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TEMPORALLY DEFINED SCHEDULES OF STIMULUS CORRELATIONS

by

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I. Introduction

A. The initial t-system

In the early 1950's, the classification of schedules delivering intermittent reinforcements was based upon a two-fold dichotomy. The principal division rested on whether the delivery of successive reinforcements was determined by the passage of time or the emission of responses. The former arrangement made up interval schedules and the latter constituted ratio schedules. Secondarily, it was possible to distinguish between fixed and variable versions of each, thus giving rise to the four basic categories of fixed interval, variable interval, fixed ratio, and variable ratio (Keller and Schoenfeld, 1950, pp. 83 - 101; Skinner, 1953a).

The separation of interval and ratio schedules was supported by consideration of both the independent and dependent variables. From the standpoint of implementing the schedules, the operations of timing and counting involve not only different dimensional systems but also arrangements which Skinner (1953b, p. 100) has characterized as being either outside the organism (i.e., intervals of time) or controlled by the behavior itself (i.e., numbers of responses). This operational distinction was further supported by systematic differences observed in the resultant behavior when it was analysed in terms of various measures: rate of responding, number of responses per reinforcement (the extinction ratio), temporal patterning of response rate, and characteristics when reinforcements were subsequently withheld altogether. The differences were regarded as by-products of the differential reinforcement of selected interresponse times (IRTs): "When a reinforcement is scheduled by a timer, the probability of reinforcement increases during any pause, and the first responses after pauses are especially likely to be reinforced. On ratio schedules responses which are part of short runs are likely to be reinforced" (Skinner, 1957, p. 349).

Working from the same differential reinforcement interpretation, Schoenfeld, Cumming, and Hearst (1956) proposed an integration of these schedules into a single conceptual and operational system which would arrange explicitly for the differential reinforcement of certain classes of IRTs through the manipulation of only temporal variables. Their schema was founded upon a period of time, t^D, in which a response could produce a reinforcement and a period of time, t^Δ, in which responses could not produce reinforcements. To deal specifically with the relationships between various classically defined schedules, they placed three restrictions on the manner in which the time periods could operate: (1) the two durations were fixed for any experimental condition, (2) the two periods operated in strict alternation, and (3) only the first response in each t^D could be reinforced. (One consequence of this last restriction was that the occurrence of a reinforced response terminated the effective length of that particular instance of a t^D.) The resultant system amounted to a periodically recurrent "time window" for reinforcement availability, and its operation was governed by two independent parameters. One of these was the cycle length or period, and it was equal to the sum of t^D and t^Δ. Subsequently called T, it determined the rate at which the time window opened. The other parameter was the proportion of the cycle devoted to t^D, and it was equal to the value of the fraction $t^D/(t^D+t^\Delta)$. Subsequently called $\bar{T}$, it determined how long the time window was open.

Consideration of these parameters suggested that several schedules could be either generated or closely mimicked by selection of appropriate values for the two time periods. For example, if the cycle length were shorter than the duration of the reinforcing stimulus and $\bar{T}$ were at or near 1.00, each response would occur in a new t^D and would, therefore, be reinforced. Extinction, on the other hand, was seen as the result of very small $\bar{T}$s; by making the duration of t^D sufficiently short, the number of reinforcements obtained would be inadequate to maintain responding. And for cycle lengths shorter than the minimal IRT, a schedule called <u>random ratio</u> would be generated in which the probability of reinforcement, given directly by the proportion of time available for reinforcement (i.e., by $\bar{T}$), is the same for each response.[1]

Most central to the attempted integration, however, were the predicted outcomes of combining various $\bar{T}$s with moderate and long cycle lengths. With $\bar{T}$ at 1.00, a classically defined fixed-interval schedule of duration T seconds would be obtained, for only the first response in each t^D+t^Δ seconds could be reinforced. (The ability to reproduce fixed-interval schedules is thus a second consequence of the restriction that only the first response in each t^D can be reinforced.) By reducing $\bar{T}$ -- that is, by concomitantly decreasing t^D and increasing t^Δ-- a contingency would be arranged for establishing high response rates because a short IRT would have a higher probability of terminating during a t^D than would a long one. In addition, since the cycle length provides a minimum inter-reinforcement interval, post-reinforcement pausing would become pronounced. The combination of spaced reinforcements, post-reinforcement pausing, and a high rate of responding is characteristic of fixed ratio scheduling. Still further reduction in $\bar{T}$ would introduce variability into the reinforcement density, for such reductions would make it less likely that every t^D would be intercepted by a response. This diversity of interreinforcement times coupled with the differential reinforcement of short IRTs is characteristic of variable ratio scheduling.

A program of research was undertaken in which most of the studies investigated the effects of reducing $\bar{T}$ while holding the cycle length constant. Collectively, they covered the effective range of T. Brandauer (1958) worked with cycles below one millisecond and provided data on random ratio schedules. Hearst (1956) used 30 seconds, Clark (1958) studied the effects of both a 2 minute and a 10 minute cycle, and Schoenfeld and Cumming (1960) worked with a 30 minute cycle. In addition, Schoenfeld and Cumming (1957) reported the effects of varying the cycle length from 30 through 0.9 seconds while keeping $\bar{T}$ constant at 0.05. The analyses generally included: (1) a determination of the functions relating response rate and the extinction ratio to the independent variable, (2) an evaluation of temporal patterning of responding by inspection of the cumulative response records and comparison of IRTs collected just before and just after reinforcements, and (3) an inspection of the cumulative records taken during a terminal extinction phase.

The experimental findings corroborated the anticipated results. The relationship between response rate and the two parameters T' and $\bar{T}$ is complex and has been summarized graphically by Schoenfeld and Cumming (1960). In general, response rate is inversely related to $\bar{T}$ for cycle lengths between 30 seconds and 10 minutes, as is the extinction ratio. Reduction of $\bar{T}$ for these cycle lengths also changes the smoothly accelerated rate "scallops" into "break and run" patterns, an observation from the cumulative records that was quantitatively verified in the IRT distributions. Cumulative records taken during extinction showed combinations of features common to extinction following training on ratio schedules and to extinction following training on interval schedules. Clark (1958) showed that: (a) the pre-feeding of a bird who had reached behavioral stability at a $\overline{T}$ of 0.004 mimicked satiation effects known for ratio, but not interval, schedules; (b) a bird whose reinforcement opportunities were yoked to the reinforcements actually earned by another subject, thereby providing for a reduction in reinforcement rate without the differential contingency for short IRTs, gave response rates directly proportional to the reinforcement density and with maintained scalloping; (c) when another bird was shifted from a $\overline{T}$ of 0.003 to a variable ratio schedule whose mean was numerically equal to the extinction ratio obtained from the temporally defined schedule, there was no observable change in behavior. Clearly, the classification system based on two temporal variables, cycle length and $\overline{T}$, showed that ratio schedules can be considered as special cases of temporally defined ones. The integration was accomplished.

Subsequent investigation within the framework of temporally defined schedules sought to extend the t-system to other areas of theoretical interest. For example, the tau-system was formulated to deal with some of the consequences of the earlier restriction that only the first response in a t^D could be reinforced (Schoenfeld and Cumming, 1960). Other extensions of the initial t-system have included work with schedules of aversive stimuli, discrimination paradigms, analyses of "contingency," and the production of variable-interval schedules.[2] It was in this last regard that a third parameter, stimulus probability, explicitly entered into the system.

B. Probability of reinforcement

One function of a probability variable in a reinforcement schedule is regulation of the occurrences of the reinforcer. To accomplish this end, any device that prearranges sequences of unreinforced response runs or interreinforcement intervals is adequate. However, in addition to its programming role, a probability variable also provides through its formal properties the services of a priori specification and integration of certain reinforcement schedules.

In the t-system, the variable $\overline{T}$ may be used as a probability "generator" for reinforcements because it is the ratio of time available for reinforcement to total time. The particular arrangement by which $\overline{T}$ interacts with responses will determine both the classification of the schedule and its specifications. It should be noted that, although the organization of the following material was dictated by the needs of the mathematical exposition, the logical development parallels the order in which, for quite different reasons, the schedules made their appearance historically.

A fundamental case arises when each response qualifies for reinforcement with a fixed probability. Each response occurrence may be considered a Bernoulli trial with an outcome of either reinforcement or nonreinforcement. Following the notation of probability theory, the likelihood of a reinforced response is written as p, and the likelihood of an unreinforced response is $1-p$, or q. As long as the probability of reinforcement is applied to each response independently of the results of earlier or later responses, several consequences may be anticipated.

For example, the probability of the sequence consisting of reinforcement, nonreinforcement, reinforcement, nonreinforcement, and nonreinforcement is: $p \cdot q \cdot p \cdot q \cdot q$, or, more simply, p^2q^3. In general, the probability of any sequence of r reinforcements among N responses is

$$p^r q^{N-r},$$

and there are exactly $\binom{N}{r}$ such sequences possible. Multiplying the probability of one sequence by the number of different orderings gives the probability of occurrence for each possible number of reinforcements:

$$\text{(1)} \qquad \text{Prob } (r|N,p) = \binom{N}{r} p^r q^{N-r}, \quad \begin{array}{l} 0 \leq r \leq N, \\ N = 1, 2, 3, \ldots \text{ and not otherwise.} \end{array}$$

Equation (1) is the function rule for the binomial distribution in fixed parameters N and p. As long as the probability of reinforcement is applied to each of the N responses independently, it is possible to evaluate the probability that there will be zero, one, ..., or N reinforcements among the fixed number of responses that are emitted.

Usually, the number of responses that the subject makes is not under the experimenter's control, and a more useful statement can be made by working with a special case of the binomial distribution. Instead of calculating the probabilities for the different numbers of reinforcements in a fixed sample size, one determines the probabilities for different numbers of unreinforced responses separating successive reinforcements. In terms of probability theory, the question is: given a reinforcement, how big must the sample be to include the next reinforcement? In this case, r is fixed at 1 and N is the variable. As there is only one sequence possible -- a run of N-1 unreinforced responses ending with the reinforced one -- the distribution reduces to

(2) $\text{Prob}\ (N|p) = pq^{N-1}$, $N = 1, 2, 3, \ldots$ and not otherwise.

Equation (2) is the function rule for the geometric distribution which here describes the relative frequencies of unreinforced run lengths of size N-1 in ratio schedules. The most probable sequence is two reinforced responses in succession, and this event occurs with a relative frequency of p; the relative frequencies of one, two, three, ..., N responses per reinforcement decreases exponentially.

The expectation of a variable is found by multiplying each possible value of the variable by its corresponding probability and then summing the resultant products (Edwards, 1964). For the geometric distribution, the range of N extends to indefinitely large numbers, but the corresponding probabilities become indefinitely small. Consequently, the continuing sum rapidly approaches the expected value as an asymptote over a finite range of N, and one can thereby arrive at the expectation of N and N^2. By definition, the former is the mean, and the difference between the latter and the square of the former is the variance (Hayes, 1963, pp. 167-171 and p. 183). The results of numerically evaluating the first two moments of the distribution for any value of p reveal that the mean of the geometric distribution is $1/p$ and the variance is q/p^2. Thus, if the probability of reinforcement is 0.01, the mean is 100; on the average, 99 unreinforced responses will separate reinforced ones, and the schedule is called <u>random ratio 100</u>.[3]

Random ratios are generated whenever the probability of reinforcement is identical for every response; hence the term <u>random</u>. In the <u>t</u>-system, equiprobability is produced by a cycle length that is considerably shorter than the minimal IRT. The provision that many cycles intervene between responses serves two purposes. First, the rule that only the first response in t^D can be reinforced becomes inconsequential because every response occurs in a different cycle. Second, the variability of IRTs relative to the fixed period of the t^D+t^Δ cycle makes the interception of a t^D by a response a chance event. On meeting these stipulations, $\bar{T}$ becomes numerically equal to p. As is connoted by the word random, the order of the various run lengths is not known even though their relative frequencies can be calculated. Some behavioral effects of random ratio schedules have been studied by Brandauer (1958), Sidley and Schoenfeld (1964), and Farmer and Schoenfeld (1967).

An evolution of schedules results from restricting the availability of reinforcement. Instead of applying to all responses, the constant probability may be assigned to only those responses occurring in a certain time period, giving rise to the class of tau-schedules (Schoenfeld and Cumming, 1957). During tau^D, random ratio prevails. In most of the work reported so far, p has been zero during tau^Δ (Cumming and Schoenfeld, 1963; Snapper, 1962). In such cases predictable run lengths of unreinforced responses in tau^D are interspersed with unknown run lengths in tau^Δ; if the probability of reinforcement is greater than zero during tau^Δ (Vickery, 1971), one deals with two varying densities of reinforcement, but both come from populations whose random ratio properties are known.

Reinforcement availability may be further restricted so that only one response in a time period T is eligible for reinforcement with some fixed, non-zero probability. For convenience, the first response in the period is used. (Alternatively, one constructs a t^D+t^Δ schedule so that

$\bar{T} = 1.00$. As is usually the case, only the first response in t^D can be reinforced, but here it is done so with probability p.) The geometric distribution still applies to each of the temporally selected responses, but every sampling trial is now separated by at least T seconds. If responding is distributed so that there is at least one response in each cycle, the geometric distribution will give the relative frequencies of the various interreinforcement times. Just as each N along the abscissa is multiplied by the T seconds required by each cycle, so are the moments of the distribution, making the mean equal to T/p and the variance equal to T^2q/p^2. As before, sequences are irregular, and such arrangements have been called <u>random-interval schedules</u> because the probability of reinforcement is equal (for the first response) in each interval (Farmer, 1962; Millenson, 1963).

These three classes of reinforcement schedules -- random ratio, <u>tau</u>, and random interval -- use, as previously explained, the $\bar{T}$ in a t^D+t^Δ schedule of very short cycle length to generate probabilities. In random ratio, the <u>t</u>-schedule stands alone, while in <u>tau</u> and random interval it is used in conjunction with other temporal variables to select a response for reinforcement. As a consequence, the geometric distribution relates the schedules in two different ways. One is a kinship between random-interval and random-ratio schedules under the control of the parameter T: identity is reached as a limit when the length of the cycle selecting responses approaches zero. The other is a communality, implicit in the moments of the distribution, of reinforcement intermittency under the control of the parameter p: reinforcement may be made as regular or irregular as desired by manipulating p. Because it is constructed from the fundamental variables t^D and t^Δ, the parameter p is thus seen to be congenial with the other parameters of the temporally defined system of classifying reinforcement schedules.

C. Stimulus discrimination and the t-system

The generic procedure for stimulus discriminations was described by Skinner (1938, p. 167) as a correlation of reinforcement with a specific aspect of some stimulus. The notation of S^D was used to indicate a discriminative stimulus that was positively correlated with reinforcement, and S^Δ, a discriminative stimulus that was negatively correlated with reinforcement. (It was by analogy with this convention that Schoenfeld, Cumming, and Hearst [1956] chose the terms t^D and t^Δ to indicate, respectively, periods of time in which reinforcements were and were not available.)

Skinner's demonstration of stimulus discrimination using an operant response was a variety of a fixed-interval schedule in which a light (S^D) appeared at the end of each dark (S^Δ) interreinforcement interval (Skinner, 1938, pp. 183-192). Because only one response was reinforced in each interval before the S^D was removed, no rate measure during S^D was possible, but discrimination of the light was to be evidenced by a reduction in the nearly constant rate of responding observed earlier under the uncued fixed-interval schedule. With the discriminative procedure, there was a substantial decline in S^Δ responding.

Given Skinner's prototypical procedure, the t-system was easily extended to include discriminative paradigms. As discussed earlier, the fixed-interval schedule is produced when $\bar{T}$ is at unity, t^D and t^Δ alternate, and only the first response in t^D is reinforced. If, in addition, a light is turned on with the start of t^D and terminated with reinforcement, Skinner's discrimination experiment is replicated. His formulation had emphasized the differences observed between cued and uncued versions of an intermittent reinforcement schedule, and the work on discriminative paradigms within the _t_-system has continued that emphasis.

In Hearst's (1956) and Clark's (1958) experiments, the reduction of t^D had resulted in a transition from interval to ratio "type" behavior, and the increased response rate was attributed to a differential reinforcement of short interresponse times inherent in the performance at early stages. As t^D became shorter, there was a greater probability of a response's getting through the "time window" by sustained periods of rapid responding than by pacing the _t_-cycle with isolated responses. Within broad temporal limits, however, the presence of an exteroceptive stimulus during t^D could allow for precise, and thus reinforced, response pacing of the cycle. The inital experiment within the _t_-system, conducted by Weissman (1958), was designed to determine the extent to which cuing of reinforcement availability in a t^D+t^Δ schedule would transmute the known effects of reducing $\overline{T}$.

Five discrimination paradigms were used, each one a variation in the temporal position of the incidental stimulus relative to the onset of t^D. One was a replication of Skinner's experiment in that the light was exactly congruent with reinforcement availability; the S^D began with t^D onset and terminated with either the first response in t^D (the only one eligible for reinforcement) or the end of t^D, whichever event occurred first. Weissman reasoned that at very small values of $\overline{T}$, t^D might be shorter than the animal's reaction time to the cue, and the discriminative response would consistently occur too late for reinforcement. Therefore, he had some groups of subjects for whom the light was a preparatory cue, preceding the beginning of t^D by a constant interval of time. By analogy with classical conditioning paradigms, both "trace" and "delay" cases were constructed. The former involved a one-second flash of light starting 10 seconds before t^D, and, for the latter, the light was present during the entire 10 seconds preceding the start of t^D. In addition, two combinations of preparatory and t^D cuing were included. In a trace-plus-t^D cue arrangement, the light was presented in each cycle first as a one-second flash and then, nine seconds later, during t^D. For a delay-plus-t^D cue arrangement, the light appeared 10 seconds preceding t^D and continued without interruption into the "time window." There was also a control group for whom no incidental stimulus was used.

When $\overline{T}$ was 1.00, Weissman found the overall rate of responding to be lower for those groups receiving a stimulus change at t^D onset (i.e., the t^D cued, the trace-plus-t^D cued, and the delay cued groups) than it was for those who had no stimulus change accompanying the start of t^D (i.e., the uncued, the trace cued, and the delay-plus-t^D cued groups). When $\overline{T}$ was progressively reduced, some animals gave rates that declined monotonically into response failure at intermediate durations of t^D, some gave rates that rose to a maximum before declining to zero at the smallest t^Ds, and some gave rates that uniformly increased as t^D decreased. There were only three animals in each of the paradigm groups, and the intra-group variability obscured any systematic differences that may have arisen due to the different temporal positions of the neutral stimulus.

In a subsequent study, Weissman (1961) reported a reliable difference between cued and uncued reductions in $\overline{T}$ when the added stimulus was coextensive with reinforcement availability (i.e., the t^D cued case above). The discrimination paradigm was used twice with an intervening stage. On the first run-through, the exposure to a $\overline{T}$ of 1.00 was sufficiently extensive for a nearly perfect discrimination to form: S^{Δ} responding extinguished, and only the isolated, reinforced responding to S^{D} was present in the steady state performance. Because there were no short interresponse times in the terminal portions of t^{Δ}, subsequent reduction of $\overline{T}$ led not to a differentiation of high rates but, rather, to increasing response failure at the successively briefer presentations of S^{D}. Then, with the incidental stimulus continuously present, thereby abolishing the discrimination, the progression of t^{D}s was repeated. Under this condition, reduction in $\overline{T}$ raised the rate of responding. In the final stage, the cue function was reinstated, but only short t^{D}s were used and the subjects were given only one-third of the previous training time at each value. Consequently, discriminative control was poor, and as $\overline{T}$ was reduced, the subjects gave performances that were between the cued and uncued functions just established.

In a third study, Weissman (1963) again reduced t^{D} in cued and uncued cases, but this time $\overline{T}$ started at 0.30 and the reductions were carried out concurrently while alternating the two situations in a multiple schedule. Under these experimental conditions, only one subject developed a nearly complete stimulus discrimination at the longest t^{D}, and the subsequent serial reduction led to no rate increase in the component with the t^{D} signal, but the usual rate increase in the component without the t^{D} stimulus. The other subjects developed some discrimination at the intial value of $\overline{T}$: their rates were lower in the component with the t^{D} signal, but S^{Δ} responding was still substantial. Consequently, reduction of $\overline{T}$ produced increased responding in both components but with proportionally more responding at each value in the uncued version.

These experiments demonstrate that when discriminative control has been established, the operation with which the neutral stimulus is correlated (here, changing the availability of reinforcements) has effects different from those obtained when the neutral stimulus is absent. They further demonstrate, however, that discriminative control is not a necessary consequence of pairing an incidental stimulus with reinforcement availability: the extent to which that stimulus acquires control over responding is dependent upon procedural details.

From the preceding studies, two parameters may be identified in the correlation of a neutral stimulus, S^N, and a reinforcing stimulus, S^R. One parameter, which entered into Weissman's 1958 experiment, is the temporal separation of the two stimuli, hereinafter called the S^N-S^R interval. Although this interval was arbitrarily arranged in that earlier work, it would be desirable to have a rational variable to control the temporal position of S^N. The second parameter, implicit in any experiment on cuing, is the extent of the correlation between the two stimuli. Usually, the correlation is either +1.00 or -1.00, defining S^D and S^Δ, respectively, but intermediate degrees of correlation can be conceptualized.

It is possible to draw these and other relevant parameters together into a generalized paradigm of stimulus correlations through the simultaneous operation of two temporally defined schedules, one programming S^N and the other programming S^R. Because both temporal and probabilistic features of stimulus presentations are to be controlled, the model presented here is based on the random-interval schedule, in which both of the variables are explicitly manipulated. Consequently, there are two cycle lengths, T_N and T_R, and two stimulus probabilities, p_N and p_R. The skeleton of the model is completed by introducing an additional variable, Φ_{N-R}, which is the phase relationship between the two cycles. Other necessary details include the duration of the stimuli, the double choice of whether their presentations will be response-contingent or response-independent, and whether the schedules will be programmed on the same or on different operanda. Finally, it is possible to apply the two probability variables independently of each other or in some interdependent fashion.

II. Method

A. Experimental variables

In this study, presentations of both stimuli were response produced, and the contingencies were arranged concurrently on a single operandum. Five different pairs of random-interval schedules were constructed. The cycle lengths were always constant at 30 seconds ($T_N = T_R = 30$ seconds), but stimulus probabilities of 1.00, 0.80, 0.40, 0.20, and 0.10 were used to make up the different schedules. In each of the pairs, the probabilities of S^N and S^R occurrence were equal ($p_N = p_R$), but they were independently generated. Stimulus density ranged, then, from constant intervals of 30 seconds to varying intervals with a mean of 300 seconds. For each of the five densities, the relative frequency distributions of the time intervals separating reinforcing stimuli (interreinforcement time, or IS^RT) and the time intervals separating neutral stimuli (IS^NT) were geometric.

Phase angle, a second independent variable, placed the start of the T_R cycle relative to the onset of the T_N cycle. Angles of 0, 0.2π, 0.4π, 0.8π, and 1.6π radians were used in interrelating the two cycles. Applied to the constant cycle length of 30 seconds, these angles produced delays of 0, 3, 6, 12, and 24 seconds, respectively, between the availability of an S^N and the availability of an S^R.

The durations of the two stimuli were set at three seconds, and their temporal relationship was determined by both the phase angle between the cycles and the stimulus probability.

Consider first the pair of schedules whose probabilities are 1.00. Both S^N and S^R appear on a fixed-interval schedule of 30 seconds. When the phase angle is zero, the first response in a T_N cycle is also the first response in a T_R cycle; therefore, the same response produces both stimuli, and S^N and S^R are coextensive. With a T_R phase lag of three seconds (and a sufficient rate of responding), however, the first response eligible for reinforcement occurs at S^N offset, and the two stimuli are temporally contiguous. At the longest phase difference, S^N becomes available 6 seconds following reinforcements, and the next S^R is due 21 seconds after an S^N terminates. (The time intervals given in these examples are approximate because only the availability, and not the delivery, of the stimuli was under the experimenter's control. The attendant uncertainty is, of course, a feature that is necessarily common to all experiments in which an event is response produced. Thus, the intervals described here are no more or no less precise than are the interreinforcement intervals in the description of a conventionally defined fixed- or variable-interval schedule. In all such situations, prearranged interstimulus times are modulated by interresponse times.)

Now consider the case where the phase angle is zero and the two probabilities are 0.10. In the long run, 10 cycles will separate the presentations of a given stimulus, but it may reappear in the very next cycle; in fact, it should do so about one-tenth of the time. Suppose an S^N to occur. If it is accompanied by an S^R, the S^N-S^R interval is zero. If the S^N appears by itself, however, the next S^R will follow in 30 seconds, or 60 seconds, or 90 seconds, and so on. Eventually, a reinforcement will occur, but another S^N may have intruded in the meantime. As the stimulus probabilities decrease, the sequence of stimuli becomes more varied, and the range of the S^N-S^R interval increases.[4]

The geometric distributions of IS^NT and IS^RT may be regarded as the parent populations from which the various S^N-S^R intervals derive. In the mathematical model, the probability of a "success" is defined only at integral multiples of N because a fraction of a trial can not occur: the coin either is or is not tossed. When it is applied to random-interval schedules, the model assigns a non-zero probability of reinforcement only at integral multiples of the T cycle. This assignment is accurate in that only the first response in the cycle can be reinforced, and the probability of reinforcement is zero at all other times in the cycle. In idealized form, the frequency distributions of IS^NT and IS^RT are discontinuous and appear as discrete line spectra. Consequently, the S^N-S^R intervals are integral multiples of the T cycle. The effect of introducing a phase lag is to add a constant to these intervals. In the example of stimulus probabilities equal to 0.10, suppose the intercycle time is 6 seconds. An S^N occurs and the next S^R could be 6 seconds away. If it does not appear at that time, S^R will occur 36, 66, 96, ... seconds later. In general, then, the S^N-S^R intervals in this experiment are distributed at values of $(\underline{n} \cdot T) + \Phi$ seconds.[5]

The values of $\underline{n}$ are zero and the positive integers. The S^N-S^R interval of zero represents the special case of simultaneity which is likely to happen only with the cycles "in phase." Generalizing across phases, however, the shortest S^N-S^R interval arises when both stimuli intrude in the same ordinally numbered cycle within the session. Because p_N and p_R are independently generated, the probability of the joint event is the product of the separate probabilities; because p_N and p_R are always equal, the probability that S^N and S^R will appear within the same cycle is p^2. By definition (Hays, 1963, p.112), the conditional probability of S^R given an S^N is the probability of their joint appearance divided by the probability of S^N:

$$\text{Prob } (S^R|S^N) = p^2/p = p.$$

The value of the parameter p, then, is (a) the reciprocal of the average number of cycles separating recurrences of a given stimulus and (b) the proportion of times that the appearance of S^N will be followed, at the appropriate phase lag, by an S^R in that cycle.

B. Subjects

Four barren, white Carneaux, hen pigeons were the subjects. They were experimentally naive and 8 to 9 years old at the start of the study. Fed once each twenty-four hours, they were reduced to 80% of their free-feeding weight some three months before experimentation began and were maintained at that weight throughout. During their adjustment to the feeding schedule, the birds were trained to eat from *E*'s hand, to stand still on the scale during weighings, and to balance on *E*'s hand in moving about the laboratory. From this repertoire, the birds readily evolved a pattern of flying from the home cage to the scale, pausing to have their weights recorded, and then flying from the scale to the experimental chamber in an adjacent room. A reinforcement of two or three maple peas was given on completion of this journey, and the reverse path was similarly maintained at the end of experimental sessions.

C. Apparatus and stimuli

The birds worked in a Lehigh Valley Electronics chamber (Model 1519, Panel B) whose essential features included an exhaust fan, an overhead light, a grain hopper, a response key, and an in-line display unit (Grason-Stadler Model E4580-152 Rev) which transilluminated the key with visual stimuli. (The key nearest the rear wall of the chamber was used. The other two operanda were removed from the panel and were replaced with air-conditioner filter material to improve the ventilation.) A relay tension-gauge reliably operated the key's microswitch with a minimal force of 10 to 12 grams. To provide a sharp focus for the rear-projected stimuli, the plastic display screen of the in-line unit was used to replace the original paddle of the response key. Projected upright at a height just equal to the diameter of the key's field, the stimuli were digits composed of white lines one-eighth of an inch thick that varied in brightness from 1.1 to 1.4 log foot-lamberts.

The field of the key was usually a broadband "green" at 0.5 log foot-lamberts, but it changed to 1.0 log foot-lamberts of white light for three seconds to provide the S^N. (The white field was obtained by punching a round hole in the projector's transparency matrix where an unused digit had been located.) The S^R was a three-second period in which the overhead light was turned off, the hopper was illuminated, and mixed grain (Purina Pigeon Grain) was accessible. The key stimuli were not interrupted during reinforcement.

The programming and recording apparatus was a transistorized digital logic (BRS Digibits) with assorted electromechanical tallying devices. Most of the time periods were derived from a single precision clock (BRS MV-4) that was disabled, as was the response input, during reinforcements; thus, the independent and the dependent variables were automatically "corrected for eating time." The durations of S^N and S^R, however, were controlled by individual one-shots.

The response input to the logic was defined by a combination of one-shots that imposed a minimum IRT of 50 milliseconds on the circuit to accomodate the electromechanical recording devices. Responses and temporal measures, the latter recorded to the nearest one-tenth of a second, were totalled on impulse counters. Printing counters were also used.

Each of the two probability generators was assembled from a high-speed pulse source (multivibrator) that drove a decimally-coded binary counter. Every tenth pulse from the counter set a flip-flop in the ON state, and the pulse from the 1, 2, 4, or 8 output stage of the counter reset the flip-flop; thus, the flip-flop was nominally ON for 10%, 20%, 40%, or 80% of the time, and an instantaneous event would have a probability of coincidence with the ON state of 0.10, 0.20, 0.40, and 0.80, respectively. Since the probability was to be assigned to responses, the requirement of instantaneity was satisfied by stopping the high-speed pulse train, thereby fixing the state of the flip-flop, for the 50 milliseconds defining each response occurrence. At the end of the first 30 milliseconds of this halt, a 1 millisecond sampling pulse was sent to an AND gate whose other leg registered the state of the flip-flop. If that leg was in the ON state, the response pulse was passed through to the rest of the programming circuitry by the probability gate.

The flip-flop cycled at a rate considerably higher than the input rate of the sampling pulse. In such an operation, the variability of the sampling pulses (IRTs) is pitted against the constant period of the probability gate. If the sampling pulses were periodic at some multiple of the gate's frequency, the pulses would always be blocked or passed, depending on the phase relationship between the two frequencies. Because IRTs are not constant, the period of the sampling pulses was irregular, and sequential assignments by the gate appeared to be independent of one another. Similarly, the two probability gates would produce identical sequences of outputs if their periods were integrally related. Mutual independence was achieved by operating the gates near, but not at, the same frequency so that the period of one was always changing relative to the other's. The probabilities so obtained were calibrated by measuring the periods and the different ON times of the gates to the nearest 10^{-5} seconds. The period of the S^N gate was 0.365 milliseconds, and the period of the S^R gate was 0.370 milliseconds. The probabilities given by the ratio of the ON time to the period were: 0.110, 0.219, 0.419, and 0.819 for S^N; 0.114, 0.216, 0.411, and 0.814 for S^R.

D. Experimental plan and procedure

Both practical and theoretical considerations dictated a "single organism" design. A given subject was exposed to each of the experimental conditions for a period sufficient to indicate reliability of the individual's data. Replication of the resulting functions was attempted by exposing additional subjects to the same or similar experimental histories. The implications of this kind of design have been discussed at length in the literature (Sidman, 1960). Given a commitment to this research philosophy, the problem is to arrange for a complete experimental exposure within a practicable segment of the subject's lifetime.

The present experiment made use of a technique, suggested by Cole (1968), that capitalizes on the relatively independent performances in a multiple schedule and which allows the individual subject to sample daily all values of an independent variable for a limited time. Each daily session consisted of a serial presentation of the five pairs of random-interval schedules. Each pair made up one component of the multiple schedule, and the components were identified for the subjects by displaying one of five digits on the response key (the digits 1, 2, 3, 4, and 5 indicated stimulus probabilities of 1.00, 0.80, 0.40, 0.20, and 0.10, respectively). A given component was in effect until 10 S^Ns and 10 S^Rs had been programmed. When one schedule finished ahead of the other one, as was usually the case, that particular schedule was suspended for the remainder of the component; when the other schedule of the pair assigned its tenth stimulus, the digit on the key changed and a different pair of schedules went into effect. The sequence of components was changed daily so as to be counterbalanced across blocks of ten days.

The experiment was arranged in three parts: preliminary training, baseline measurements, and stimulus pairing. During the first two stages, the assignment of the neutral stimulus was programmed in time by the interaction of the independent variables with responses, but S^N was not presented to the subjects; that is, the field of the pecking key remained green throughout these sessions even though the programming and recording apparatus was operating on the basis of 10 S^Ns and 10 S^Rs per component. The purpose of this control was three-fold. First, it allowed performances to stabilize with characteristics determined exclusively by the various densities of unconditioned reinforcements. Second, it allowed for three-second sampling of these performances, prior to S^N intrusion, at different points in time relative to the position of the reinforcer. Third, it provided throughout the entire course of the experiment the departures from idealized random-interval reinforcement that necessarily arose when one schedule terminated in a component ahead of the other one.

Preliminary training.- In the presence of the green key, the birds were trained to eat from the grain hopper whenever it was briefly presented and then, by successive approximations, to peck at the key. After about 100 reinforcements of every peck, schedules of intermittent reinforcement were introduced. The five probabilities of reinforcement were programmed in decreasing order with their associated digits projected on the key, and ten reinforcements were given daily on each schedule. For two days, T was zero (i.e., the birds worked on random ratios). Then, the cycle length was gradually increased: 3 seconds for five days, 6 seconds for two days, and 15 seconds for two days. Finally, the interval was set at 30 seconds, and the order of probabilities was changed daily.

For the next 30 days, six components were run each day (and their sequences were counterbalanced over blocks of six days). For the extra component, one of the schedules was repeated, a different pair being chosen each day. At the end of this stage, each subject had collected 360 S^Rs on every pair in a multiple schedule context. The five-component multiple schedule described earlier was then used for the remainder of the experiment.

Baseline stabilization and measurement.- One hundred and thirty baseline sessions were given on the five-component multiple schedule, bringing to 1,660 the total number of reinforcements earned on each of the random-interval schedules. During the last fifty days in which S^N was withheld, the phase angle was changed daily. Five angles were scheduled in ten sequences that distributed the daily change in a counterbalanced fashion. Because the data collected at this time were to be grouped by phase angle as well as by consecutive sessions, the daily ordering of the schedules was arranged to be counterbalanced across the 10 samples at each phase angle as well as across each of the five 10-day blocks of sessions. The phase angles used in this measurement series provided an arithmetic series of 0, 6, 12, 18, and 24 seconds of intercycle time.

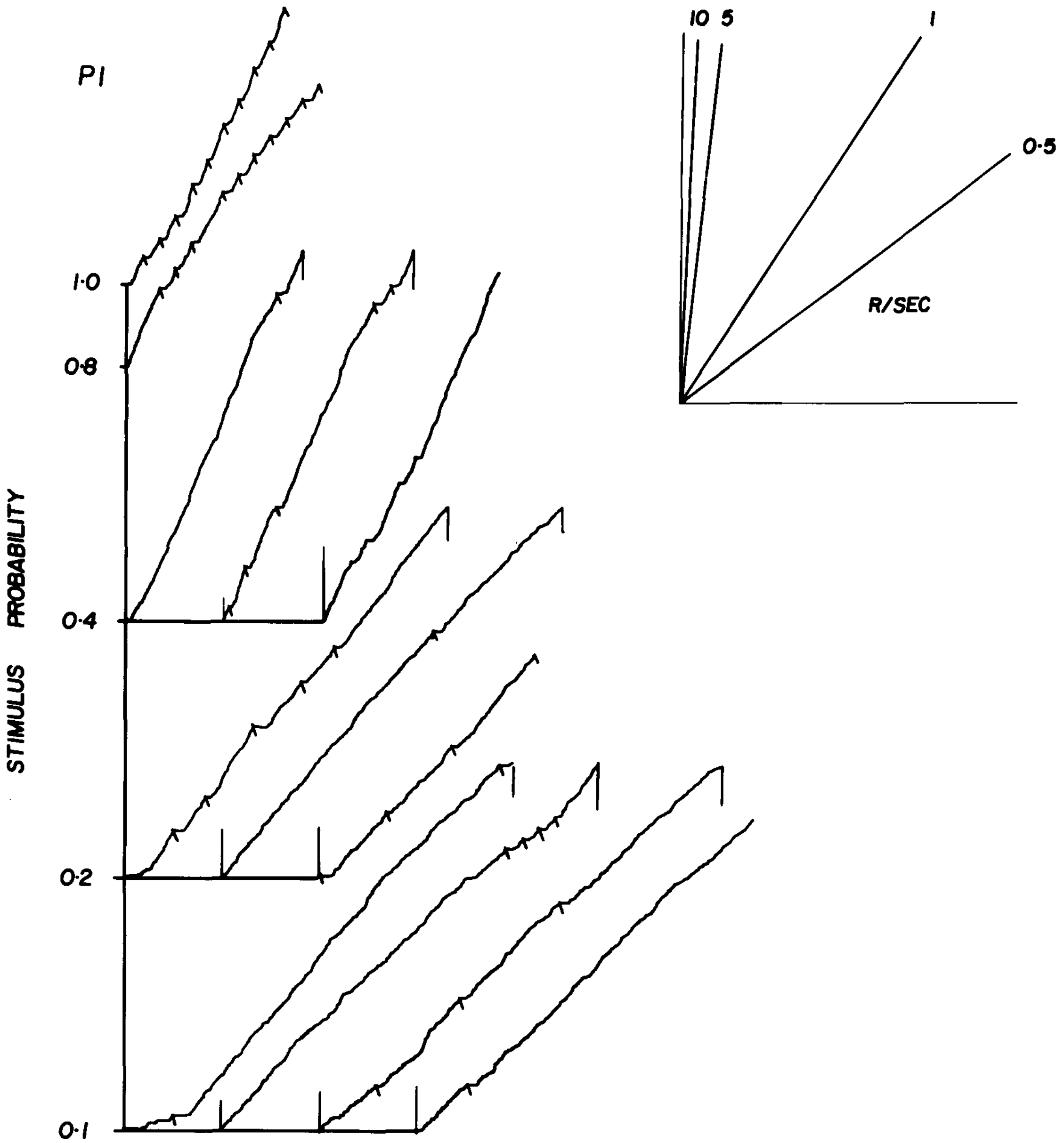
Pairing of S^N and S^R.- With the key actually changing color during the three-second periods of S^N, the subjects were run at a given phase angle for blocks of sessions. The intercycle times used in this stage of the experiment were 0, 3, 6, 12, and 24 seconds, and of all the possible orderings, two seemed of obvious interest. One of these starts with the cycles coextensive and continues in a series of progressively increasing temporal separations; the other begins with the maximum separation and systematically reduces the intercycle time to zero. Accordingly, subjects P1 and P4 worked through the increasing series, and P2 and P3 worked through the decreasing series. Each bird spent 30 sessions at the initial phase angle and 40 sessions at each of the others.

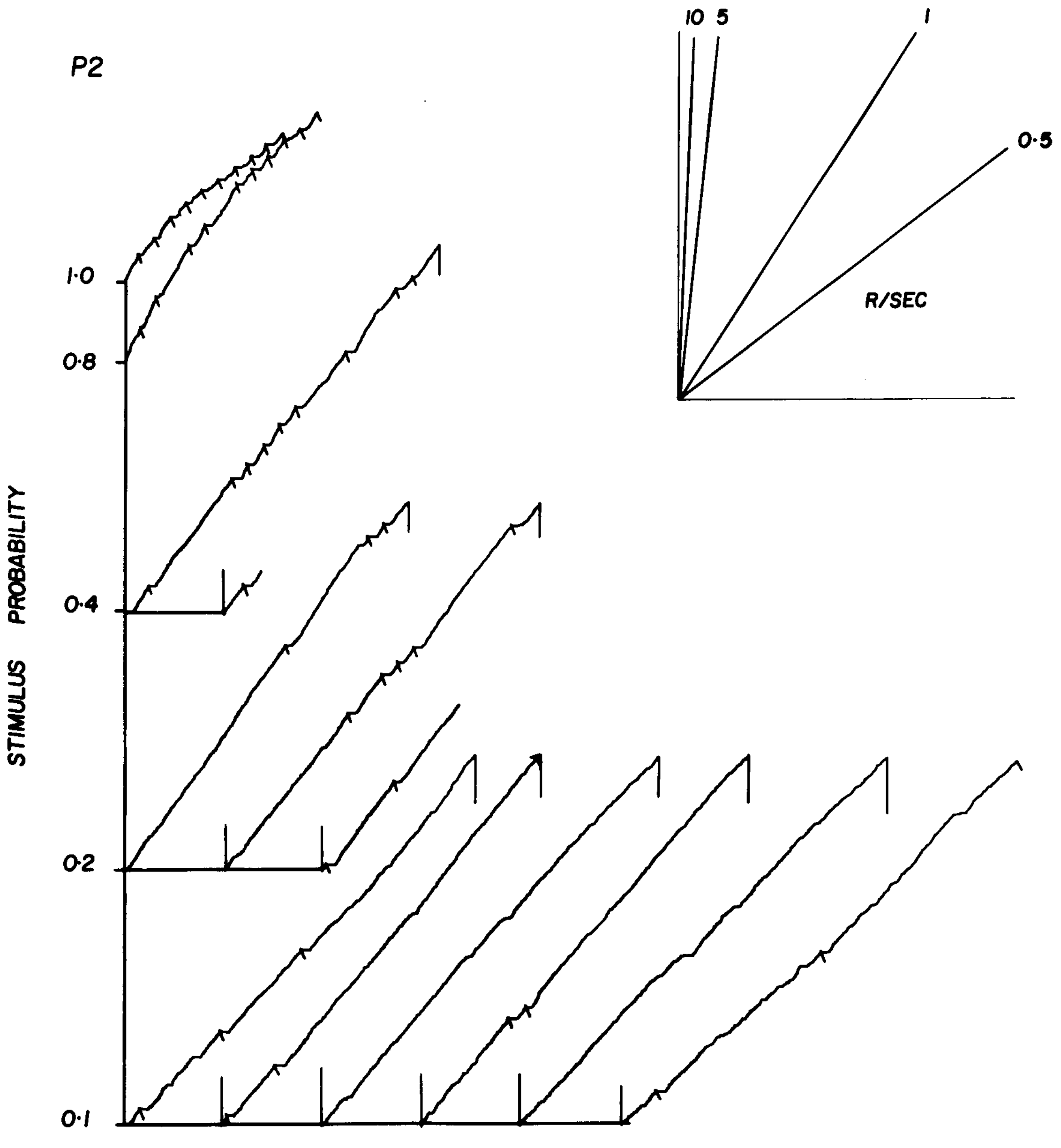
III. Results and Discussion

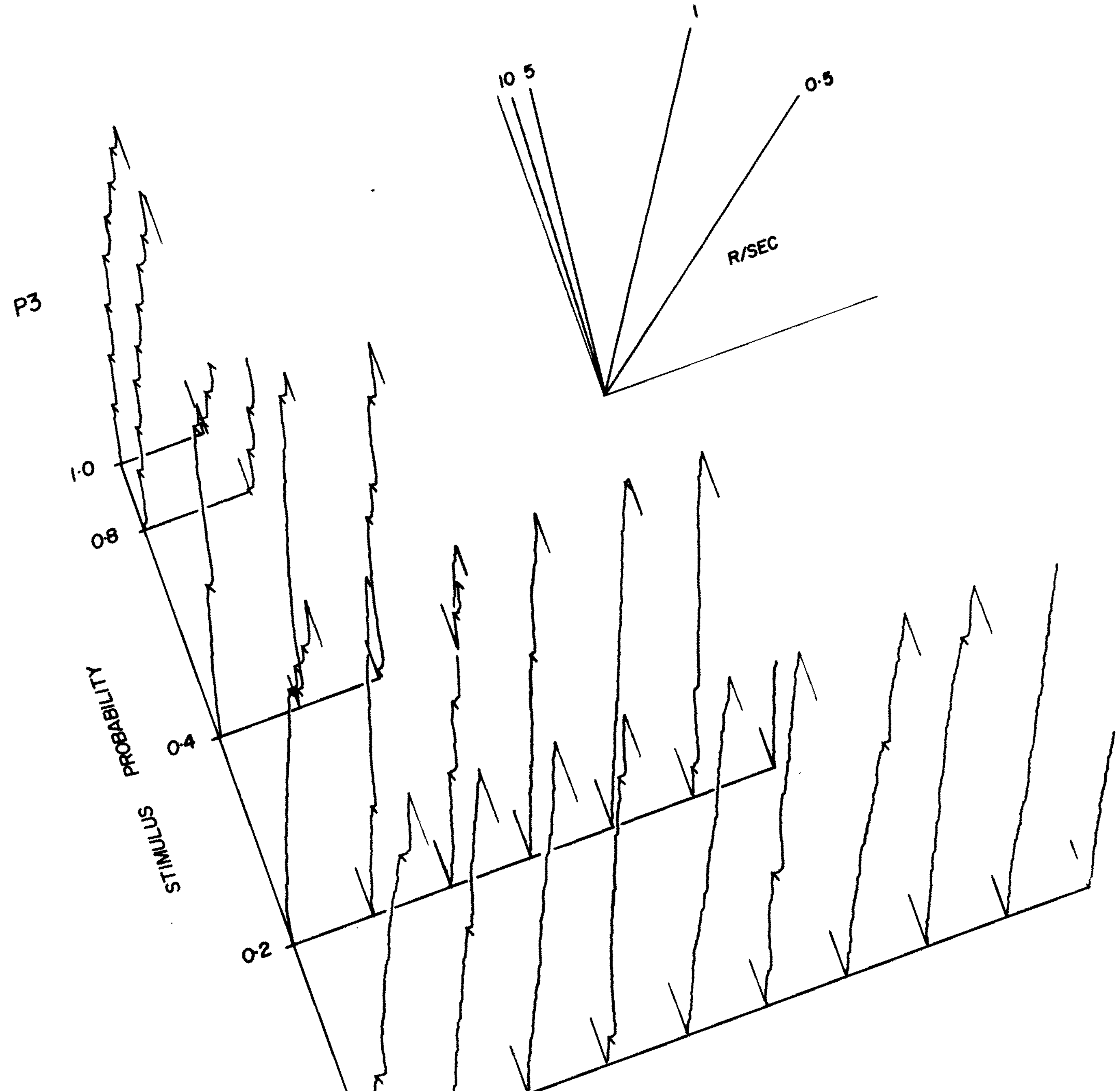
A. The random-interval baselines

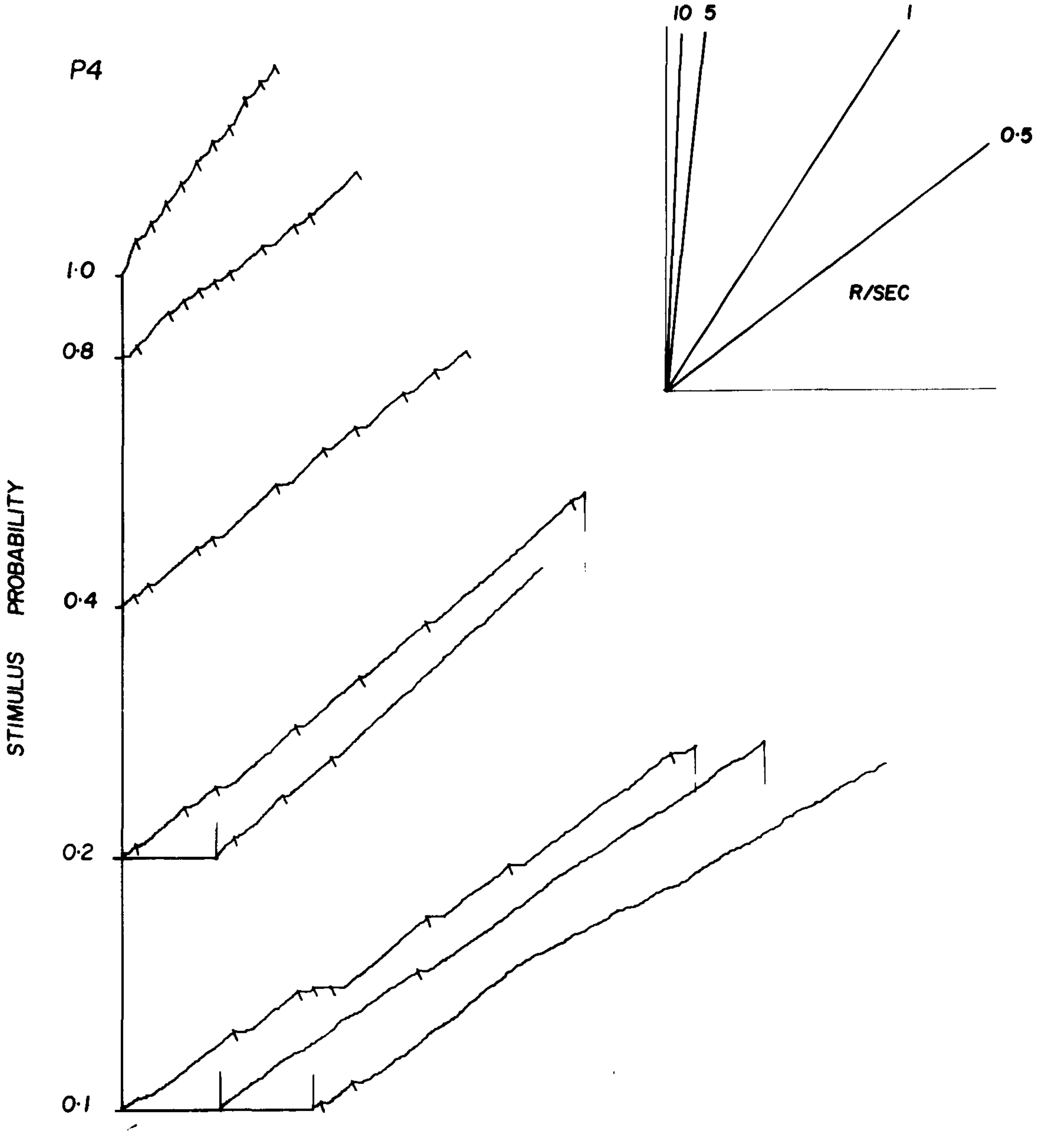
Figure 1 provides an overview of several features that are representative of the baseline performances into which S^N subsequently was intruded. First, the density of reinforcements may be seen to decrease with stimulus probability. Interreinforcement times as long as one hour were occasionally recorded when *p* was 0.10, but, as the record for P1 indicates (in the second segment at this probability), there were still instances in which reinforcements occurred in several consecutive cycles. Second, the cumulative records for the fixed-interval component do not show a consistent, or even a predominant, gradual rate acceleration across the interval. Rather, there was an abrupt transition from the post-reinforcement pause to a response rate that appears to be essentially constant throughout the remainder of the interval. (The extent of a temporal gradient in this rate change will be examined more closely in the discussion of Fig. 7.) This characterization seems about equally accurate for describing responding at the lower reinforcement probabilities, although an increase in the post-reinforcement pause and the "grain" of the records might be third and fourth features, respectively, to be noted. Where there are reinforcements in successive cycles at the lower probabilities, the records are similar in appearance to those obtained at the higher probabilities for all birds except P4. There were also instances among the lower probabilities where, for the same three birds, pausing occurred

Fig. 1a - d. Records from one entire session at the end of the baseline period showing the cumulative number of responses as a function of time. The records from each component of the multiple random-interval schedule have been separated and displaced along the vertical axis according to the probability of reinforcement. The pen reset at multiples of 450 responses, and the resulting segments have been compressed along the horizontal axis; the short diagonal strokes through the records mark reinforcements.


PI
1·0
0·8
0·4
0·2
0·1
STIMULUS PROBABILITY
10 5
1
0·5
R/SEC


P2
10 5
1
0·5
R/SEC
1·0
0·8
0·4
0·2
0·1
STIMULUS PROBABILITY

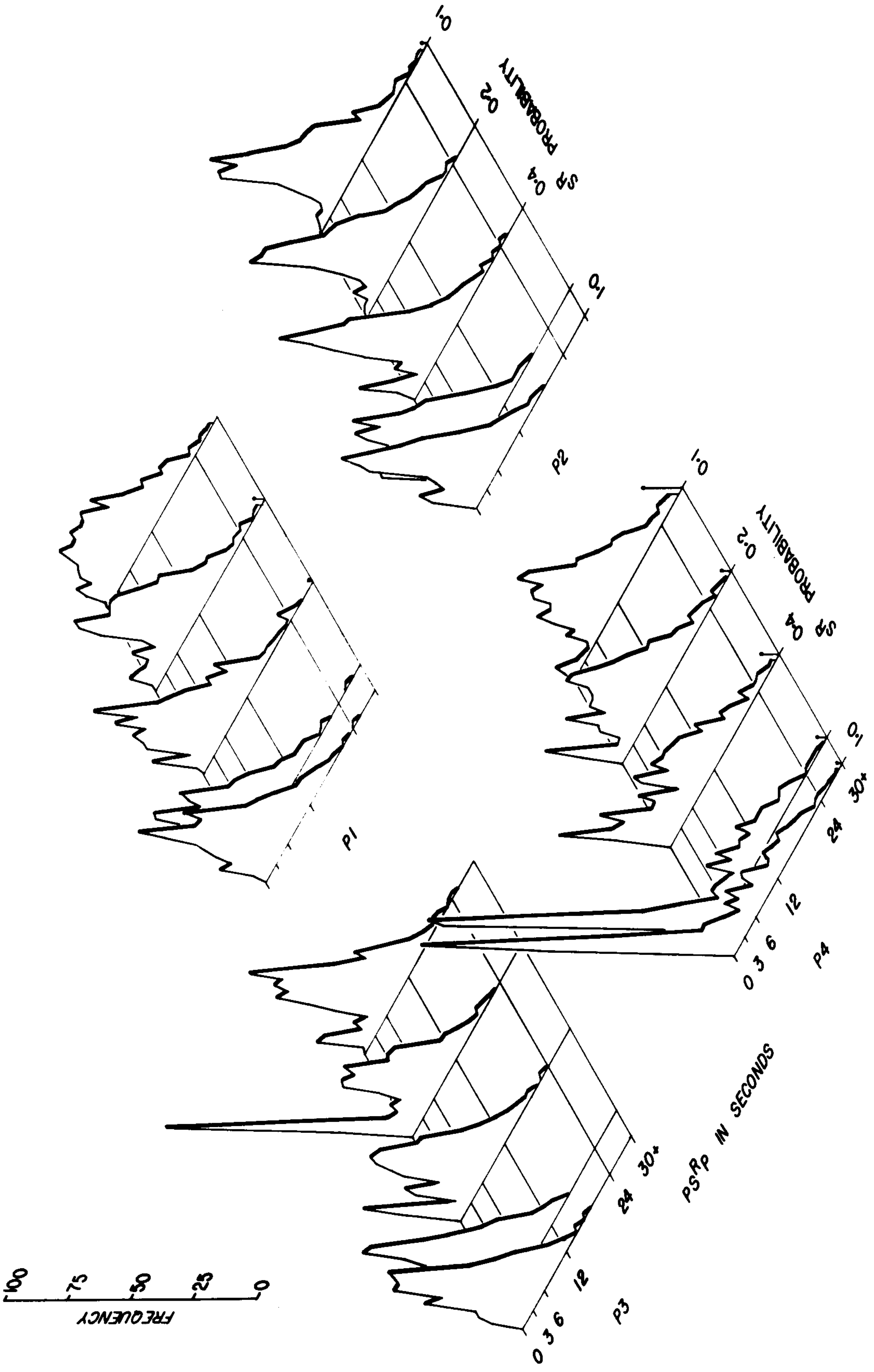

P3
10
5
1
0·5
R/SEC
1·0
0·8
0·4
0·2
0·1
STIMULUS PROBABILITY


P4
STIMULUS PROBABILITY
1·0
0·8
0·4
0·2
0·1
R/SEC
10
5
1
0·5

at intervals about equal to T seconds, and the return to the prevailing rate was about as abrupt as it was after a reinforcement (Fig. 1a, $p = 0.40$, last segment; Fig 1b, $p = 0.10$, early part of the first and middle part of the third and fifth segments; Fig. 1c, $p = 0.20$, middle of the third segment). These pauses aside, the linearity of the records for all birds at the lower probabilities, where interruption of responding by a reinforcement was less frequent, is noteworthy. A fifth feature is that performances of the individual birds differ in absolute rate, length of post-reinforcement pausing, and local irregularities when they are compared on any schedule, but each bird's own characteristics are consistent across the schedules studied.

Post-reinforcement pausing (PS^RP) is detailed in Fig. 2. As the probability of reinforcement decreased, the distribution of the latency of the first response after reinforcement shifted towards the longer values. A description of this increase is complicated, however, by occurrences of bi-modality in these distributions. There is a grouping of PS^RPs that progresses from about five or six seconds at fixed-interval 30 seconds to about twelve or fifteen seconds at random-interval 300 seconds. But there was also a tendency among all four animals to resume responding between 1.5 and 3.5 seconds after a reinforcement. Evidence of this shorter PS^RP may be seen in Fig. 2 in the distributions for each animal at every reinforcement probability. The finding is a reliable one; it was evident in all five of the 10-day blocks that were pooled to produce Fig. 2, and it was present in the earlier baseline data as well. There is no consistent pattern of changes in the relative frequencies of the shorter and longer PS^RPs with the change in reinforcement probability.

Fig. 2. Frequency distributions of the post-reinforcement pausing (PS^RP) under random-interval reinforcement. Each grid gives the data for one animal with separate distributions for the different probabilities of reinforcement. The data are shown in one-second class intervals and were pooled over the last 50 days (N = 500) of baseline training.


P1
P2
P3
P4
PROBABILITY
SP
0.1
0.2
0.4
0.1
0 3 6 12 24 30+
PSRP IN SECONDS
FREQUENCY
0
25
50
75
100

Casual observations of the animals revealed that at the end of reinforcement, a bird would withdraw its head from the feeding device and walk around the experimental space, stopping occasionally to pick up any grains that had spilled on the floor during the eating time. On many occasions, however, a bird would withdraw its head and return immediately to the key, making one or two responses before touring the chamber (this pattern was especially common for P4, as may be inferred from the distributions shown in Fig. 2 at probabilities of 1.00 and 0.80). The variables governing the alternations between these classes of post-reinforcement performance are not known, although it should be emphasized that, because the cycle clocks did not operate during reinforcements, a new cycle could not begin during S^R, and responding immediately after a reinforcement was never reinforced.

Previous accounts of random-interval behavior have reported only the mean PS^RP, and the distributional characteristics of this datum are not available in the literature for comparison. Apart from their bi-modality, the present distributions also exhibit a slight positive skew, and, for that reason, quartiles are presented in Table 1 for summarizing purposes. The medians are inversely related to reinforcement probability, but there is no such relationship apparent for the measure of variability, which shows little change. For all birds, 75% of the pauses terminated within the first cycle after reinforcement, even when the average number of cycles separating reinforcements was ten.

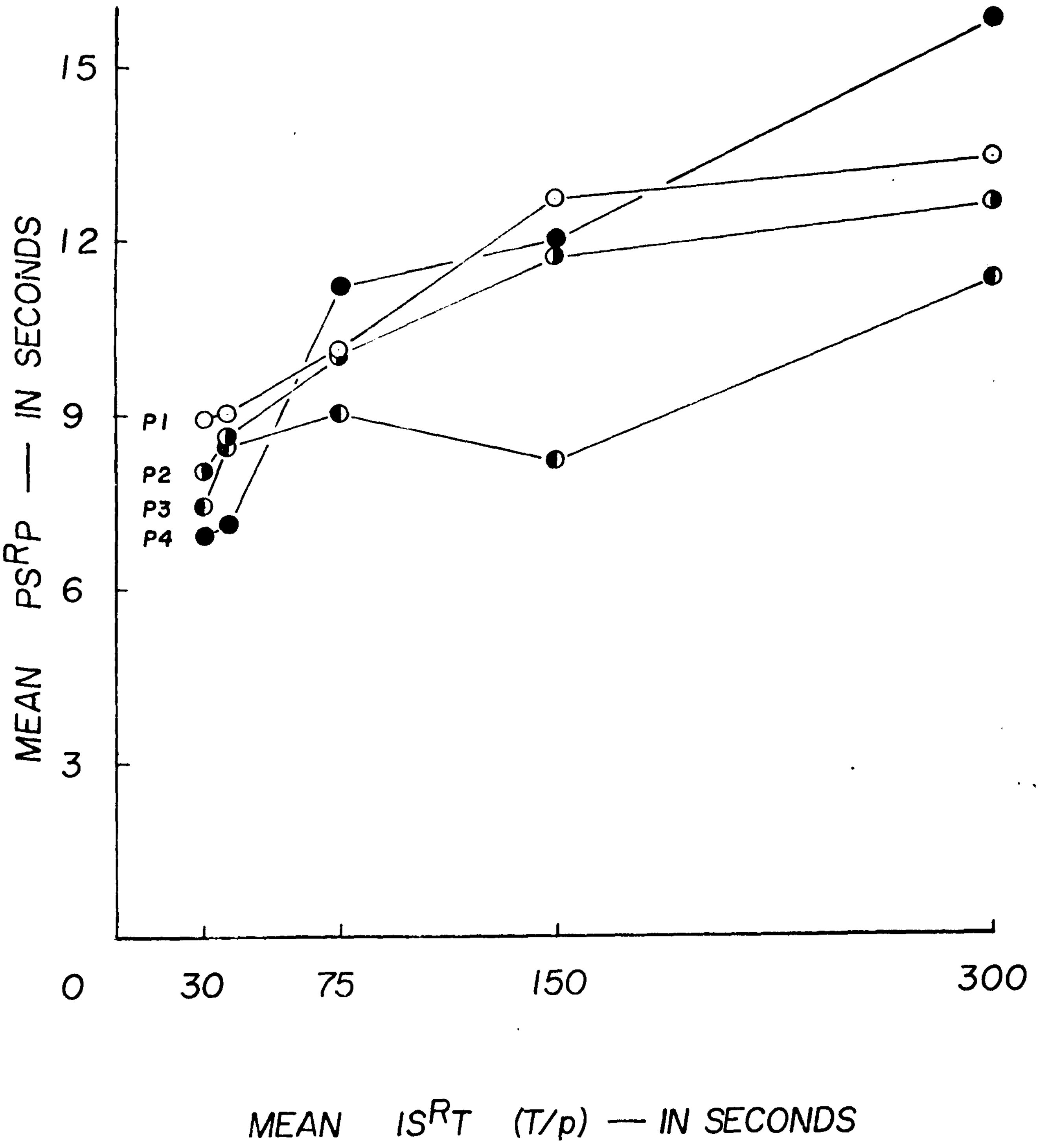
In order to make a direct comparison between the random-interval baselines produced here and those reported in the literature, the mean PS^RP is shown in Fig. 3 as a function of the mean interreinforcement time, T/p. (It may be mentioned here that in describing both the independent

TABLE 1

Summary of the frequency distributions of the post-reinforcement pausing shown in Fig. 2. The quartiles and the interquartile ranges are given in seconds

Bird Number	Statistic	Probability of reinforcement				
		1.0	0.8	0.4	0.2	0.1
P1	Q1	6.5	5.9	6.8	9.9	8.9
	Q2	8.9	8.5	9.9	12.9	12.9
	Q3	11.6	11.7	12.9	16.1	17.1
	Q3 - Q1	5.1	5.8	6.1	6.2	8.2
P2	Q1	6.2	6.2	8.4	10.3	9.5
	Q2	8.3	8.9	10.6	12.2	12.3
	Q3	10.4	11.4	12.8	15.2	15.0
	Q3 - Q1	4.2	5.2	4.4	4.9	5.5
P3	Q1	5.5	6.5	5.9	2.9	9.0
	Q2	7.7	8.8	9.5	8.9	11.6
	Q3	9.7	10.8	10.9	11.9	13.9
	Q3 - Q1	4.2	4.3	5.0	9.0	4.9
P4	Q1	2.3	2.9	5.1	7.8	12.1
	Q2	3.6	3.4	11.0	12.6	15.8
	Q3	11.0	11.9	16.1	15.9	19.2
	Q3 - Q1	8.7	9.1	11.0	8.1	7.1

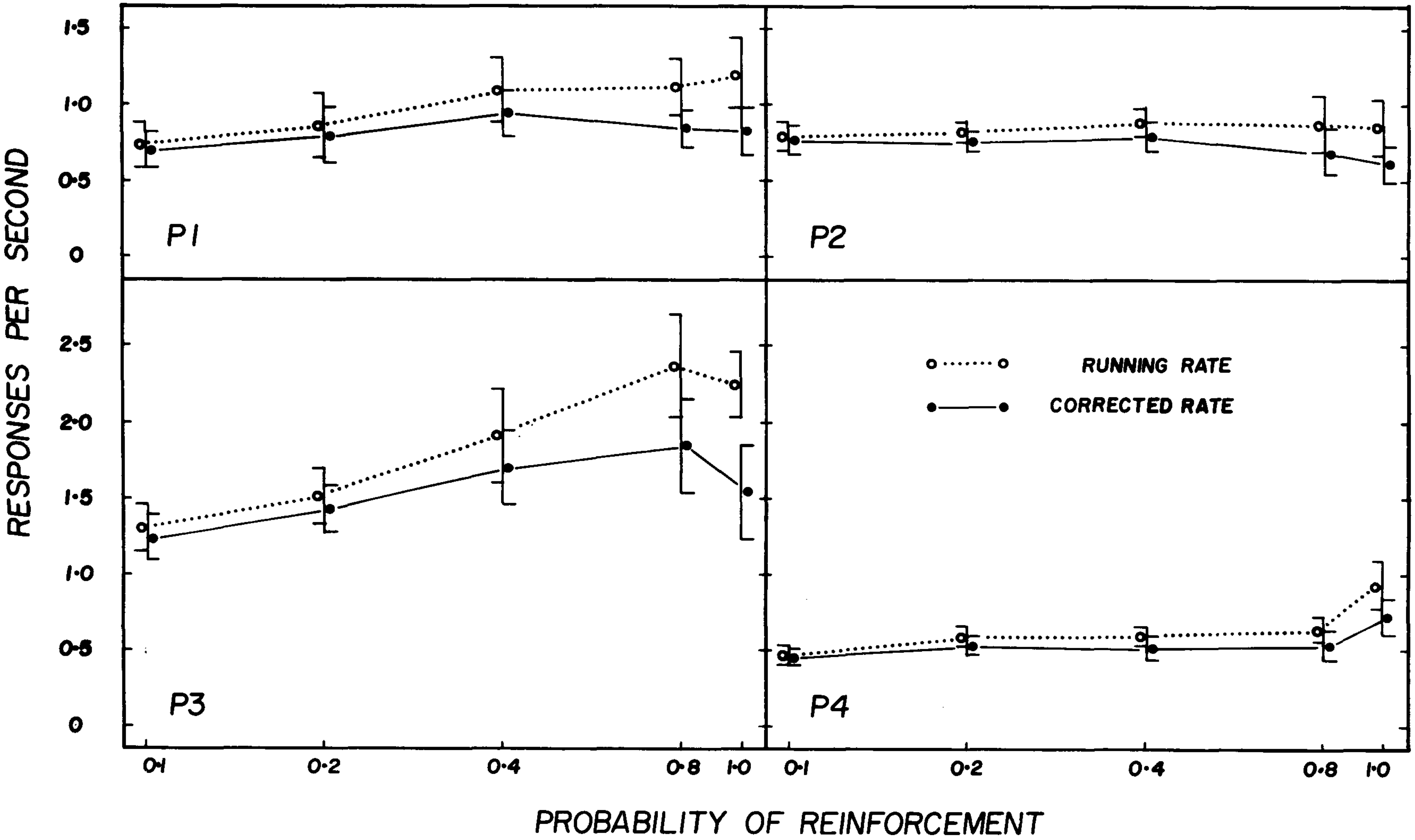
Fig. 3. Mean post-reinforcement pause as a function of the mean interreinforcement interval on random-interval schedules. The values of $PS^{R}P$ are the arithmetic means of the distributions shown in Fig. 2, and the ratio of T/p is the expected value of the theoretical distribution describing each random-interval schedule.


MEAN PS^{R}P — IN SECONDS
15
12
9
6
3
0
P1
P2
P3
P4
30
75
150
300
MEAN IS^{R}T (T/p) — IN SECONDS

and the dependent variables, the arithmetic mean is the value around which the sum of the signed deviations is zero. Although it is the statistic most frequently appearing in the literature, the mean does not necessarily represent the "typical case." It is for this reason that attention is drawn in the present report to the distributional characteristics of various measures.) In Farmer's (1962) experiment, groups of animals were assigned different, fixed values of T and worked through a series of decreasing probabilities, sampling the latter one at a time. The mean PS^RP was directly proportional to T/p for a T of 1.0 seconds, but it was inversely proportional to T/p for a T of 60 seconds. For the two birds in the 30-seconds group, with which the present data should be compared, the mean PS^RP was essentially constant at 21 seconds. Across the different groups, the mean PS^RP increased as a linear function of T when p was 1.00. The effect of T, the unit of interreinforcement time, can also be seen in the random-interval baselines reported by Cole (1968) and by Lachter (1970). In those two studies, the probability of reinforcement was alsays 0.10, and T varied from 0 to 24 seconds. Mean PS^RP was a monotonic, increasing function of T/p, covering a range, in Lachter's study, of about 1.0 to 5.0 seconds. The data from the present study show that p, which determines the variation in interreinforcement time, will also alter the PS^RP.

In Fig. 4, two response rates have been plotted as a function of reinforcement probability. Farmer has argued that if PS^RP is not excluded from the rate computation, the response rate "would appear lower at the higher reinforcement frequencies ... due to a greater proportion of time occupied by the pause after reinforcement, rather

Fig. 4. Response rate as a function of reinforcement probability in random-interval schedules. The points are the arithmetic means, and the brackets show the range of plus and minus one standard deviation, for the daily rates averaged over the last 50 days of baseline training. In calculating "corrected rate," reinforcement duration (eating time) is not included; for "running rate," $PS^{R}P$ is also excluded.


RESPONSES PER SECOND
1·5
1·0
0·5
0
P1
P2
2·5
2·0
1·5
1·0
0·5
0
P3
P4
○·······○ RUNNING RATE
●——● CORRECTED RATE
0·1
0·2
0·4
0·8
1·0
0·1
0·2
0·4
0·8
1·0
PROBABILITY OF REINFORCEMENT

than to any decrease in rate while responding" (Farmer, 1962, p. 27). In the present study, the number of reinforcements was constant in each component, and PS^RP was shown to vary inversely with reinforcement probability. Nevertheless, Fig. 4 clearly shows that the difference between corrected and running rates reflects, as stated by Farmer, differences in the proportion of total time occupied by the PS^RP. The functions for both rate measures are similar in shape and absolute value to those reported for Farmer's 30-seconds group over the same range of interreinforcement times. Apparently, then, the device of sampling several probabilities daily in a multiple schedule does not introduce its own effects into the control over interresponse times exercised by the variables T and p. However, the individual differences in the functions for baseline conditions support the choice of a single-organism experimental design and, perhaps, anticipate idiosyncrasies among the behavioral effects of the intruding stimulus.

B. The intruded stimulus

In the analysis that follows, it will be possible to examine various behavioral effects of the added stimulus with regard to (a) the different temporal positions occupied by the stimulus and (b) the change in performance due to S^N intrusion. The former analysis, which describes absolute effects, is based simply on data collected during the final stage of the experiment, when S^N was presented. The latter evaluation, which is relativistic, incorporates as a frame of reference the ten-day samples collected at the end of the baseline stage, before S^N was introduced. (Because 0.2π radians was not included among the baseline determinations, an extrapolation from the data actually obtained was necessary in expressing the change from baseline; the assumptions underlying the extrapolation will be discussed when these results are shown.) For either analysis, there may be some question regarding the representativeness of the data selected for presentation. Two of the underlying issues--those of behavioral stability and independence of the observations--will be discussed briefly with supporting observations before the detailed analysis is given.

The concept of stability may be clarified by considering the elementary experiment in any physical science. A fixed arrangement of independent variables is set up, and measurements of the system are taken for an indefinitely long period of time. Somewhere in this period, the system will necessarily undergo a transition from its initial level to the resultant steady state produced by the new set of experimental conditions. The transition may be rapid or slow, include a small or large effect, and be descriptively simple or complex, but, in all cases, the notion of stability is embodied in two interrelated questions. One asks: when is the system stable, when is the transition over? The second question is: how stable is the system, how much fluctuation is there in the steady state? Both questions would be ideally answered if there were no variation in the data, but, since all physical measures exhibit variability, the conventional methods of dealing with the stability questions have necessarily been ways of dealing with variability.

Two sources of variability are usually conceptualised in the elementary experiment. One arises by collecting data while the system is still in transition to its steady state, and the other comes from the operation of unknown and uncontrolled parameters. Both sources are thought to be present early in the experiment, but only the second would continue if the constant conditions were extended for a sufficient time. Consequently, to provide an answer to the first question, the experimenter tries to discriminate between the trend or time-dependent course of the measurements, which marks the transitional phase, and the irregular variability or "noise," which marks the final steady state. In practice, the separation is hard to achieve since it rests, in part, on the rate of transition relative to the rate of collecting samples of data. If the transition to the steady state occurs rapidly enough to take place entirely within a single sample, it may be undetected. On the other hand, if the transition takes place over a prolonged period of time, sequential tests for equality between adjacent samples can reach any stated significance criterion while the transition is still in progress. And because "noise" of sufficient amplitude will hide orderly sequential changes, the separation may be further obscured by the relative magnitudes of the transitional and the uncontrolled variation.

The first aspect of the stability issue, the separation of the transition from the steady state, was routinely treated in the early work in the _t_-system. A criterion variability was used to determine the length of exposure to an experimental condition (e.g., Schoenfeld, Cumming, and Hearst, 1956; Hearst, 1956; Schoenfeld and Cumming, 1957), and it dealt with the overall rate of responding. The first seven sessions of an experiment were arbitrarily assigned to the transition period. Thereafter, a block of three consecutive sessions was compared with the three immediately following sessions: the difference between the two three-day means was expressed as a percentage of the mean for all six sessions. If the difference was less than 5%, it was accepted as within the range characterizing steady state. If the criterion was not met, the exposure was continued, and a new test was made on the six day period obtained by including the next experimental session. In this way, a non-cumulative test, based on a "running average," carried the duration of exposure up to a given reduction in variability, and then the independent variable was given a new value.

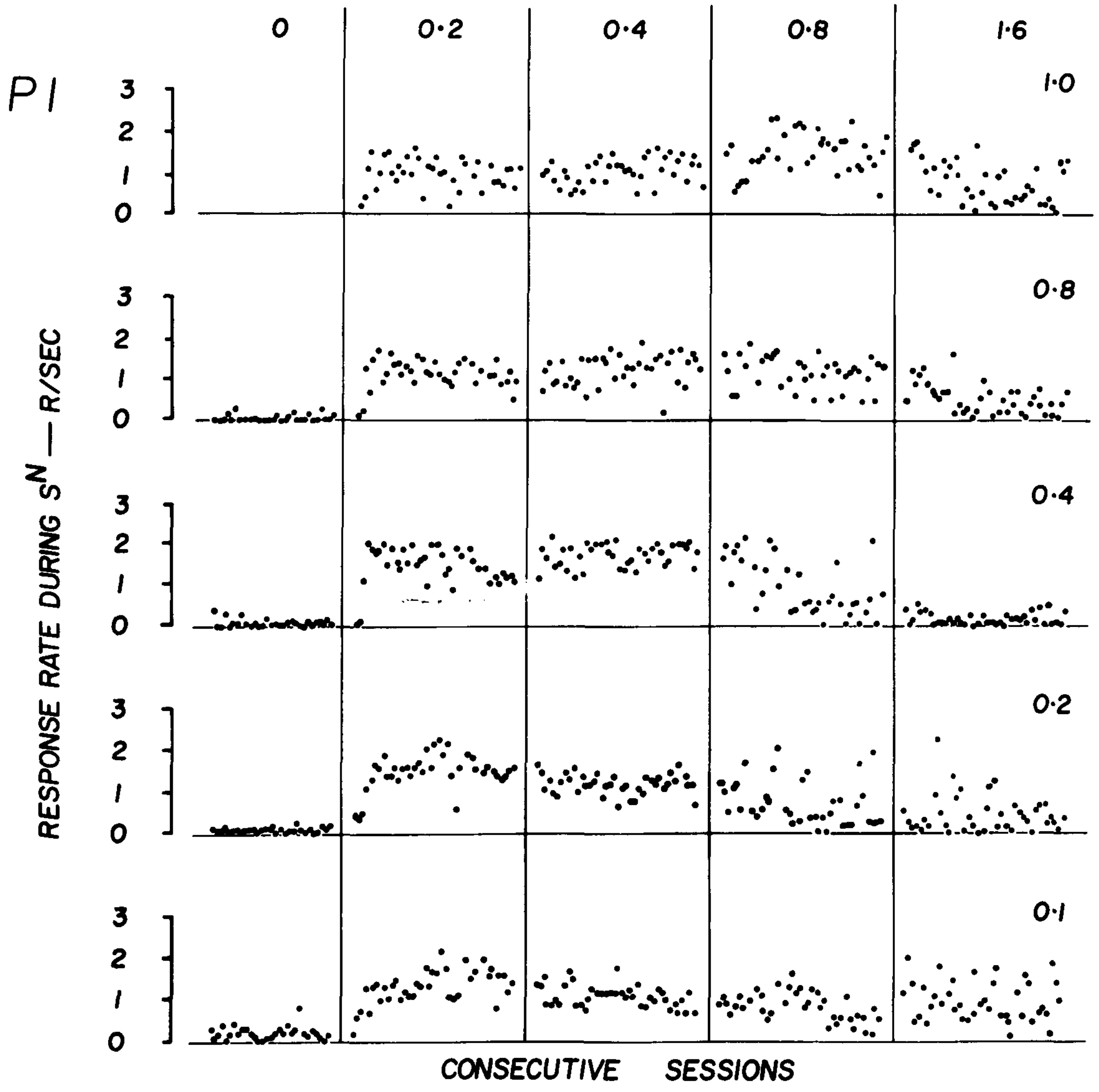
The criterion was satisfactory in that it was sufficiently stringent to meet professional acceptance, yet it was sufficiently relaxed to permit completion of the experiments. But its adequacy for judging "steadiness of state"--that is, its accuracy in predicting subsequent values of the dependent variable--remained to be empirically determined by the elementary experiment of prolonging exposure to an invariant t^D+t^Δ schedule. In one experiment by Cumming and Schoenfeld (1960), this was done for over 200 sessions. The first instance of meeting the criterion proved to be atypical of later performance, since calculations for the subsequent sessions often gave supra-criterion differences. Rather, the analysis suggested that the 5% criterion tended on repeated applications to select six-day means at random. Nevertheless, it was found that after forty hours of exposure to the schedule, the 90% fiducial limits, based on twenty-day samples, generally included the overall mean of the 200 days (discounting the first seven-day "transition period"). In another, similar study, Sidley and Schoenfeld (1964), using groups of subjects on various random-ratio schedules, showed again that, in terms of the 95% and 99% confidence intervals, forty to fifty hours of exposure give fairly asymptotic response rates.

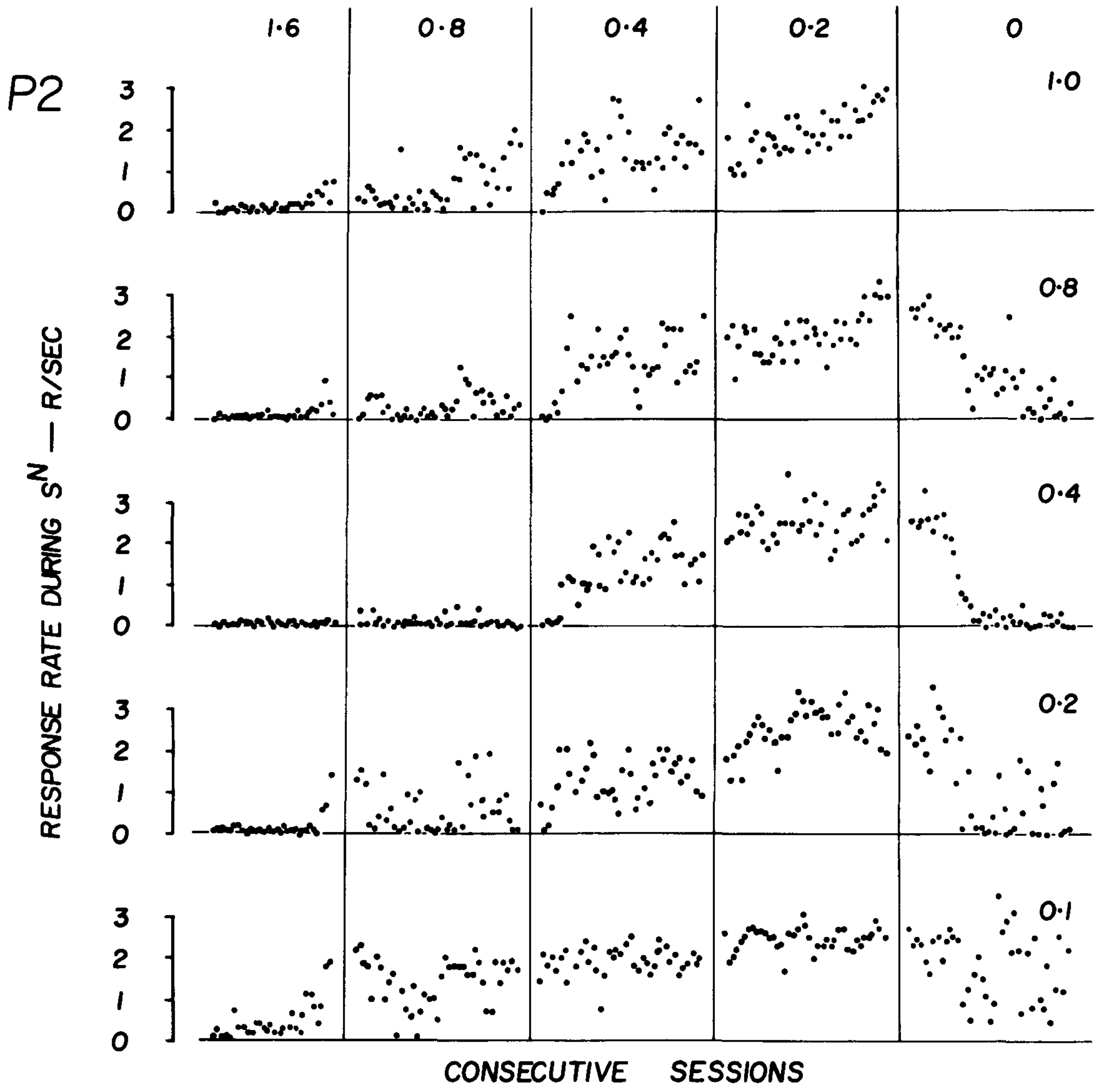
The selection of <u>any</u> critical difference criterion imposes an arbitrary character on the definition of steady state, and there are several important drawbacks in doing so. Two have already been mentioned:

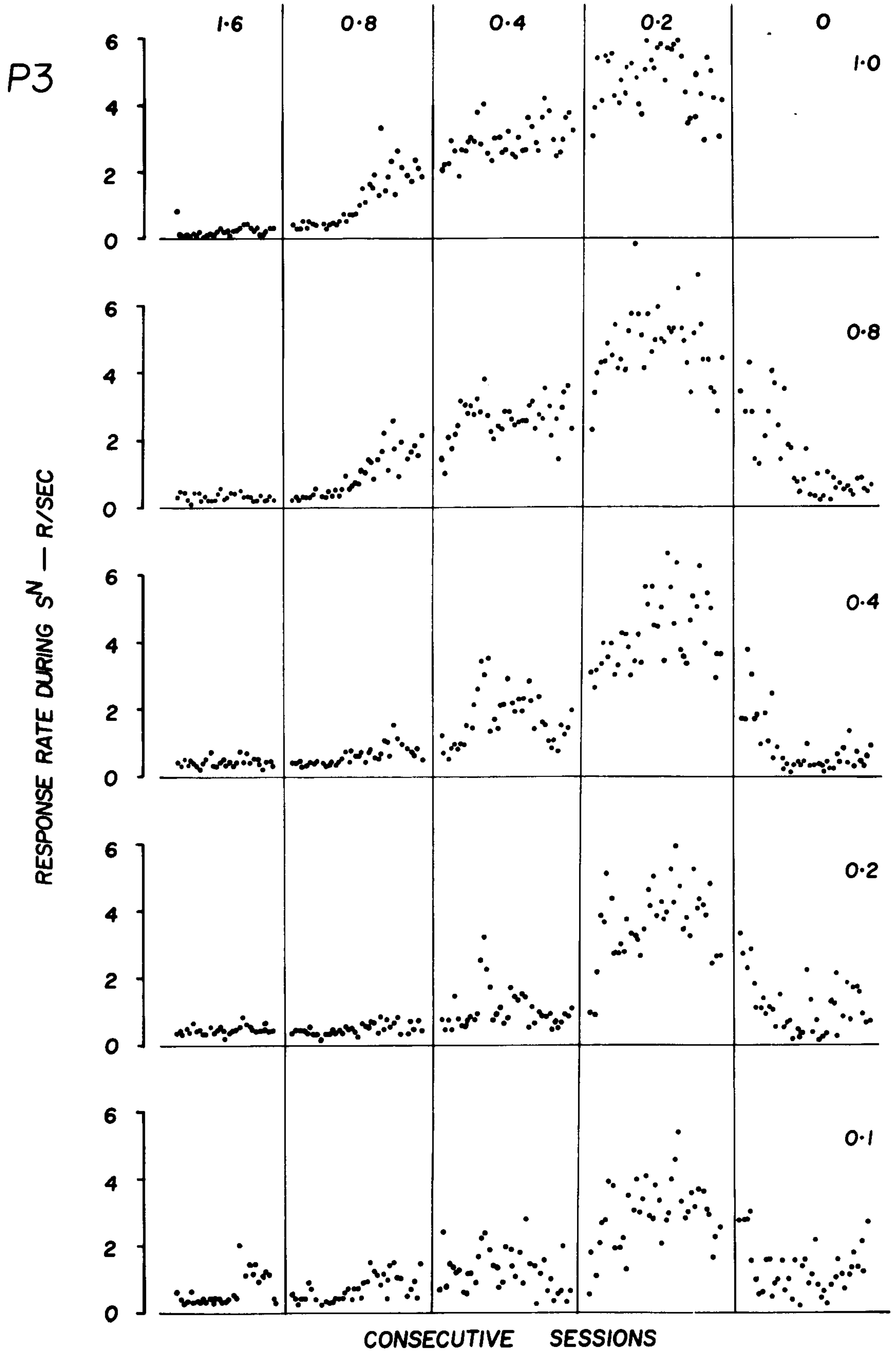
the exposure terminates on an atypical sample (and perhaps does so necessarily, cf. Melton [1936]), and, for any particular difference adopted, it is possible to define a trend of sufficiently shallow slope to be undetectable. A third consequence is that the criterion relegates control of the experiment to the dependent variable, thereby precluding replication (Since it was the results that determined the course of the initial experiment, another investigator can know only the behavior that is to be attained but not the details of producing it). Most importantly, the ascription of steady state characteristics to any pre-assigned level of performance preempts the other aspect of the stability concept and, in so doing, forces an artificial answer to the second question of how the stability of the system progresses under a given set of experimental conditions. If, on the other hand, exposure length is treated as an independent variable, the mechanics of stability becomes an empirical matter to be investigated on its own merits.

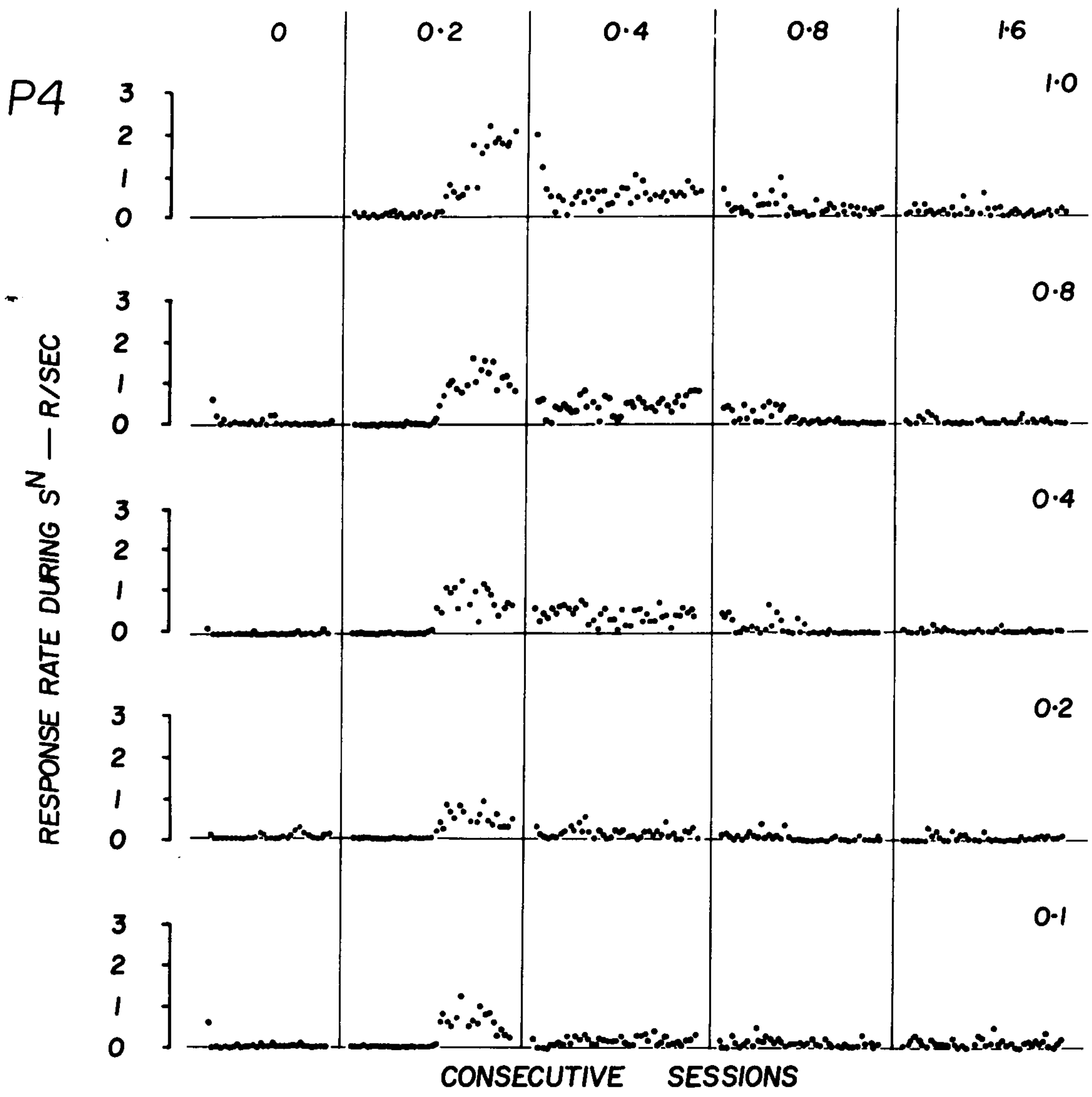
Some aspects of this discussion are illustrated by reference to Fig. 5a - d. Showing the average daily rate of responding during S^N for the entire period of stimulus intrusion, it provides a capsule history of one effect of the added stimulus. In addition, Fig. 5e shows the same datum for "the elementary experiment": an additional bird, P9, had S^N added to the random-interval baselines at the single phase angle of 0.4π radians. Control data are shown for the 60 baseline sessions. The neutral stimulus was then added and the experiment was allowed to continue without change for 120 sessions. For this bird, the transition in the S^N response rate from stimulus-off to stimulus-on began within the first session (the first 10 stimulations). Over the remaining 119 sessions there were both gradual and abrupt

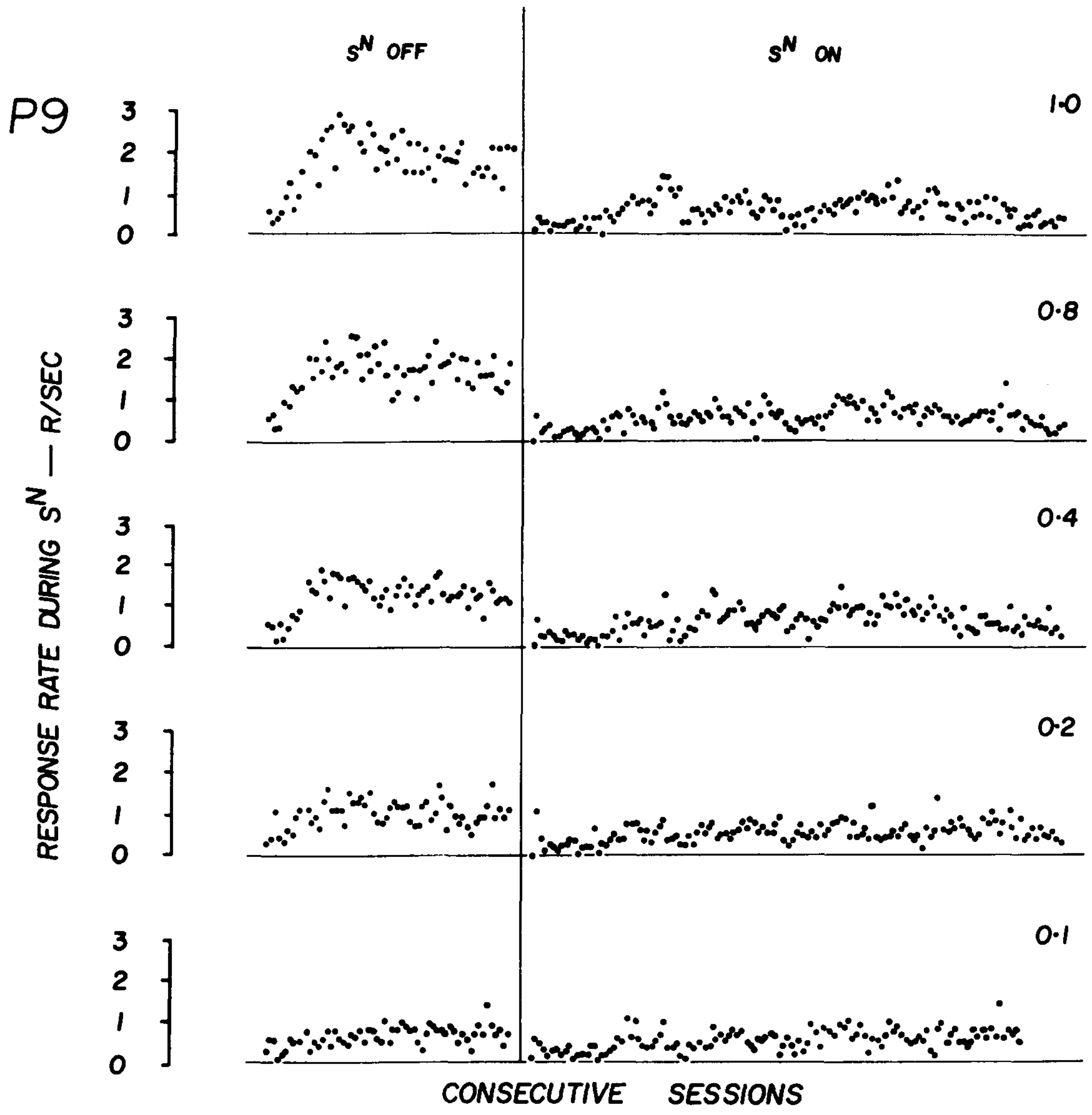
Fig. 5a - e. Time course of one effect of the intruding stimulus. The dependent variable is the average daily rate of responding in the presence of S^N. The rows are for the different stimulus probabilities, and the columns indicate the sequence of the phase angle between the T_N and the T_R cycles. There were 30 days of exposure to the first phase difference and 40 days of exposure to all the others (A few days' data are not shown because of an occasional failure in the data recording devices). For all phase angles except zero, each data point is the average of the rate during 10 stimulus intrusions; at zero radians, the number of intrusions depends on p.


P1
0
0·2
0·4
0·8
1·6
1·0
0·8
0·4
0·2
0·1
3
2
1
0
RESPONSE RATE DURING S^N — R/SEC
CONSECUTIVE SESSIONS


P2
1·6
0·8
0·4
0·2
0
1·0
0·8
0·4
0·2
0·1
3
2
1
0
RESPONSE RATE DURING S^N — R/SEC
CONSECUTIVE SESSIONS


P3
1·6
0·8
0·4
0·2
0
1·0
0·8
0·4
0·2
0·1
0
2
4
6
RESPONSE RATE DURING S^N — R/SEC
CONSECUTIVE SESSIONS


P4
0
0·2
0·4
0·8
1·6
1·0
0·8
0·4
0·2
0·1
0
1
2
3
RESPONSE RATE DURING S^N — R/SEC
CONSECUTIVE SESSIONS


P9
S^N OFF
S^N ON
1·0
0·8
0·4
0·2
0·1
3
2
1
0
RESPONSE RATE DURING S^N — R/SEC
CONSECUTIVE SESSIONS

changes in the average daily rate, but there is no indication that the effects of S^N would have been substantially different had the exposure been terminated earlier or later.

The initial effect of stimulus intrusion was also immediate for the principal subjects. Although the effect of stimulus probability interacted with that of phase angle, inspection of Fig. 5a - d shows that responding during S^N was generally highest at 0.2π radians and lowest at 0 (or 2.0π) radians, and all birds began their exposure to S^N at a temporal position that produced little or no responding during the stimulus. For P2 and P3, whose first S^N position was close to, but not at, that which produced the minimal rates, there was some rate increase after the initial effect.

Thereafter, the "latency" or "hysteresis" of the effect of changing the phase angle between T_N and T_R varied considerably. For example, the phase angle was changed directly from 0 to 0.2π radians for P1 and P4, and the effect is apparent by the third session for P1; but for P4, whose rates went from minimal to maximal values, the behavioral effect of the new phase angle is not evident in these data for 23 sessions.

A casual inspection of Fig. 5 reveals several instances of trends, yet there are numerous instances where such "transitions" are missing. For example, there is a well-defined time course in the data from P2 at the transition from 0.2π to 0 radians at stimulus probability of 0.4, but the transition at stimulus probability of 0.1 shows no such Gestalt. And although the rate for P3 over the entire intruding stimulus period shows a gradual increase to a maximum at 0.2π radians followed by a rapid decrease at 0 radians, a close inspection of the variation at any single phase angle reveals no clearly distinguishable separation of "transition" from "steady state." For all birds at all combinations of phase angle and stimulus probability, there were periods ranging from three to six consecutive sessions when the daily response rates showed virtually no variation. These instances of local stability were not consistently located with respect to exposure time, nor did they predict the direction or magnitude of change in rate for the subsequent sessions.

A different problem is embodied in the notion of independence of the observations. In this experiment there is the possibility of "order effects" from the sequential assignments of the phase angles and the possibility of interaction effects from the multiple arrangements of stimulus probabilities. Both kinds of effects are typically viewed as confounding or contaminating the behavioral functions to be reported. In the formal repeated-measurement experimental designs, the statistical practices for handling such "nuisance factors" require different, randomly chosen orders or assignments as a point of departure. Such an assignment does not, of course, eliminate the contribution of a variable so handled; it merely obscures the role of the variable. If one assumes that the variable to be randomised is actually a determinant of the phenomenon under investigation (if it were not, the problem would be non-existent), the statistical approach has several shortcomings. Truly random assignments would not be entirely different, and the random sampling "with constraints" used in most experiments to meet the prerequisites of statistical models do not literally do so. More importantly, the essence of an experiment in a deterministic science is direct experimental control; if a variable controls a phenomenon, that variable should be controlled and not allowed to operate at random. It is perhaps for this reason that counterbalancing is often used instead of quasi-random assignments. Nonetheless, for every *N* values of that variable there are *N*! different orderings. If the experimenter felt that the variable made a difference, he would ideally arrange for all *N*! orderings and report all *N*! functions because each one is as "real" as any other one.

The practices in the present experiment are a compromise between the statistical and the deterministic approaches just mentioned. The ordering of phase angles was felt, on _a priori_ consideration of the variables, to be a potentially powerful determinant. Although it was not feasible to arrange for all 120 different orderings, the two serial arrangements used here seemed most likely to lead to the detection of systematic effects, if any were present. The counterbalancing of the daily orderings of stimulus schedules was more within the traditions of statistical control; presumably, the counterbalancing distributed uniformly among the different schedules all the implicit variables, such as the time course of the change in food deprivation during the sessions, the accumulative effects of response expenditure, the transitions among stimulus probabilities, etc.

Counterbalancing does not, however, deal with the kinds of interactions often encountered in multiple schedules (e.g., Herrnstein and Brady, 1958; Reynolds, 1961a, 1961b, 1961c, 1963). It is likely that the performance under any one of the present schedules was different from the performance that would have been obtained had that schedule been studied in isolation or in some other context. This is not to say that any one context is "correct" or gives "the true picture"; rather, one must recognise that the functions from any one experiment are strictly applicable to only those situations that have been identically arranged.

One measure of mutual independence of responding in the various components may be found in the intercorrelation matrix that gives the Pearson product-moment correlation coefficient for each possible pair of schedules. If the interactions among the schedules were determined by the degree of schedule similarity (i.e., stimulus probability), the absolute value of the coefficients would decrease monotonically as a function of the distance, along row or column, from the main diagonal.

The intercorrelations for the data shown in Fig. 5 are presented in Table 2 for both the entire exposure periods and for just the last ten days at each phase angle. Although there are large ($\pm$ 0.90) and small (0.00) intercorrelations, the tables lack the patterning of values that is dictated by simple interdependencies. At the phase angle where the response rate changes from near zero to a high value, or _vice versa_, at all stimulus probabilities (for example, P4 at 0.2π radians), the intercorrelations for the entire period are necessarily positive and large, reflecting the functional as well as the uncontrolled effects. Confining the computation to the last ten days reduced the magnitude and changed the sign of many of the coefficients, thereby supporting the notion of daily independence of performance among the schedules. Because of these observations, and in concordance with the discussion of behavioral stability, the data on intruded stimulus effects reported below are based on the last ten sessions at each phase angle, following 30 (or 20) prior sessions of exposure.

Frequency distributions of the numbers of responses made during the three-second S^N periods are shown in Fig. 6a - d. In the data collected at the end of baseline conditions (S^N OFF), the change in

Table 2a-d

Intercorrelations (Pearson product-moment correlation coefficients) of responding during S^N intrusion among the five components of the multiple schedule. A separate matrix is given for each phase angle, Φ. In the left-hand columns, the cross-products were averaged over all sessions at that phase angle; in the right-hand columns, cross-products were averaged for only the last ten days at that phase angle.

P1

Φ	ALL SESSIONS						LAST 10 DAYS				
	Stimulus Probability						Stimulus Probability				
	1.00	0.80	0.40	0.20	0.10		1.00	0.80	0.40	0.20	0.10
0						1.00					
		1.00				0.80		1.00			
		.13	1.00			0.40		.29	1.00		
		-.18	-.07	1.00		0.20		-.35	-.40	1.00	
		.05	.01	-.03	1.00	0.10		-.18	-.51	-.10	1.00
0.2π	1.00					1.00	1.00				
	.29	1.00				0.80	.02	1.00			
	.60	.54	1.00			0.40	.58	.08	1.00		
	.12	.26	.46	1.00		0.20	-.09	-.12	.24	1.00	
	.09	.22	.33	.69	1.00	0.10	.23	.63	.44	.19	1.00
0.4π	1.00					1.00	1.00				
	.24	1.00				0.80	.06	1.00			
	.18	.22	1.00			0.40	-.04	-.11	1.00		
	.06	-.21	.14	1.00		0.20	.15	-.22	.47	1.00	
	-.01	-.20	-.31	-.01	1.00	0.10	.46	-.24	-.75	-.12	1.00
0.8π	1.00					1.00	1.00				
	.09	1.00				0.80	.32	1.00			
	-.28	.24	1.00			0.40	-.61	-.39	1.00		
	-.23	-.09	.52	1.00		0.20	-.43	-.91	.56	1.00	
	.42	.05	-.12	-.13	1.00	0.10	.78	.19	-.63	-.36	1.00
1.6π	1.00					1.00	1.00				
	.40	1.00				0.80	.07	1.00			
	.05	.32				0.40	.01	.46	1.00		
	-.13	-.33	-.25	1.00		0.20	-.58	-.01	-.06	1.00	
	.63	.07	-.20	-.01	1.00	0.10	.73	-.23	-.10	-.50	1.00

Table 2b

P2

Φ	ALL SESSIONS						LAST 10 DAYS				
	Stimulus Probability						Stimulus Probability				
	1.00	0.80	0.40	0.20	0.10		1.00	0.80	0.40	0.20	0.10
1.6	1.00					1.00	1.00				
	.61	1.00				0.80	.44	1.00			
	.06	.38	1.00			0.40	-.09	.47	1.00		
	.65	.32	.23	1.00		0.20	.63	.17	.33	1.00	
	.66	.37	.22	.75	1.00	0.10	.43	.09	.39	.80	1.00
0.8	1.00					1.00	1.00				
	.45	1.00				0.80	-.39	1.00			
	-.11	.20	1.00			0.40	-.68	.56	1.00		
	.04	.34	.10	1.00		0.20	-.74	.46	.69	1.00	
	.23	.25	.18	.30	1.00	0.10	.22	-.14	-.46	-.56	1.00
0.4	1.00					1.00	1.00				
	.47	1.00				0.80	-.02	1.00			
	.55	.71	1.00			0.40	-.07	.58	1.00		
	.22	.51	.63	1.00		0.20	.08	-.06	.56	1.00	
	.48	.17	.31	.28	1.00	0.10	.23	-.02	.46	.35	1.00
0.2	1.00					1.00	1.00				
	.55	1.00				0.80	.90	1.00			
	.26	.39	1.00			0.40	.68	.69	1.00		
	.30	-.12	.16	1.00		0.20	-.32	-.23	.10	1.00	
	.35	.23	.11	.30	1.00	0.10	.74	.84	.69	.09	1.00
0						1.00					
		1.00				0.80		1.00			
		.83	1.00			0.40		-.33	1.00		
		.60	.79	1.00		0.20		.00	.77	1.00	
		.46	.33	.34	1.00	0.10		.12	-.38	-.56	1.00

Table 2c

P3

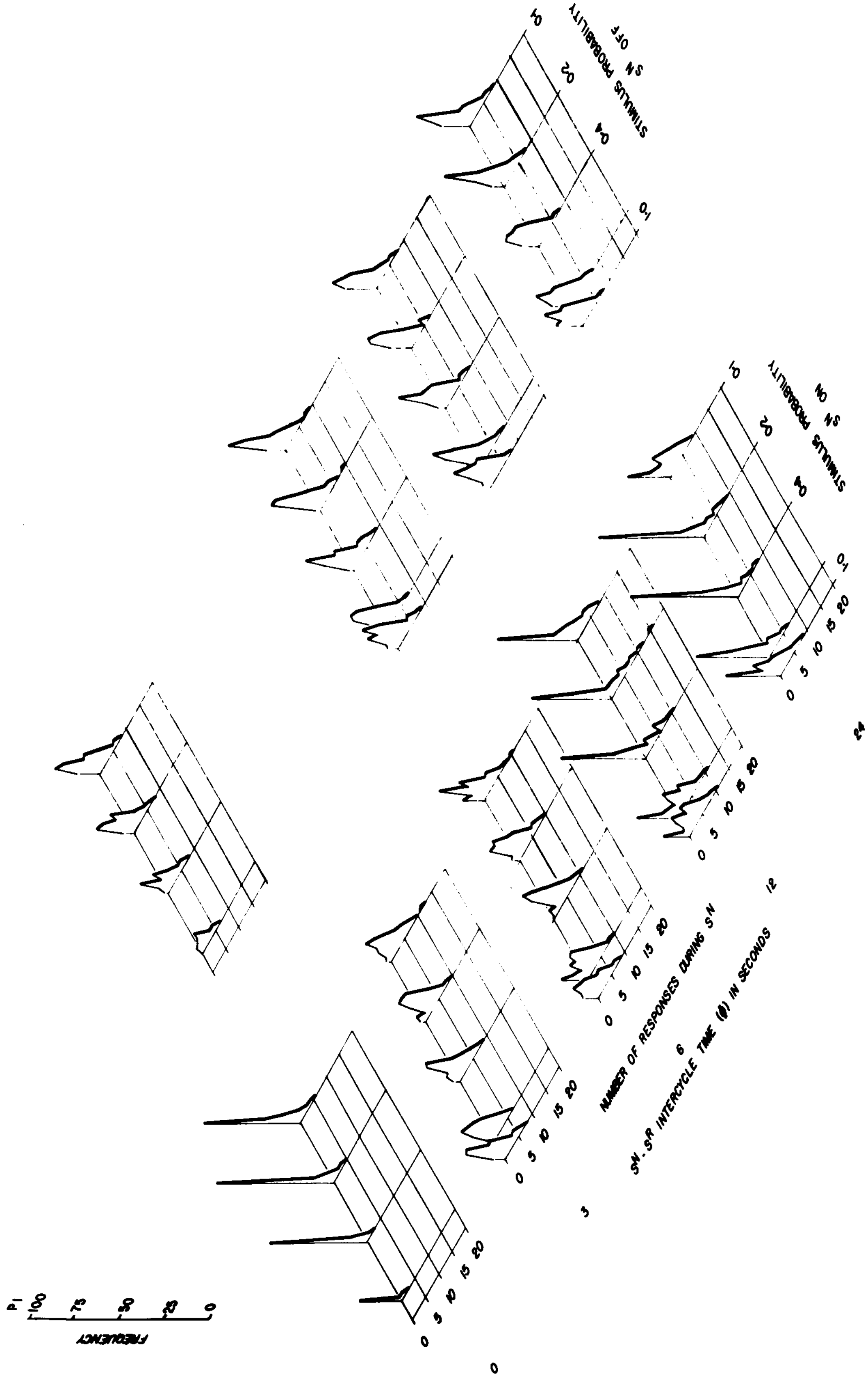
Φ	ALL SESSIONS						LAST 10 DAYS				
	Stimulus Probability						Stimulus Probability				
	1.00	0.80	0.40	0.20	0.10		1.00	0.80	0.40	0.20	0.10
1.6	1.00					1.00	1.00				
	-.02	1.00				0.80	.34	1.00			
	.15	.22	1.00			0.40	.48	.72	1.00		
	.21	.12	.34	1.00		0.20	.51	.19	.19	1.00	
	.26	.12	.50	.46	1.00	0.10	-.23	.15	.31	.34	1.00
0.8	1.00					1.00	1.00				
	.84	1.00				0.80	.30	1.00			
	.72	.68	1.00			0.40	-.36	-.36	1.00		
	.60	.39	.61	1.00		0.20	.02	-.32	.35	1.00	
	.58	.73	.49	.31	1.00	0.10	-.08	.77	.04	-.29	1.00
0.4	1.00					1.00	1.00				
	.65	1.00				0.80	.67	1.00			
	.33	.45	1.00			0.40	.49	.50	1.00		
	.09	.30	.61	1.00		0.20	.52	.52	.84	1.00	
	.12	.02	.33	.40	1.00	0.10	.49	.27	.10	.27	1.00
0.2	1.00					1.00	1.00				
	.47	1.00				0.80	.32	1.00			
	.26	.25	1.00			0.40	.17	.60	1.00		
	.46	.40	.46	1.00		0.20	.20	.43	.47	1.00	
	.39	.48	.36	.61	1.00	0.10	-.03	.59	.82	.77	1.00
0						1.00					
		1.00				0.80		1.00			
		.65	1.00			0.40		-.08	1.00		
		.42	.59	1.00		0.20		.17	-.31	1.00	
		.37	.62	.58	1.00	0.10		.25	.04	-.39	1.00

Table 2d

P4

Φ	ALL SESSIONS						LAST 10 DAYS				
	Stimulus Probability						Stimulus Probability				
	1.00	0.80	0.40	0.20	0.10		1.00	0.80	0.40	0.20	0.10
0						1.00					
		1.00				0.80		1.00			
		.61	1.00			0.40		.29	1.00		
		-.02	.34	1.00		0.20		-.35	-.40	1.00	
		.81	.62	.07	1.00	0.10		-.18	-.51	-.10	1.00
0.2	1.00					1.00	1.00				
	.86	1.00				0.80	-.21	1.00			
	.71	.86	1.00			0.40	-.27	.48	1.00		
	.66	.80	.86	1.00		0.20	-.22	.15	.20	1.00	
	.63	.82	.92	.84	1.00	0.10	-.26	.74	.75	.56	1.00
0.4						1.00	1.00				
	.36	1.00				0.80	.58	1.00			
	.03	.37	1.00			0.40	.36	.25	1.00		
	.10	.11	.27	1.00		0.20	.00	-.03	.25	1.00	
	-.01	.22	.06	.41	1.00	0.10	-.19	.02	-.22	-.19	1.00
0.8	1.00					1.00	1.00				
	.39	1.00				0.80	.49	1.00			
	.63	.46	1.00			0.40	.34	-.16	1.00		
	.12	.27	.07	1.00		0.20	-.36	-.19	-.18	1.00	
	.32	.15	.24	.08	1.00	0.10	.43	.20	-.01	-.20	1.00
1.6	1.00					1.00	1.00				
	.07	1.00				0.80	.04	1.00			
	.04	.17	1.00			0.40	.22	.37	1.00		
	-.11	.14	.01	1.00		0.20	-.26	-.12	.09	1.00	
	.21	.02	.25	.01	1.00	0.10	-.21	.00	.38	.64	1.00

Fig. 6a - d. Frequency distributions of the numbers of responses made during the three-second periods of S^N. The temporal position of these periods relative to reinforcements was controlled by the combinations of stimulus probability and phase difference. Each grid shows the distributions at all probabilities and one intercycle time. The distributions for S^N ON were collected during the last 10 days at each phase angle, and the data for S^N OFF are based on an equal number of uncued three-second samples taken under the phase sampling procedure used at the end of the baseline stage of the experiment. All distributions except those at 0 seconds contain 100 samples.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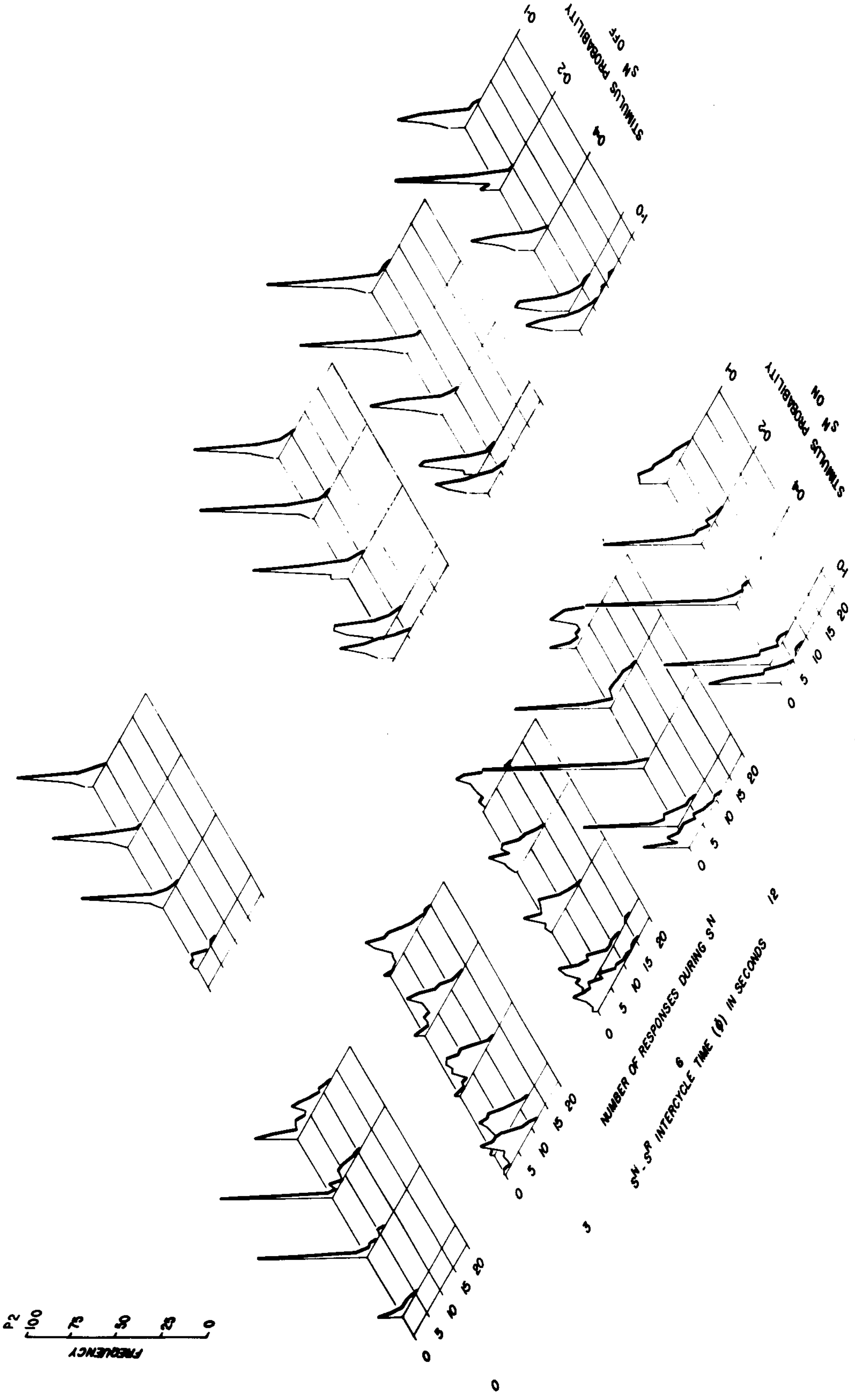
S^N OFF
0.1
0.2
0.4
1.0
STIMULUS PROBABILITY
S^N ON
0.1
0.2
0.4
1.0
0
5
10
15
20
NUMBER OF RESPONSES DURING S^N
S^N-S^R INTERCYCLE TIME (θ) IN SECONDS
0
3
6
12
24
FREQUENCY
Pi
100
75
50
25
0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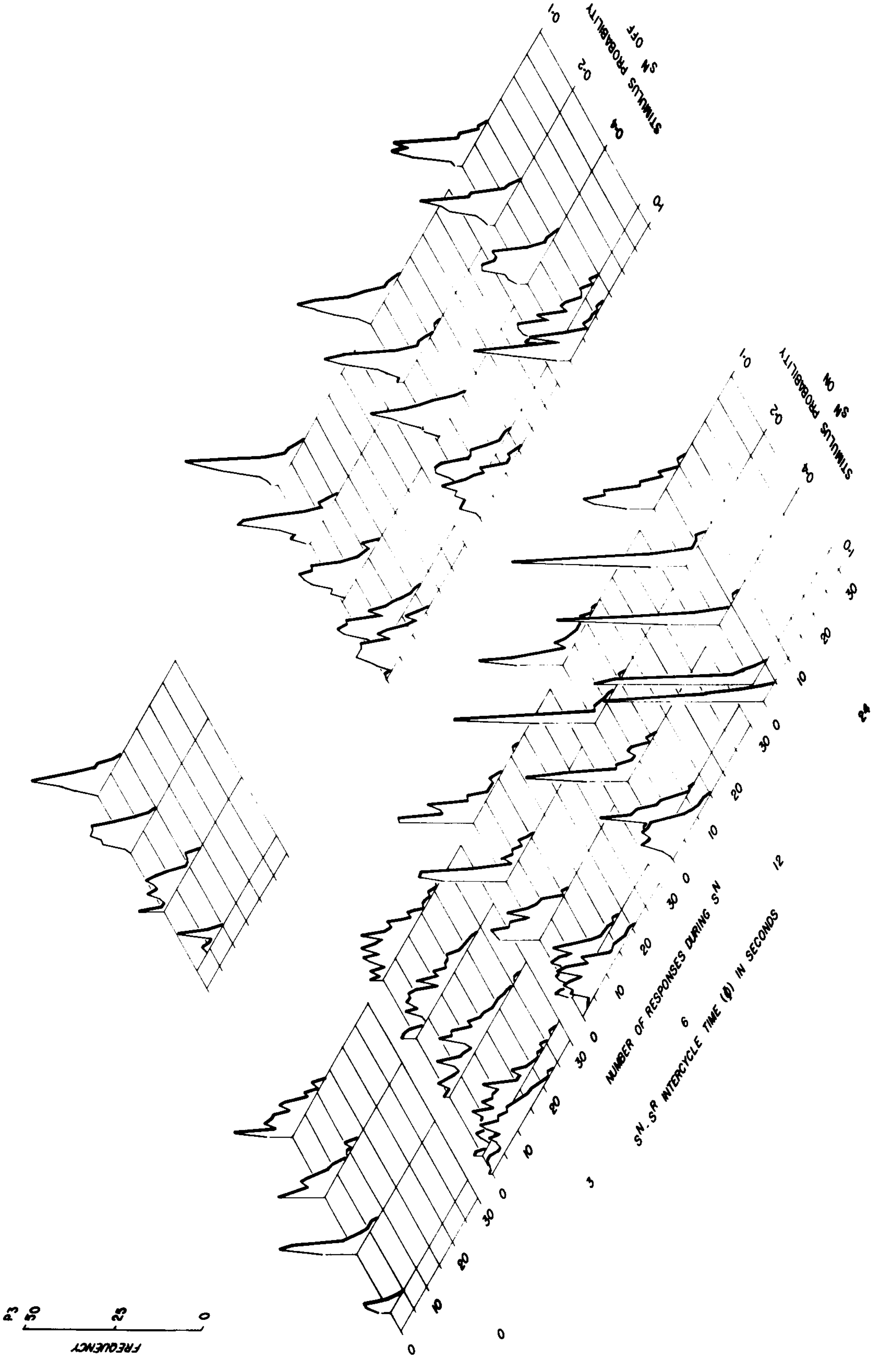
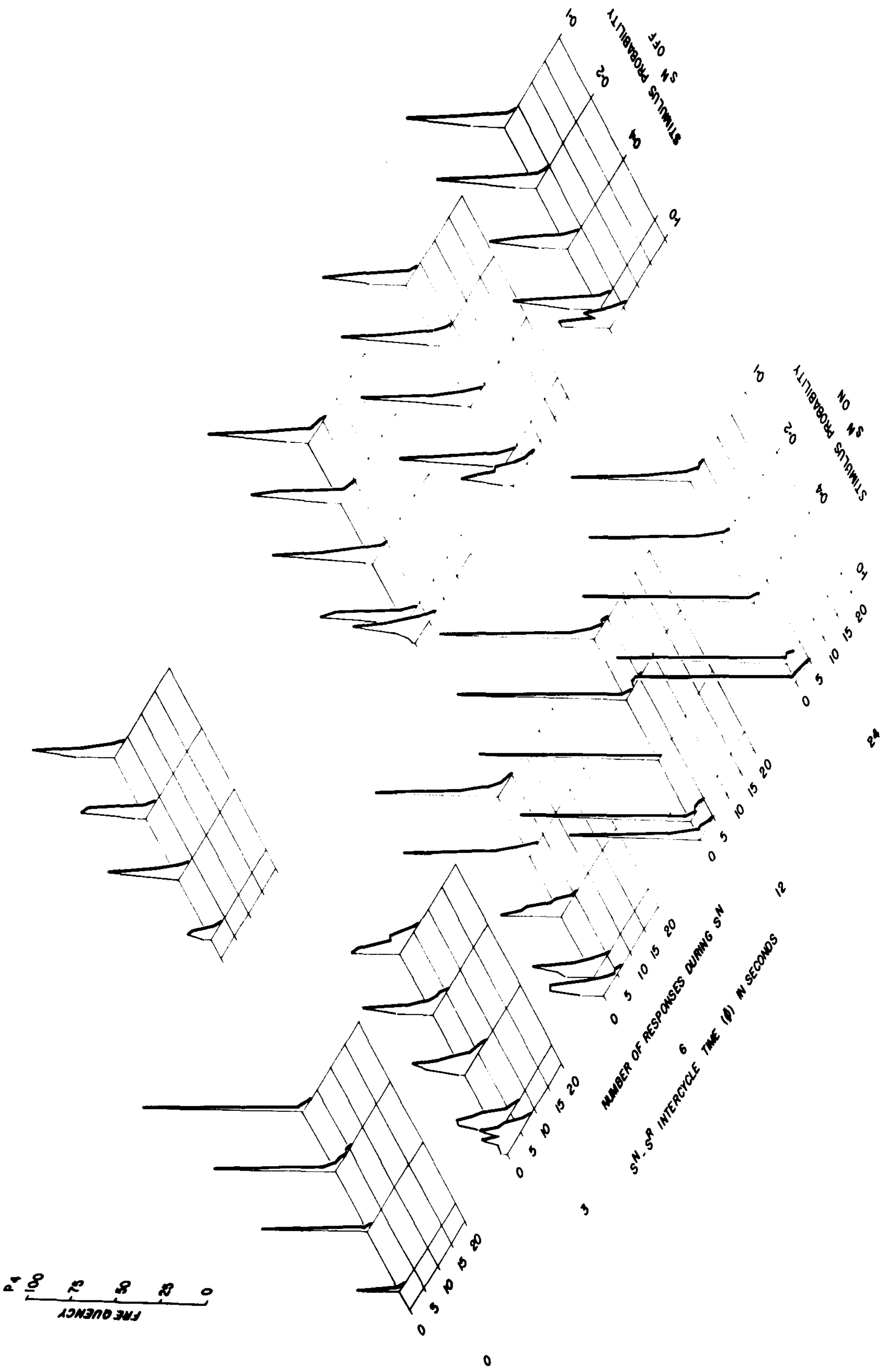
S^N OFF
0.1
0.2
0.4
1.0
STIMULUS PROBABILITY
S^N ON
0.1
0.2
0.4
1.0
0 5 10 15 20
NUMBER OF RESPONSES DURING S^N
S^N-S^R INTERCYCLE TIME (ϕ) IN SECONDS
0
3
6
12
24
FREQUENCY
P2
100
75
50
25
0


STIMULUS PROBABILITY
S^N OFF
S^N ON
0.1
0.2
0.4
1.0
0
10
20
30
NUMBER OF RESPONSES DURING S^N
$S^N.S^R$ INTERCYCLE TIME (T̸) IN SECONDS
0
3
6
12
24
FREQUENCY
P3
50
25
0

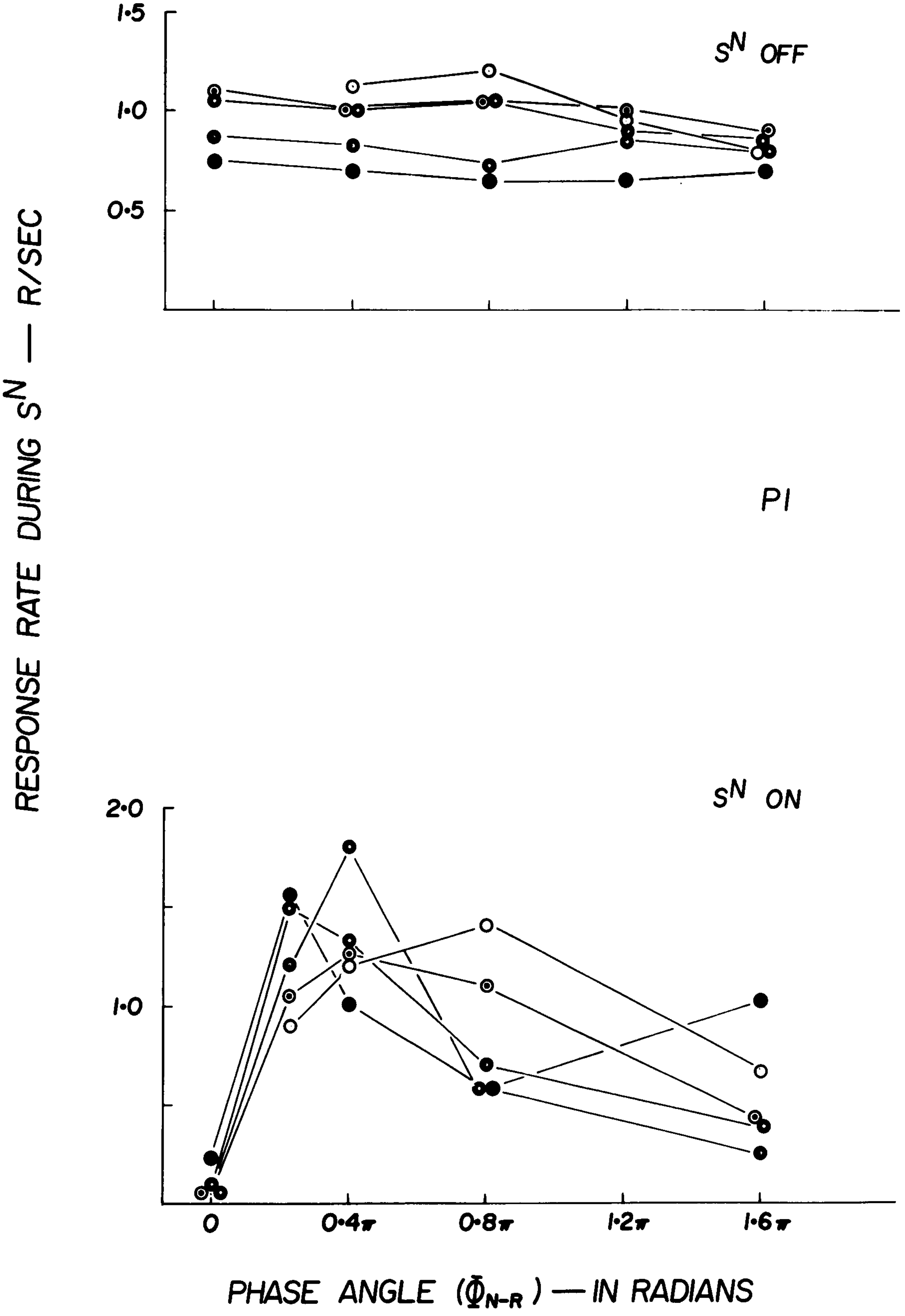

STIMULUS PROBABILITY
S^N OFF
0.1
0.2
0.4
1.0
STIMULUS PROBABILITY
S^N ON
0.1
0.2
0.4
1.0
0 5 10 15 20
NUMBER OF RESPONSES DURING S^N
S^N-S^R INTERCYCLE TIME (t̄) IN SECONDS
0
3
6
12
24
FREQUENCY
P4
100
75
50
25
0

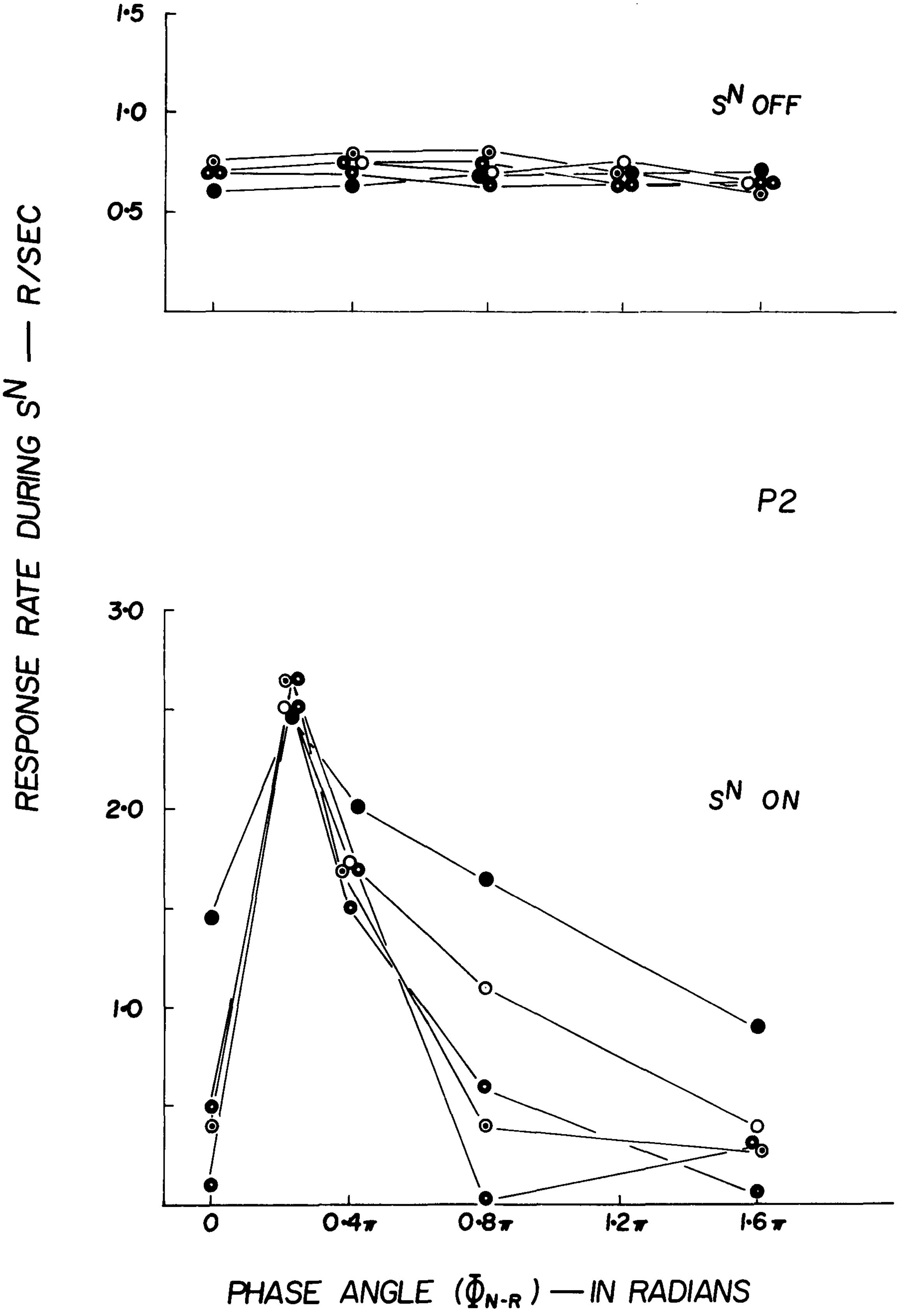
temporal position of the response sample relative to the moment of reinforcement availability obtained by changing the phase angle had little effect on the form of the distributions. However, the reduced frequency of responding at the lower reinforcement probabilities produced, at all phase angles, some increase in kurtosis, in positive skewness, or both. When the neutral stimulus was present (S^N ON), the phase angle had a considerable effect on the form of the distributions. At the two intercycle times which provided the longest intervals between the end of an S^N and the next potential S^R (0 and 24 seconds), the mode was reduced to 0 or 1 responses, and the proportion of the distribution it represented increased, making the distributions *L*-shaped. However, when the intercycle time permitted temporal contiguity of S^N and S^R, the rate of responding during S^N increased, as may be seen by increases in the value of the mode and the upper limit of the range. In all cases, the extremely positive skewness was reduced, although this effect of the phase relationship was somewhat modified by stimulus probability.

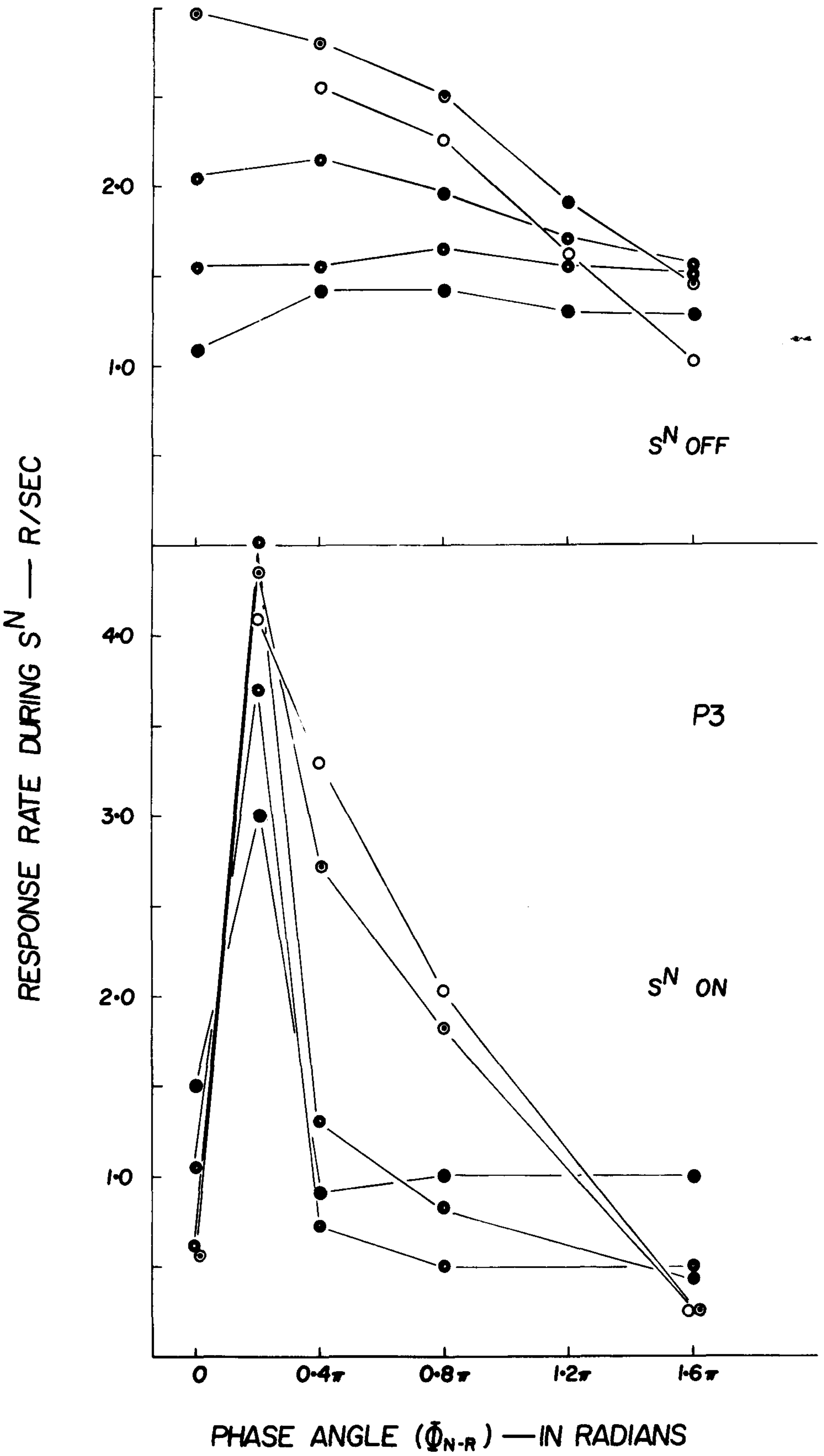
An average S^N response rate was calculated from the total number of responses during the stimulus presentation and the total stimulus duration, both accumulated over the ten days. The comparable data from the baseline sessions (upper panels in Fig. 7a - d) showed some effects of both independent variables, although the magnitudes of the effects varied for the different birds. The rates for P3, for example, covered the largest range and indicated, by their inverse relationship to the phase angle, a "temporal discrimination" at reinforcement probabilities of 1.00 and 0.80. (The phase angle is given with $\mathcal{T}_N$ leading. Therefore, an increase in the angular or temporal difference means that S^N occurred earlier in the $\mathcal{T}_R$ cycle.) On the other hand, the

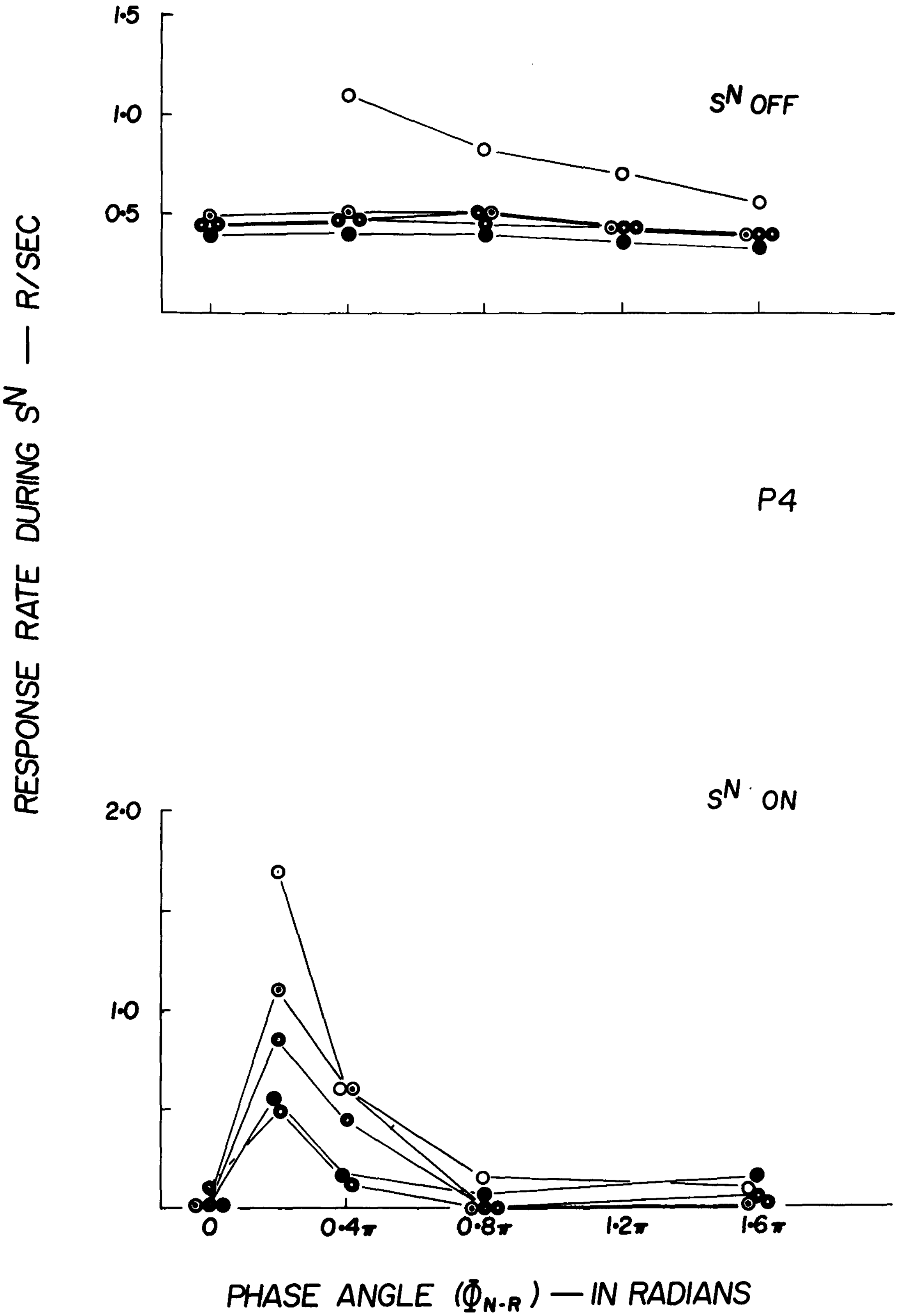
Fig. 7a - d. The effects of S^N intrusion, phase angle, and stimulus probability on local responding. The pooled mean response rate during the three-second periods is shown in the upper panels for the baseline stage (S^N OFF) and in the lower panels for the intrusion of the neutral stimulus (S^N ON). The position of the samples relative to reinforcements was determined jointly by the phase angle between the two *T* cycles (indicated along the abscissa) and stimulus probability (shown here as a parameter). The legend for stimulus probability is:

symbol	*p*
○	1.00
⊙	0.80
⦿	0.40
◉	0.20
●	0.10


1·5
1·0
0·5
S^N OFF
P1
2·0
1·0
S^N ON
0
0·4π
0·8π
1·2π
1·6π
RESPONSE RATE DURING S^N — R/SEC
PHASE ANGLE (Φ_{N-R}) — IN RADIANS


1·5
1·0
0·5
S^N OFF
P2
3·0
2·0
1·0
S^N ON
0
0·4π
0·8π
1·2π
1·6π
RESPONSE RATE DURING S^N — R/SEC
PHASE ANGLE (Φ_N-R) — IN RADIANS


RESPONSE RATE DURING S^N — R/SEC
2·0
1·0
S^N OFF
4·0
3·0
2·0
1·0
P3
S^N ON
0
0·4π
0·8π
1·2π
1·6π
PHASE ANGLE ($\Phi_{N\text{-}R}$) —IN RADIANS


1·5
1·0
0·5
S^N OFF
P4
2·0
1·0
S^N ON
0
0·4π
0·8π
1·2π
1·6π
RESPONSE RATE DURING S^N — R/SEC
PHASE ANGLE ($\Phi_{N\text{-}R}$) — IN RADIANS

baseline average S^N response rate for P2 was nearly constant for all combinations of intercycle time and stimulus probability. When the neutral stimulus was intruded into these time periods, the response rate changed as a function of both parameters of the intrusion (lower panels of Fig. 7). Generally, the S^N response rate was maximal when the intercycle time difference equalled the duration of S^N and decreased as the temporal separation increased (although P1, at some stimulus probabilities, responded with a maximum rate at other phase angles). The interaction of this phase effect with stimulus probability is seen in the differences in the shape of the functions at each probability.

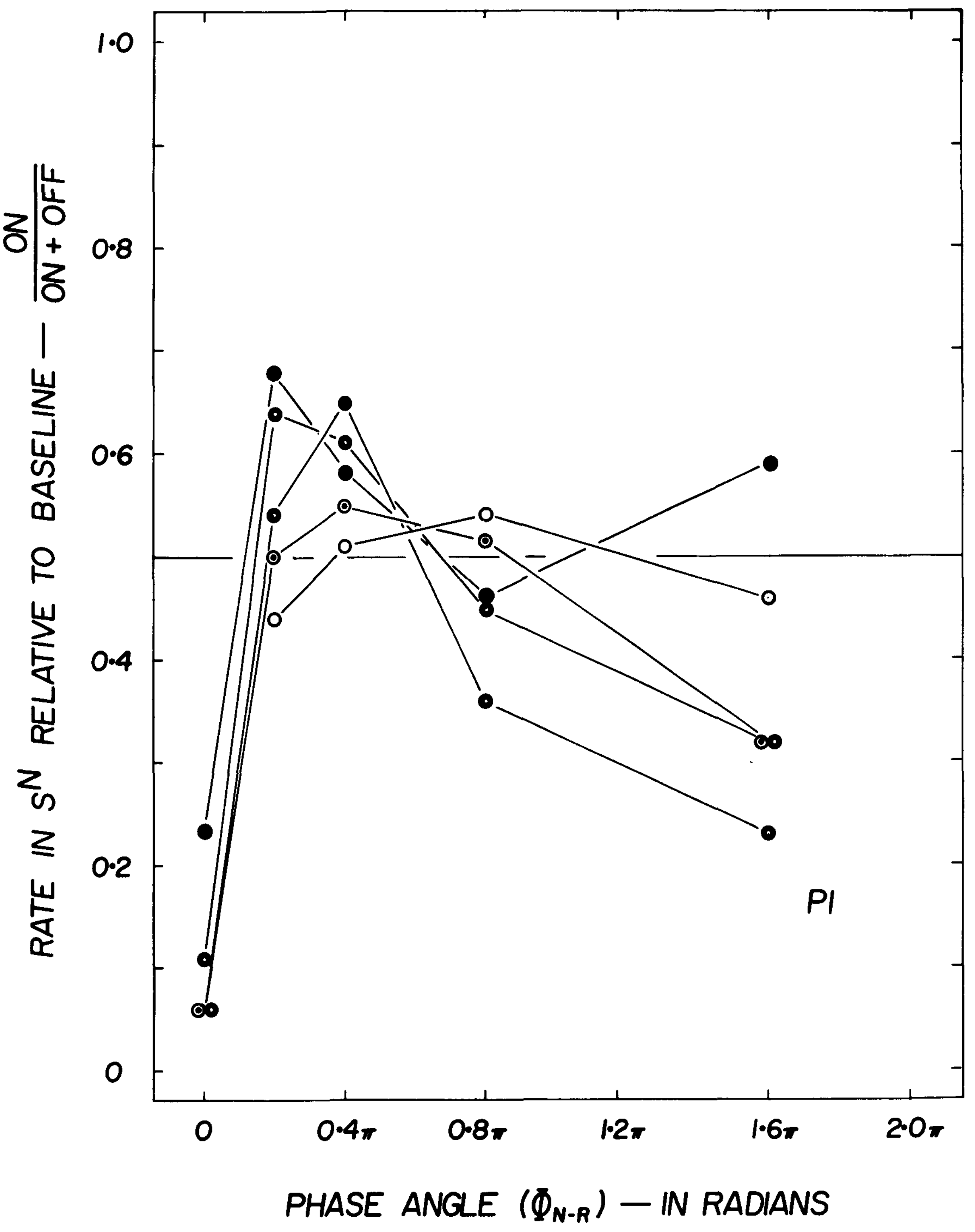
Because each bird gave a different set of baseline performances with respect to the two independent variables and to one another, the generality of the interactions and the magnitude of the changes due to stimulus intrusion are difficult to assess from the absolute rates. Therefore, a measure was sought that would express the amount of change relative to the baseline performances.

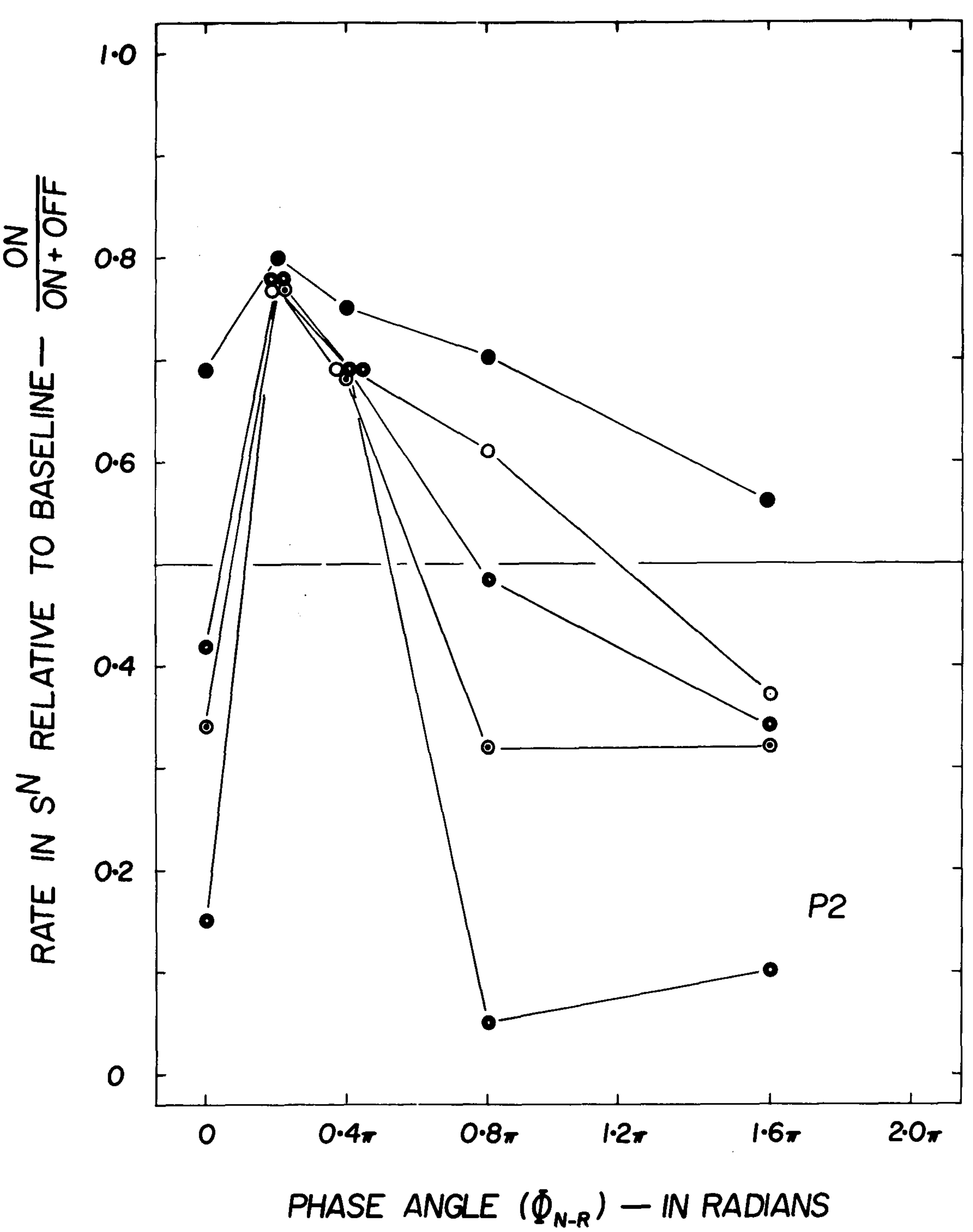
A variety of rate indices have appeared in the literature, but the one commonly reported for assessing the effects of intruding a variety of stimuli is the ratio: $\text{rate}_A/(\text{rate}_A + \text{rate}_B)$, where conditions A and B are in effect for equal times (e.g., Annau and Kamin, 1961; Azrin and Hake, 1969; Meltzer and Brahlek, 1970; Pierrel _et_ _al_., 1970). In successive discrimination experiments where no reinforcements are delivered during S^Δ, the ratio approaches 1.00 as responding during S^Δ declines to zero, whether or not the rate during S^D changes. In conditioned suppression experiments, the ratio approaches 0.00 as the response rate during the conditional stimulus approaches zero, whether or not there is an "out of stimulus," or pre-CS rate change. It is apparent, then, that either limit is reached only when there is no responding during one of the two conditions. In the present usage, condition B represents the baseline data and condition A represents S^N intrusion. Because responding always occurred during the baseline sampling, the denominator of the fraction must always be larger than the numerator, and the ratio can never reach 1.00, no matter how great the rate increase during S^N. If, however, responding ceased entirely in the presence of the neutral stimulus, then the numerator and the fraction would be zero.

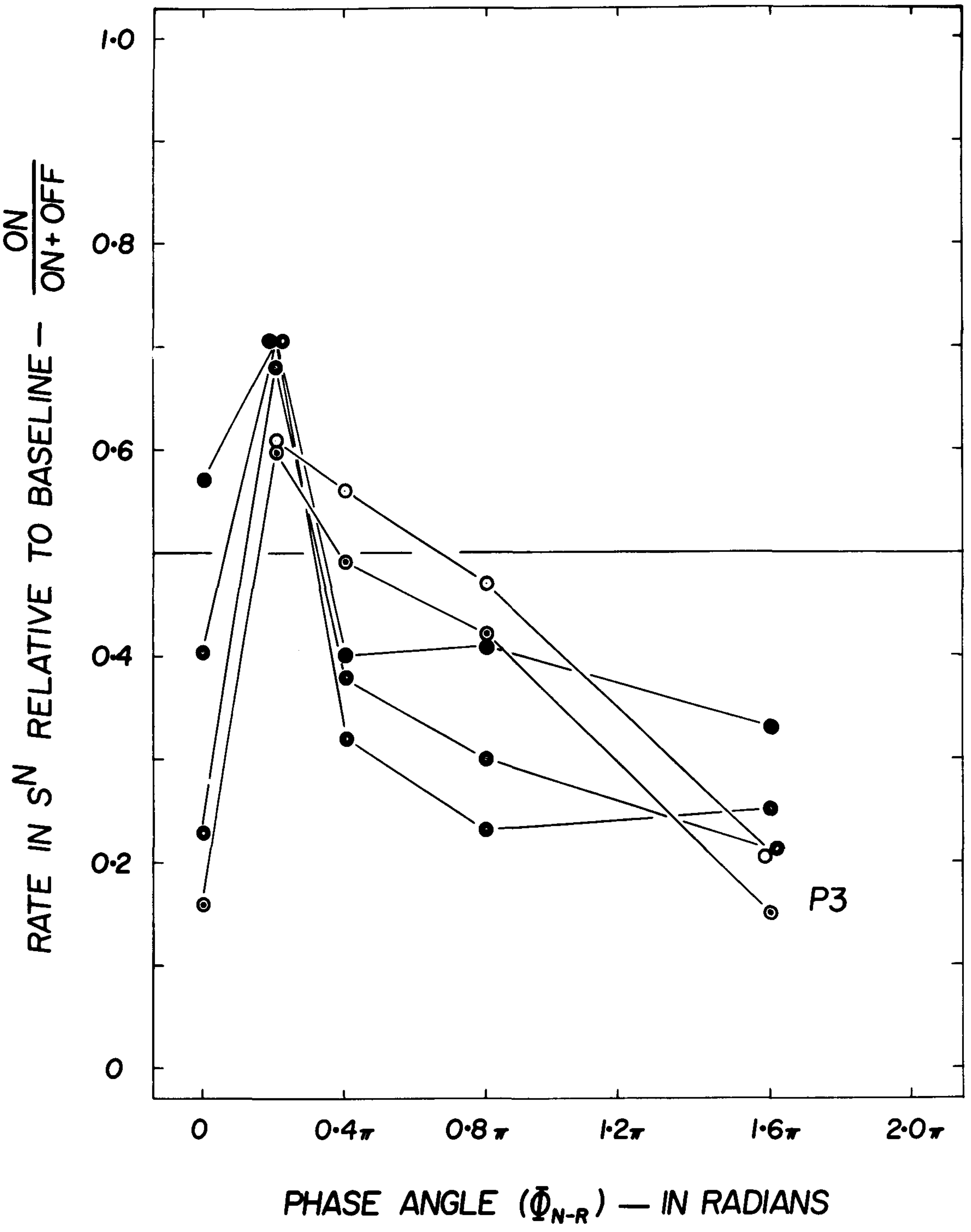
As noted earlier, the use of any relative measure in the present experiment is complicated by the absence of baseline measurements at the angle of 0.2π radians. Consequently, the three-second rates at this angle had to be approximated prior to calculating the index. At each stimulus probability except 1.00, the rate at 0.2π radians was taken as lying halfway between those measured at 0 and 0.4π radians. (Inspection of the functions over this region suggested no obstacle to the linear interpolation.) For the fixed-interval component, in which there could be no S^N response rate when the cycles were "in phase," different estimation procedures were used. For both P1 and P3, the functions at stimulus probabilities 1.00 and 0.80 were assumed to be parallel through the region in question, and the fixed-interval rate at 0.2π radians was obtained by the addition of an appropriate constant to the value estimated for the stimulus probability of 0.80. For P4, the fixed-interval function was assumed to extend towards 0 radians at a constant slope from which the estimated rate was determined. For P2, the same estimated rate was used for the two probabilities 0.80 and 1.00.

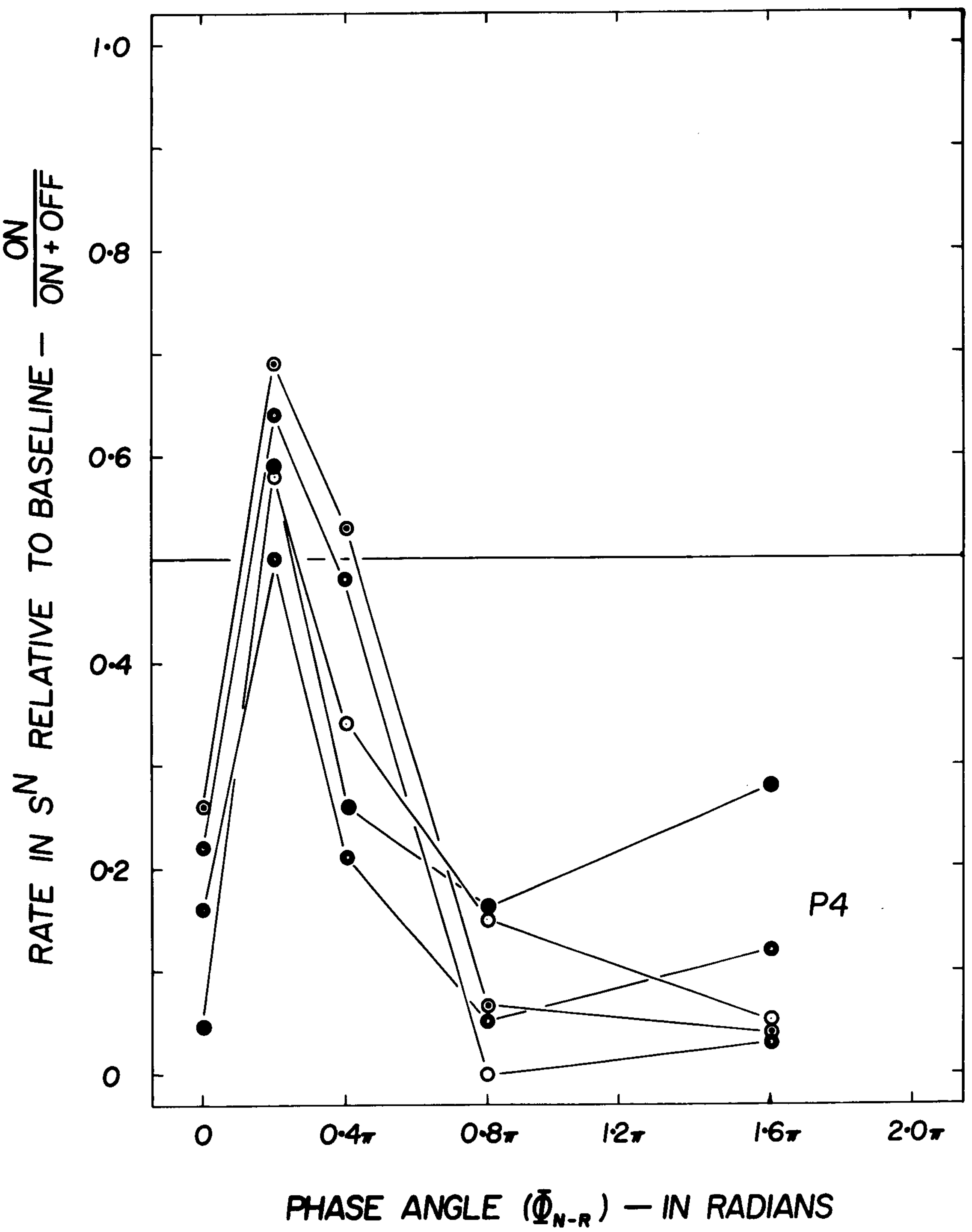
Fig. 8a-d. Change in the S^N response rate due to stimulus intrusion. The data from Fig. 7 have been combined to form the ratio: S^N ON rate / (S^N ON rate + S^N OFF rate). Identical response rates under baseline and added stimulus conditions would have produced a relative rate of 0.50, and a 10% variation would fall within the limits of 0.475 and 0.525. The legend for probability is:

symbol	*p*
○	1.00
⊙	0.80
◉	0.40
◙	0.20
●	0.10


RATE IN S^N RELATIVE TO BASELINE — $\frac{ON}{ON + OFF}$
1·0
0·8
0·6
0·4
0·2
0
0
0·4π
0·8π
1·2π
1·6π
2·0π
PHASE ANGLE (Φ_{N-R}) — IN RADIANS
PI


RATE IN S^N RELATIVE TO BASELINE— $\frac{ON}{ON+OFF}$
1·0
0·8
0·6
0·4
0·2
0
0
0·4π
0·8π
1·2π
1·6π
2·0π
PHASE ANGLE (Φ_{N-R}) — IN RADIANS
P2


RATE IN S^N RELATIVE TO BASELINE — $\frac{ON}{ON+OFF}$
1·0
0·8
0·6
0·4
0·2
0
0
0·4π
0·8π
1·2π
1·6π
2·0π
P3
PHASE ANGLE ($\bar{\Phi}_{N-R}$) — IN RADIANS

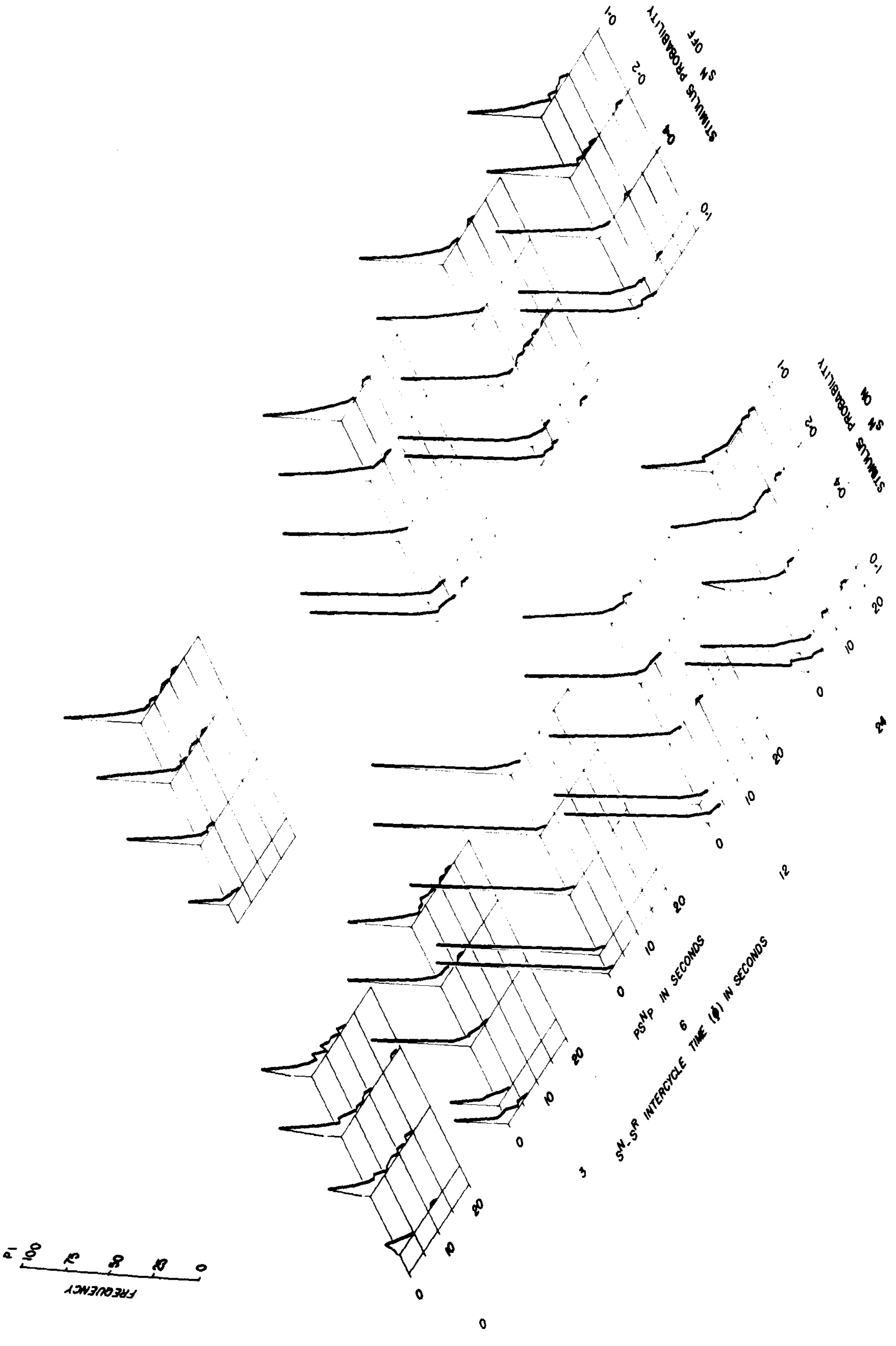

RATE IN S^N RELATIVE TO BASELINE — $\frac{ON}{ON + OFF}$
1·0
0·8
0·6
0·4
0·2
0
0
0·4π
0·8π
1·2π
1·6π
2·0π
P4
PHASE ANGLE (Φ_{N-R}) — IN RADIANS

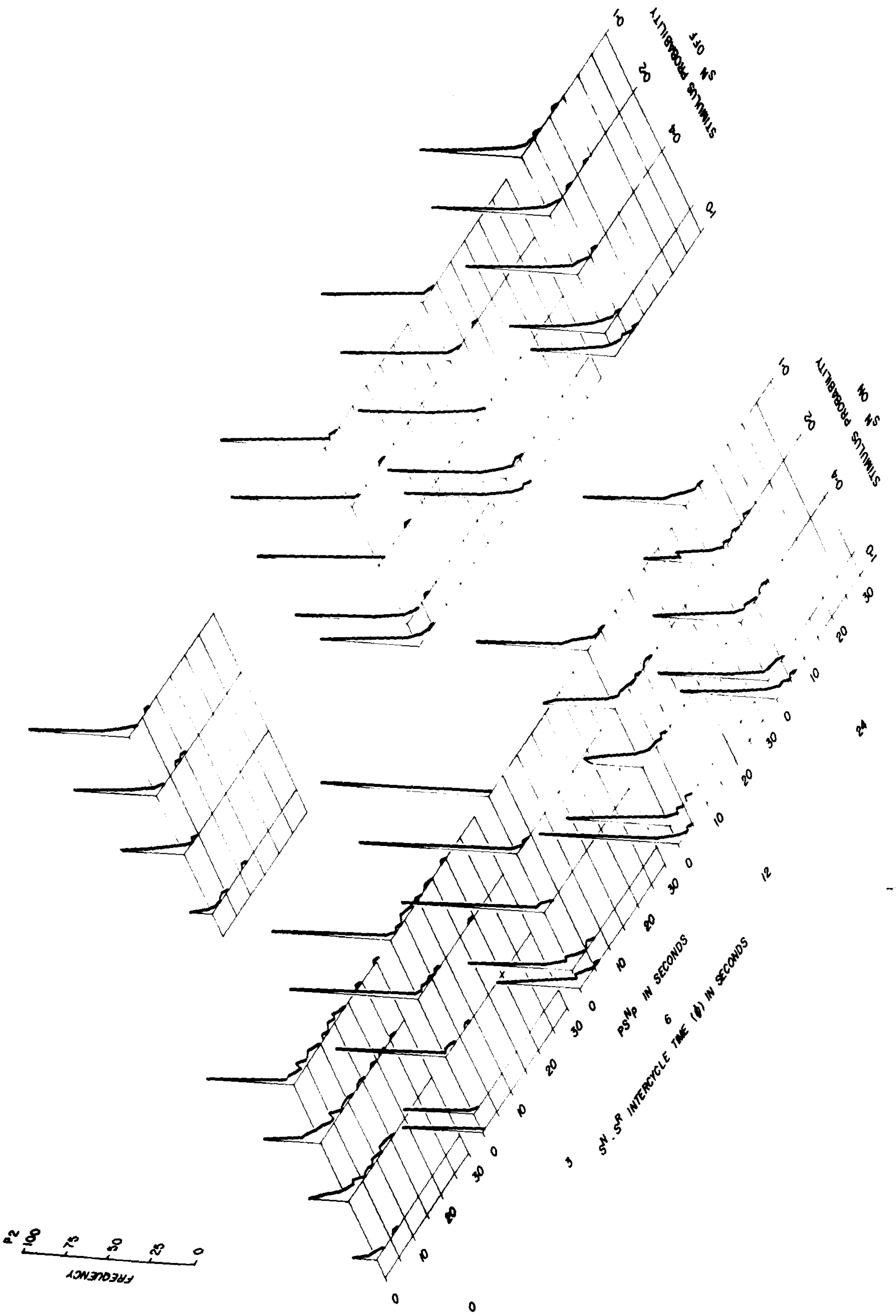
The resulting S^N rate ratios are shown in Fig. 8a-d. These functions also exhibit a maximum and a minimum at the same phase angles as did the absolute rate functions in Fig. 7, but the slopes are somewhat different. Even when their differences in baseline performances have been taken into account, the several birds are seen to have responded differently at particular phase and probability combinations. During S^N intrusions at a probability of 0.10, for example, P2 responded at an increased rate at each intercycle time, but the other birds showed at this probability a rate increase relative to baseline at only one or two of the intercycle times. Nevertheless, with the possible exception of P1's data, the individual differences seen here are no more striking, nor any more detrimental to the generality of control excercised by the T_N-T_R relationship, than are the intersubject differences in, say, the particulars of stimulus generalization gradients. Some of the differences may be related to the two orders of exposure to the various phase angles. Thus, for P1 and P4, whose initial exposure to S^N was at 0 (or 2.0π) radians of displacement from T_R, responding during S^N at this angle was reduced from baseline at all stimulus probabilities. For P2 and P3, on the other hand, exposure to 0 radians came last and immediately following the angle that produced the maximal S^N response rates. For these subjects, the S^N response rate at 0 radians was increased from its baseline value at stimulus probability of 0.10, and showed less decreases at the other probabilities than did the rates for P1 and P4.

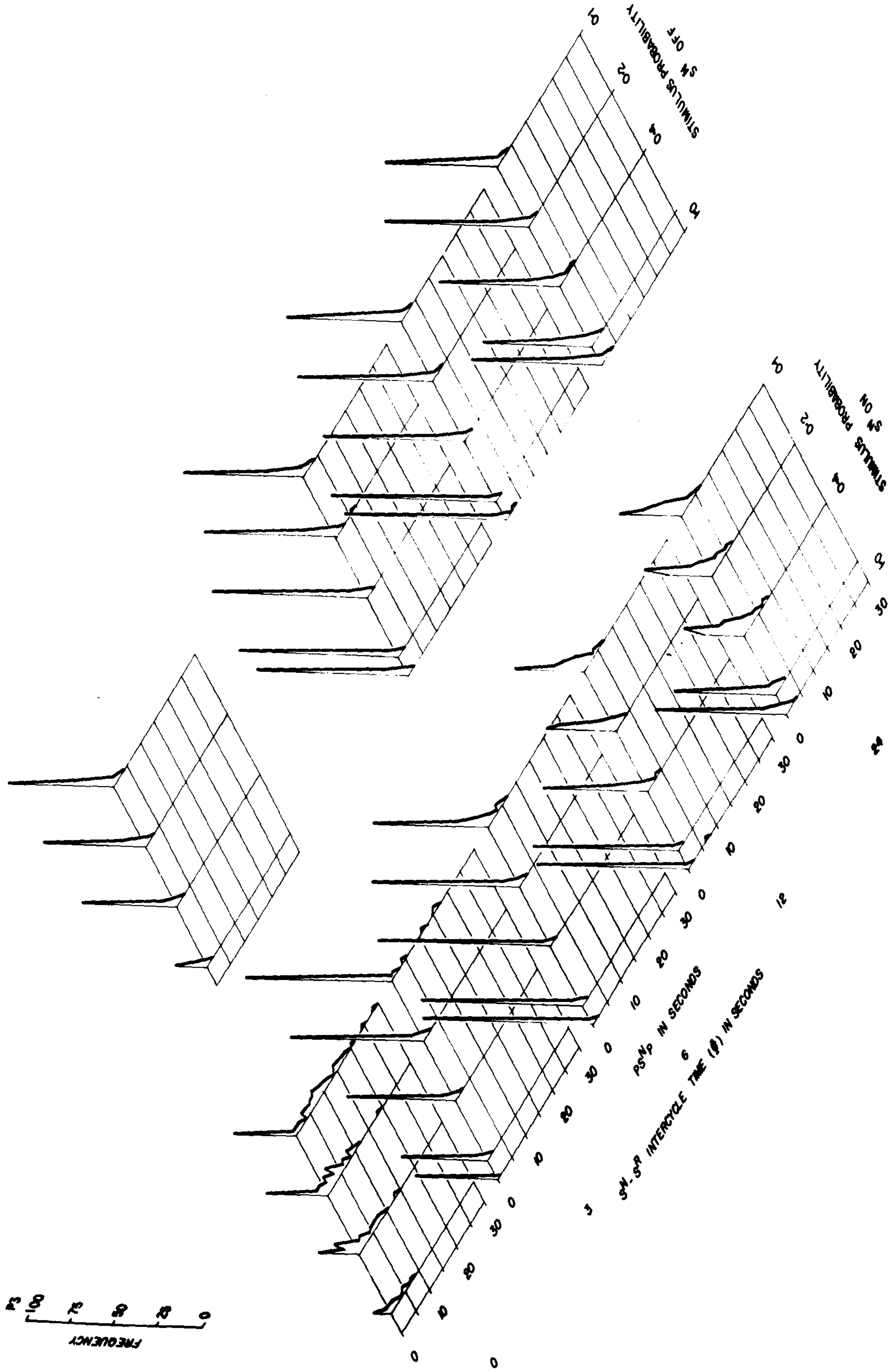
If the same data are replotted so that stimulus probability is scaled along the abscissa and phase angle is the parameter, the resultant functions (not shown) are more complex. For all of the birds, these curves can be separated by phase angle into two groups. At phase angles of 0.2π and 0.4π radians, responding during S^N either was unaffected by stimulus probability or was inversely related to stimulus probability. At all the other phase angles, the relative S^N response rate functions show a minimum at a probability of either 0.40 or 0.20. For all but two of the twenty functions (five phase angles for each of four birds), the response rate was higher at stimulus probability 0.10 than at 0.20. The division of probability effect by phase angle is consistent with the observation made earlier that the presentation of S^N temporarily increased the rate of responding when the modular S^N-S^R interval was short but temporarily decreased the rate of responding when the modular interval was long.

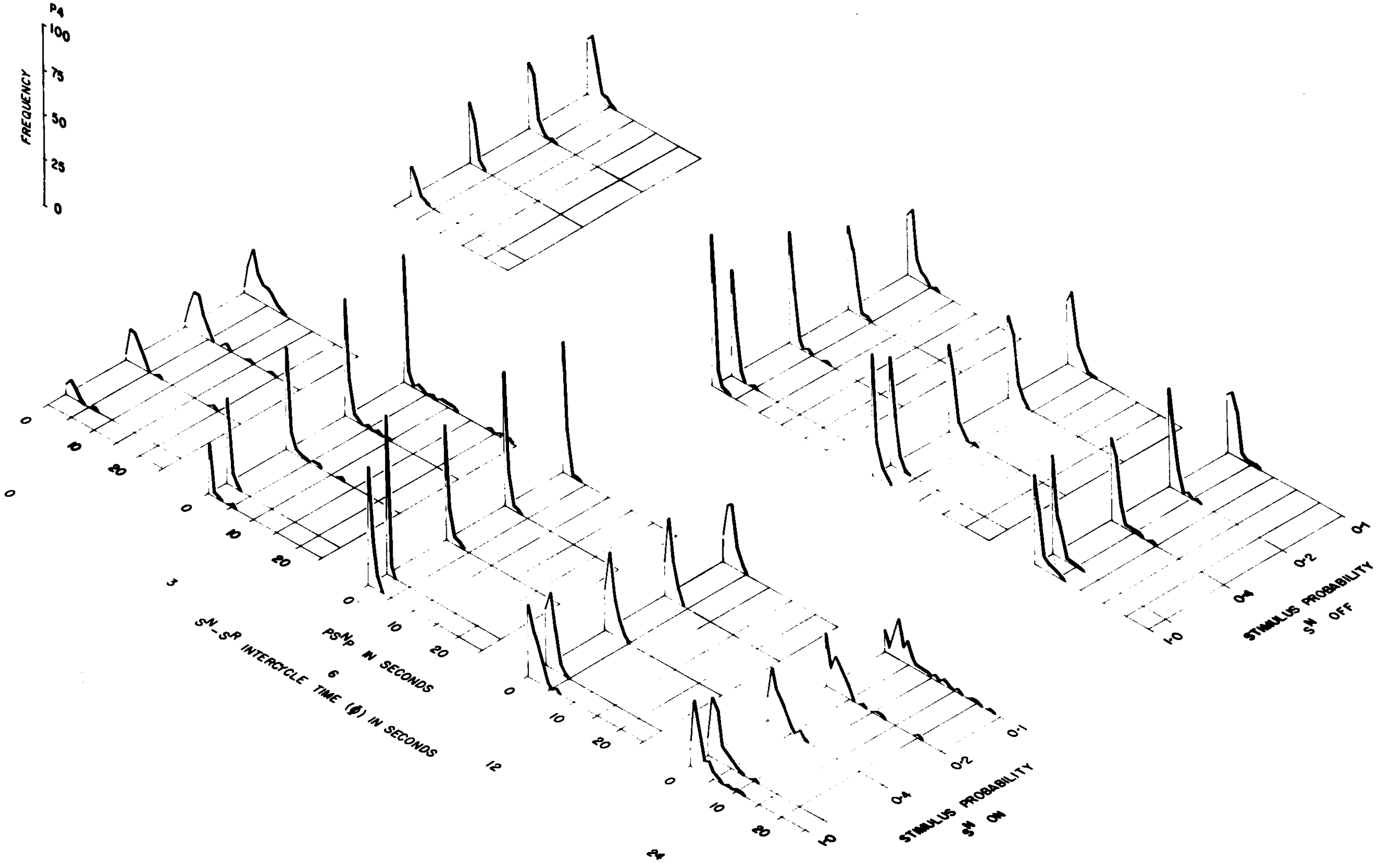
Figure 9a-d presents frequency distributions of the pause in responding immediately after the S^N periods (PS^NP). Because the offset of each three-second period occurred independently of responding, these pauses were various, unspecified fractions of the interresponse times prevailing under local conditions. During the baseline stage, the distributions were L-shaped with the mode (0.45 seconds) falling in the first class-interval. Although there was little difference in these distributions due to the phase variable, stimulus probability had a small, inverse effect on the proportion of longer pauses. When S^N was presented, the distributions of post-S^N pausing also reflected the intercycle difference. At phase angles of 0 and 1.6π radians, which were seen to have produced the lowest S^N response rates, the longest PS^NPs were obtained: the range increased with a consequent reduction in the frequency (and, in some cases, increase in the value

Fig. 9a-d. Frequency distributions of the post-S^N pause in responding (PS^NP). Data accumulated over the last 10 days at each position of S^N intrusion and data accumulated over comparable uncued positions during the baseline conditions are shown separately in one-second class intervals.


STIMULUS PROBABILITY
S^N OFF
S^N ON
0.1
0.2
0.4
0.1
0.2
0.4
PS^NP IN SECONDS
S^N-S^R INTERCYCLE TIME (φ) IN SECONDS
0
10
20
0
3
6
12
24
FREQUENCY
Pi
100
75
50
25
0


STIMULUS PROBABILITY
S^N OFF
0.1
0.2
0.4
1.0
STIMULUS PROBABILITY
S^N ON
0.1
0.2
0.4
1.0
30
20
10
0
24
12
6
3
0
0
PS^N_P IN SECONDS
S^N.S^R INTERCYCLE TIME (Ø) IN SECONDS
x
FREQUENCY
P2
100
75
50
25
0


STIMULUS PROBABILITY
SΔ OFF
0.1
0.2
0.4
0.8
STIMULUS PROBABILITY
SΔ ON
0.1
0.2
0.4
0.8
0
10
20
30
PS^{N}_{P} IN SECONDS
S^{N}_{D}-S^{R} INTERCYCLE TIME (T) IN SECONDS
0
3
6
12
24
X
FREQUENCY
0
25
50
75
100

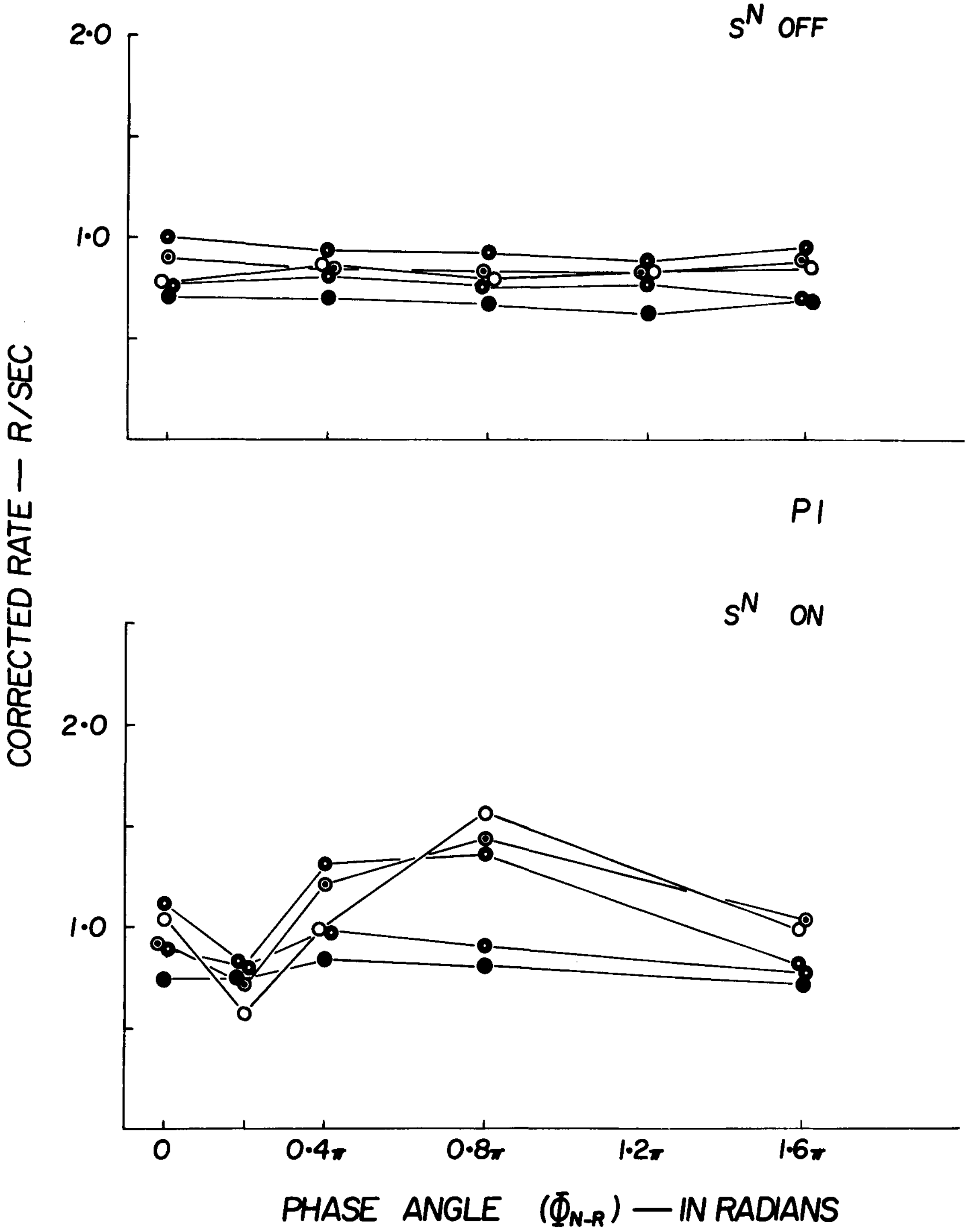

P4
FREQUENCY
100
75
50
25
0
0
10
20
0
10
20
0
10
20
0
10
20
0
10
20
0
3
6
12
24
PS^{N}_{P} IN SECONDS
S^{N}-S^{R} INTERCYCLE TIME (ϕ) IN SECONDS
0·1
0·2
0·4
1·0
STIMULUS PROBABILITY
S^{N} ON
0·1
0·2
0·4
1·0
STIMULUS PROBABILITY
S^{N} OFF

of) the mode. Conversely, at those phase and probability combinations that produced the maximal S^N response rates, the shortest PS^NPs were obtained, as indicated by the decrease in range and the increase in modal frequency. The complementary relationship between the S^N response rate and PS^NP is not unexpected, since each sample of the former immediately preceded a sample of the latter. If an animal was responding at a high rate during the stimulus, termination of the stimulus would subdivide a short interresponse time and yield a short PS^NP. On the other hand, the interval between termination of the stimulus and the next measured response would be long if an animal was doing something other than responding in the way that was being experimentally measured (key pecking) during S^N.

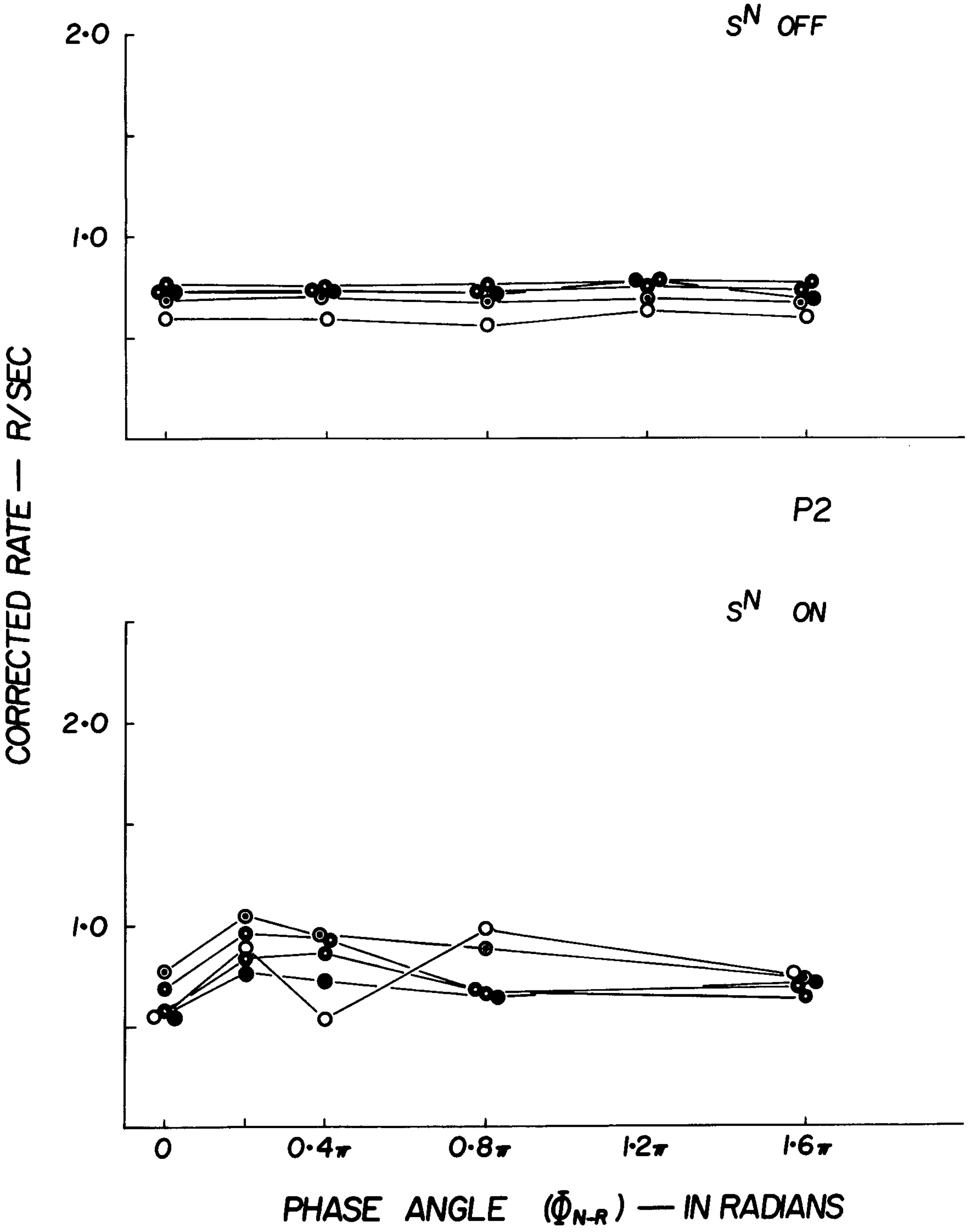
In the absence of S^N, each bird had her own pattern of approach to the operandum, her own stance at the key, and her own topography of key pecking. P3, for instance, usually stood with her feet planted at some distance to the right of the key and pecked by stretching her neck sideways, whereas P4 habitually weaved back and forth in front and to the right side of the panel, pecking the key once each time she passed it. During the appearance of S^N, however, the usual "chain" of responses was replaced. During those phase and probability combinations which functioned as discriminative stimuli for the measured response, all birds would, on the change in key color from green to white, take up a fixed position directly in front of the key and peck rapidly, concentrating the pecks at a particular spot on the rim of the key. (The change in localization of the peck, together with a frequently observed change to pecking with an open beak, often produced "misses" of the key during S^N.) This clearly defined mode

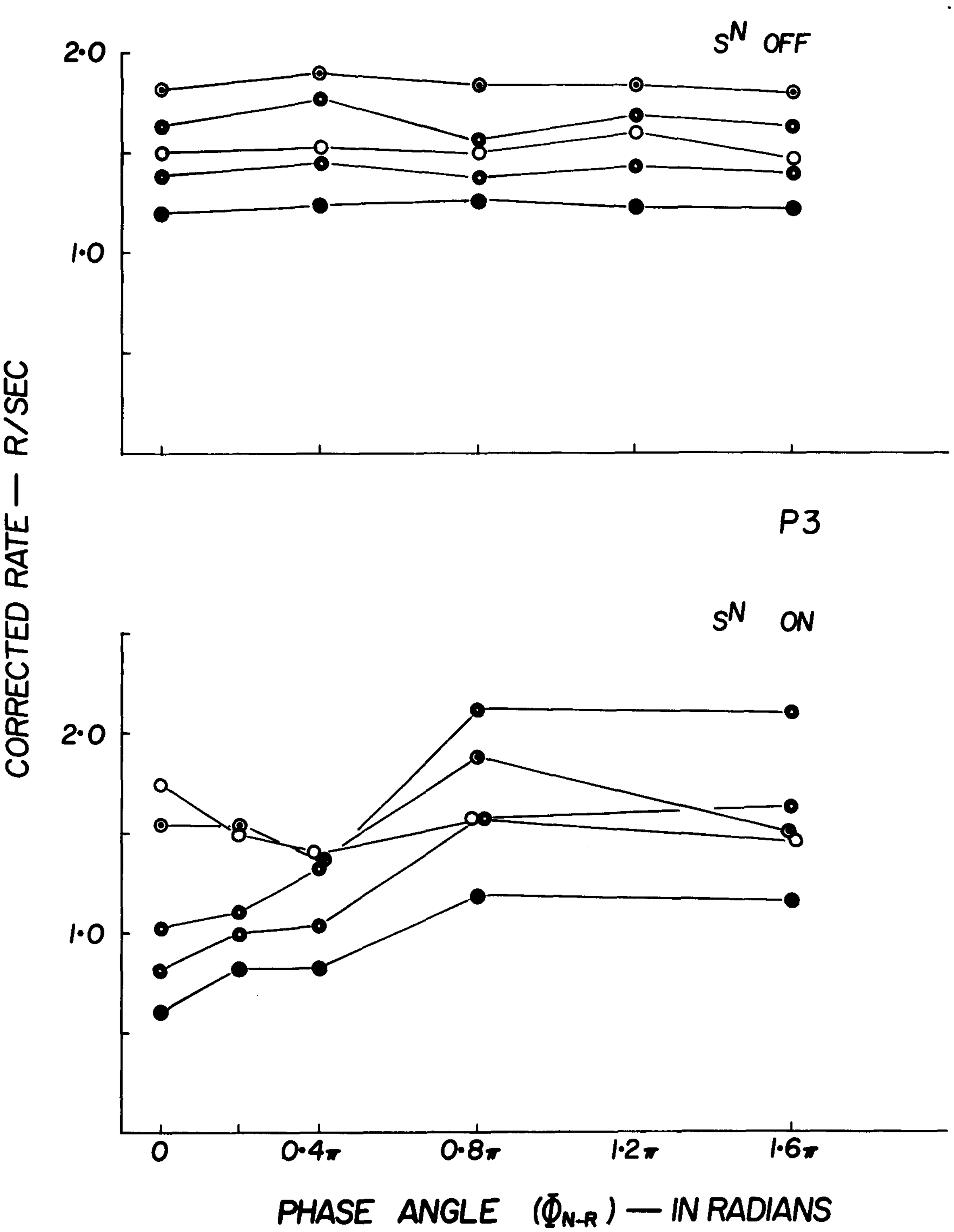
Fig. 10a-d. The effects of S^N intrusion on corrected response rate (number of responses divided by experimental time minus eating $[S^R]$time). The code for stimulus probability is:

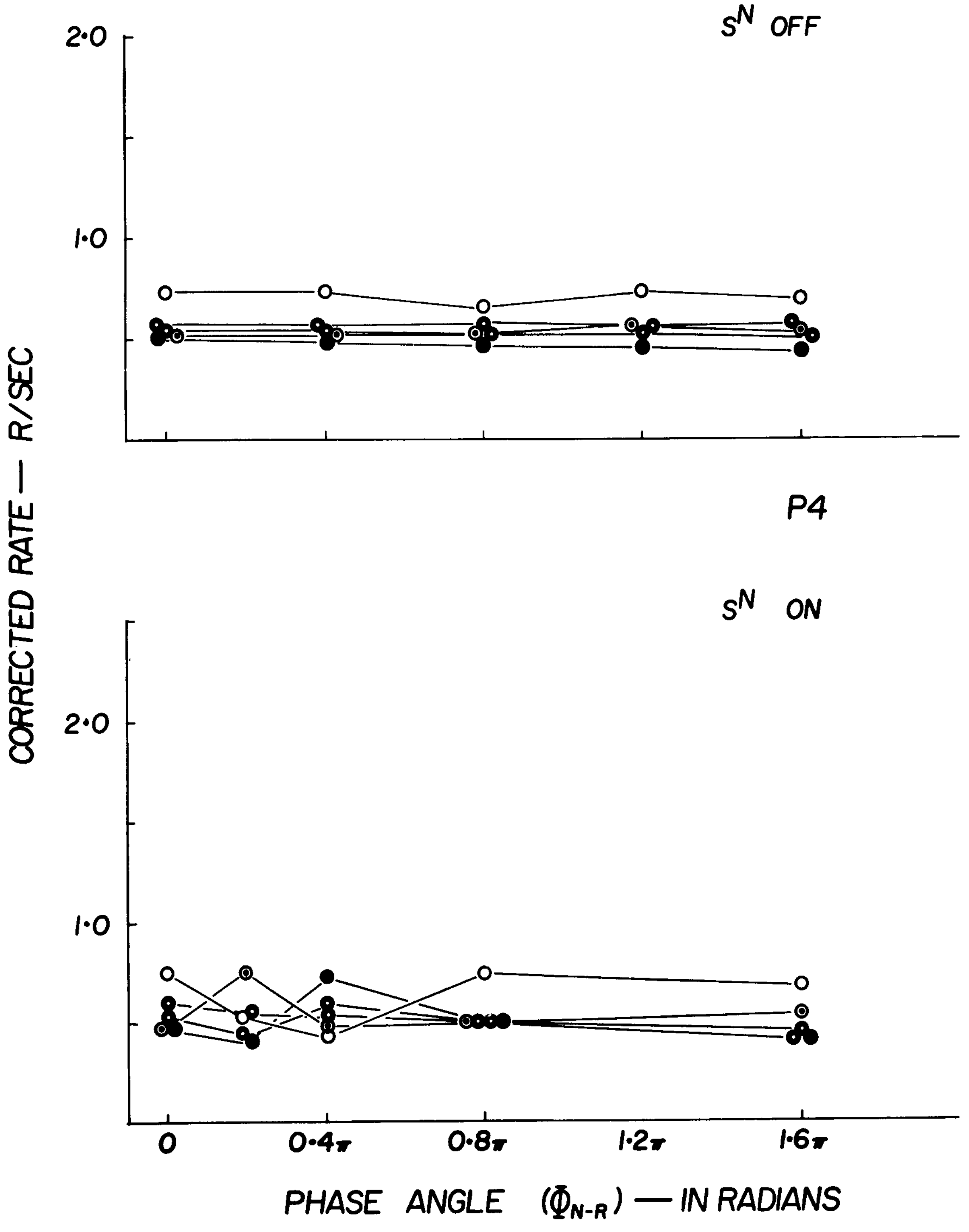
symbol	*p*
○	1.00
◎	0.80
◉	0.40
◉	0.20
●	0.10



S^N OFF
2·0
1·0
P1
S^N ON
2·0
1·0
0
0·4π
0·8π
1·2π
1·6π
CORRECTED RATE — R/SEC
PHASE ANGLE (Φ_{N-R}) — IN RADIANS


S^N OFF
2·0
1·0
P2
S^N ON
2·0
1·0
CORRECTED RATE — R/SEC
0
0·4π
0·8π
1·2π
1·6π
PHASE ANGLE (Φ_N-R) — IN RADIANS


S^N OFF
2·0
1·0
CORRECTED RATE — R/SEC
P3
S^N ON
2·0
1·0
0
0·4π
0·8π
1·2π
1·6π
PHASE ANGLE (Φ_N-R) — IN RADIANS


S^N OFF
P4
S^N ON
2·0
1·0
2·0
1·0
CORRECTED RATE — R/SEC
0
0·4π
0·8π
1·2π
1·6π
PHASE ANGLE (Φ_N-R) — IN RADIANS

of responding was then interrupted by either a reinforcement or the change in key color back to green. In the latter case, the birds would usually circle the box before returning to their customary mode and rates of pecking. At the lower stimulus probabilities, when the S^N response rate was lower on the average, there was a greater likelihood that termination of S^N would immediately interrupt responding and thereby give rise to one of the long PS^NPs, while at the higher probabilities, the S^N usually terminated during a "burst" of responses. Quite a different pattern was observed at those phase and probability combinations that produced low response rates during S^N. Each bird either turned partially away from the key or completely circled the box during the presentation of S^N. The former routine did not quite fill up the three-second period, but the latter resulted in both an extremely low S^N response rate and a long PS^NP. The consistency of this behavioral pattern that took the place of key-pecking during the intrusion of a stimulus has been noted by other investigators in other contexts.

The changes in both the S^N rate and the PS^NP would obviously affect the corrected rate of responding within a probability component. In the upper panel of Fig. 10a-d, the means are shown for the end of the baseline period. (These are the same data, separated now by phase angle as well as by stimulus probability, that were pooled over the phase angles to obtain the means shown in Fig. 4.) Because there was no exteroceptive event correlated with the phase angle, these rates would be expected to differ systematically only with regard to reinforcement probability, and they are, in fact, quite free of variation across the different phase angles. The intrusion of S^N, of course, altered the average component rate. At each probability, the daily total duration of S^N was 30 seconds, whereas the duration of components of the multiple schedule ranged from 5 to 50 minutes (in expected value). Consequently, the range of variation among the components due to S^N intrusion was directly proportional to stimulus probability, reflecting the increasing proportion of component time occupied by S^N with increasing stimulus probability. However, the functions are not simple copies of the S^N response rate functions reduced proportionally in amplitude. On the contrary, there is no systematic relationship between the two sets with regard to either the angular locus of the maximum rate at a given probability or the relationship between rate and stimulus probability for a particular phase angle. This absence of a monotonic transformation of rate during S^N (and the inversely varying PS^NP) to corrected rate suggests that the effects of intruding the neutral stimulus were not confined just to its presence and withdrawal.

One possibility for more distal effects is that the pausing after reinforcements was altered because of the various positions of S^N with regard to the reinforcer. From Fig. 11, a comparison of the quartiles from the S^N ON and S^N OFF distributions of PS^RP can be made. As one would expect, the median PS^RP with the neutral stimulus totally absent was independent of phase angle, but it was inversely related to reinforcement frequency (see also Fig. 3). When the neutral stimulus was intruded, PS^RP was generally greater in (a) either the locus or extent of range and (b) the median value. Once again, the several birds produced different functions with regard to the phase variable, but a particular bird's functions were similar across the different probability values.

Another possibility for the discrepancies between the S^N

Fig. 11. The effects of S^N intrusion on PS^RP. The solid line connects medians of the 10-day samples taken at the end of baseline conditions; the dotted line connects the medians of the samples taken at the last 10 days of exposure to each phase angle when S^N was present. The brackets show the location of the inter-quartile ranges.

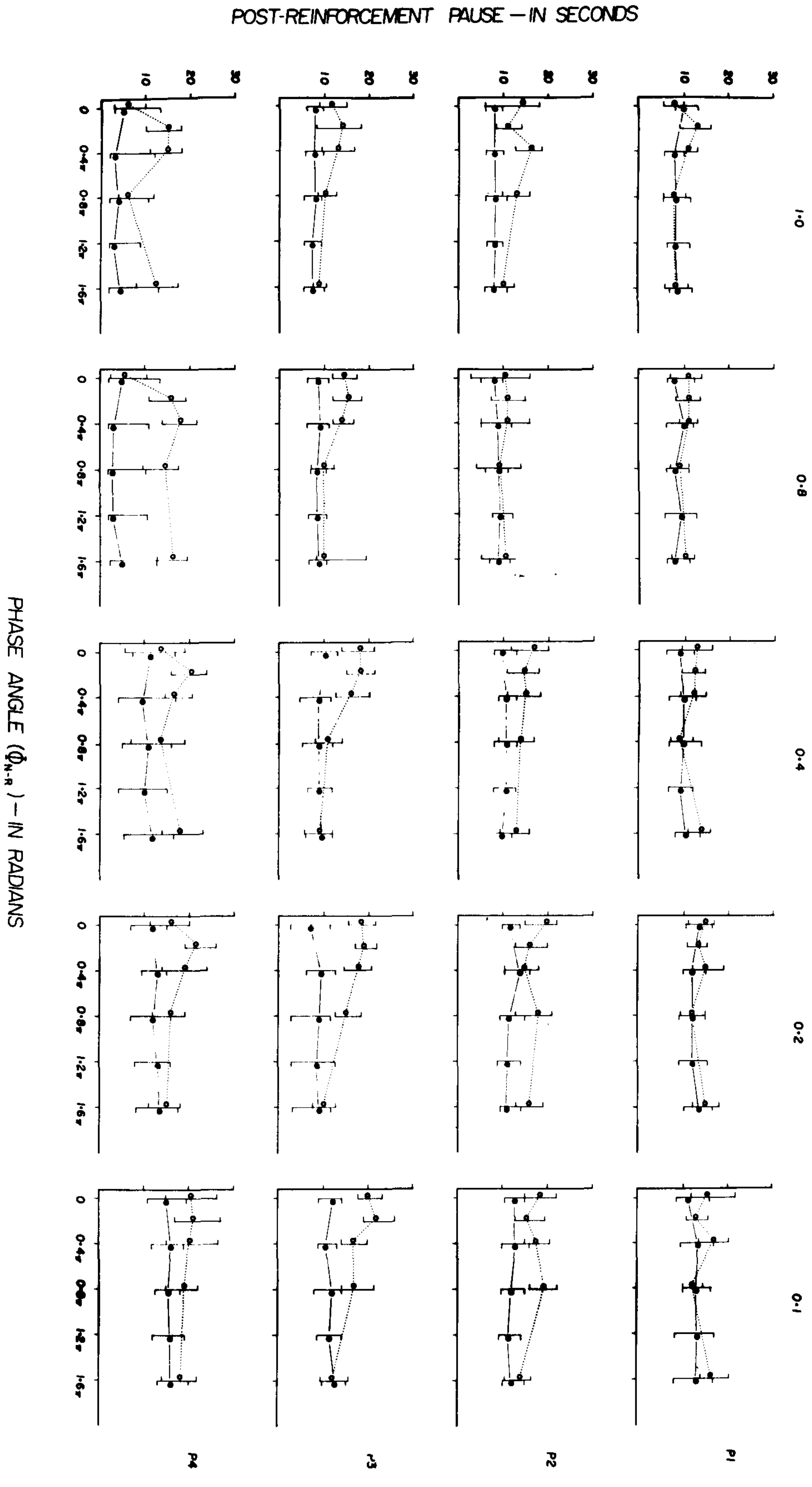
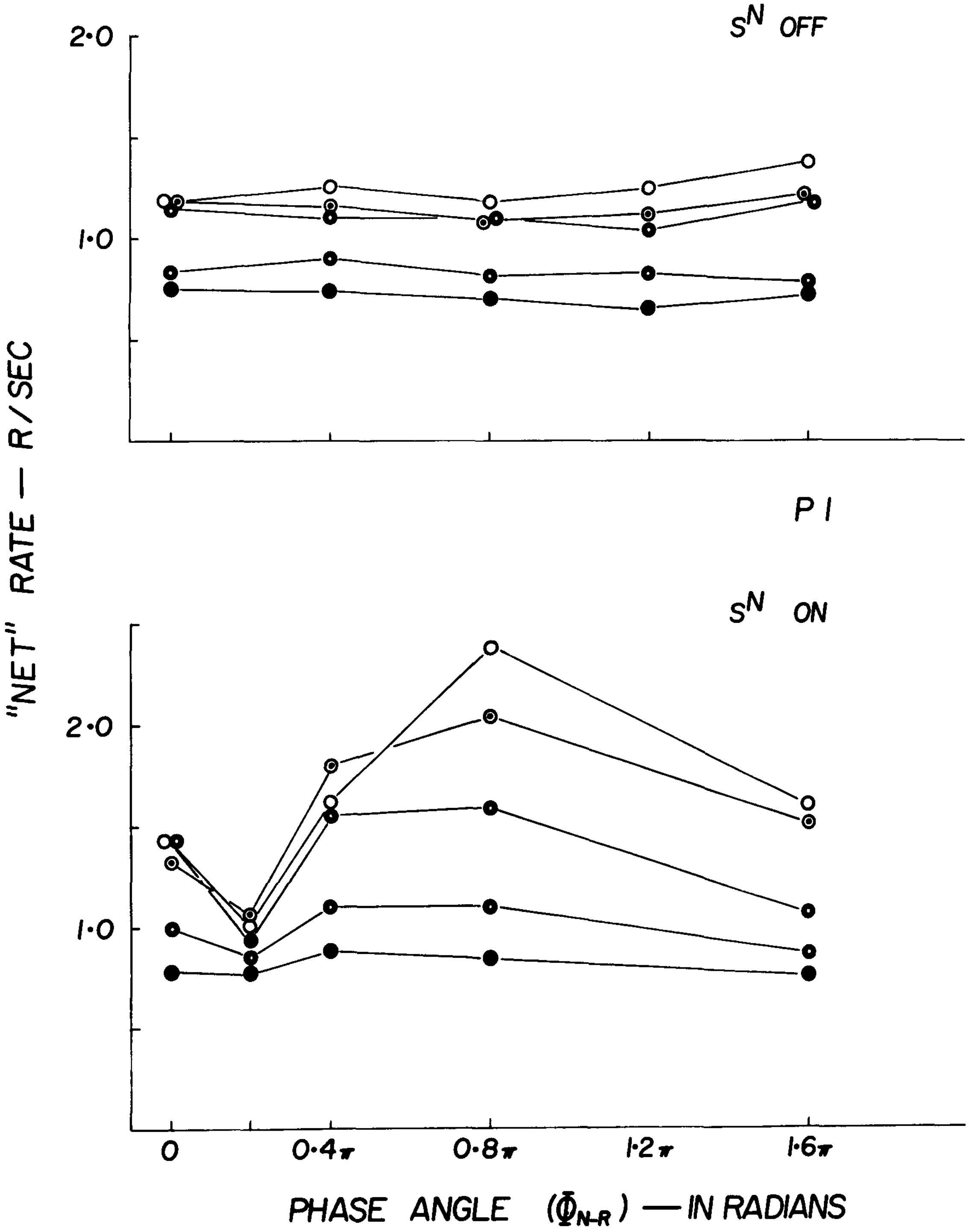
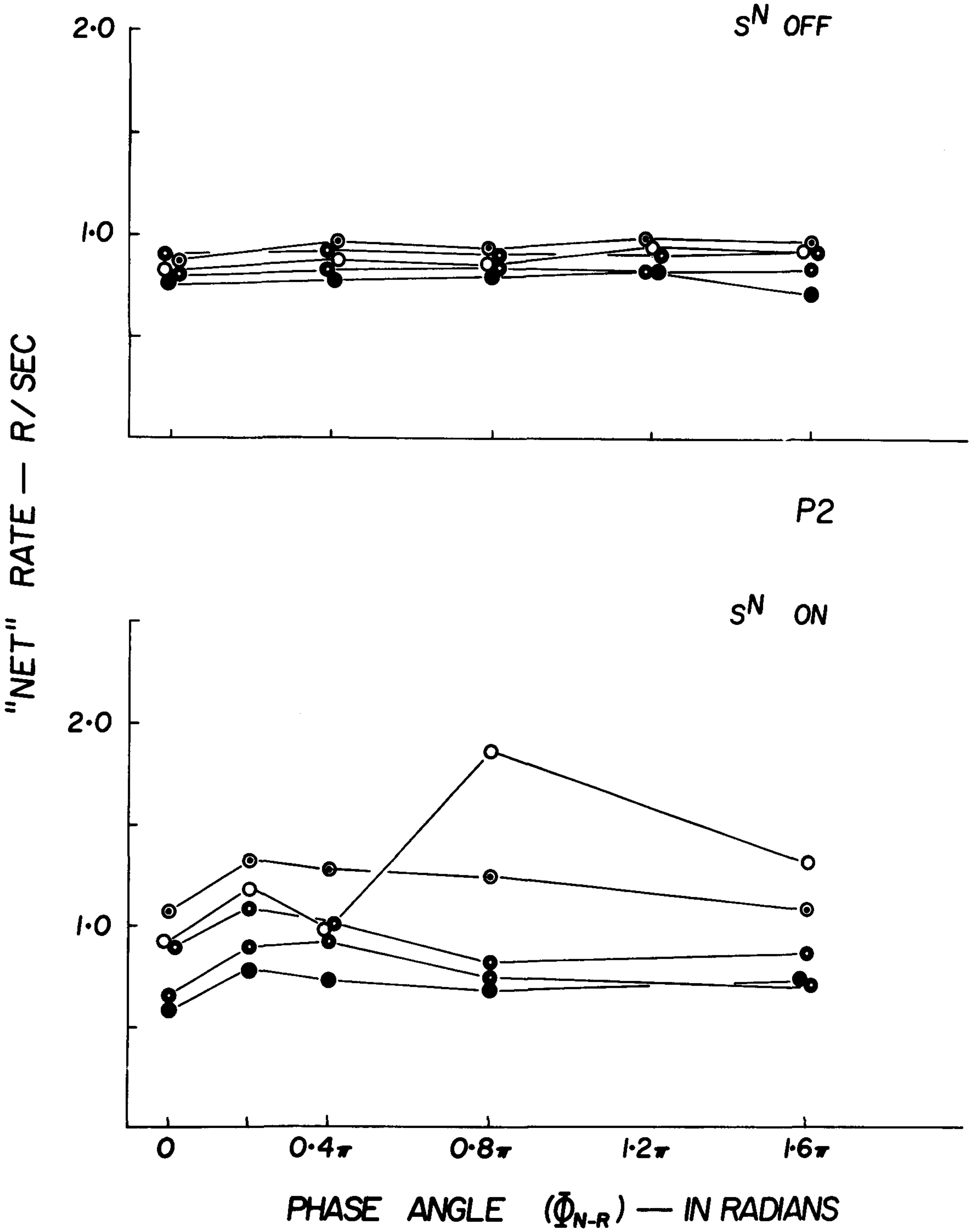
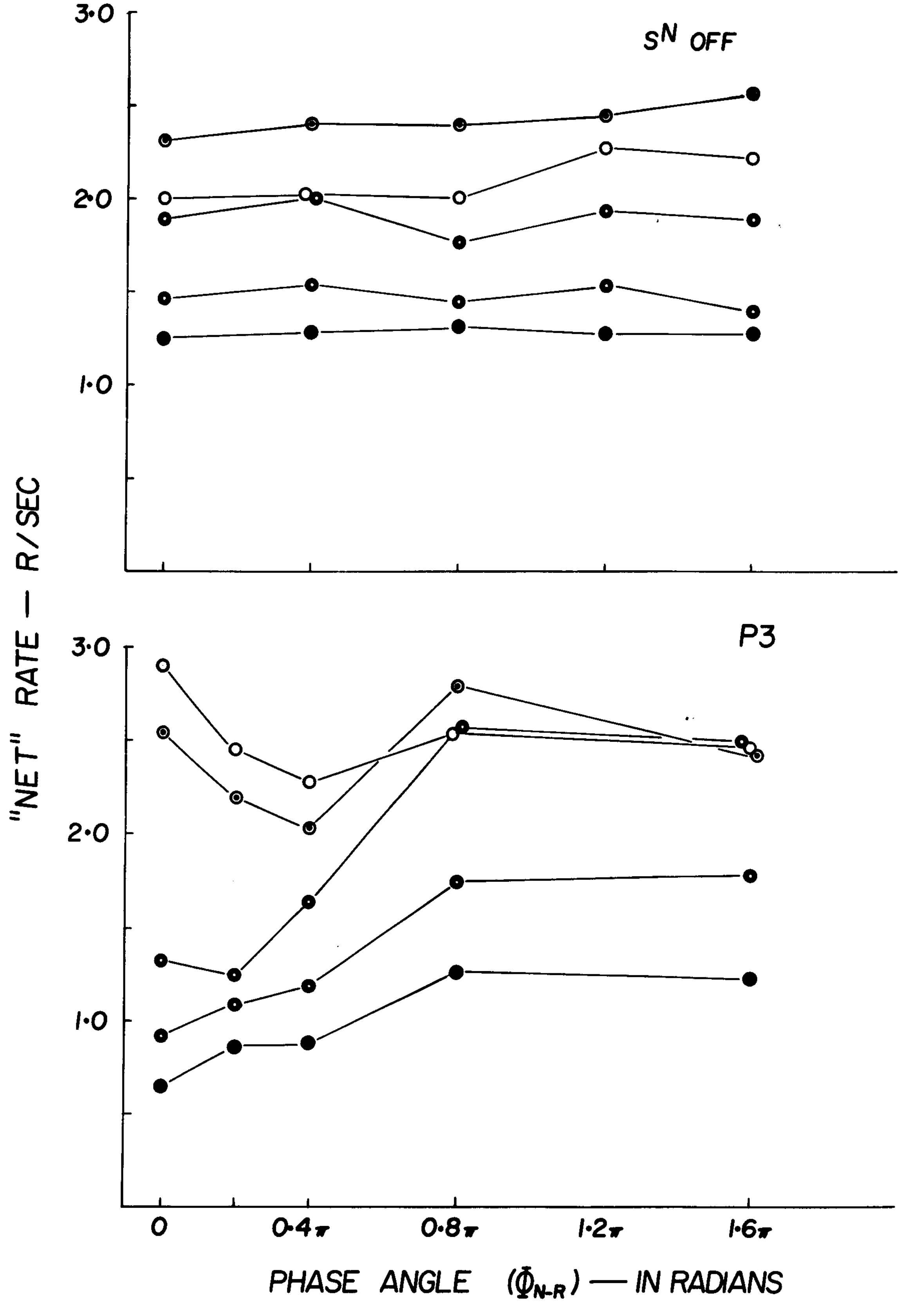

POST-REINFORCEMENT PAUSE — IN SECONDS
PHASE ANGLE (Φ_N-R) — IN RADIANS
1·0
0·8
0·4
0·2
0·1
P1
P2
P3
P4
10
20
30
0
0·4π
0·8π
1·2π
1·6π

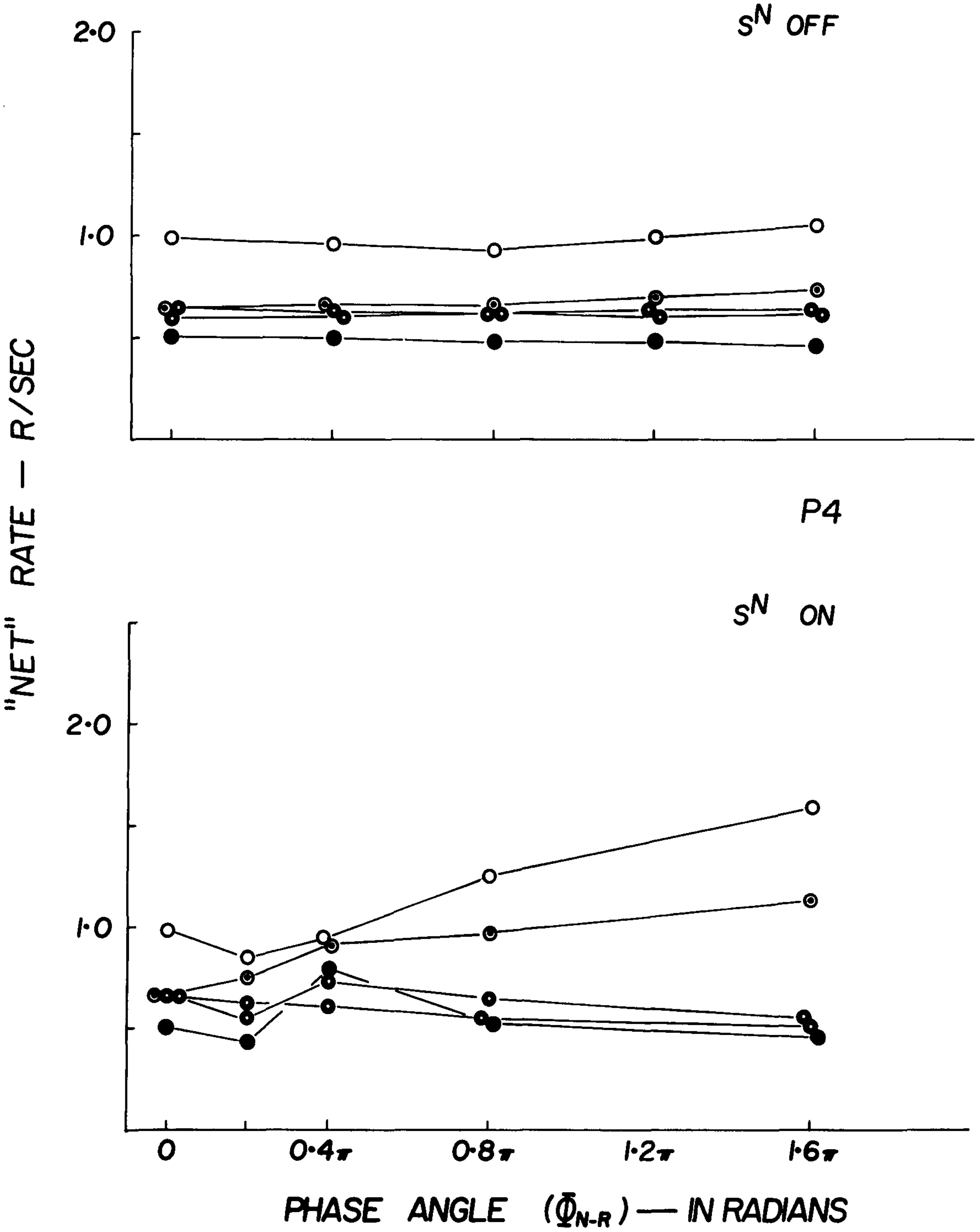
Fig. 12a-d. Additional effects of S^N intrusion. "Net" rate is the rate of responding when eating time, PS^RP, S^N duration and responding, and PS^NP are excluded from the calculation. The stimulus probabilities are coded as:

symbol	*p*
○	1.00
◉	0.80
⦿	0.40
⦿	0.20
●	0.10


S^N OFF
2·0
1·0
P I
S^N ON
2·0
1·0
0
0·4π
0·8π
1·2π
1·6π
"NET" RATE — R/SEC
PHASE ANGLE (Φ_N-R) — IN RADIANS


2·0
1·0
S^N OFF
P2
S^N ON
2·0
1·0
0
0·4π
0·8π
1·2π
1·6π
"NET" RATE — R/SEC
PHASE ANGLE (Φ_{N-R}) — IN RADIANS


S^N OFF
P3
"NET" RATE — R/SEC
3·0
2·0
1·0
0
0·4π
0·8π
1·2π
1·6π
PHASE ANGLE (Φ_N-R) — IN RADIANS

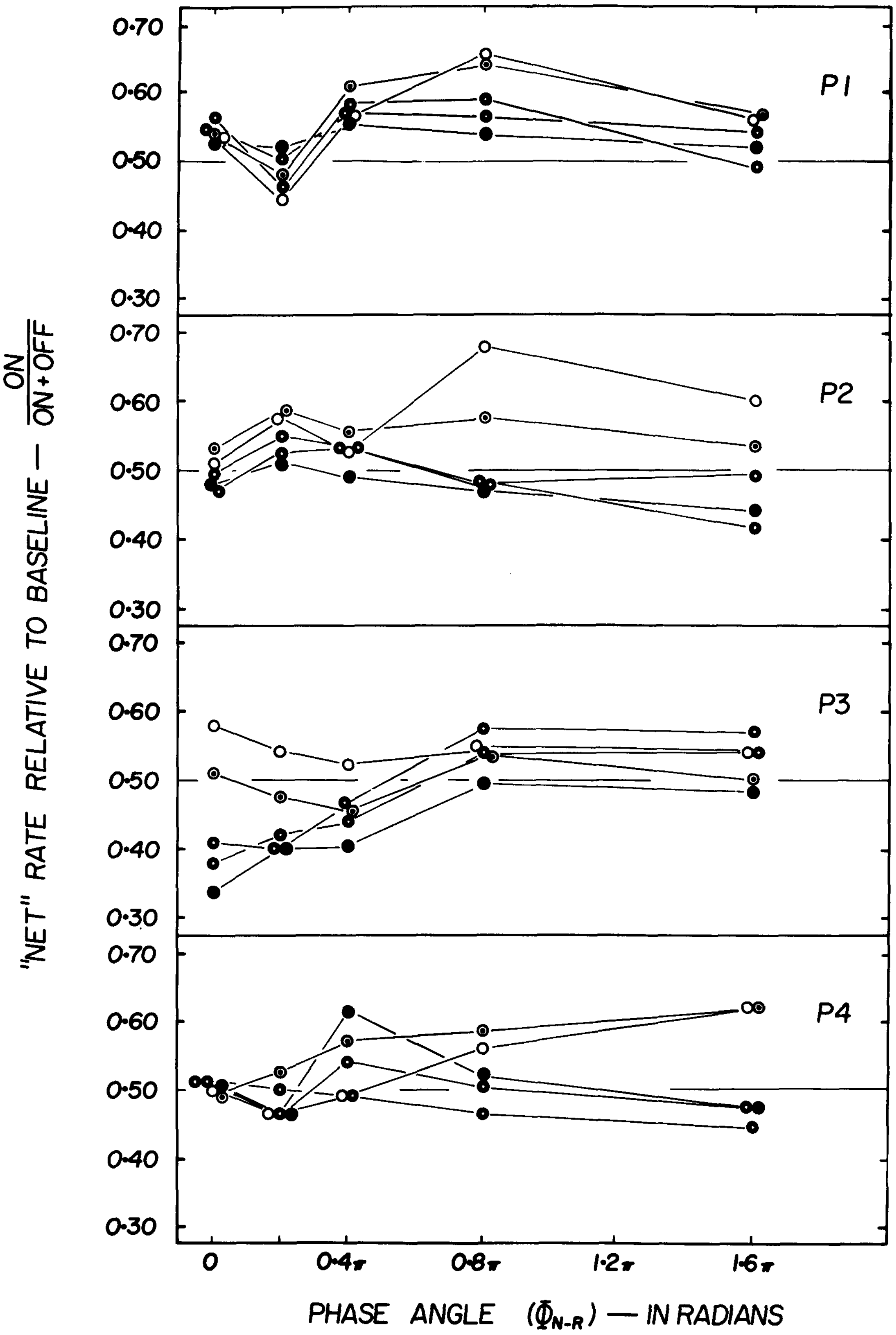

2·0
1·0
S^N OFF
P4
S^N ON
2·0
1·0
"NET" RATE — R/SEC
0
0·4π
0·8π
1·2π
1·6π
PHASE ANGLE (Φ_{N-R}) — IN RADIANS

response rates and the corrected rates is that the likelihood of responding was changed at still other points in time, times which were not immediately tied to the intrusion or termination of either stimulus. Accordingly, a "net" response rate, from which were excluded eating time, PS^RP, S^N duration and responding, and PS^NP, was calculated and is shown in Fig. 12a-d. The "net" rates are higher than the corrected rates for the higher reinforcement densities, due largely to the removal of the PS^RP, but they are similar to the corrected rates in angular location of the maxima and minima. Therefore, the introduction of S^N altered the tendency to respond at times other than during or immediately following intrusion of S^N and S^R. This effect, now evaluated in terms of each animal's baseline performance, is shown again in Fig. 13. The two independent variables, whose joint operation positioned the stimuli, interacted in controlling responding, but, as with the other measures, the interactions differed among the birds. Thus, a ranking of the functions by stimulus probability for magnitude or direction of rate change from baseline would not be uniform across the birds, nor are the angular positions of the rate maxima and minima similar among the subjects.

All of the functional relationships have been presented with the intercycle phase angle as the independent variable and stimulus probability as the parameter. This arrangement was chosen because it imposes order on the data: for responding in the presence of S^N, the various functions appear as a family of curves whose generic form is related to phase angle in a way that is both simple and similar among subjects. Nevertheless, despite the generality implied by

Fig. 13. Change in the "net" response rate relative to baseline. The rates shown in Fig. 12 have been combined in the ratio described in pages 73-74. The stimulus probabilities are coded as:

symbol	*p*
○	1.00
⊙	0.80
⦿	0.40
◉	0.20
●	0.10


"NET" RATE RELATIVE TO BASELINE — ON / ON + OFF
0·70
0·60
0·50
0·40
0·30
P1
P2
P3
P4
0
0·4π
0·8π
1·2π
1·6π
PHASE ANGLE (Φ_{N-R}) — IN RADIANS

expressing the relative position of the two cycles in terms of phase angle, the form of these functions should not be taken as absolute. The S^N response rates were maximal at an angle of 0.2π radians because the corresponding intercycle time equalled the duration of S^N. The choice of a different duration for either the cycle length or for S^N would alter the temporal relationship between a particular phase angle and the availability of S^R relative to S^N, and it was this relationship that determined the behavioral functions.

C. Concluding remarks

The t-system as originally proposed (Schoenfeld, Cumming, and Hearst, 1956) may be regarded as a "miniature system." Two irreducible independent variables were identified, and from them emerged the intrinsic parameters T, $\overline{T}$, and p. Given the temporal nature of these parameters, the t-system could be expected to incorporate various features of interval schedules, and of course it did so. In addition, the same temporal parameters made contact with and revealed continuities among other phenomena that had been previously treated as unrelated or fundamentally different.

The extension of random-interval schedules to the concurrent programming of multiple events is also, to some degree, a "miniature system." The parameters of the model are indigenous to temporally defined schedules, yet the procedure of varying the correlation between two stimuli resembles features of other experiments in which an added stimulus was paired with reinforcements. While some of the interrelationships have been discussed in the literature, others have not.

For example, the paradigm in the present work derives, in part, from a set of experiments recently reported by Farmer and Schoenfeld which introduced the concept of "the intruding stimulus." Farmer and Schoenfeld maintained responding on a 60-second fixed-interval schedule of reinforcement and presented an S^N in one-tenth of each interval. The position of the added stimulus within the fixed interval was the independent variable. In one study (Farmer and Schoenfeld, 1966a) the intrusion of S^N was response-produced, and in another (Farmer and Schoenfeld, 1966b) S^N was presented independently of the animal's behavior. The results in both cases were substantially the same. When S^N was located in the last, or next to the last, tenth of the interreinforcement interval, responding before S^N was reduced relative to the baseline but, for three of the four birds, was locally increased during (and following) S^N. When the interval separating S^N and S^R was increased, the response rate preceding S^N was the same as or just slightly higher than the nearly zero rate obtained in the same portion of the baseline fixed-interval schedule; during S^N, responding was both locally and relatively reduced, but it increased across the remainder of the interval.

Because they used a fixed-interval schedule as the basis of their procedure, Farmer and Schoenfeld were able to demonstrate separately the behavioral changes preceding, accompanying, and following the intrusion of S^N. The fixed-interval arrangement is a special case within the present model: the periodic appearance of S^N and S^R, the unitary conditional probability of the one given the other, and the constant S^N-S^R interval all arise from setting the stimulus probabilities at 1.00. In recasting Farmer and Schoenfeld's experiments within the t-system, the intruding stimulus paradigm has been generalized. Through temporal variables it is possible to evaluate the effects of S^N intrusion on various rates and temporal patterns of responding, at various frequencies of stimulation by both S^N and S^R, and at various conditional relations between the two stimuli. In exchange for this parametric utility, however, the present extension necessarily sacrificed the separate visibilities of antecedent, concurrent, and subsequent effects of S^N because the sequence of the stimuli was not constant.

One of the behavioral effects of S^N made visible by Farmer and Schoenfeld's procedure was that of conditioned reinforcement. The earliest demonstrations of conditioned reinforcement had required a two-step procedure. In the initial establishing stage, a neutral stimulus was paired with an unconditioned reinforcer. Then, in the testing stage, the neutral stimulus was used alone as a response-produced effect to either condition a new response or retard the extinction of one that had been previously conditioned. The conditioned reinforcing power of S^N was measured by the increase in the number of responses that had been made during a preliminary operant level determination or by a control group for whom S^N and S^R had never been paired (for reviews of the methodology and its findings see Myers, 1958, and Wike, 1966).

Several variables emerged as critical in establishing S^N as a conditioned reinforcer. One is the S^N-S^R interval used during the pairing stage. If the interval is negative so that S^N appears after the start of S^R, S^N will not increase the number of responses made in the subsequent extinction test period (Schoenfeld, Antonitis, and Bersh, 1950). But if the interval is positive and the onset of

S^N precedes the onset of S^R during the pairing stage, the subsequently measured conditioned reinforcing power of S^N is maximum for short intervals and decreases as a function of the S^N-S^R interval. This temporal gradient holds whether, during the pairing stage, S^N was continuous throughout the interval (Bersh, 1951) or had appeared only briefly at the start of the interval (W. O. Jenkins, 1950).

Another important variable of the establishing operation is the number of S^N-S^R pairings. Several studies (e.g., Bersh, 1951; Hall, 1951; Miles, 1956) have shown that the increment in responding during the testing period is an increasing, negatively accelerated function of the number of prior paired presentations. Additional variables are involved in the scheduling of S^N, both during the establishing and the testing stages. When only a percentage of S^Ns is followed by S^Rs, and when only some responses are subsequently allowed to produce S^N, the temporal patterning of responding conforms to the schedule of S^N presentation, and the intermittency makes the conditioned reinforcer more "durable" (Stevenson and Reese, 1962; Zimmerman, 1957, 1969).

A consideration of the variables in the present study suggests that some of the conditions for establishing S^N as a conditioned reinforcer were operative in this experiment. For example, the phase difference between T_N and T_R generated a unit of time that was a fixed S^N-S^R interval when p was 1.00 and a modular S^N-S^R interval when p was less than 1.00. In addition to its role in modulating the S^N-S^R interval, the probability variable also controlled the intermittency of S^N and S^R (i.e., the schedule of stimulus intrusions) and the number of S^N-S^R pairings. Furthermore, the present procedure contained features common to the testing procedures for conditioned reinforcement in that, first, the presentation of S^N was response-produced, and, second, the context in which S^N appeared more closely approximated experimental extinction as the probability of reinforcement decreased. Given this identification of the independent variables, it is possible to interpret the response rate increases relative to the baseline as showing the effects of conditioned reinforcement.

It is also possible to interpret the same data as demonstrating the effects of a stimulus discrimination. It was shown that, depending on the values of the phase and probability variables, the added stimulus in this study functioned as a cue for responding or not responding. Since it was within the context of discrimination paradigms that the present model was developed, the discriminative function of S^N is not unexpected. What may be unexpected in light of contemporary definitions of stimulus functions is (a) the gradation of responding across the range of phase differences and (b) the absence of a monotonic relationship between responding during S^N and stimulus probability.

Consider the rate of responding during S^N in the fixed-interval component. When the phase angle was 0.2π radians, the schedules resembled Dinsmoor's (1951) procedure for measuring the effects of the positive stimulus (S^D) during discrimination training. His experiment repeated a three-minute cycle consisting of two minutes of S^Δ followed by one minute of S^D; the first response after three minutes terminated S^D and produced a reinforcement. By the end of training, the average rate during the third minute of the cycle was approximately three times higher than it was for a control group, and the percentage of responses per cycle occurring in S^D had increased from 33% to about 70%. Dinsmoor (1951, p. 361) concluded that "periodic reinforcement in the presence of an arbitrary stimulus, coupled with nonreinforcement in its absence, is a suitable procedure for the establishment of a discrimination." (One procedural difference between Dinsmoor's experiment and the present one is the role of response dependency in controlling S^N. The model presented here allows for the various options, but Farmer and Schoenfeld (1966a) have shown that the response dependency does not significantly change the performance in the presence of S^N.)

But what of the function of S^N at other positions in the fixed interval? For those who define S^Δ as a stimulus in whose presence responding is not reinforced, the neutral stimulus must be viewed as an S^Δ at all phase angles except the one of contiguity with S^R. However, the fixed-interval functions in Fig. 8 show that the direction and magnitude of the change in response rate in the presence of the added stimulus varied continuously with the intercycle time difference.

It may be noted that because the S^N response rates were measured over equal intervals of time in which no reinforcements intervened, the procedure meets H. M. Jenkin's (1965) requirements for an unconfounded measure of stimulus control during discrimination training. Jenkins argues that even if the reinforcement densities used during the periods of positive and negative stimuli do not produce a performance differential (i.e., a discrimination based on the reinforcement density), it is possible that, when the positive and negative stimuli are superimposed, the interaction of the schedules with the stimuli will introduce a bias on the tendencies to respond to the stimuli. This bias would confound the measures of stimulus control (Jenkins, 1965, p. 367). The rationale of the present study holds that the interaction of the added stimulus with the reinforcement schedule is what produces the differential responding usually identified as a stimulus discrimination. It was one aim of the present experiment to measure the extent of that response differential as a function of the variables regulating the interaction.

The present work brought in as an additional variable $p(S^R|S^N)$, the conditional probability of reinforcement within a cycle that contained the neutral stimulus. A conditional probability of zero means no reinforcement if S^N has appeared (correlation of S^N with the absence of reinforcement); a conditional probability of unity means imminent reinforcement (correlation of S^N with the presence of reinforcement); and, a conditional probability of 0.50 represents a "relatively uncorrelated" situation, since within that cycle the probabilities of presence and absence of reinforcement are equal. From this viewpoint, S^N should have functioned as a discriminative stimulus for responding when it was presented at the probability of 1.00, and as a discriminative stimulus for not-responding when it was presented at the probability of 0.10. At the probability of 0.40, S^N should have produced little change from the baseline rate. Yet the data show that stimulus probability <u>per</u> <u>se</u> had little or no effect across its range when the phase angle was small and that S^N response rates were higher when p was 0.10 than when p was 0.20. This failure of stimulus probability to emerge as a powerful determinant in the present situation is consistent with Eckerman's (1969) observation that, in a successive discrimination paradigm, the interspersion of positive stimulus presentations not ending in a reinforcement does not detract from the effectiveness of those presentations that do.

The absence of a monotonic relationship between stimulus probability and the rate of responding during S^N offers a challenge to the "stimulus selection" theory of attention recently offered by Sutherland (1964a,b) and Mackintosh (1965). These theorists hold that discrimination learning is a two-stage process, and the first step involves learning which features of the stimulus input are the relevant ones. Sutherland (1959) had proposed a stimulus-analysing mechanism that must be "switched in" if the appropriate dimensions of the cue are to acquire control over responding. The switching in of a particular analyser is determined by "differences in its outputs being consistently associated with the subsequent occurence of events of importance to the animal" (Sutherland, 1964a, p. 57). The appeal of this inferred mechanism has led to the widely held position that "discrimination learning can then be viewed as a process by which a subject's behavior comes under the control of those stimulus elements in the discriminanda which are correlated with the presence versus the absence of reinforcement, as compared to those which are relatively uncorrelated with reinforcement" (Wagner, 1969, p. 83). However, the relative rate measures in the present experiment showed that S^N exercised stimulus control regardless of its correlation with reinforcement.

Although it is possible to interpret S^N as a conditioned reinforcer and as a discriminative stimulus, one may also regard S^N as an irrelevant stimulus: reinforcement was never conditional upon responding in the presence of S^N. In fact, the present experiment shares features with a procedure used by Morse and Skinner (1957) to produce what they called <u>sensory superstition</u>. They maintained responding with a variable-interval schedule whose mean interreinforcement interval was 60 seconds. In addition, once each experimental hour, they intruded a neutral stimulus for four minutes independently of the program of reinforcement availabilities. Over the course of the experiment, the neutral stimulus sometimes coincided with a high density of reinforcement and sometimes coincided with a low density of reinforcement. In the former case, the rate of responding was subsequently seen to increase during S^N, and Morse and Skinner named the increase a <u>positive sensory superstition</u>. When reinforcements did not become available during S^N, the rate during subsequent intrusions decreased, and Morse and Skinner called this effect a <u>negative sensory superstition</u>. In their procedure, a response pattern was produced in which one kind of S^N effect actually gave way to the other, but the transitions were not under the experimenter's control. In addition to the lack of behavioral stability observed in their procedure, Morse and Skinner noted that the duration of the incidental stimulus, the schedule of reinforcement, and the performance generated by the schedule are all relevant in determining the frequency of adventitious reinforcement. In a way, the present experiment was an investigation of some of those parameters. The behavioral effects obtained here were stable, however, because the interrelationships between the stimuli were controlled.

The concept of contingency is too broad to be examined here, but it may be noted that the analysis in many experiments involving the concurrent scheduling of multiple stimuli has assumed that mutually independent programs preclude the existence of a contingency.

Thus, Rescorla (1967) has proposed that a random relationship between CS and UCS is the appropriate control for the contingency present in Pavlovian conditioning. Following Rescorla's argument, Davis and MacIntire (1969) arranged a "no-contingency" control procedure of pairing a tone (CS) and an electric shock (UCS) which were both superimposed on a baseline variable-interval schedule of reinforcement (the conditioned suppression procedure). They claimed that CS and UCS may have been occasionally paired, but "such a pairing occurs strictly under a random distribution of events and predicts nothing about the order of events on subsequent trials"(Davis and MacIntire, 1969, p. 633). Their procedures consisted of dividing the experimental session into equal time periods and using the entries of a random-number table to locate the particular time periods in which CS and UCS would appear; for the "no-contingency" variant, different parts of the random-number table were used to schedule CS and UCS.

Two comments may be made about this experimental operation. First, it is a technique for generating concurrent random-interval schedules, and, as the discussion of the present experimental variables indicated, there are certain predictable interrelationships between the CS and the UCS that are determined by the randomization process. Second, it has been accepted for some time that contingency means nothing more than a temporal proximity of events (Skinner, 1948). The experimenter may <u>schedule</u> concurrent programs independently, but the subject necessarily <u>samples</u> the events in a sequence; in this sense it is not possible to arrange multiple presentations of different events without some particular contingency arising. The present experiment shows, as a case in point, that over a wide range of interstimulus intervals and conditional probabilities, the interpolation of a neutral stimulus into a concurrent but independent schedule of reinforcements alters the baseline performance.

It has been fashionable for experimenters to proliferate the number of ways in which a stimulus may be presented to a subject, and to assign arbitrarily a specialized function for each method of presentation. This practice often obscures the parameters of the experimental operation, as well as the dependence of a particular effect on the particular values of those parameters. The designation "intruded stimulus" may serve as a useful alternative, not only because it is the most global term, but also because the attendant physical operations are themselves unequivocable.

IV. Summary

A generalized paradigm of stimulus correlations was developed from the experimental parameters encountered in a temporally defined system of reinforcement schedules. The paradigm is organized around the random-interval schedule, in which the first response in each recurrence of an invariant time period is reinforced at probability *p*.

In this study, a pair of random-interval schedules was concurrently programmed for a single operandum. One schedule controlled the availability of the reinforcing stimulus, S^R; the other controlled the availability of a neutral stimulus, S^N. The length of the two time cycles was set at 30 seconds, and stimulus probabilities of 1.00, 0.80, 0.40, 0.20, and 0.10 were used to make five pairs of schedules. For a given pair of schedules, the S^N and S^R probabilities were always equal but independently generated; as a consequence, the value of *p* was also the conditional probability that, given the occurrence of one stimulus, the other stimulus would appear within the same cycle.

The phase relationship between the two cycles was used as a second independent variable to place the start of the S^R cycle relative to the onset of the S^N cycle. With the fixed periods of 30 seconds, phase angles of 0, 0.2π, 0.4π, 0.8π,and 1.6π radians produced S^N-S^R intercycle times of 0, 3, 6, 12, and 24 seconds, respectively.

The interaction of the two variables, phase difference and stimulus probability, positioned one stimulus relative to the other, and each of the 25 combinations was sampled by four pigeons as follows. Stimulus probability was encoded in a five-component multiple schedule whose discriminative stimuli (digits projected on the pecking-key operandum) were associated with particular pairs of random-interval schedules. A bird worked on all five of the paired schedules daily, and a given component was in effect until 10 S^Ns (three-second changes in key color) and 10 S^Rs (three-second accesses to grain) were delivered. The presentation order of the schedules was changed daily so as to be fully counterbalanced over each block of 10 days. The phase differences were arranged systematically: two birds went through an increasing series, and two birds went through a decreasing series. A phase angle was in effect for 40 consecutive sessions.

The dependent variables consisted of the number of responses per component, the duration of the component (minus S^R time), and frequency distributions of the post-S^R pauses in responding, the numbers of responses during S^N, and the post-S^N pauses in responding. Various response rate measures were obtained from these data, and comparisons were made with analagous data collected during an earlier baseline stage in which only S^R was delivered.

Although the random-interval baselines were obtained in a multiple schedule, the functions relating response rate to S^R probability were similar to those in the literature obtained through serial exposure to the different values of the schedule's parameters. The frequency distributions of the post-S^R pause were bi-modal at all probabilities of reinforcement.

The effect of interpolating S^N into this baseline was dependent chiefly on the phase relationship between the two cycles. When the S^R cycle lagged by just the duration of S^N (0.2π radians of angular separation), responding increased during and immediately following the S^N intrusion. At the maximum separation of the cycles (0 radians), responding decreased during and immediately following the S^N intrusion. The effects of the probability variable were complex, less pronounced, and less consistent among the subjects. The calculation of a response rate over a period that included neither the S^R and S^N presentation nor the latency of the first response following the termination of either stimulus indicated that the addition of S^N also changed the baseline performance at points in time not immediately contiguous with occurrences of either stimulus.

The relationship of this paradigm to some other studies in the literature on stimulus correlations was discussed. It was suggested that the discriminative function, the conditioned reinforcing function, and the irrelevant cue function of a stimulus are all special cases of varying the correlation of that stimulus with a reinforcer. The impossibility of concurrently scheduling two stimuli without some interrelationship existing between them was noted, and the relevance of that fact to certain theoretical issues was suggested.

Footnotes

1. This point is elaborated in the section on probability (pp. 6-11) and in the apparatus section under Method (pp. 21-23).

2. These extensions are the subject of a book currently in preparation by W. N. Schoenfeld and B. K. Cole (Eds.) *Stimulus schedules: the t-τ systems of behavior theory*. To be published by Appleton-Century Crofts, Inc.

3. Feller (1957, p. 253) gives the mean as q/p and the variance as q/p^2. In Feller's derivation, the distribution is obtained by evaluating pq^k, where k is the number of failures preceding the first success. Thus, success occurs at the k+1, or Nth, trial, and $k = N-1$. Because the subtraction of a constant (here, one trial) from all values of a variable decreases the expected value of the variable by the value of that constant, the numerical effect of q in the numerator of the mean makes $E(k) = E(N)-1$. If, for example, p is 0.01, Feller's derivation gives a mean of 99 rather than 100. This difference parallels the earlier practice in reinforcement theory of calling a fixed ratio 100 schedule a ratio of 99:1. The two expressions for the variance are identical, of course, because the subtraction of a constant from all values of a variable does not affect its variance.

4. An analysis of interstimulus times (IS^XT) in terms of successive pairs of stimuli requires frequency distributions for the durations of the intervals in each of nine dyads: S^N-S^N; S^R-S^R;

S^N-S^R; S^R-S^N; S^N-S^N&S^R; S^R-S^N&S^R; S^N&S^R-S^N; S^N&S^R-S^R; S^N&S^R-S^N&S^R.
The distribution of events among these nine exhaustive categories varies with the values of both Φ and p.

5. Departure from the model are introduced, as said previously, by the variability of IRTs. One can exactly predict the interstimulus times to the same level of precision that he can specify the response rate. Thus, the qualification "if the animal makes at least one response in every cycle" allows one to predict IS^RTs to the nearest T seconds. If IRTs were uniformly one millisecond, one could predict IS^RTs to the nearest millisecond. The effect of IRT variability on a frequency distribution of interstimulus times is to disperse slightly the discrete frequencies into modes at integral multiples of T seconds. A similar dispersion holds for the distribution of S^N-S^R (and all other dyadic) intervals.

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