}$=0.25				
p=1.000	1.7150	2.1950	7.9550	50.6000
	(2.1800)	(1.7600)	(8.2400)	(39.3101)
p=0.500	1.5800	2.5850	6.3950	31.7700
p=0.250	1.6200	1.8200	10.5950	37.8050
p=0.125	1.4900	2.9500	10.7900	26.5900
$\bar{X}$=	1.7170	2.2620	8.7960	37.2150
S.D.=	0.2711	0.5073	1.8717	9.0337

Table 16

Post-reinforcement pause for S5

T-cycle lengths are in seconds. P_Sr values are in seconds. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

	T			
	1	4	16	64
$\bar{T}$=1.00				
p=1.000	0.9950	1.0950	3.7600	5.2650
	(1.0800)	(2.1150)	(3.3250)	(4.0400)
p=0.500	0.7300	1.6000	2.8850	5.3550
p=0.250	0.7200	1.1900	2.3650	7.6500
p=0.125	0.9050	1.4850	3.7200	7.7650
$\bar{X}$=	0.8860	1.4970	3.2110	6.0150
S.D.=	0.1595	0.4027	0.5907	1.6305
$\bar{T}$=0.75				
p=1.000	1.0100	0.9850	2.7550	3.3250
	(1.4200)	(2.0400)	(4.1100)	(12.3400)
p=0.500	1.1000	1.9700	6.3400	10.1150
p=0.250	1.8950	3.1900	6.7000	9.0750
p=0.125	2.2450	3.3850	8.9400	13.7800
$\bar{X}$=	1.5340	2.3140	5.7690	9.7270
S.D.=	0.5272	0.9841	2.4023	4.0254
$\bar{T}$=0.50				
p=1.000	1.4050	2.1500	7.1850	36.6150
	(1.2050)	(2.3050)	(8.1600)	(31.0350)
p=0.500	1.6300	2.9250	11.2300	33.1100
p=0.250	1.6100	9.1350	11.5300	34.9200
p=0.125	1.7050	2.9000	12.6400	31.3750
$\bar{X}$=	1.5106	3.8830	10.1490	33.4110
S.D.=	0.2043	2.9564	2.3464	2.3677
$\bar{T}$=0.25				
p=1.000	1.4650	2.4950	10.3950	21.0500
	(1.3500)	(3.0250)	(10.9900)	(27.4550)
p=0.500	1.5800	3.2400	12.0250	31.9650
p=0.250	1.9000	5.4750	16.1150	39.8350
p=0.125	1.8200	4.7400	14.9200	41.6250
$\bar{X}$=	1.6230	3.7950	12.8890	32.3860
S.D.=	0.2329	1.2556	2.5052	8.5709

Tables 17-21

Component rates and discrimination indices for S1-S5

T-cycle lengths are in seconds. Rates in t^D (R^D) and t^Δ (R^Δ) are in responses per second. Discrimination indices (D.I.) are computed as defined in the text. Values in parentheses are recovery values at p=1.000. All tabled values are means of five sessions.

Table 17

Component rates and discrimination indices for S1

		T			
		1	4	16	64
$\bar{T}$=0.75					
p=1.000	R^D	2.5332	2.9580	1.3546	0.9606
		(2.5926)	(1.7127)	(1.0034)	(0.1671)
	R	1.3939	0.7200	0.1150	0.1436
		(1.4217)	(0.9000)	(0.4900)	(0.4950)
	D.I.	0.6662	0.8100	0.9185	0.8516
		(0.6569)	(0.6635)	(0.6743)	(0.2552)
p=0.500	R^D	3.1972	2.4168	1.0023	0.6707
	R	1.9102	0.5744	0.3222	0.5364
	D.I.	0.6296	0.8080	0.8116	0.5562
p=0.250	R^D	3.8252	1.6795	0.9987	0.5988
	R	3.5724	0.6405	0.3056	0.3952
	D.I.	0.6062	0.7259	0.7528	0.5972
p=0.125	R^D	3.5943	0.9153	9.8950	0.2802
	R	1.8919	0.4736	0.3094	0.3004
	D.I.	0.6563	0.6688	0.7403	0.4887
$\bar{X}$	R^D	3.1485	1.3365	1.0508	0.5355
	R	1.8380	0.6617	0.3084	0.3747
	D.I.	0.6430	0.7352	0.7795	0.5498
$\bar{T}$=0.50					
p=1.000	R^D	2.7264	1.7919	1.2757	0.1119
		(2.3535)	(1.7347)	(0.8630)	(0.1711)
	R	0.4996	0.9700	0.4600	0.1593
		(0.8393)	(2.6200)	(0.7000)	(0.2466)
	D.I.	0.8481	0.6516	0.7457	0.4072
		(0.7377)	(0.4025)	(0.5597)	(0.3899)
p=0.500	R^D	3.7236	1.7273	1.0536	0.1594
	R	1.1191	1.1481	0.5594	0.2868
	D.I.	0.7695	0.6025	0.6689	0.3607
p=0.250	R^D	3.5625	1.1895	0.8956	0.2196
	R	1.4482	0.9328	0.3112	0.1600
	D.I.	0.7096	0.5634	0.7534	0.6118
p=0.125	R^D	4.7847	1.3887	0.7655	0.1867
	R	1.6126	1.4261	0.2767	0.0895
	D.I.	0.7415	0.4834	0.7357	0.6972
$\bar{X}$	R^D	3.4281	1.5664	0.9709	0.1697
	R	1.1038	1.4195	0.4606	1.1884
	D.I.	0.7613	0.5407	0.6927	0.4934

Table 17 (continued)

Component rates and discrimination indices for S1

		T			
$\bar{T}$=0.25		1	4	16	64
p=1.000	R^D	3.9152	2.1918	0.9930	0.1639
		(4.5459)	(1.8312)	(0.6896)	(0.4118)
	R^Δ	0.8253	1.3000	0.3150	0.1188
		(1.7166)	(1.0839)	(0.3133)	(0.2613)
	D.I.	0.8280	0.6364	0.7801	0.5737
		(0.7220)	(0.6384)	(0.5705)	(0.5338)
p=0.500	R^D	5.5015	2.8681	1.1391	0.2684
	R^Δ	1.3888	1.2424	0.1125	0.0438
	D.I.	0.8037	0.7014	0.9092	0.8615
p=0.250	R^D	5.3951	2.3118	1.0114	0.5927
	R^Δ	2.1440	1.0556	0.2384	0.1170
	D.I.	0.7141	0.6878	0.8114	0.7697
p=0.125	R^D	6.0666	1.9509	1.0329	0.7242
	R^Δ	2.2736	0.6904	0.1717	0.0741
	D.I.	0.7274	0.7415	0.8573	0.9039
$\bar{X}$	R^D	5.0849	2.2308	0.9727	0.3922
	R^Δ	1.6697	1.0745	0.2302	0.1230
	D.I.	0.7590	0.6811	0.7857	0.7285

Table 18

Component rates and discrimination indices for S2.

		T			
		1	4	16	64
$\overline{T}=0.75$					
p=1.000	R^D	1.6993	1.7306	1.6890	0.5876
		(1.4714)	(2.0050)	(0.8215)	(0.2816)
	R^Δ	0.7733	0.3527	0.6400	0.7236
		(0.6446)	(0.6276)	(1.8300)	(1.7303)
	D.I.	0.7132	0.8410	0.7121	0.4230
		(0.6754)	(0.7648)	(0.3115)	(0.1434)
p=0.500	R^D	1.9366	1.9581	0.9943	0.3691
	R^Δ	0.9282	0.4198	1.1500	1.1155
	D.I.	0.6836	0.8238	0.4618	0.2497
p=0.250	R^D	2.1303	1.9628	0.7434	0.3885
	R^Δ	1.3091	0.5096	1.9158	1.3036
	D.I.	0.6198	0.7929	0.2833	0.2324
p=0.125	R^D	1.8007	1.9138	0.6252	0.2680
	R^Δ	1.1926	0.5374	1.9660	1.4602
	D.I.	0.6038	0.7813	0.2207	0.1563
$\overline{X}$	R^D	1.8077	1.9141	0.9747	0.3790
	R^Δ	0.9696	0.4892	1.5004	1.2666
	D.I.	0.6592	0.8008	0.3979	0.2410
$\overline{T}=0.50$					
p=1.000	R^D	0.9739	1.3752	0.5819	0.1882
		(1.0495)	(1.4124)	(0.5061)	(0.1129)
	R^Δ	0.3925	1.0628	1.3359	1.1013
		(0.3094)	(1.0994)	(1.9068)	(1.3810)
	D.I.	0.7275	0.5645	0.3015	0.1472
		(0.7710)	(0.5598)	(0.2098)	(0.0756)
p=0.500	R^D	0.9959	1.4153	0.6051	0.1750
	R^Δ	0.2895	1.2380	1.5068	1.0354
	D.I.	0.7759	0.5293	0.2863	0.1451
p=0.250	R^D	1.0888	1.6533	0.6465	0.2850
	R^Δ	0.4483	1.3145	1.5469	0.8538
	D.I.	0.7262	0.5571	0.2960	0.2525
p=0.125	R^D	1.5266	1.7845	0.4808	0.1726
	R^Δ	0.5766	1.2994	1.6440	1.2592
	D.I.	0.7231	0.5742	0.2283	0.1212
$\overline{X}$	R^D	1.1269	1.5209	0.5641	0.1867
	R^Δ	0.3931	1.2028	1.5881	1.1261
	D.I.	0.7447	0.5570	0.2644	0.1483

Table 18 (continued)

Component rates and discrimination indices for S2.

		T			
		1	4	16	64
$\overline{T}$=0.25					
p=1.000	R^D	1.0632	1.4609	0.4911	0.1842
		(1.4768)	(1.5287)	(0.5492)	(0.2098)
	R^Δ	0.2445	1.1896	1.5442	1.4363
		(0.6998)	(1.4755)	(1.3248)	(1.1822)
	D.I.	0.8069	0.5502	0.2422	0.1130
		(0.7203)	(0.5090)	(0.2936)	(0.1573)
p=0.500	R^D	1.8265	1.7065	0.6379	0.1854
	R^Δ	0.3179	1.3094	1.4092	1.2585
	D.I.	0.8459	0.5057	0.3081	0.1409
p=0.250	R^D	1.8085	1.3850	0.5721	0.2307
	R^Δ	0.9123	1.5872	1.2062	1.0490
	D.I.	0.6619	0.4661	0.3227	0.1804
p=0.125	R^D	2.2674	1.3742	0.5461	0.2580
	R^Δ	1.1077	1.6571	1.3092	0.9194
	D.I.	0.6786	0.4529	0.2918	0.2205
$\overline{X}$	R^D	1.6885	1.5287	0.5492	0.2098
	R^Δ	0.6998	1.4755	1.3248	1.1822
	D.I.	0.7203	0.5090	0.2936	0.1573

Table 19

Component rates and discrimination indices for S3.

		T			
		1	4	16	64
$\overline{T}$=0.75					
p=1.000	R^D	2.4088	2.3470	1.0436	0.7364
		(2.8587)	(2.0026)	(0.4675)	(0.1991)
	R^Δ	2.2514	0.6400	0.7602	0.4013
		(1.8970)	(1.6712)	(1.2637)	(0.5375)
	D.I.	0.5432	0.7860	0.5772	0.6391
		(0.6107)	(0.5483)	(0.2661)	(0.2487)
p=0.500	R^D	2.3222	1.9968	0.8070	1.0925
	R^Δ	2.0192	0.5826	0.7872	0.7596
	D.I.	0.5379	0.7749	0.5054	0.5878
p=0.250	R^D	2.6852	1.5774	0.8066	0.8345
	R^Δ	1.7274	1.3246	1.0831	0.5947
	D.I.	0.6085	0.5436	0.4262	0.5807
p=0.125	R^D	2.1080	1.3615	0.4710	0.6095
	R^Δ	1.2979	1.4696	1.1434	0.7352
	D.I.	0.6192	0.4815	0.2881	0.4733
$\overline{X}$	R^D	2.4766	1.8571	0.7191	0.7106
	R^Δ	1.8386	1.1376	1.0075	0.6057
	D.I.	0.5841	0.6269	0.4126	0.5059
$\overline{T}$=0.50					
p=1.000	R^D	2.8520	2.1991	0.4191	0.1692
		(3.8127)	(2.2636)	(0.2916)	(0.1029)
	R^Δ	1.2802	1.7300	0.8970	0.2659
		(1.6312)	(1.9200)	(0.5970)	(0.3556)
	D.I.	0.6929	0.5594	0.3185	0.3940
		(0.6978)	(0.5424)	(0.3968)	(0.2310)
p=0.500	R^D	3.2277	1.7196	0.3290	0.2256
	R^Δ	2.1093	1.8671	0.9998	0.2495
	D.I.	0.6041	0.4682	0.2454	0.4789
p=0.250*	R^D	3.0919	1.3045	0.2280	0.2356
	R^Δ	2.2537	1.8961	0.8467	0.4914
	D.I.	0.5678	0.4063	0.2131	0.3497
p=0.125	R^D	3.2168	1.0673	0.2406	0.1195
	R^Δ	1.6803	1.5614	1.3493	0.8798
	D.I.	0.6580	0.4054	0.1544	0.1323
$\overline{X}$	R^D	3.2402	1.7853	0.3017	0.1706
	R^Δ	1.7917	1.7949	0.8780	0.4484
	D.I.	0.6459	0.4763	0.2656	0.3172

*computed on the basis of four sessions

Table 19 (continued)

Component rates and discrimination indices for S3.

		T			
$\bar{T}=0.25$		1	4	16	64
p=1.000	R^D	5.5145	2.4235	0.4356	0.1504
		(3.8696)	(1.7675)	(0.4673)	(0.1311)
	R^Δ	1.5154	1.4815	0.5784	0.3696
		(1.8692)	(1.0733)	(0.5092)	(0.4402)
	D.I.	0.7862	0.6206	0.4308	0.2808
		(0.7055)	(0.6177)	(0.4816)	(0.2604)
p=0.500	R^D	5.0996	1.6182	0.4682	0.2379
	R^Δ	1.7837	0.7099	0.3061	0.3171
	D.I.	0.7364	0.6971	0.6099	0.3651
p=0.250	R^D	3.8325	1.4058	0.4517	0.1382
	R^Δ	2.1892	0.8941	0.3869	0.3781
	D.I.	0.6359	0.6071	0.5356	0.2589
p=0.125	R^D	4.1022	1.3016	0.3659	0.1139
	R^Δ	1.7735	0.9623	0.8580	0.7782
	D.I.	0.6987	0.5719	0.5288	0.2687
$\bar{X}$	R^D	4.4837	1.7033	0.4377	0.1543
	R^Δ	1.8262	1.0733	0.5092	0.4402
	D.I.	0.7055	0.6177	0.4816	0.2604

Table 20

Component rates and discrimination indices for S4.

		T			
		1	4	16	64
$\bar{T}$=0.75					
p=1.000	R^D	1.4987	3.1323	1.1683	0.5362
		(1.8045)	(2.2843)	(1.2490)	(0.1505)
	R^{Δ}	0.3494	0.5171	0.6800	0.5088
		(0.7696)	(0.5571)	(2.5100)	(1.1538)
	D.I.	0.8195	0.8604	0.6399	0.5213
		(0.7032)	(0.7995)	(0.3310)	(0.1052)
p=0.500	R^D	2.0071	2.5008	1.1554	0.2048
	R^{Δ}	0.8933	0.6316	1.2172	0.8148
	D.I.	0.6984	0.8018	0.4801	0.2141
p=0.250	R^D	2.3948	1.9952	0.9450	0.2415
	R^{Δ}	1.2187	0.5952	1.4023	0.6810
	D.I.	0.6682	0.7683	0.4016	0.2694
p=0.125	R^D	2.6718	2.0199	0.8490	0.1673
	R^{Δ}	1.2919	1.0726	2.0235	1.0989
	D.I.	0.6911	0.6522	0.2949	0.1295
$\bar{X}$	R^D	2.0754	2.3865	1.0733	0.2601
	R^{Δ}	0.9046	0.6747	1.5666	0.8515
	D.I.	0.7161	0.7764	0.4295	0.2479
$\bar{T}$=0.50					
p=1.000	R^D	2.3163	1.5157	0.8976	0.0580
		(2.2435)	(1.6917)	(0.8013)	(0.1157)
	R^{Δ}	0.2574	0.3500	1.8315	0.3952
		(0.1751)	(0.5987)	(2.7250)	(0.3100)
	D.I.	0.9095	0.8160	0.3271	0.1543
		(0.9285)	(0.7434)	(0.2261)	(0.2680)
p=0.500	R^D	2.3314	1.5736	0.8285	0.0767
	R^{Δ}	0.6318	0.7314	1.8453	0.4610
	D.I.	0.7837	0.6847	0.3111	0.1838
p=0.250	R^D	2.9711	1.5674	0.5856	0.1207
	R^{Δ}	0.7650	1.3839	2.1440	0.7752
	D.I.	0.7951	0.5324	0.2154	0.1364
p=0.125	R^D	3.2767	1.9549	0.6296	0,1041
	R^{Δ}	0.9514	1.6567	2.3408	0.8859
	D.I.	0.7748	0.5380	0.2192	0.1080
$\bar{X}$	R^D	2.6278	1.6607	0.7485	0.0950
	R^{Δ}	0.5561	0.9441	2.1773	0.5655
	D.I.	0.8383	0.6629	0.2598	0.1701

Table 20 (continued)

Component rates and discrimination indices for S4.

		T			
		1	4	16	64
$\bar{T}=0.25$					
p=1.000	R^D	2.6161	1.6089	0.4434	0.0984
		(1.6339)	(1.2081)	(0.4458)	(0.1327)
	R^{Δ}	0.2222	0.2466	1.4039	0.1617
		(0.6630)	(0.8460)	(0.7367)	(0.0521)
	D.I.	0.9237	0.8725	0.2512	0.4474
		(0.7071)	(0.6106)	(0.4147)	(0.7823)
p=0.500	R^D	2.9934	1,7379	0.6375	0.1538
	R^{Δ}	0.3760	0.8903	1.7044	0.5213
	D.I.	0.8898	0.6875	0.2751	0.2362
p=0.250	R^D	2.7099	1.4828	0.5350	0.1580
	R^{Δ}	0.9287	1.2372	1.2442	0.5724
	D.I.	0.7549	0.5503	0.3277	0.2206
p=0.125	R^D	3.2557	1.8814	0.7781	0.1985
	R^{Δ}	1.2310	1.6229	0.8998	0.5972
	D.I.	0.7257	0.5370	0.4664	0.2722
$\bar{X}$	R^D	2.6418	1.5838	0.5680	0.1483
	R^{Δ}	0.6842	0.9586	1.1978	0.3813
	D.I.	0.8002	0.6514	0.3470	0.3917

Table 21

Component rates and discrimination indices for S5.

		T			
		1	4	16	64
$\bar{T}$=0.75					
p=1.000	R^D	1.8523	1.4201	0.6757	0.4816
		(1.4819)	(1.0051)	(0.6060)	(0.1951)
	R^Δ	0.9512	1.3600	1.1200	0.0538
		(0.6753)	(0.7800)	(0.3368)	(0.1138)
	D.I.	0.6948	0.5143	0.8628	0.8979
		(0.6963)	(0.5741)	(0.6611)	(0.6009)
p=0.500	R^D	1.7592	0.9885	0.4100	0.3043
	R^Δ	1.2106	0.6020	0.0168	0.0241
	D.I.	0.6021	0.6271	0.9610	0.9233
p=0.250	R^D	1.1028	0.7269	0.4596	0.2512
	R^Δ	0.8519	0.3300	0.1279	0.1351
	D.I.	0.5723	0.6940	0.7994	0.6944
p=0.125	R^D	0.9767	0.7118	0.4379	0.1608
	R^Δ	0.7157	0.3209	0.1715	0.1304
	D.I.	0.5751	0.6909	0.7210	0.5686
$\bar{X}$	R^D	1.4346	0.9705	0.5178	0.2786
	R^Δ	0.8809	0.6786	0.1546	0.0914
	D.I.	0.6281	0.6201	0.8011	0.7370
$\bar{T}$=0.50					
p=1.000	R^D	1.9480	1.0329	0.3655	0.0657
		(2.2165)	(1.0389)	(0.3757)	(0.0757)
	R^Δ	0.5809	1.1300	0.2250	0.1200
		(0.5500)	(0.9477)	(0.0850)	(0.0430)
	D.I.	0.7680	0.4772	0.6239	0.3617
		(0.7890)	(0.5295)	(0.7987)	(0.6454)
p=0.500	R^D	1.6520	1.0437	0.3106	0.0854
	R^Δ	0.5992	0.5589	0.1093	0.0518
	D.I.	0.7399	0.6533	0.7378	0.6353
p=0.250	R^D	1.2609	0.8400	0.3801	0.1203
	R^Δ	0.4596	0.2345	0.0843	0.0316
	D.I.	0.7260	0.7848	0.8164	0.7912
p=0.125	R^D	1.4377	0.8519	0.3763	0.1259
	R^Δ	0.5068	0.1474	0.0535	0.0293
	D.I.	0.7595	0.8537	0.8764	0.8099
$\bar{X}$	R^D	1.6850	0.9615	0.3572	0.0946
	R^Δ	0.5393	0.6026	0.1114	0.0551
	D.I.	0.7565	0.6597	0.7706	0.6487

Table 21 (continued)

Component rates and discrimination indices for S5

		T			
		1	4	16	64
$\overline{T}$=0.25					
p=1.000	R^{D}	3.4153	1.3924	0.4317	0.1738
		(2.5081)	(1.2071)	(0.4322)	(0.1276)
	R^{Δ}	0.5521	0.8321	0.0678	0.0600
		(1.0203)	(0.7456)	(0.0583)	(0.0783)
	D.I.	0.8596	0.6224	0.8731	0.7198
		(0.7048)	(0.6366)	(0.8844)	(0.6231)
p=0.500	R^{D}	3.1051	1.4298	0.5372	0.1641
	R^{Δ}	0.8781	0.4968	0.0376	0.0324
	D.I.	0.7804	0.7575	0.9365	0.8369
p=0.250	R^{D}	2.7129	1.0870	0.4750	0.1638
	R^{Δ}	0.8000	0.1446	0.0204	0.0247
	D.I.	0.7755	0.8817	0.9591	0.8708
p=0.125	R^{D}	1.7058	1.1448	0.6571	0.1886
	R^{Δ}	0.5676	0.1340	0.0152	0.0189
	D.I.	0.7648	0.8965	0.9761	0.9089
$\overline{X}$	R^{D}	2.6891	1.2522	0.0506	0.1636
	R^{Δ}	0.7636	0.4706	0.0399	0.0429
	D.I.	0.7770	0.7589	0.9258	0.7919

Table 22

Corrected and running response rate parameter values for equation (16). B and k are defined in the text. The proportion of variance accounted for by the regression line (r^2) and the standard error around the regression line (S.E.) are reported.

S1

Corrected rate					Running rate				
$\overline{T}$	B	k	r^2	S.E.	$\overline{T}$	B	k	r^2	S.E.
1.00	0.9893	0.3283	0.7529	0.6990	1.00	0.9985	0.2510	0.8025	1.4693
0.75	0.9692	0.5218	0.6377	0.6381	0.75	0.9716	0.4443	0.6779	1.1604
0.50	0.9137	0.2969	0.9141	0.3958	0.50	0.9271	0.2369	0.8787	1.0854
0.25	0.9112	0.5344	0.7649	0.5673	0.25	0.9228	0.4163	0.7934	1.3119

S2

$\overline{T}$	B	k	r^2	S.E.	$\overline{T}$	B	k	r^2	S.E.
1.00	0.9886	0.4842	0.6332	0.4198	1.00	0.9867	0.3245	0.6760	2.4449
0.75	0.9833	0.6156	0.9457	0.1570	0.75	0.9832	0.4541	0.8767	1.4449
0.50	0.9919	0.9749	0.3670	0.2512	0.50	0.9911	0.6831	0.5667	0.3442
0.25	0.9979	0.9419	0.0225	0.3006	0.25	0.9959	0.7033	0.2469	0.5945

S3

$\overline{T}$	B	k	r^2	S.E.	$\overline{T}$	B	k	r^2	S.E.
1.00	0.9889	0.4505	0.7057	0.4467	1.00	0.9881	0.3527	0.7436	1.7097
0.75	0.9810	0.6188	0.4660	0.4727	0.75	0.9825	0.5090	0.5673	1.5100
0.50	0.9508	0.5185	0.8197	0.4603	0.50	0.9579	0.3941	0.8645	1.0339
0.25	0.9645	0.8346	0.6701	0.7184	0.25	0.9677	0.6529	0.7164	1.1208

Table 22 (continued)

Corrected and running response rate parameter values for equation (16).

S4

Corrected rate					Running rate				
$\overline{T}$	B	k	r^2	S.E.	$\overline{T}$	B	k	r^2	S.E.
1.00	0.9810	0.3852	0.8739	0.3636	1.00	0.9780	0.2616	0.8294	3.7394
0.75	0.9681	0.4383	0.9294	0.3371	0.75	0.9712	0.3004	0.8822	1.6979
0.50	0.9548	0.4364	0.7690	0.4737	0.50	0.9726	0.3283	0.8506	2.9528
0.25	0.9253	0.4947	0.3987	0.4655	0.25	0.9720	0.4519	0.6746	0.6458

S5

$\overline{T}$	B	k	r^2	S.E.	$\overline{T}$	B	k	r^2	S.E.
1.00	0.9700	0.6985	0.8647	0.4943	1.00	0.9684	0.5066	0.6518	0.6878
0.75	0.9408	1.0456	0.8124	0.3012	0.75	0.9409	0.7537	0.7630	1.0456
0.50	0.7801	0.7772	0.9581	0.1779	0.50	0.8642	0.5892	0.7828	1.9636
0.25	0.7966	1.4552	0.9020	0.3826	0.25	0.8337	0.7121	0.8212	0.8603

Table 23

Parameter values for post-reinforcement pause data fitted to equation (17). The slope (a) and intercept (c) values, as well as the proportion of variance accounted for by the regression line (r^2) and the standard error around the regression line (S.E.) are shown.

S1

$\overline{T}$	a	c	r^2	S.E.
1.00	0.0336	0.9550	0.8000	0.4247
0.75	0.1333	0.3256	0.6544	0.2451
0.50	0.3699	-0.9747	0.8289	4.2539
0.25	0.2616	0.5056	0.8223	3.0779

S2

$\overline{T}$	a	c	r^2	S.E.
1.00	0.0561	1.3424	0.7603	0.7969
0.75	0.2288	0.6830	0.7757	3.1141
0.50	0.3047	1.0619	0.9696	1.3656
0.25	0.2232	1.4909	0.9589	1.1965

S3

$\overline{T}$	a	c	r^2	S.E.
1.00	0.0560	1.4402	0.7375	1.4919
0.75	0.1570	0.6857	0.5887	3.3223
0.50	0.2541	0.9082	0.8206	3.0281
0.25	0.2047	1.2132	0.9363	1.3513

S4

$\overline{T}$	a	c	r^2	S.E.
1.00	0.0797	1.1367	0.7903	1.0413
0.75	0.2987	-0.1654	0.7847	3.9607
0.50	0.5485	-1.2095	0.8922	4.8210
0.25	0.5740	0.3004	0.9239	4.1738

S5

$\overline{T}$	a	c	r^2	S.E.
1.00	0.0767	1.2727	0.8199	0.9097
0.75	0.1227	2.2277	0.6368	2.3456
0.50	0.4985	1.6458	0.9745	2.0416
0.25	0.4755	2.5696	0.8850	4.3389

Table 24

Total T-cycles and proportion of T-cycles intercepted by a response. The columns labelled "Tot." contain the total T-cycles for the stated $\bar{T}$ and p values for the entire five sessions at those values. The columns labelled "Prop." contain the proportion of that total number of T-cycles in which there was at least one response in t^D. Values in parentheses are recovery values at p=1.000.

S1

$\bar{T}$	p	T							
		1		4		16		64	
		Tot.	Prop.	Tot.	Prop.	Tot.	Prop.	Tot.	Prop.
1.00	1.000	78	0.9615	75	1.0000	75	1.0000	75	1.0000
		(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	149	0.9866	143	1.0000	158	1.0000	154	1.0000
	0.250	337	0.9941	265	1.0000	294	1.0000	311	1.0000
	0.125	624	0.9824	672	1.0000	565	1.0000	600	1.0000
0.75	1.000	75	1.0000	75	1.0000	75	1.0000	76	0.9868
		(79)	(0.9424)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	139	0.9928	144	1.0000	143	1.0000	154	1.0000
	0.250	375	0.9813	268	1.0000	316	1.0000	330	1.0000
	0.125	710	0.9056	631	0.9540	591	1.0000	501	0.9840
0.50	1.000	85	0.8824	75	1.0000	75	1.0000	75	1.0000
		(95)	(0.8065)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	142	0.9718	142	1.0000	163	1.0000	142	1.0000
	0.250	330	0.9152	314	0.9490	265	0.9962	308	1.0000
	0.125	743	0.9300	570	0.9772	449	1.0000	688	0.9637
0.25	1.000	118	0.6375	75	1.0000	75	1.0000	75	1.0000
		(95)	(0.7895)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	185	0.8865	168	0.9464	139	1.0000	183	1.0000
	0.250	301	0.8804	334	0.9731	345	0.9865	332	0.9940
	0.125	830	0.8566	708	0.9463	675	0.9822	706	0.9915

Table 25

Total T-cycles and proportion of T-cycles intercepted by a response. The columns labelled "Tot." contain the total T-cycles for the stated $\bar{T}$ and p values for the entire five sessions at those values. The columns labelled "Prop." contain the proportion of that total number of T-cycles in which there was at least one response in t^D. Values in parentheses are recovery values at p=1.000.

S2

$\bar{T}$	p	T							
		1		4		16		64	
		Tot.	Prop.	Tot.	Prop.	Tot.	Prop.	Tot.	Prop.
1.00	1.000	85	0.8824	75	1.0000	75	1.0000	75	1.0000
		(77)	(0.9740)	(81)	(0.9259)	(75)	(1.0000)	(75)	(1.0000)
	0.500	218	0.6147	162	1.0000	169	0.9763	163	1.0000
	0.250	404	0.8589	329	0.9544	733	1.0000	296	0.9764
	0.125	693	0.9683	562	0.9982	567	0.9418	691	0.9986
0.75	1.000	82	0.9146	76	0.9868	75	1.0000	75	1.0000
		(126)	(0.5952)	(76)	(0.9868)	(75)	(1.0000)	(75)	(1.0000)
	0.500	182	0.8956	144	0.9792	163	0.9939	133	1.0000
	0.250	293	0.9556	324	1.0000	326	1.0000	342	0.9971
	0.125	641	0.9204	632	1.0000	546	1.0000	535	0.9981
0.50	1.000	225	0.3333	92	0.8152	75	1.0000	75	1.0000
		(186)	(0.4032)	(78)	(0.9615)	(77)	(0.9740)	(75)	(1.0000)
	0.500	377	0.4111	172	0.9070	163	1.0000	128	1.0000
	0.250	880	0.4068	422	0.9597	290	0.9966	279	1.0000
	0.125	1128	0.5375	568	0.9947	641	0.9891	560	0.9911
0.25	1.000	362	0.2072	94	0.7979	80	0.9375	76	0.9868
		(252)	(0.2976)	(82)	(0.9146)	(77)	(0.9740)	(75)	(1.0000)
	0.500	431	0.3155	166	0.9157	148	0.9797	142	1.0000
	0.250	1088	0.3778	532	0.9380	483	0.9710	308	0.9903
	0.125	1270	0.4858	679	0.9588	662	0.9486	575	0.9878

Table 26

Total T-cycles and proportion of T-cycles intercepted by a response. The columns labelled "Tot." contain the total T-cycles for the stated $\overline{T}$ and p values for the entire five sessions at those values. The columns labelled "Prop." contain the proportion of that total number of T-cycles in which there was at least one response in t^D. Values in parentheses are recovery values at p=1.000.

S3

$\overline{T}$	p	T							
		1		4		16		64	
		Tot.	Prop.	Tot.	Prop.	Tot.	Prop.	Tot.	Prop.
1.00	1.000	78	0.9615	75	1.0000	75	1.0000	75	1.0000
		(85)	(0.8824)	(78)	(0.9615)	(75)	(1.0000)	(75)	(1.0000)
	0.500	167	0.9880	162	0.9938	159	1.0000	149	1.0000
	0.250	230	0.9273	351	0.9972	273	1.0000	318	0.9969
	0.125	761	0.8896	598	0.9933	668	1.0000	697	0.9440
0.75	1.000	79	0.9494	76	0.9868	75	1.0000	75	1.0000
		(77)	(0.9740)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	140	0.9643	136	1.0000	153	1.0000	173	1.0000
	0.250	314	0.9809	303	1.0000	317	1.0000	323	1.0000
	0.125	740	0.8757	663	0.9955	634	0.9811	665	0.9970
0.50	1.000	85	0.8824	76	0.9868	77	0.9740	75	1.0000
		(76)	(0.9868)	(75)	(1.0000)	(78)	(0.9615)	(75)	(1.0000)
	0.500	149	0.9396	142	1.0000	151	1.0000	135	1.0000
*	0.250	258	0.9295	287	0.9965	274	0.9927	285	1.0000
	0.125	608	0.9243	667	0.9775	656	1.0000	589	1.0000
0.25	1.000	85	0.8824	75	1.0000	75	1.0000	75	1.0000
		(108)	(0.6944)	(76)	(0.9868)	(75)	(1.0000)	(75)	(1.0000)
	0.500	188	0.8777	168	1.0000	149	1.0000	155	1.0000
	0.250	382	0.7984	314	0.9940	298	1.0000	324	1.0000
	0.125	692	0.8194	694	0.9646	573	0.9965	591	1.0000

*Computed on the basis of four sessions.

Table 27

Total T-cycles and proportion of T-cycles intercepted by a response. The columns labelled "Tot." contain the total T-cycles for the stated $\overline{T}$ and p values for the entire five sessions at those values. The columns labelled "Prop." contain the proportion of that total number of T-cycles in which there was at least one response in t^D. Values in parentheses are recovery values at p=1.000.

S4

$\overline{T}$	p	T							
		1		4		16		64	
		Tot.	Prop.	Tot.	Prop.	Tot.	Prop.	Tot.	Prop.
1.00	1.000	76	0.9868	75	1.0000	75	1.0000	75	1.0000
		(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	163	0.9632	142	1.0000	137	1.0000	144	1.0000
	0.250	324	0.9815	318	1.0000	407	1.0000	290	1.0000
	0.125	550	0.9800	627	1.0000	651	1.0000	658	1.0000
0.75	1.000	90	0.8333	75	1.0000	75	1.0000	75	1.0000
		(88)	(0.8523)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	174	0.9195	156	1.0000	152	1.0000	174	1.0000
	0.250	348	0.9339	288	0.9965	297	1.0000	318	0.9528
	0.125	541	0.9889	639	1.0000	539	1.0000	699	0.9714
0.50	1.000	90	0.8333	75	1.0000	75	1.0000	75	1.0000
		(97)	(0.7732)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	162	0,8827	145	0.9655	147	1.0000	131	1.0000
	0.250	339	0.8584	329	0.9878	336	1.0000	304	0.9704
	0.125	631	0.9271	742	0.9946	530	1.0000	674	0.9585
0.25	1.000	131	0.5725	78	0.9615	77	0.9740	75	1.0000
		(227)	(0.3304)	(96)	(0.7812)	(75)	(1.0000)	(75)	(1.0000)
	0.500	219	0.7397	177	0.9153	125	1.0000	148	1.0000
	0.250	496	0.6109	288	0.9410	308	1.0000	303	1.0000
	0.125	792	0.7109	700	0.9757	600	0.9983	685	0.9956

Table 28

Total T-cycles and proportion of T-cycles intercepted by a response. The columns labelled "Tot." contain the total T-cycles for the stated $\overline{T}$ and p values for the entire five sessions at those values. The columns labelled "Prop." contain the proportion of that total number of T-cycles in which there was at least one response in t^D. Values in parentheses are recovery values at p=1.000.

S5

$\overline{T}$	p	T							
		1		4		16		64	
		Tot.	Prop.	Tot.	Prop.	Tot.	Prop.	Tot.	Prop.
1.00	1.000	75	1.0000	75	1.0000	75	1.0000	75	1.0000
		(107)	(0.7009)	(76)	(0.9868)	(75)	(1.0000)	(76)	(0.9868)
	0.500	199	0.9146	151	0.9801	137	0.9927	160	1.0000
	0.250	380	0.8737	377	0.9894	389	1.0000	329	0.9970
	0.125	985	0.6213	707	0.9844	559	0.9893	587	0.9847
0.75	1.000	94	0.7979	76	0.9868	75	1.0000	75	1.0000
		(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)	(75)	(1.0000)
	0.500	157	0.8217	165	0.9333	145	0.9862	163	1.0000
	0.250	492	0.5936	329	0.9271	381	0.9843	364	1.0000
	0.125	1188	0.4840	728	0.9162	664	0.9910	576	0.8542
0.50	1.000	112	0.6696	75	1.0000	75	1.0000	76	0.9868
		(94)	(0.7979)	(76)	(0.9868)	(75)	(1.0000)	(76)	(0.9868)
	0.500	226	0.5929	150	0.9000	161	0.9379	157	0.9554
	0.250	646	0.4783	319	0.9028	353	0.9773	327	0.9847
	0.125	1028	0.5516	887	0.8850	660	0.9652	568	0.9912
0.25	1.000	117	0.6410	82	0.9146	77	0.9740	75	1.0000
		(150)	(0.5000)	(86)	(0.8721)	(76)	(0.9868)	(75)	(1.0000)
	0.500	258	0.6279	212	0.7075	155	0.9613	166	0.9819
	0.250	618	0.5761	396	0.7374	342	0.9620	291	0.9897
	0.125	1762	0.3224	919	0.7889	659	0.9712	618	0.9919

Table 29

Predicted and obtained interreinforcer times as a function of T, $\overline{T}$, and p. All tabled values are means of five sessions. All values of T and $I_{S}r$ are in seconds. Values in parentheses are recovery values at p=1.000.

S1

$\overline{T}$	p	T							
		1		4		16		64	
		Pred.	Obt.	Pred.	Obt.	Pred.	Obt.	Pred.	Obt.
1.00	1.000	1.00	1.04	4.00	4.01	16.00	16.00	64.00	64.00
		(1.00)	(1.01)	(4.00)	(4.00)	(16.00)	(16.00)	(64.03)	(64.03)
	0.500	2.00	1.99	8.00	7.60	32.00	33.76	128.00	132.35
	0.250	4.00	4.50	16.00	14.12	64.00	66.04	256.00	271.52
	0.125	8.00	8.32	32.00	35.86	128.00	120.60	512.00	525.49
0.75	1.000	1.00	1.00	4.00	4.00	16.00	16.00	64.00	64.88
		(1.00)	(1.06)	(4.00)	(4.00)	(16.00)	(16.00)	(64.00)	(64.02)
	0.500	2.00	1.85	8.00	7.75	32.00	30.51	128.00	131.44
	0.250	4.00	5.06	16.00	14.64	64.00	67.49	256.00	281.67
	0.125	8.00	9.74	32.00	34.47	128.00	126.44	512.00	427.70
0.50	1.000	1.00	1.14	4.00	4.01	16.00	16.03	64.00	64.06
		(1.00)	(1.25)	(4.00)	(4.02)	(16.00)	(16.03)	(64.00)	(64.06)
	0.500	2.00	1.90	8.00	7.59	32.00	33.51	128.00	121.20
	0.250	4.00	9.47	16.00	21.20	64.00	66.59	256.00	386.90
	0.125	8.00	9.91	32.00	30.40	128.00	96.22	512.00	587.40
0.25	1.000	1.00	1.57	4.00	4.02	16.00	16.02	64.00	64.05
		(1.00)	(1.28)	(4.00)	(4.28)	(16.00)	(16.03)	(64.00)	(64.05)
	0.500	2.00	2.43	8.00	8.97	32.00	29.66	128.00	156.19
	0.250	4.00	4.01	16.00	17.87	64.00	73.67	256.00	283.43
	0.125	8.00	11.07	32.00	37.76	128.00	144.03	512.00	602.86

Table 30

Predicted and obtained interreinforcer times as a function of T, $\bar{T}$, and p. All tabled values are means of five sessions. All values of T and $I_{S}r$ are in seconds. Values in parentheses are recovery values at p=1.000.

S2

$\bar{T}$	p	T							
		1		4		16		64	
		Pred.	Obt.	Pred.	Obt.	Pred.	Obt.	Pred.	Obt.
1.00	1.000	1.00	1.14	4.00	4.00	16.00	16.00	64.00	64.75
		(1.00)	(1.03)	(4.00)	(4.32)	(16.00)	(16.00)	(64.00)	(64.03)
	0.500	2.00	2.93	8.00	8.64	32.00	36.06	128.00	139.21
	0.250	4.00	5.38	16.00	17.55	64.00	80.45	256.00	252.70
	0.125	8.00	9.28	32.00	29.94	128.00	120.97	512.00	590.42
0.75	1.000	1.00	1.10	4.00	4.09	16.00	16.05	64.00	64.04
		(1.00)	(1.68)	(4.00)	(4.06)	(16.00)	(16.02)	(64.00)	(64.02)
	0.500	2.00	2.43	8.00	7.75	32.00	34.82	128.00	113.58
	0.250	4.00	3.96	16.00	17.78	64.00	68.98	256.00	291.93
	0.125	8.00	8.70	32.00	34.50	128.00	116.90	512.00	456.82
0.50	1.000	1.00	3.01	4.00	4.93	16.00	16.01	64.00	64.03
		(1.00)	(2.49)	(4.00)	(4.19)	(16.00)	(16.32)	(64.00)	(64.03)
	0.500	2.00	5.52	8.00	9.19	32.00	34.84	128.00	109.36
	0.250	4.00	11.76	16.00	22.49	64.00	68.98	256.00	291.93
	0.125	8.00	15.98	32.00	30.30	128.00	136.76	512.00	364.66
0.25	1.000	1.00	4.84	4.00	5.01	16.00	17.07	64.00	64.87
		(1.00)	(3.37)	(4.00)	(4.38)	(16.00)	(16.44)	(64.00)	(64.02)
	0.500	2.00	5.47	8.00	8.86	32.00	31.60	128.00	121.20
	0.250	4.00	15.51	16.00	28.38	64.00	130.06	256.00	262.86
	0.125	8.00	16.93	32.00	36.21	128.00	141.29	512.00	490.71

Table 31

Predicted and obtained interreinforcer times as a function of T, $\overline{T}$, and p. All tabled values are means of five sessions. All values of T and $I_{S}r$ are in seconds. Values in parentheses are recovery values at p=1.000.

S3

$\overline{T}$	p	T							
		1		4		16		64	
		Pred.	Obt.	Pred.	Obt.	Pred.	Obt.	Pred.	Obt.
1.00	1.000	1.00	1.04	4.00	4.00	16.00	16.01	64.00	64.02
		(1.00)	(1.16)	(4.00)	(4.17)	(16.00)	(16.02)	(64.00)	(64.02)
	0.500	2.00	2.23	8.00	8.64	32.00	33.93	128.00	127.21
	0.250	4.00	4.41	16.00	18.72	64.00	58.28	256.00	271.55
	0.125	8.00	10.16	32.00	65.76	128.00	142.54	512.00	609.09
0.75	1.000	1.00	1.06	4.00	4.01	16.00	16.02	64.00	64.04
		(1.00)	(1.03)	(4.00)	(4.01)	(16.00)	(16.02)	(64.00)	(64.03)
	0.500	2.00	1.87	8.00	7.34	32.00	32.73	128.00	147.65
	0.250	4.00	4.20	16.00	16.19	64.00	67.68	256.00	275.67
	0.125	8.00	9.89	32.00	35.46	128.00	132.52	512.00	567.86
0.50	1.000	1.00	1.22	4.00	4.01	16.00	16.25	64.00	64.03
		(1.00)	(1.02)	(4.00)	(4.01)	(16.00)	(16.24)	(64.00)	(64.02)
	0.500	2.00	1.99	8.00	7.58	32.00	32.25	128.00	123.75
	0.250	4.00	4.31	16.00	19.83	64.00	73.23	256.00	246.78
	0.125	8.00	8.11	32.00	35.18	128.00	139.98	512.00	503.05
0.25	1.000	1.00	1.14	4.00	4.01	16.00	16.02	64.00	64.04
		(1.00)	(1.44)	(4.00)	(4.06)	(16.00)	(16.02)	(64.00)	(64.05)
	0.500	2.00	2.51	8.00	8.98	32.00	31.81	128.00	132.29
	0.250	4.00	5.10	16.00	16.76	64.00	63.59	256.00	274.52
	0.125	8.00	9.23	32.00	34.63	128.00	122.28	512.00	504.38

Table 32

Predicted and obtained interreinforcer times as a function of T, $\bar{T}$, and p. All tabled values are means of five sessions. All values of T and I_{S^r} are in seconds. Values in parentheses are recovery values at p=1.000.

S4

$\bar{T}$	p	T							
		1		4		16		64	
		Pred.	Obt.	Pred.	Obt.	Pred.	Obt.	Pred.	Obt.
1.00	1.000	1.00	1.02	4.00	4.03	16.00	16.01	64.00	64.93
		(1.00)	(1.00)	(4.00)	(4.00)	(16.00)	(16.02)	(64.00)	(64.03)
	0.500	2.00	2.18	8.00	7.58	32.00	29.27	128.00	122.96
	0.250	4.00	4.33	16.00	16.96	64.00	86.88	256.00	249.79
	0.125	8.00	7.34	32.00	33.44	128.00	138.91	512.00	561.66
0.75	1.000	1.00	1.20	4.00	4.01	16.00	16.02	64.00	64.05
		(1.00)	(1.18)	(4.00)	(4.03)	(16.00)	(16.04)	(64.00)	(64.04)
	0.500	2.00	2.32	8.00	8.40	32.00	32.45	128.00	148.50
	0.250	4.00	4.66	16.09	15.48	64.00	63.42	256.00	271.43
	0.125	8.00	7.23	32.00	34.17	128.00	109.67	512.00	592.61
0.50	1.000	1.00	1.20	4.00	4.03	16.00	16.01	64.00	64.89
		(1.00)	(1.27)	(4.00)	(4.01)	(16.00)	(16.03)	(64.00)	(64.01)
	0.500	2.00	2.17	8.00	7.75	32.00	31.39	128.00	111.81
	0.250	4.00	4.58	16.00	17.56	64.00	71.69	256.00	259.43
	0.125	8.00	8.42	32.00	39.52	128.00	113.08	512.00	575.16
0.25	1.000	1.00	1.75	4.00	4.18	16.00	16.47	64.00	64.04
		(1.00)	(3.03)	(4.00)	(5.14)	(16.00)	(16.07)	(64.00)	(64.05)
	0.500	2.00	2.92	8.00	9.46	32.00	26.69	128.00	126.30
	0.250	4.00	6.61	16.00	15.37	64.00	65.74	256.00	259.59
	0.125	8.00	10.56	32.00	37.33	128.00	128.01	512.00	584.67

Table 33

Predicted and obtained interreinforcer times as a function of T, $\overline{T}$, and p. All tabled values are means of five sessions. All values of T and $I_{S}r$ are in seconds. Values in parentheses are recovery values at p=1.000.

S5

$\overline{T}$	p	T							
		1		4		16		64	
		Pred.	Obt.	Pred.	Obt.	Pred.	Obt.	Pred.	Obt.
1.00	1.000	1.00	1.00	4.00	4.00	16.00	16.00	64.00	64.08
		(1.00)	(1.45)	(4.00)	(4.10)	(16.00)	(16.07)	(64.00)	(64.89)
	0.500	2.00	2.77	8.00	8.09	32.00	29.28	128.00	136.64
	0.250	4.00	5.08	16.00	20.12	64.00	83.02	256.00	285.71
	0.125	8.00	13.31	32.00	37.74	128.00	119.49	512.00	501.32
0.75	1.000	1.00	1.25	4.00	4.07	16.00	16.04	64.00	64.14
		(1.00)	(1.35)	(4.00)	(4.00)	(16.00)	(16.24)	(64.00)	(64.06)
	0.500	2.00	2.11	8.00	8.90	32.00	31.08	128.00	139.15
	0.250	4.00	6.56	16.00	17.70	64.00	81.40	256.00	311.02
	0.125	8.00	15.86	32.00	37.93	128.00	142.08	512.00	492.73
0.50	1.000	1.00	1.50	4.00	4.02	16.00	16.02	64.00	65.76
		(1.00)	(1.25)	(4.00)	(4.06)	(16.00)	(16.06)	(64.00)	(64.57)
	0.500	2.00	3.03	8.00	8.02	32.00	34.38	128.00	134.07
	0.250	4.00	8.52	16.00	17.10	64.00	75.51	256.00	248.38
	0.125	8.00	13.71	32.00	47.37	128.00	140.83	512.00	484.73
0.25	1.000	1.00	1.56	4.00	4.38	16.00	16.49	64.00	64.05
		(1.00)	(2.00)	(4.00)	(4.61)	(16.00)	(16.24)	(64.00)	(64.05)
	0.500	2.00	3.44	8.00	11.33	32.00	33.11	128.00	141.69
	0.250	4.00	8.24	16.00	21.16	64.00	73.00	256.00	248.38
	0.125	8.00	22.89	32.00	49.03	128.00	140.69	512.00	527.52

Table 34

Session length as a function of p. Tabled data are session length means and standard deviations in minutes computed over all five sessions at each value of p for all values of $\overline{T}$. Values in parentheses are recovery values at p=1.000.

		S1		S2		S3	
$\overline{T}$	p	$\overline{X}$	S.D.	$\overline{X}$	S.D.	$\overline{X}$	S.D.
1.00	1.000	23.57	0.04	24.07	0.86	23.56	0.03
		(23.53)	(0.01)	(23.62)	(0.08)	(23.64)	(0.16)
	0.500	46.62	8.52	49.45	6.95	45.57	5.76
	0.250	91.22	6.52	92.22	8.55	91.34	21.80
	0.125	176.62	32.73	190.57	47.36	211.17	28.26
0.75	1.000	23.90	0.49	23.67	0.10	24.43	1.64
		(23.53)	(0.02)	(23.76)	(0.19)	(23.54)	(0.02)
	0.500	45.36	3.44	42.18	6.54	46.92	3.14
	0.250	95.17	5.89	98.61	5.60	93.98	12.59
	0.125	153.24	38.24	158.27	17.68	191.64	28.02
0.50	1.000	23.57	0.04	24.42	0.34	23.63	0.09
		(23.30)	(0.62)	(24.13)	(0.24)	(23.59)	(0.11)
	0.500	43.54	5.57	42.49	7.46	43.89	6.61
	0.250	109.73	7.67	87.16	10.11	103.30	12.01
	0.125	184.96	43.23	169.71	15.40	175.69	39.34
0.25	1.000	23.68	0.04	25.45	0.63	23.53	0.01
		(23.67)	(0.16)	(24.45)	(0.22)	(23.62)	(0.06)
	0.500	51.87	5.55	46.51	10.00	45.89	1.89
	0.250	98.21	15.08	106.22	31.00	93.65	13.25
	0.125	203.25	34.89	175.94	22.85	170.72	16.05

Table 34 (continued)

Session length as a function of p.

		S4		S5	
$\overline{T}$	p	$\overline{X}$	S.D.	$\overline{X}$	S.D.
1.00	1.000	23.78	0.42	24.13	0.59
		(24.12)	(1.16)	(23.98)	(0.45)
	0.500	43.00	5.16	46.78	5.50
	0.250	92.62	11.08	101.76	11.50
	0.125	189.43	40.74	172.35	26.62
0.75	1.000	23.95	0.26	28.36	6.75
		(23.58)	(0.02)	(23.76)	(0.13)
	0.500	50.46	4.89	47.82	4.99
	0.250	92.15	10.01	107.38	14.87
	0.125	189.75	36.10	176.94	18.08
0.50	1.000	23.80	0.46	24.13	0.54
		(23.58)	(0.06)	(23.87)	(0.47)
	0.500	40.78	4.44	48.04	3.65
	0.250	91.43	11.41	98.46	6.45
	0.125	188.24	28.47	176.31	22.08
0.25	1.000	24.00	0.45	23.89	0.30
		(24.47)	(0.35)	(24.12)	(0.36)
	0.500	43.87	4.23	50.07	8.17
	0.250	99.71	22.66	91.09	9.64
	0.125	195.00	29.00	190.46	35.49

Table 35

Response rates and parameter values obtained by fitting the tabled data to equation (16). Data are taken from Cole (1968), Cumming & Schoenfeld (1957), and Skinner (1938). All values of T are in seconds. Values in the body of the table are response rates (R) and predicted response rates (R') in responses per second. Skinner's data are uncorrected for reinforcement time. All other data are corrected response rates.

Cole (1968)

		T					
		3	6	12	24	B	k
S1	R	1.92	1.31	1.11	0.99	0.9797	0.5795
	R'	1.58	1.44	1.23	0.95		
S2	R	2.02	1.20	0.81	0.69	0.9577	0.5272
	R'	1.53	1.28	0.97	0.65		
S3	R	1.39	1.02	0.80	0.64	0.9622	0.7030
	R'	1.22	1.08	0.86	0.62		

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Schoenfeld & Cumming (1957)

		T							
		0.94	1.88	3.75	7.50	15.0	30.0	B	k
S7	R	2.36	2.67	1.75	1.53	1.04	0.57	0.9538	0.3353
	R'	2.64	2.37	1.97	1.47	0.97	0.58		
S8	R	4.72	3.36	3.49	2.23	0.67	1.13	0.9701	0.3094
	R'	2.96	2.74	2.37	1.87	1.32	0.83		
S9	R	2.31	2.01	2.02	1.74	0.82	0.43	0.9337	0.2716
	R'	2.99	2.52	1.92	1.30	0.79	0.44		

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Skinner (1938)

		T					
		180	300	420	540	B	k
S1	R	0.09	0.07	0.06	0.05	0.9704	6.3111
	R'	0.09	0.07	0.06	0.05		
S2	R	0.05	0.05	0.04	0.04	0.9795	13.7451
	R'	0.06	0.05	0.04	0.04		
S3	R	0.13	0.11	0.09	0.06	0.9792	3.3923
	R'	0.14	0.10	0.08	0.07		

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