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The Highest Local Density of Reinforcement Controls Overall Post-Reinforcement Pause Duration on Ratio Schedules

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THE HIGHEST LOCAL DENSITY OF REINFORCEMENT CONTROLS OVERALL POST-REINFORCEMENT PAUSE DURATION ON RATIO SCHEDULES

by

Elliott J. Bonem

A dissertation submitted in partial fulfillment
of the requirements for the degree

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Elliott Bonem

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ABSTRACT

The Highest Local Density of Reinforcement Controls Overall Post-Reinforcement Pause Duration on Ratio Schedules

by

Elliott J. Bonem, Doctor of Philosophy
Utah State University, 1988

Major Professor: Dr. Edward K. Crossman
Department: Psychology

A series of experiments were conducted with pigeons to investigate the variables responsible for differential post-reinforcement pause (PRP) durations found on ratio schedules. In Experiment I, behavior on fixed-ratio (FR) and variable-ratio (VR) schedules were compared to behavior evoked by two interpolated schedules. The addition of a single FR 1 component to the FR 50 baseline schedule reduced the overall PRP to a duration comparable to that found on the VR 50 schedule. The addition of both an FR 1 and an FR 215 component to an FR 50 baseline reduced PRP and IRT durations below those on a VR 50 schedule.

Experiments II and III were designed to isolate the conditions under which the smallest ratio component exerts predominant control over PRP duration. The results of Experiment II demonstrated that a local increase in reinforcement density was a necessary, but not sufficient condition for reducing median PRP duration. That is, exposure to a response-independent increase in reinforcement density attenuated, but did not eliminate the reduction in median PRP duration associated with the interpolated FR 1 component. The results of Experiment III demonstrated that neither random session location of the FR 1 component nor unsignaled presentation of the FR 1 component were necessary conditions for reducing the duration of the PRP. That is, a brief, response-dependent increase in reinforcement density was a sufficient condition for reducing PRP duration given a subject free from historical exposure to response-independent reinforcement.

It was concluded that the difference in PRP duration produced by two, comparably-sized, fixed- and variable-ratio schedules is a function of the size of the smallest ratio component present in the reinforcment schedule. More generally, the highest local density of reinforcement controls the overall duration of the PRP on a response-dependent, ratio schedule.

(224 pages)

CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

As Morse (1966) astutely observed: "A simple schedule is one that is simple to specify and program rather than one that has a simple relation to behavior" (p. 77). As one of the four basic reinforcement schedules, the fixed-ratio schedule (FR) has been investigated in numerous experiments since it was first described by Skinner (1938). Yet, despite nearly fifty years of study, researchers are still perplexed by the pattern of behavior evoked by FR schedules.

One particularly puzzling aspect of FR performance is the pause in responding which follows reinforcement delivery. Because the rate of reinforcer delivery on FR schedules is directly dependent upon the rate of response emission, pausing following reinforcer delivery has the effect of reducing the rate of reinforcer presentation below the maximum technically possible. The substantial pause duration on FR schedules appears to violate the notion that higher rates of reinforcer presentation are preferred to lower rates (Staddon, 1979). Clearly, the problem is to explain why substantial post-reinforcement pauses (PRPs) occur on FR schedules. Appeals to physiological processes (e.g., aftereffects of eating or fatigue from the response count just completed) to explain PRP durations are not helpful because substantial PRP durations are not found on comparably-sized, variable-ratio (VR) schedules (Ferster & Skinner, 1957). Appeals to discriminative processes are also inadequate. Ferster and Skinner's (1957) suggestion that a reinforcer delivery sets the occasion for not responding fails to explain why a response terminating the PRP would ever be emitted. Shull's (1979) maximization account of PRP duration (during the PRP, animals engage in behavior controlled by reinforcers outside the response class required for delivery of the programmed reinforcer) cannot explain why reinforcers (not programmed by the experimenter) do not control behavior on comparably-sized VR schedules. Harzem and Harzem's (1981) suggestion that conditioned and unconditioned inhibitory effects of a reinforcing stimulus control PRP duration also fails to explain why substantial PRP durations are not found on VR schedules.

Another approach to explain why substantial PRP durations occur on FR schedules is to compare the structure of the FR schedule to other comparably sized ratio schedules which do not evoke a substantial PRP duration. The obvious structural difference between FR schedules and other ratio schedules involves the lack of variability of ratio component size. On an FR schedule, the ratio response requirement across a session remains unchanged, whereas on other ratio schedules (i.e., random ratio or variable ratio schedules), the size of the ratio requirement varies across a session. If, as suggested, PRP duration is dependent upon the size and range of ratio components during a session, one issue is to identify what aspect of a distribution of ratio components controls the duration of the PRP.

A mixed FR schedule contains aspects of both FR and VR schedules in that a minimum number of different ratio components are presented within a session. Studies of mixed schedules have determined that when ratio components are randomly presented, PRP duration is controlled "by the response requirement of the small component" (Alferink & Crossman, 1978, p. 144). However, PRP durations on variable ratio schedules (which can be conceptualized as a mixed schedule with many different ratio components) are not solely controlled by the smallest ratio requirement present in a session. This is because PRP duration on VR schedules (with an FR 1 component present in each VR schedule) increases as the mean size of the VR schedule is increased (Priddle-Higson, Lowe, & Harzem, 1976). Thus, although the smallest ratio component in a session does affect PRP duration, other variables are also involved in controlling PRP duration. These other variables have not yet been identified.

The following survey of the literature summarizes the patterns of behavior observed on fixed-, mixed-, interpolated-, variable-, and random-ratio reinforcement schedules. Independent variables found to jointly influence both the pause after reinforcement and response rate are discussed for each ratio schedule. Experiments directly comparing behavior on fixed and variable ratio schedules are discussed next, followed by a presentation of the experiments that were conducted.

CHAPTER II

SURVEY OF THE RELEVANT LITERATURE

A schedule of reinforcement is a rule specifying the conditions under which a particular reinforcing stimulus will be presented to an organism (Schoenfeld, 1970). Exposing an organism to a particular rule, or contingency of reinforcement, results in the emission of a characteristic pattern of responding which is systematic and orderly. Procedural manipulations of the contingencies of reinforcement often result in changes in response patterning (Ferster & Skinner, 1957). The analysis of systematic manipulations of these contingencies of reinforcement constitutes the study of schedules of reinforcement.

Dependent Variables

Skinner (1938) proposed that rate of response serve as the primary dependent variable for investigating schedule maintained behavior. Over the past two decades, additional dependent variables have come to supplement response rate as measures of schedule performance. These additional dependent variables, measure behavior with more refinement and permit analysis of more fundamental units of behavior (Peele, Casey, & Silverberg, 1984). Molecular measures of schedule performance permit analysis of the factors shaping response rate itself (either the time duration between consecutive responses or the physical characteristics constituting the topography of the response).

Nearly all dependent variables utilized in studies of ratio reinforcement schedules include a temporal parameter (Zeiler, 1977). Ratio behavior is often described in terms of the post-reinforcement pause (PRP), the interresponse-time (IRT), and the interreinforcement-interval (IRI). For example, on a ratio schedule, a PRP is evoked following reinforcement. The PRP ends when a response is emitted and is followed by periods of time (IRTs) which occur between subsequent responses. The final IRT (or response) in a ratio is followed by a mechanical event (e.g., food presentation), thereby ending the IRI. These three temporal variables (PRP, IRT, and IRI) are the primary dependent variables from which additional measures (e.g., sequential dependencies, IRTs per opportunity) are derived.

Ratio Schedules

A ratio schedule is in effect when reinforcement delivery is dependent only on the number of emitted responses. Specifically, a change in exteroceptive stimulus conditions (i.e., presentation of a reinforcing stimulus) occurs whenever the last, of a specified number of responses is emitted. The classification of ratio schedules is based on the degree to which signaled response requirements vary from ratio to ratio component. When the components are constant (no ratio to ratio variation), a fixed-ratio (FR) schedule is in effect. When the response requirement between reinforcers varies from component to component (e.g., the value of the schedule is the average of a number of different ratios), a variable-ratio (VR) schedule is in effect. When the ratio components consist or only two or three different ratio sizes, a mixed-ratio (*mix*) schedule is in effect. When a single novel response requirement is inserted into a schedule comprised of constant response requirements between reinforcers, an interpolated (*inter*) schedule is in effect. In fixed, mixed, variable, random, and interpolated reinforcement schedules, there is a perfectly positive correlation between frequency of response emission and frequency of reinforcer presentation. Under any given ratio schedule, the overall density of reinforcer presentations increase as responses are emitted more frequently.

Fixed Ratio Performance

Descriptions of performance generated by FR reinforcement schedules appear in a variety of secondary sources (e.g., Keller & Schoenfeld, 1950; Nevin, 1973; Zeiler, 1977). These secondary sources, along with cumulative records presented in primary sources (e.g., Ferster & Skinner, 1957) indicate that behavior emitted on moderately valued FR schedules is typified by a pause after reinforcement followed by a burst of high-rate responding which continues until reinforcement delivery. The PRP and rate from the first response through the last response in a ratio are, by common practice, separately analyzed (Powell, 1970). This practice is empirically based since various independent variables differentially affect PRPs and IRTs (Shull, 1979).

PRP duration on FR. A within-session analysis of PRP durations on basic FR schedules was first presented by Powell (1968). Powell found a great deal of variability in PRP duration from one reinforcer to the next at FR sizes ranging from FR 50 to FR 120. Although the large interval size used restricts the detail of the frequency distribution, visual analysis revealed that the variability of PRP durations increased as FR size increased. Later studies confirmed this relation by demonstrating that the standard deviation of PRP durations increases as FR size (Meunier, Starratt, & Sergio, 1979) or IRI (Korber, Cole, & Ramirez, 1981) increases. However, the absolute value of the standard deviation appears to be dependent on the amount of training that precedes the measure of PRP variability. While the overall relation between FR size and PRP variability is maintained with extended training, the standard deviation of PRPs decreases substantially with extended exposure to a particular FR schedule (Korber et al., 1981).

Manipulations that affect PRP duration. Various independent variables can affect PRP durations. Mean and median PRP duration have been found to lengthen as either the size of the FR requirement is increased (Crossman, Heaps, Nunes, & Alferink, 1974; Felton & Lyon, 1966; Ferster & Skinner, 1957; Powell, 1968; Skinner, 1938), or the duration of the interreinforcement interval (IRI) is lengthened (Killeen, 1969; Neuringer & Schneider, 1968). Mean PRP duration has been found to decrease when the magnitude of reinforcement is increased (Inman & Cheney, 1974; Meunier & Starratt, 1979; Powell, 1969), but this effect reverses when magnitude is varied within a session (Harzem & Harzem, 1981; Lowe, Davey, & Harzem, 1974).

Under some circumstances, manipulations of deprivation level have been found to lengthen PRP duration. Rapidly satiating a deprived organism lengthens PRP duration (Mallott, 1966; Sidman & Stebbins, 1954), whereas gradually decreasing the deprivation level of an organism (e.g., slowly returning a pigeon to ad lib weight in the course of an experiment) has no effect on PRP duration (Ferster & Skinner, 1957).

PRP and delay of reinforcement. A number of studies have inserted periods of delay into FR schedules to determine whether selective lengthening of the IRI affects PRP duration. These studies have found that both the location and relative duration of the delay, affect the duration of the PRP.

Two typical delay procedures used to study rat and pigeon behavior are timeout (removing the discriminative stimulus) and blackout (removing all visual stimuli from the chamber). Utilizing a within-session design, Ferster and Skinner (1957) exposed pigeons to an FR 50 schedule in which a 60 s blackout followed 50% of the reinforcement. Although this condition was conducted for only four sessions, the duration of the pause following a blackout was consistently shorter than the pause duration following reinforcement.

Mazur and Hyslop (1982) exposed pigeons to three separate FR schedules (50, 100, 150). During each condition, a 30 s timeout (or intertrial interval) followed reinforcement on a random 50% of the ratio components. In general, the median duration of a pause immediately following a reinforcer delivery was longer than the duration of a pause following a timeout. As FR size was increased, the absolute difference between the median duration post-timeout pause and post-reinforcement pause also increased. Mazur and Hyslop suggested that the observation of behavioral contrast (the shorter PRP duration following blackout ratios) primarily operates on the pause immediately following the blackout.

Richards and Blackman (1981) exposed pigeons to an FR 40 schedule and manipulated blackout duration following a reinforcer delivery across conditions. Whereas Ferster and

Skinner (1957) found shorter pauses following 60 s blackouts, Richards and Blackman found longer pauses following identically located 60 s blackouts. However, when the duration of the blackout was reduced to 30 s (as in Mazur & Hyslop, 1982), pauses following blackouts (PBPs) were shorter in duration than pauses following reinforcer deliveries (PRPs). When blackout duration following reinforcement was 10 s, PRP and PBP durations were indistinguishable.

In summary, the effect of inserting a delay between the reinforcer and the first response is dependent on the relative duration of the delay. With the exception of the 60 s delay condition studied by Richards and Blackman (1981), pauses following the delay were shorter than pauses following reinforcer deliveries. Although delay appears primarily to affect the pause immediately following the delay, little agreement exists concerning which behavioral principle operates to shorten pauses (Mazur & Hyslop, 1982).

Varying the duration of a timeout in the middle of an FR also affects PRP duration. Barowsky and Mintz (1978) exposed pigeons to a three component multiple FR 50 schedule in which two components contained timeouts following the thirtieth response. One component contained a 2.5 s timeout, a second component contained a 10 s timeout, while a third component had no timeout. In general, as the duration of the timeout was increased, the duration of the

PRP also increased. When plotted in log coordinates, the relation between blackout duration and PRP duration was nearly linear.

Several studies have inserted a delay between the last response in a ratio and reinforcer delivery. These studies have generally found a positive relation between delay duration and PRP duration. Morgan (1972) exposed rats to an FR 9 schedule and examined the influence of 0.75 s, 3 s, and 12 s delays following ratio completion. Results indicated that PRP duration increased as delay duration increased. Similarily, Meunier and Ryman (1974) reported that median PRP duration increased systematically as different duration delays (0 s, 5 s, and 10 s) were inserted between the last response on FR 45 and pellet delivery. Topping, Johnson, and McGlynn (1973) examined PRP durations of pigeons as a function both of FR size (10, 75, or 150) and delay duration (0 to 180 s) between the last response and reinforcer delivery. When PRP durations on the three FR schedules were compared at each of six delay durations, it was found that as either delay duration or FR size increased, the mean of the median PRPs also increased.

The importance of delay location in controlling PRP duration was demonstrated (within sessions) in a study by Barowsky and Mintz (1975). Each pigeon was exposed to a three component multiple FR 60 schedule in which one component contained a 10 s timeout (darkening of the response key) following the tenth response (early), a second component contained an identical timeout following the fiftieth response (late), and a third component contained no timeout component. The median PRP duration was found to be shortest with no timeout, intermediate with the timeout early in the ratio, and longest with the timeout late in the ratio. Irrespective of duration, the later in a ratio a timeout was inserted, the longer the duration of the median PRP which preceded that component.

In summary, it appears that the influence of delay (blackout or timeout) on PRP duration is dependent on a variety of factors. A moderate duration delay presented immediately following a reinforcer either reduces or does not affect overall PRP duration. This same delay duration progressively lengthens PRP duration the closer (temporally or in terms of the number of responses remaining before reinforcer delivery) its location to a reinforcer delivery. Additionally, the longer the relative duration of the inserted delay, the longer the accompanying PRP duration.

IRTs on FR schedules. The interresponse time (IRT) is currently the predominant measure of response strength utilized in the analysis of schedule performance (Gentry, Weiss, & Laties, 1983). In terms of IRTs, the major issues that have been addressed involve describing IRT durations within an FR, across a session, and across experimental conditions. Although a number of studies have addressed these issues, no comprehensive account of FR responding has appeared in the literature (Mazur, 1983).

IRTs within an FR. Analyses of IRT durations within FR schedules have revealed differences in IRT durations as a function of ordinal IRT position. Gott and Weiss (1972) studied the transition from FR 1 to FR 30 in nine pigeons. A within-ratio analysis of IRT durations revealed that following the change to FR 30, the first few ratios were emitted at a high steady rate. Thereafter, this pattern of responding broke down, with long IRTs (IRTs greater than 1 s) appearing at all ordinal positions within the FR 30. Gradually, long IRTs decreased in frequency (without regard to ordinal placement) in the last one-half of the ratio. A stable pattern of IRTs was generally observed after 100, FR 30 components had been completed.

Once responding stabilized at FR 30, Gott and Weiss (1972) observed a number of systematic within-session relationships. The duration of IRTs in the second half of the FR 30 tended to be shorter than the duration of IRTs in the first half of the ratio. Additionally, IRTs tended to progressively shorten from the beginning of the FR 30 to the middle one-third of the ratio. Finally, long IRTs were most frequent early in the FR 30 (ordinal IRT positions 1 to 5), less frequent in the remainder of the first 14 IRTs, and were virtually never present during the last half of the ratio (ordinal IRT positions 16 to 30). These findings suggest that although not describable by a simple rule, systematic patterns of IRTs do occur within FR schedules.

Mazur and Hyslop (1982) similarly described performance on FR 50, FR 100, and FR 150. In all FR schedules studied, IRTs shortened in duration through the first 20 to 40 percent of the ratio as long and intermediate duration IRTs decreased in frequency. During the remainder of the FR, short IRT durations were generally maintained until reinforcer presentation. Capehart, Eckerman, Guilkey, and Shull (1980) also reported that running response rate (the PRP was excluded from the calculation of response rate) from the first to fifth responses of an FR was slower than the running response rate from the fifth response to reinforcement delivery.

The IRT patterns described above do not, however, accurately describe much of FR behavior. Mazur and Hyslop (1982) note that the IRT pattern that received focus in their publication was characteristic of only some of the ratios observed within a session. Under other ratios in a session, "There was an abrupt transition from a long PRP to rapid responding" (p. 149). Additionally, other researchers have reported an increase in IRT duration towards the end of each ratio on small sized FRs (Crossman, Trapp, Bonem, & Bonem, 1985) and on modified FR schedules (Davison, 1969b; Platt & Senkowski, 1970). For these reasons, the generality of any description of FR performance must take into account

FR size.

IRT patterns across a session. Gott and Weiss (1972) analyzed the FR 30 performance of nine pigeons to determine whether IRT durations change in frequency as a session progresses. Fifteen years earlier, Ferster and Skinner (1957) had observed (from cumulative records) that responding appeared to be maintained at a constant rate throughout a session. Apparently concurring with Ferster and Skinner (1957), Gott and Weiss (1972) found no linear relationship when mean IRTs for each FR component were analyzed by ordinal position within the ratio. However, when IRTs emitted in halves of the session were compared, IRTs near the end of each ratio were found to be shorter in the second session half than comparable IRTs in the first half of the session. When thirds of the session were compared, the only significant change was a trend toward shorter values of reinforced IRTs in the middle third of the session. This analysis suggests that IRTs vary in duration as a function of ordinal position in a session. The implications of this second-order deviation (Skinner, 1938) have not been explored.

IRT duration and FR size. A number of studies have found a relation between the local rate of responding and FR size. Boren (1961) and Barofsky and Hurwitz (1968) found that as the FR requirement increased (e.g., from FR 10 to FR 80), the local rate of responding (excluding the PRP and reinforcement time) also increased until a critical ratio was reached. Following the critical ratio, further increases in FR size were accompanied by decreases in local response rate. Although this relation between response rate and FR size is often observed, many reversals in this relation occur in the course of an experiment (Felton & Lyon, 1966; Ferster & Skinner, 1957; Powell, 1968).

Mazur and Hyslop (1982) investigated the effects of FR size on IRT durations. Three pigeons were separately exposed to three FR schedules (FR 50, FR 100, and FR 150). Interestingly, IRT distributions were similar across all FR sizes despite the fact that running response rate (measured from the first response in the ratio to reinforcement delivery) decreased as FR size was increased. Analysis of IRT durations revealed that the primary reason running response rate decreased as FR size increased was an increase in the mean duration of IRTs greater than 1 s (long IRTs). The duration, not the frequency of long IRTs increased as FR size increased. Utilizing different FR schedules and rats as subjects, Mazur (1983) also found that the decrease in running response rate observed as FR size increased was "almost entirely the result of different proportions of time spent [in IRT] pausing" (p. 304).

Mixed Fixed-Ratio Performance

In a prototypical mixed schedule of reinforcement, two or more unsignaled component schedules randomly alternate following each reinforcement delivery. When the component schedules are FR schedules, the resulting compound schedule is termed a mixed fixed-ratio schedule (*mix* FR FR). Behavior emitted on a particular *mix* FR FR schedule is dependent upon the regularity with which FR components are presented, the relative difference in ratio size between the small and large ratio components, and the proportion of small to large ratio components present in a session.

Repetitive component alternation on mixed FR FR. When the same sequence of ratio components is repeatedly presented to an organism, the PRP before the small ratio component is shorter in duration than the PRP emitted before the large ratio component. Findley (1962) exposed rats to a complex multiple schedule in which two mixed FR FR FR schedules alternated. Rats were exposed to three ascending FR components in the presence of a red light (FR 25, FR 75, and then FR 225) and three descending FR components in the presence of a green light (FR 225, FR 75, and then FR 25). Findley reported that PRP durations before large ratio components were longer in duration than PRP durations before short ratio components, regardless of the location of a component schedule within the three-component sequence of schedules. Keehn (1965) exposed rats to a *mix* FR 15 FR 45 FR 15 FR 135 schedule and found a similar relation between PRP duration and the size of the following FR. Although both large FR components were preceded by an FR 15 component, the mean PRP duration before the FR 135 component was longer than the mean PRP duration before the FR 45 component.

The relation between PRP duration and upcoming FR component size found on sequentially alternating mixed schedule components is similar to PRP durations emitted on schedules explicitly signaling the presence of different components (i.e., multiple schedules). Crossman (1971) compared the PRP durations of pigeons on mixed schedules to PRP durations on comparably sized multiple schedules. Under both mixed and multiple schedules, the size of one FR component was both increased and decreased while the other component was maintained at FR 10. For both mixed and multiple schedules, increasing the size of the large FR component resulted in an increase in median PRP duration preceding the large component and a decrease in median PRP duration preceding the small (FR 10) component. Although the relation between PRP duration and FR size on mixed and multiple schedules were similar, there were some differences. Under multiple schedules, differential PRP durations were evident after the constant FR component was increased to FR 25 (*mult* FR 10 FR 25), whereas on the mixed-schedule component, PRP durations remained undifferentiated until the FR component was increased to FR 50 (*mix* FR 10 FR 50).

Random component alternation on mixed FR FR. When the

FR components of a mixed schedule alternate randomly after each reinforcer, the behavior observed "suggests a variable-ratio with rather rough grain" (Ferster & Skinner, 1957, p. 583). Ferster and Skinner (1957) exposed pigeons to a mix FR 50 FR 190 schedule in which the FR components randomly alternated following a reinforcer delivery. Under random component alternation, PRP durations were relatively short following both ratio components. Of greater interest, a phenomenon termed priming was observed during some large ratio components. A prime occurred when, following a relatively short duration PRP, a burst of responses approximately equal in number to the size of the small FR was emitted. Assuming a reinforcer was not delivered on the small FR component, a within-ratio pause then occurred (post-prime pause). The duration of the post-prime pause was, according to Ferster and Skinner (1957), related to the size of the large FR component.

From this study, Ferster and Skinner (1957) developed the Mean-Ratio Hypothesis which suggests that on a mixed schedule, mean PRP duration is "appropriate to the mean of the mixed components" (p. 594). That is, the PRP on a mix FR 10 FR 50 should be similar in duration to the mean PRP on an FR 30 schedule. Summarizing, PRP duration on mixed schedules is influenced by the size of an FR component, the proportion of large to small FR components, and regular versus random alternation of schedule components.

Variables controlling priming on mixed FR FR schedules. There is empirical support for the notion that different variables control priming, the post-prime pause, and the PRP. Alferink and Crossman (1978) demonstrated that the duration of the mean PRP in a two component mixed FR schedule is controlled by the smaller FR component, not the mean PRP of the FR components on a mixed FR FR schedule. This conclusion does not support Ferster and Skinner's (1957) Mean-Ratio Hypothesis. Increasing the size of the smaller FR component increased both mean PRP duration and the number of responses emitted in the prime (Alferink & Crossman, 1975), while increasing the size of the larger FR component increased only the duration of the post-prime pause (Alferink & Crossman, 1975). Additionally, Crossman and Silverman (1973) found that increasing the proportion of small to large ratio components decreased the duration of PRPs and increased the frequency of primes. However, the frequency of primes decreased when more than one small ratio was presented for every four large ratios.

Under certain parameters, mixed-schedule performance does resemble performance on a comparably-sized variable-ratio schedule (Ferster & Skinner, 1957). That is, studies which have examined behavior on mixed-schedules have described a number of manipulations which reduce PRP durations (Crossman, 1971) and increase mean response rate (Alferink & Crossman, 1975). This similarity between behavior evoked by variable- and mixed-ratio schedules is observed when the following conditions are present in a mix FR FR schedule: 1) FR components randomly alternate; 2) the proportion of small to large components is at least one small FR for every four large FR components; and 3) the response requirement on the large-sized mix component is at least five times as large as the response requirement on the small-sized mix component (Crossman & Silverman, 1973).

IRTs on mixed FR FR schedules. Analyses of PRP durations and the frequencies and durations of post-prime pauses have tended to dominate the literature on mixed schedules. In contrast, the literature on response rates and IRT durations on mixed FR schedules is quite meager. Ferster and Skinner (1957) interpreted cumulative records of two pigeons exposed to a mix FR 60 FR 360 schedule as indicating little relation between running response rate and the preceding response requirement or the PRP. Crossman (1971) evaluated the influence of ratio size (in the large component of a mix FR FR) on mean response rate and concluded: "Unlike the pause data, these rate data were extremely variable and did not appear to be related to changes in L [the long ratio] in any simple, systematic manner" (p. 542).

An IRT analysis of mixed FR FR performance was presented by Mazur (1983). Rats lever pressed on four, mixed FR FR schedules (2, 18; 4, 36; 8, 72; 16, 144). Ratio components randomly alternated following delivery of a milk reinforcer. Distributions of IRTs were calculated for each rat on the four mixed schedules. Overall, these IRT distributions were similar across mixed schedules, with no tendency for the modal IRT to shift toward longer values as the sizes of the mixed schedule components increased. However, the duration of long IRTs (IRTs greater than 1 s) increased as the response requirements on the mixed schedule were increased.

The durations of IRTs were also analyzed by Mazur (1983) as a function of ordinal position within a mixed component. In general, at all mixed FR FR values, the probability of a long IRT first increased to a maximum about 10 to 20 percent of the way through a ratio (the small ratio component was always 11 percent the size of the large ratio component) and then decreased in probability over the remainder of the ratio. This description is consistent with previous studies (e.g., Alferink & Crossman, 1978) which have demonstrated that the post-prime pause (a long IRT) following a priming run is approximately equal to (in terms of number of responses) the response requirement of the smaller FR component.

Variable-Ratio Performance

When a schedule of reinforcement contains a large number of unsignaled FR components, it is termed a variable-ratio (VR) schedule. Ferster and Skinner (1957) interpreted cumulative records of behavior on variable-ratio schedules with pigeons as indicating that VR schedules generate a high constant rate of responding with little or no pausing immediately following reinforcement. Periods of pausing tended to occur within large ratio components of high-valued VR schedules (Ferster & Skinner, 1957, p. 403).

PRP duration on VR schedules. A number of within-session analyses of PRP durations on VR schedules have appeared in the literature. Suboski (1965) exposed 8 rats to a VR 16 schedule and found that PRP duration was negatively correlated with the number of responses in the immediately preceding VR component. That is, if the preceding VR component was relatively large, the immediately following PRP duration tended to be relatively short. Suboski also reported that PRP durations increased from the beginning to the end of a session, a process he assumed was related to satiation (Sidman & Stebbins, 1954). Although this study appeared in the literature over two decades ago, the relations described by Suboski have not been empirically replicated by other researchers.

Priddle-Higson, Lowe, and Harzem (1976, Experiment II) reported a different within-session phenomenon which affects individual PRP durations. Rats were exposed to a VR 40 reinforcement schedule on which reinforcement was randomly omitted on 50 percent of the ratios. The duration of the

PRP following reinforcement omission was consistently shorter than the duration of the PRP following reinforcement. This finding is in agreement with previous studies of reinforcement omission on fixed-interval schedules (Staddon & Innis, 1966; 1969) and on FR schedules (McMillan, 1971), but has not been replicated for VR schedules.

Priddle-Higson et al. (1976, Experiment I) also exposed rats to three VR schedules (10, 40, and 80) and randomly presented five different concentrations of a milk reinforcer within four test sessions. A subsequent within-session analysis revealed that for each rat on every VR schedule studied, the median duration of the PRP was an increasing function of the concentrations of the reinforcer. That is, PRP durations following high milk concentrations were longer than PRP durations following more diluted milk concentrations. Although only a few within-session analyses of PRP durations have been performed with VR schedules, it appears that the variables that affect PRP duration on the other basic schedules of reinforcement also affect PRP durations on VR schedules.

<u>PRP duration and VR size</u>. A number of studies have reported a positive relationship between PRP duration and VR size. Powell (1972) exposed two crows to a sequence of basic schedules of reinforcement. Among these schedules were three VR schedules (50, 75, and 100). Powell's

analysis of cumuluative records of VR performance suggested that PRP duration tended to increase as VR size increased.

Priddle-Higson et al. (1976), in a study designed to evaluate the influence of reinforcement magnitude and omission, exposed rats to three VR schedules (10, 40, and 80). Subsequent analysis of lever-pressing revealed that PRP duration increased as VR size increased. Similar relations between VR size and PRP duration were reported in a study attempting to evoke attack behavior in rats (Webbe, DeWeese, & Malagodi, 1974) and in a study which exposed a single pigeon to three VR schedules (Pear & Rector, 1979).

Crossman, Bonem, and Phelps (1987) used pigeons as subjects and found a slight increase in PRP duration as VR size was increased from VR 5 to VR 80. The increase in PRP duration as VR size was increased was modest at best, with the PRP on FR schedules showing a robust increase as FR size was increased. Although the data are limited, it appears that the positive relation between VR size and PRP duration has generality primarily to rats, with pigeons and crows demonstrating only a modest increase in PRP duration as VR size increases.

IRTs on VR schedules. Analyses of IRT durations on VR schedules have failed to find reliable patterns of IRTs on VR schedules. Kintsch (1965) exposed two rats to VR 9 and VR 15 reinforcement schedules. The durations of individual IRTs were later manually measured from an event record in

0.5 s units. Initial analysis of IRT durations on both VR schedules revealed that mean IRT duration was stable from session to session. Within-session behavior was also evaluated. An analysis of IRT duration as a function of ordinal position within a ratio revealed that IRT duration decreased during the first five responses on a VR component (a 'warm-up' effect) and then either remained constant (one rat) or slowly increased in duration (a second rat) until the reinforcer was delivered. Further analysis compared the frequency distrubutions of successive IRT pairs following the warm-up to determine whether sequential dependencies were present in VR behavior. Kintsch (1965) concluded that although IRTs of similar duration tend to occur together within a VR schedule component, sequential IRT dependencies account for only a small amount of the variability observed in IRT durations.

Priddle-Higson et al. (1976) reported a relationship between mean IRT duration and VR size. Rats were exposed to three VR schedules (10, 40, 80). As VR size was increased, the duration of the mean session IRT also increased. This result is logically compatible with the observation that within-ratio pausing increases as VR size is increased (Ferster & Skinner, 1957). However, the specific changes in IRT duration that accompany increases in IRT duration have yet to be described.

There is no evidence, however, that there is a reliable relation between VR size and IRT duration with pigeon subjects. Crossman et al. (1987) examined the behavior of pigeons on FR, VR, and RR schedules. Within each type of ratio schedule, the size of the ratio was varied in an irregular sequence. At various ratio sizes (5,10,40,80), no differences were found among mean IRT duration and ratio size. These results do not support the relation between IRT duration and ratio size reported by both Suboski (1965) and Priddle-Higson et al. (1976). It is not clear whether species or procedural differences account for the the differences in control highlighted by this discrepancy.

Comparisons Between Fixed- and Variable-Ratio Schedule Performance

Behavior on an FR schedule differs from behavior emitted on a VR schedule. Relatively long duration PRPs characterize behavior on fixed-ratio schedules while relatively short duration PRPs characterize behavior on variable-ratio schedules. Fixed- and variable-ratio schedules also differ in running response rate; FR schedules tend to evoke high, steady response rates while VR schedules evoke high response rates with occasional within-ratio pauses (Zeiler, 1977).

Within-subject comparisons on FR and VR.

A number of within-subject comparisons of performance emitted on FR and VR schedules have appeared in the literature. Ferster and Skinner (1957) compared the performance of a single pigeon on large-sized FR and VR schedules. A pigeon was initially exposed to gradually increasing VR schedules until a VR 360 was in effect. When responding on VR 360 stabilized, the schedule was changed to FR 360. The VR and FR schedules were again presented at a later time. Ferster and Skinner reported that on VR 360, responses were emitted at a moderate rate whereas on FR 360, responses were emitted at a lower rate with frequent long, within-ratio pauses (ratio strain). Similar differences in VR and FR response rates were found when the pigeon was exposed to the VR and FR schedules for a second time. Ferster and Skinner concluded that on very large ratio sizes, VR schedules maintain higher response rates (with the PRP included in the rate calculation) than comparably-sized FR schedules.

Suboski (1965) compared behavior emitted on a small-sized FR schedule to behavior on a comparably-sized VR schedule. Two groups of rats were exposed to either an FR 16 or a VR 16 reinforcement schedule for 21 days. The schedules were then reversed so that each rat responded on both an FR 16 and a VR 16 reinforcement schedule. Behavior emitted on FR and VR schedules was subsequently compared using inferential statistical tests. Surprisingly, none of the expected differences between VR and FR performance was found in the grouped data. That is, no statistically significant differences were found between FR and VR PRPs, running response rates, or overall response rates. However, mean PRP and running response rate did differ based on the sequence of exposure to the two schedules. Presenting the VR 16 following exposure to the FR 16 schedule produced an immediate reduction in PRP duration and running response rate, whereas presenting the FR following VR exposure produced little immediate change in PRP duration or running response rate.

Crossman et al. (1987) compared key-pecking of pigeons on FR, VR, & RR schedules. Within each type of ratio schedule, the size of the ratio (5, 10, 40, 80) was varied in an irregular sequence. No large, reliable differences were identified among overall response rates (PRP plus running response rate) as a function of ratio type. This similarity in overall response rates held despite noticeable differences in the pattern of behavior; that is, the primary performance difference among the three types of ratio schedules was the relatively longer PRP duration on the FR schedule. Crossman et al. (1987) concluded that the patterns of behavior determined by the relative weightings of the PRP and running response rate were primarily controlled by the type of ratio schedule (fixed, variable, or random), whereas the overall rate of responding was controlled by the size of the ratio.

The similarities between VR and FR performance reported by Suboski (1965) and Crossman et al. (1987) are in contrast to Ferster and Skinner's (1957) report of distinct differences in VR 360 and FR 360 performance (FR 360 following VR 360). This difference can be reconciled if differences in VR and FR performance are found to become more pronounced as ratio size is increased.

Comparisons Between Fixed- and Random-Ratio Schedule Performance.

Under a random-ratio (RR) schedule, the probability that any given response will be immediately followed by a reinforcer is constant (e.g., on an RR 50 schedule, each response has a 0.02 probability of being followed by a reinforcer delivery irrespective of the number of previously emitted responses). Behavior emitted on RR schedules is similar, but not identical to behavior emitted on VR schedules (Brandauer, 1959). Differences between VR and RR schedule performance may be due to the design of a particular VR schedule. That is, the components constituting the VR schedule or the order of VR component presentation may be quite different from the size and order of component presentation on a comparably-sized RR schedule. Although the importance of VR component distributions and the order of VR component presentation has never been empirically demonstrated for VR schedules, variable-interval schedule performance changes as these variables are modified (Catania & Reynolds, 1968).

One thorough analysis with rats compared within-subject performance on FR and RR schedules. Mazur (1983) exposed four rats to four different pairs of equal-sized FR and RR schedules (10, 20, 40, and 80) in separate ascending and descending pairs of conditions. Comparisons between FR and RR performance revealed several differences. At all ratio sizes, mean PRP duration on FR schedules was longer than mean PRP duration on comparably sized RR schedules. On FR schedules, mean PRP increased substantially as ratio size increased, whereas on RR schedules, mean PRP either increased slightly (2 rats) or was not related (2 rats) to the size of the ratio. Running response rates and overall response rates also were different on FR and RR schedules. With one exception (one rat at a ratio size of 10), running response rates were higher on FR than on comparably-sized RR schedules. However, when the PRP was added to the rate calculation (overall response rate), no consistent difference between FR and RR behavior was found.

To identify the source of the difference between running response rates on FR and RR schedules, Mazur (1983) analyzed IRTs. Frequency distributions of IRTs less than one second on FR and RR schedules did not systematically differ from one another. In fact, the modes of each IRT frequency distribution were similar at all ratio sizes both within and between FR and RR schedules. Differences between FR and RR schedule performance were noted when long IRTs (IRTs greater than one second) were examined. Although the probability of a long IRT increased as ratio size increased on both FR and RR schedules, within-ratio ordinal locations of long IRTs differed between the schedules. Under all FR schedules, the probability and duration of a long IRT was highest at the start of a ratio component and decreased as responses were emitted. In contrast, the probability and duration of long IRTs on the RR schedules studied remained constant across all ordinal locations within an RR component.

One of the conditions of the Crossman et al. (1987) study compared performance between FR and RR schedules within pigeons at various ratio sizes (5, 10, 40, 80). No reliable differences were found among overall response rates (PRP plus running response rate) as a function of ratio type. It was concluded that the relative durations of the PRP and running response rate observed on ratio schedules were primarily controlled by the type of ratio schedule (fixed, variable, or random), whereas the overall rate of responding was controlled by the absolute size of the mean ratio.

The Mazur (1983) and Crossman et al. (1987) studies support the notion that differences between running response rates (response rate calculated without the PRP duration) on FR and RR schedules are controlled by moment-to-moment changes in the probability of reinforcement. On an FR schedule, the probability of reinforcement is zero at the beginning of each ratio component; Animals pause (PRP or IRT greater than 1 s) immediately after reinforcement and during the first few responses of a ratio component. On an RR schedule, the probability of reinforcement is constant at all ordinal locations within a ratio component; Animals pause equally frequently at all ordinal positions within an RR component. Logically, performance on a VR schedule should be similar to RR performance to the extent that VR component sizes are well distributed and randomly presented.

> Insofar as performance on ratio schedules can be characterized as consisting of only two behavior categories -- steady, continuous responding and pausing .... the problem is reduced to specifying when pauses will occur and how long they will last (Mazur, p. 306).

Interpolated Schedules

A variation of the mixed schedule is the interpolated schedule which "... has the effect of a complex probe" (Ferster & Skinner, 1957, p. 643). Although rarely discussed in the literature, interpolated schedules of reinforcement seem to provide a methodology for carefully observing the effects of different variables on a baseline of stable responding.

Under an interpolated schedule of reinforcement, an unsignaled, relatively brief period on one schedule is inserted into a background schedule which occupies the main part of a session. For example, on FR 1 *inter* FR 100, a single FR 1 schedule component is inserted into an experimental period consisting of FR 100 components. In general, the interpolated component "has the effect of a complex probe" (Ferster & Skinner, 1957, p. 643).

Ferster and Skinner (1957) described performances of two pigeons exposed to four interpolated schedules: fixed-interval 1 min interpolated fixed-interval 15 min (FI 1 *inter* FI 15); fixed-ratio 30 interpolated fixed-interval 15 min (FR 30 *inter* FI 15); fixed-ratio 50 interpolated fixed-interval 15 min (FR 50 *inter* FI 15); and fixed-ratio 50 interpolated variable-interval 5 min (FR 50 *inter* VI 5). The interpolated components were primarily presented during six (one pigeon) or eight (second pigeon) hour sessions. Each interpolation was presented in a block (usually 16 reinforcements) approximately once per hour.

FR 30 interpolated FI 15 and FR 50 interpolated FI 15. Performances generated by the interpolated schedules again differed between pigeons. For one pigeon, IRTs and PRPs were consistently short (with occasional pausing within the FI 15 component) during both schedule components. For this pigeon, a local effect was present following the block of FR 30 components. Immediately following the return to the FI 15 schedule, IRT duration increased. Following completion of a number of intervals, IRT duration returned to its initial short duration. The PRPs and IRTs of the second pigeon were more typical of multiple schedule performance in that response patterning specific to the component in effect dominated. For both pigeons, altering the interpolated component to an FR 50 increased the duration, not the frequency, of the priming runs which occasionally occurred during the FI schedule component.

FR 50 interpolated VI 5. Ferster and Skinner (1957) reported that overall response rates were similar when either the FR 50 or VI 5 min component was in effect. The duration of the PRP emitted during the FR 50 component were shorter in duration than PRP durations found on a standard FR 50 schedule. Performance during the VI 5 min component included occasional priming and pausing throughout the session. The second pigeon was run only four sessions on this schedule and performance never stabilized.

Comparison between VI and FR interpolated VI. Catania and Reynolds (1968, Experiment II) exposed two pigeons to schedules equated for overall density: a VI 123 s and an FR 1 inter VI 108 s schedule. Under the interpolated schedule, a reinforcer followed a single response every fifteenth reinforcer until 61 reinforcements had occurred. For both pigeons, the effect of the added FR 1 component spread to the initial few seconds of the VI interval. For both birds, local response rates during the time shortly after reinforcement increased. However, the effect of the FR 1 interpolation (or the zero-s interval) on overall response rate was inconsistent. For one pigeon, rates of responding did not substantially differ between schedules. For the other pigeon, overall rate of responding on the interpolated schedule was higher than on the schedule without the FR 1 component. Thus, for one bird, the local effect of the interpolated FR 1 component was excitatory, but the overall effect was inhibitory (i.e., an example of behavioral contrast). For the second bird, both the local and the overall effect of the FR 1 component were excitatory (i.e., an example of positive induction). The reason for this difference in performance was not resolved by Catania and Reynolds (1968).

<u>FT interpolated FR</u>. Interpolated schedule performance has also been studied utilizing response-independent reinforcement components. Edwards, Peek, and Wolfe (1970, Experiment I) initially exposed two rats to an FR schedule (FR 35 or FR 50). When response rate had stabilized, reinforcer rate was systematically increased across conditions by adding a fixed-time (FT) schedule to run simultaneous with the FR baseline schedule (conjoint FT FR). An analysis of mean response rate revealed an inverse relation between response rate and the rate of FT reinforcement (controlled by reducing FT duration). That is, as the rate of FT reinforcement increased, overall response rate decreased.

Edwards et al. (1970, Experiment II) studied the effects of interpolating a single FT schedule into numerous

FR schedules (e.g., conjoint FT FR). The term conjoint describes a reinforcement schedule in which two schedule components simultaneously operate, independent of the behavior of the organism. Three rats were exposed to a moderately sized FR schedule (FR 50 or FR 40) until response rate stabilized. Over a series of conditions, FR size was varied (counterbalanced across rats) while the simultaneous FT schedule was held at the same temporal duration (e.g., FT 23 s). Comparisons between response rates on each conjoint schedules revealed that as FR size decreased (e.g., FR 50 to FR 6), mean response rate decreased. That is, as the relative density of response-independent reinforcement increased, response rate decreased. This is the same relation reported when the size of a basic FR schedule (without the FT component) is reduced (Powell, 1968).

The two experiments conducted by Edwards et al. (1970) demonstrate that the effects of interpolating response-independent reinforcement on an FR schedule are dependent on both FR size and FT duration. When the relative rate of interpolated FT reinforcement was increased on a moderately sized FR, response rate decreased. When the size of the FR requirement was reduced while the duration of the FT component was held constant, response rate also decreased. Thus a conjoint FT 23 s FR 50 evoked a higher response rate than a conjoint FT 23 s FR 5 schedule of reinforcement.

Summary of interpolated schedules. Behavior evoked by the interpolated schedules described in the section above was different among subjects. Ferster and Skinner (1957) as well as Catania and Reynolds (1968) have reported unstable behavior for half (one bird) the pigeons studied. The results of the Edwards et al. (1970) study are also difficult to interpret. The results of Edwards et al. (Experiment I) demonstrated that as the duration of the FT schedule was increased, response rate increased. That is, as the relative density of response-independent reinforcement decreased, response rate increased. In Experiment II, as the relative rate of response independent reinforcement decreased, (by decreasing FR size), response rate decreased. It is not clear whether these results are a a function of unique behavioral histories or whether the behavior evoked by conjoint FT FR schedules is idiosyncratic.

The literature demonstrates that interpolated schedules evoke both performance unique to the combination of component schedules as well as performance specific to the schedule component in effect (performance resulting from strong control by each schedule component independent of other schedule components in effect). The limited experimentation and intersubject variability on interpolated schedules restricts our ability to predict which type of performance will be emitted by a particular organism.

General Summary of the Ratio-Schedule Literature

One approach to determining why substantial PRP durations occur on FR schedules is to compare the structure of the FR schedule to other comparably-sized ratio schedules which do not evoke a substantial PRP duration. The obvious structural difference between FR schedules and other ratio schedules involves the lack of variability in ratio component size. On an FR schedule, the ratio response requirement across a session remains unchanged, whereas on other ratio schedules (i.e., random-ratio or variable-ratio schedules), the size of the response requirement of each ratio component varies across a session. Given that the PRP duration decreases as the variability of components increases on interpolated fixed-interval schedules (Catania & Reynolds, 1968), it seems critical to determine whether this same relation occurs on interpolated fixed-ratio schedules.

A mixed FR schedule contains aspects of both FR and VR schedules in that a minimum number of different ratio components are presented within a session. Studies of mixed schedules have determined that when ratio components are ramdomly presented, PRP duration is controlled "... by the response requirement of the small component" (Alferink & Crossman, 1978, p. 144). However, PRP durations on variable-ratio schedules (a mixed schedule with many different ratio components) cannot only be controlled by the smallest-ratio requirement present in a session. This is because PRP duration on VR schedules (with an FR 1 component present in each VR schedule) increases as the mean size of the VR schedule is increased (Priddle-Higson et al., 1976). Thus, although the smallest-ratio component in a session does affect PRP duration, other variables, as yet unidentified, are also involved.

Purpose of the Research

The purpose of this investigation is to clarify the control exerted over PRP and IRT durations by the smallest ratio component present in a session. The literature suggests that the presence of a small-sized ratio component shortens PRP duration relative to PRP duration in its absence (Ferster & Skinner, 1957). Alferink and Crossman (1978) suggest that this same variable (a small ratio component) controls PRP duration on mixed FR schedules. Catania and Reynolds (1968), using fixed-interval schedules, similarily demonstrated that presenting a single, short fixed-interval (FI) component resulted in a decrease in mean PRP duration below that found on a standard FI 108 s schedule. Experiment I determined whether inserting a single FR 1 component into a session of 30, FR 50 schedule components (FR 1 inter FR 50) would reduce the mean PRP duration below that found on a standard FR 50 schedule. If schedule performances on FR and VR schedules primarily differ in PRP duration, and if PRP duration is controlled by the smallest ratio component present in a session, then PRP durations on the VR 50, FR 1 *inter* FR 50, and FR 1/FR 215 *inter* FR 50 schedules should be indistinguishable.

The interpolation of a single FR 1 component into an FR 50 schedule simultaneously alters a number of variables. Experiment II determined whether, in order to observe reduced PRP durations, it is necessary for the FR 1 component to be response-dependent or whether the interpolation of response-independent reinforcement will also reduce PRP duration. Additionally, Experiment II permitted evaluation of the control exerted by the short interreinforcement interval (independent of response dependency) in reducing PRP duration.

Finally, Experiment III isolates the control exerted by discriminative properties of the interpolated FR 1 schedule component in reducing overall PRP duration. That is, by pairing a visual stimulus with the FR 1 component, and by fixing its location within a session (with respect to the number of FR 50 components previously completed), the effect on PRP duration of two discriminative properties of the interpolated FR 1 schedule were investigated. Taken together, the results of these experiments isolate those characteristics of the interpolated schedule which may be responsible for making mixed FR schedule performance similar to that observed on VR schedules.

CHAPTER III

EXPERIMENT I: SYNTHESIZING VARIABLE-RATIO PERFORMANCE

One purpose of Experiment I was to demonstrate that adding a single FR 1 to a session of 30, FR 50 components reduces the duration of the median post-reinforcement pause (PRP) below that found on a simple FR 50 schedule of reinforcement. The particular value of the larger FR component was selected for two reasons: Presentation of an FR 50 component results in a PRP duration long enough to permit detection of a reduction in duration, yet is not large enough to produce ratio strain (Ferster & Skinner, 1957). An additional purpose of this experiment was to determine whether inter response times (IRTs) of pigeons under an FR 1 Interpolated FR 50 schedule of reinforcement resembled IRTs on either a comparably sized variable-ratio (VR) reinforcement schedule or on a basic FR 50 reinforcement schedule. Finally, this experiment determined if the median duration of PRPs under an FR 1 interpolated FR 50 reinforcement schedule resembled either PRPs on an FR 1 schedule (i.e., if the shortest FR component controls PRP duration) or PRPs under a VR 48.5 reinforcement schedule (i.e., if the arithmetic mean of the ratio components controls PRP duration).

Method

General Procedure

Subjects. Four experimentally-naive common barn pigeons of unknown age and gender served. Each pigeon was maintained throughout each experiment at approximately 80% of its ad lib weight. Whenever the weight of a pigeon (recorded prior to each daily session) deviated by more than 15 gm from its 80% weight, the session was cancelled for that day. All supplemental food was provided in the home cage approximately 30 minutes following an experimental session. Water was continuously available in the home cage.

Apparatus. Four identical pigeon chambers (Coulbourn Instruments Modular Small Animal Test Cage, model E10-10) with interior dimensions of 28.5 x 29 x 24 cm individually housed pigeons during experimental sessions. One of the walls contained a houselight (GE 1820 bulb operated at 25 V dc), three response keys (only the center key was operative), and an opening for food delivery.

The circular 2.5 cm response keys, 8 cm apart (center to center) were located 18.5 cm from the chamber floor. A force of movement of approximately 5 N through a distance of 1 mm was required to close a microswitch located behind the center response key. An Industrial Electronics Engineers in-line digital display unit transilluminated the center response key with approximately 8 lumens of red illumination

(Kodak Wratten Filter #23A). The response key was darkened during reinforcement.

Reinforcer presentations consisted of 3 s access to pigeon checkers (Purina Racing Pigeon Checkers) available inside a food aperture. The 5.8 x 5.8 cm food aperture was centered 3.75 cm above the floor. The raising of the food aperature was accompanied by the illumination of an unfiltered GE 1820 bulb (operated at 25 V dc) located inside the food aperture. Each chamber was enclosed in a ventilated, light and sound attenuated box. An exhaust fan was continuously operated throughout experimental sessions.

Experimental events were controlled in a separate room by a Commodore VIC-20 microcomputer (Crossman, 1984), interfaced to the experimental chamber. In conjunction with the VIC-20, a Commodore 1541 disk drive recorded all critical experimental events (at a resolution of 0.01 s) onto a floppy disk (Hessel, 1985). The data on the 1541 floppy disk were transferred to, and data analysis was performed on an IBM-compatible XT Turbo microcomputer. A Gerbrands cumulative recorder provided a visual record of responding during all sessions.

<u>Training</u>. A number of training procedures were used to develop a stable rate of key pecking on the baseline FR 50 schedule of reinforcement. On the first day, each pigeon was individually placed in a chamber with 10 gm of pigeon checkers available inside the food aperture. An autoshaping

procedure was then initiated. Each autoshaping session began with the illumination of the houselight which remained illuminated during the the entire session. For a given autoshaping trial, the center response key was first darkened for 54 s (the intertrial interval or ITI), and then transilluminated with red light for a maximum of 6 s (the interstimulus interval or ISI). Whenever a key peck occurred during the ISI, the response key was darkened and the illuminated food hopper was raised for 3 s. Whenever a keypeck did not occur during the ISI, the response key was darkened after 6 s had elapsed and the illuminated hopper was raised for 3 s. Key pecks during the ITI were recorded but had no scheduled consequence. This procedure continued to recycle until 50 hopper lifts were presented. The autoshaping phase ended when a minimum of 20 ISI key-pecks occurred during a session. All pigeons met this response criterion within two sessions.

Each pigeon was next exposed, one reinforcement schedule per day, to the following ascending series of VR schedules: VR 1; VR 5; VR 10; VR 20; VR 30; VR 40. The VR schedules were selected to minimize variability in training regimen brought on by the possible development of ratio-strain. The houselight was continuously illuminated during each session. Whenever the key-peck contingency on the center response key was met, the red, center response key was darkened and the hopper and hopper light were presented for 3 s. Each session ended following 30 hopper presentations.

Experimental Phases

Following completion of the training phase, Experiment I consisted of five conditions. Table 1 summarizes the order of conditions for the four pigeons.

Fixed ratio 50. Exposure to an FR 50 schedule of reinforcement constituted the first condition for the four pigeons. Each FR 50 condition began with the illumination of the houselight and red transillumination of the center response key. After 50 key pecks occurred, the center response key was darkened and the hopper light and hopper were presented for 3 s. These events continued to recycle until either 30 hopper presentations occurred or 45 minutes elapsed, whichever occurred first. This condition remained in effect until the criteria for stability were met (see below).

Variable ratio 50. The four pigeons were also exposed to a VR 50 schedule of reinforcement. Sessions began as described in the FR 50 condition and key pecks meeting the response contingency had the same effect as in the FR 50 condition. The 31 values constituting the VR 50 (more precisely, a VR 48.4) reinforcement schedule were randomly combined into different sequences such that each VR sequence was presented only once every seven sessions (See Appendix

Table 1

Summary of Conditions for Each Subject in Experiment I

Pigeons 1 and 2		*Pigeons 3 and 4*	
Order	Conditions	Order	Conditions
1.	FR 50	1.	FR 50
2.	VR 50	2.	FR 1 *inter* FR 50 (1)
3.	FR 1 *inter* FR 50 (1)	3.	FR1/FR 215 *inter* FR 50
4.	FR 1/FR 215 *inter* FR 50	4.	VR 50
5.	FR 1 *inter* FR 50 (2)	5.	FR 1 *inter* FR 50 (2)

A). The values which consitituted the VR 50 schedule approximated an exponential distribution and ranged from a ratio size of 1 to a ratio size of 215 (Fleshler & Hoffman, 1962). The full range of values are presented in Appendix B. Each session ended when the 31st hopper presentation occurred or 45 minutes elapsed, whichever occurred first. This condition remained in effect until the criteria for stability were fulfilled.

FR 1 interpolated FR 50. The four pigeons were also exposed to an FR 1 *inter* FR 50 schedule of reinforcement. Each session was conducted as described in the FR 50 condition with one exception. While 30 FR components were each followed by a hopper presentation after 50 key pecks (FR 50), one FR component was followed by a hopper presentation after just one key peck (FR 1). Thus, during each session, pigeons were exposed to a total of 31 hopper presentations, with all response contingencies presented on the center response key. The FR 1 component was located in a different serial position each day within the 30, FR 50 components (See Appendix B).

FR 1-FR 215 interpolated FR 50. As an additional condition, the four pigeons were exposed to an FR 1-FR 215 *inter* FR 50 schedule of reinforcement. Each session was conducted as described in the FR 50 condition with two exceptions: both an FR 1 and an FR 215 component (the largest and smallest value present in the VR 50 schedule) comprised two of the thirty-one total components. The components were programed to occur in a different serial position each day within the 29, FR 50 components (See Appendix B). Each session ended when the 31st hopper presentation occurred or 45 minutes elapsed, whichever occurred first. This condition remained in effect until the criteria for stability were fulfilled.

Stability criteria. The decision to change conditions was controlled by the following rules for determining stable behavior. Behavior was considered stable when, for five consecutive sessions, the following criteria were met: 1) no new low or high median IRT or PRP occurred; 2) no trend in median IRT or PRP was evident; and 3) a minimum of 20 sessions were conducted for the condition. When these criteria were not met within 30 sessions, the condition was discontinued and a new condition was presented.

Results

This analysis begins with the presentation of whole-session dependent measures for each subject for each condition conducted in Experiment I. These dependent measures include overall response rate, session time, median PRP, semi-interquartile range (SIR) of the PRP, median IRT, SIR of the IRT, PRP and IRT frequency distributions, and cumulative records. A summary of these dependent measures across the various schedules studied is then presented.

Rather than average individual data across the last five sesions as is often done, the data shown in the following tables and figures were computed from a single session. The session selected for analysis had a value of the median PRP which was the median of the median PRPs in the last five sessions of a condition (hereafter referred to as the median session). This more conservative approach, although more likely to highlight variability within a session, is preferable since it preserves the stream of behavior typical of each individual subject. The variability of the median session is indicated by presentation of the last five-day ranges for median PRP and median IRT for all pigeons in Experiment I.

Comparisons Across Dependent Measures

Overall response rate. The overall response rates (omits the first pause in a session, duration of reinforcement, and response duration) for each subject at each ratio type are presented in Table 2. For all pigeons, the overall response rates emitted on FR 50, VR 50, and FR 1 inter FR 50 (1) were slower than the overall response rates emitted on FR 1/FR 215 *inter* FR 50. In general, the overall response rate for each pigeon on VR 50 was lower than the overall response rate on any other schedule studied. Exceptions to this generalization were observed for Pigeon E1

Table 2

Summary Statistics for Experiment I Computed from the Median PRP Session from the Last Five Sessions of Each Condition

Subject	Condition	Sequence of Conditions	Sessions	Overall response rate (R's/s)	Session Time (min)
E1	FR 50	1	25	1.12	38.76
	VR 50	2	25	1.77	25.76
	FR 1 (1)	3	25	1.44	31.03
	FR 1/FR 215	4	22	2.45	20.66
	FR 1 (2)	5	25	1.98	23.44
E2	FR 50	1	25	2.88	16.61
	VR 50	2	20	2.82	17.11
	FR 1 (1)	3	25	2.91	16.86
	FR 1/FR 215	4	27	2.94	17.99
	FR 1 (2)	5	28	2.97	18.15
E3	FR 50	1	25	2.21	24.19
	VR 50	4	26	1.66	27.45
	FR 1 (1)	2	20	1.79	25.40
	FR 1/FR 215	3	26	2.56	24.42
	FR 1 (2)	5	27	0.83	45.00

(table continues)

Subject	Condition	Sequence of Conditions	Sessions	Overall response rate (R's/s)	Session Time (min)
E4	FR 50	1	25	3.00	16.42
	VR 50	4	26	2.41	19.53
	FR 1 (1)	2	20	2.96	16.70
	FR 1/FR 215	3	25	3.07	16.94
	FR 1 (2)	5	25	3.16	15.72

on FR 50 and on the second exposure to FR 1 _inter_ FR 50, and for Pigeon E3 on the second exposure to FR 1 _inter_ FR 50. Additionally, for each pigeon, overall response rate under FR 50 was lower than the response rate emitted under the second exposure to FR 1 _inter_ FR 50, with the exception of Pigeon E3. Finally, again with the exception of Pigeon E3, the overall response rate on the first exposure to FR 1 _inter_ FR 50 was lower than the overall response rate emitted under the second exposure to FR 1 _inter_ FR 50.

Session time. The session times for all pigeons at each ratio type are also presented in Table 2. Note that in Table 2, the notation for each interpolated schedule is abbreviated. For example, FR 1 (1) represents the first exposure to the FR 1 _inter_ FR 50 schedule. FR 1 (2) represents the second exposure to the FR 1 inter FR 50 schedule. This notation was used throughout all tables presented in Experiment I.

Session time essentially mirrors the overall response rate measure. Session time was calculated as the time elapsed between the initiation and termination of the experimental session. Thus, temporal periods absent from the overall response rate measure but encompassed in the calculation of session time included (1) the warm-up pause which begins a session, (2) hopper duration, and (3) response duration. The session time data were consistent with the overall response rate data. In general, the time required to complete a VR 50 session was longer than the time required to complete an FR 1/FR 215 inter FR 50 session (with the exception of Pigeon E2), an FR 50 session (with the exception of Pigeon E1), or an FR 1 inter FR 50 (1) session (again with the exception of Pigeon E1).

PRP frequency distributions. Figure 1 contains plots of the relative frequencies of PRPs from the median session for all pigeons in all conditions. The labels on the abcissa represent the midpoint of the boundary for each category of PRPs in 0.5 s bins. Thus, the 3.25 category (or bin) contains the percentage of PRPs that were between 3.0 s and 3.495 s in duration. The rightmost category includes all PRPs that were 9.75 seconds or longer. Table 3 presents some summary statistics which refine interpretation of the central tendency and variability of the PRP distributions.

The most consistent difference in PRP distributions was the location of the modal PRP on FR 50 and VR 50 schedules. For all pigeons, the mode on FR 50 was located at a longer duration PRP than the mode on VR 50, while the mode at VR 50 was the same value as the mode on FR 1/FR 215 inter FR 50. For three of four pigeons, the mode at FR 1 inter FR 50 (2) was indistinguishable from the mode at VR 50, while for three of four pigeons, the mode at FR 1 inter FR 50 (1) was longer than the mode at VR 50.

Median post-reinforcement pause duration. At a given ratio size, differences in PRP durations are the benchmark

Figure 1. Relative frequency distributions of PRPs for each subject for each condition studied in Experiment I. Bin size was 0.5 seconds. Values on the X axis are the midpoints of the class intervals or "bins". The session presented is the session which contained the median of the median PRP from the last five days of a condition. The rightmost bin includes PRPs equal to or greater than 9.75 s.

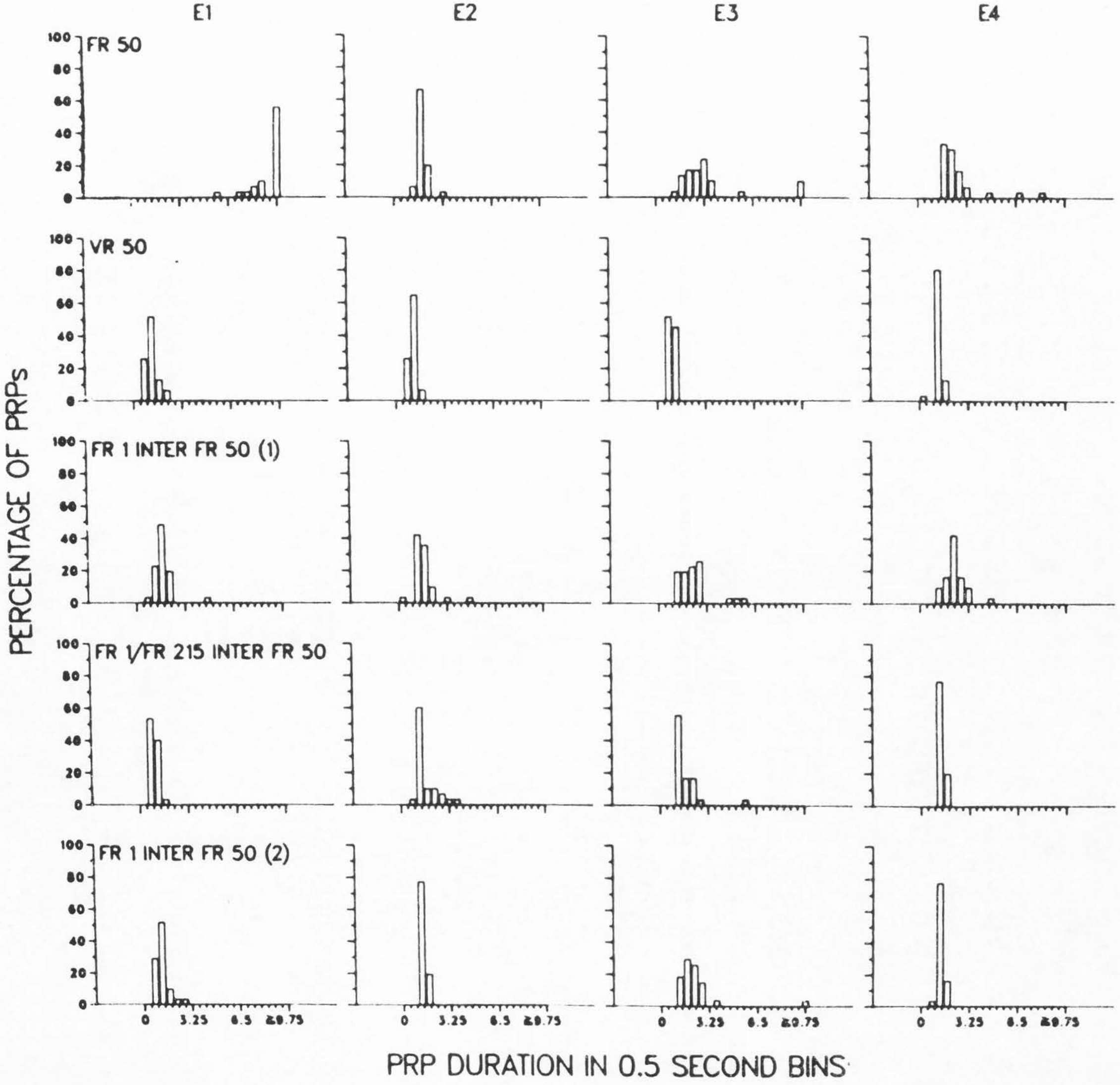

E1
E2
E3
E4
FR 50
VR 50
FR 1 INTER FR 50 (1)
FR 1/FR 215 INTER FR 50
FR 1 INTER FR 50 (2)
PERCENTAGE OF PRPs
0
20
40
60
80
100
0
3.25
6.5
≥9.75
PRP DURATION IN 0.5 SECOND BINS

Table 3

Summary of Central Tendency and Variability Measures for Experiment I Computed from the Median PRP Session

		PRP			IRT		
Subject	Condition	Mdn	SIR	Mode	Mdn	SIR	Mode
E1	FR 50	10.57	3.69	11.25	0.42	0.20	0.38
	VR 50	1.14	0.27	1.25	0.45	0.06	0.43
	FR 1 (1)	1.65	0.38	1.75	0.42	0.04	0.38
	FR 1/FR 215	0.98	0.10	0.75	0.38	0.03	0.38
	FR 1 (2)	1.10	0.29	1.25	0.42	0.04	0.38
E2	FR 50	1.83	0.15	1.75	0.31	0.03	0.33
	VR 50	1.10	0.29	1.25	0.33	0.03	0.33
	FR 1 (1)	1.52	0.23	1.25	0.31	0.03	0.33
	FR 1/FR 215	1.34	0.40	1.25	0.31	0.02	0.33
	FR 1 (2)	1.27	0.27	1.25	0.31	0.03	0.33
E3	FR 50	2.99	0.78	3.25	0.38	0.12	0.33
	VR 50	0.98	0.14	1.25	0.61	0.15	0.63
	FR 1 (1)	2.24	0.74	2.75	0.40	0.12	0.38
	FR 1/FR 215	1.41	0.48	1.25	0.36	0.12	0.33
	FR 1 (2)	2.01	0.52	1.75	0.42	0.18	0.38

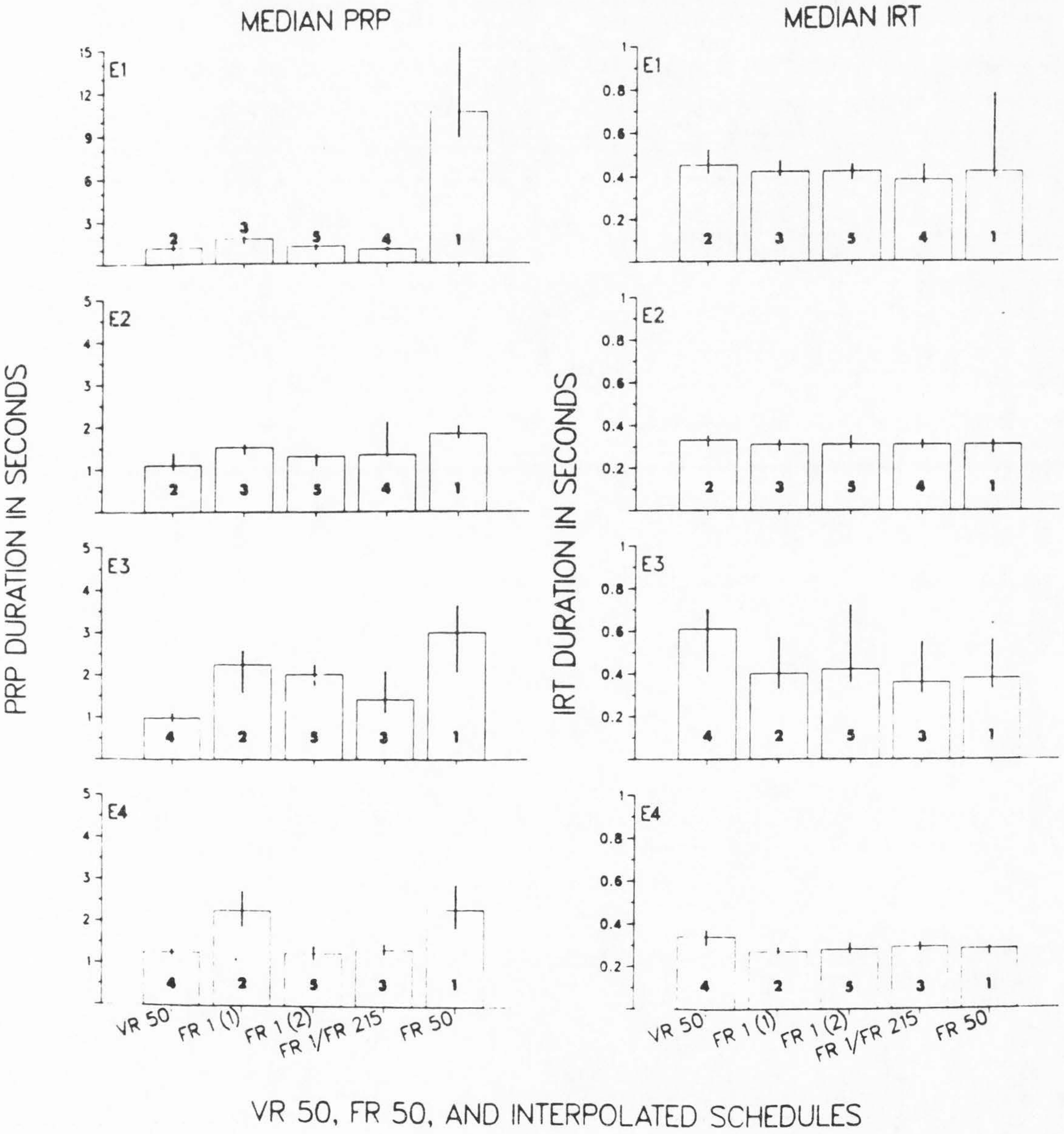
(table continues)

Subject	Condition	PRP			IRT		
		Mdn	SIR	Mode	Mdn	SIR	Mode
E4	FR 50	2.31	0.51	1.75	0.28	0.02	0.28
	VR 50	1.27	0.11	1.25	0.34	0.04	0.33
	FR 1 (1)	2.27	0.60	2.25	0.27	0.02	0.28
	FR 1/FR 215	1.34	0.13	1.25	0.29	0.02	0.28
	FR 1 (2)	1.26	0.25	1.25	0.28	0.03	0.28

in distinguishing VR from FR schedules. To provide a general measure of any change in PRP duration across conditions, the left column of Figure 2 displays median PRP duration as a function of the schedules of reinforcement studied in Experiment I. The error lines intersecting each bar are the quartile ranges of the PRP (25th to 75th percentiles) within the session presented. The judgment of a difference between two conditions was based on the degree of quartile range overlap. Within a given pigeon's performance, any overlap between the quartile range of the PRP between conditions was not judged to represent a reliable difference. Across pigeons, two conditions were considered reliably different from one another only when three of the four pigoens had no overlap in quartile ranges for that condition.

The median PRP duration emitted on the FR 50 schedule was longer than the PRP duration emitted on all schedules of reinforcement (with the exception of Pigeon E4 on the first FR 1 <u>inter</u> FR 50 condition). For all pigeons, median PRP duration on the VR 50 schedule was shorter than the PRP duration upon first exposure to the FR 1 <u>inter</u> FR 50 schedule. Upon second exposure to the FR 1 <u>inter</u> FR 50 schedule, median PRP durations between the VR 50 and FR 1 <u>inter</u> FR 50 did not systematically differ. Median PRP durations on the first and second exposure to the FR 1 inter FR 50 did not consistently differ from median PRP durations

Figure 2. Median PRP and median IRT duration as a function of FR 50, and interpolated schedules for all subjects in Experiment I. The error line intersecting each bar represents the quartile range for that condition. The session selected for presentation contained the median of the median PRP for the last five sessions of a condition. The number inside each bar represents the order in which the pigeon was exposed to a particular condition. Note the different scale for Pigeon E1 on the ordinate of the PRP figure.


MEDIAN PRP
MEDIAN IRT
PRP DURATION IN SECONDS
IRT DURATION IN SECONDS
E1
E2
E3
E4
15
12
9
6
3
5
4
3
2
1
0.8
0.6
0.4
0.2
VR 50
FR 1 (1)
FR 1 (2)
FR 1/FR 215
FR 50
VR 50, FR 50, AND INTERPOLATED SCHEDULES

on the FR 1/FR 215 inter FR 50 schedule.

A measure of variability is necessary to adequately evaluate the reliability of apparent differences between median values among the schedules of reinforcement studied. The semi-interquartile range of the median PRP is presented in Table 3 as a measure of within-session variability of the PRP. Within a session, PRPs emitted on a VR 50 schedule were more stable than on an FR 1 inter FR 50 schedule. The SIR of the PRP on the VR 50 schedule was generally smaller than the SIR on the FR 1 inter FR 50 (1 and 2) schedule (with the exception of Pigeon E2 on FR 50 and the second exposure to FR 1 inter FR 50; and Pigeon E1 on the first exposure to FR 1 inter FR 50 and FR 1/FR 215 inter FR 50). Additionally, with the exception of Pigeon E2, the SIR of the PRP on both FR 1 inter FR 50 conditions was greater than the SIR of the PRP on FR 1/FR 215 inter FR 50. Finally, again with the exception of Pigeon E2, the SIR of the PRP on the first exposure to FR 1 inter FR 50 was greater than the SIR of the PRP on FR 50, but not consistently different from the SIR on the second exposure to FR 1 inter FR 50 or FR 1/FR 215 inter FR 50.

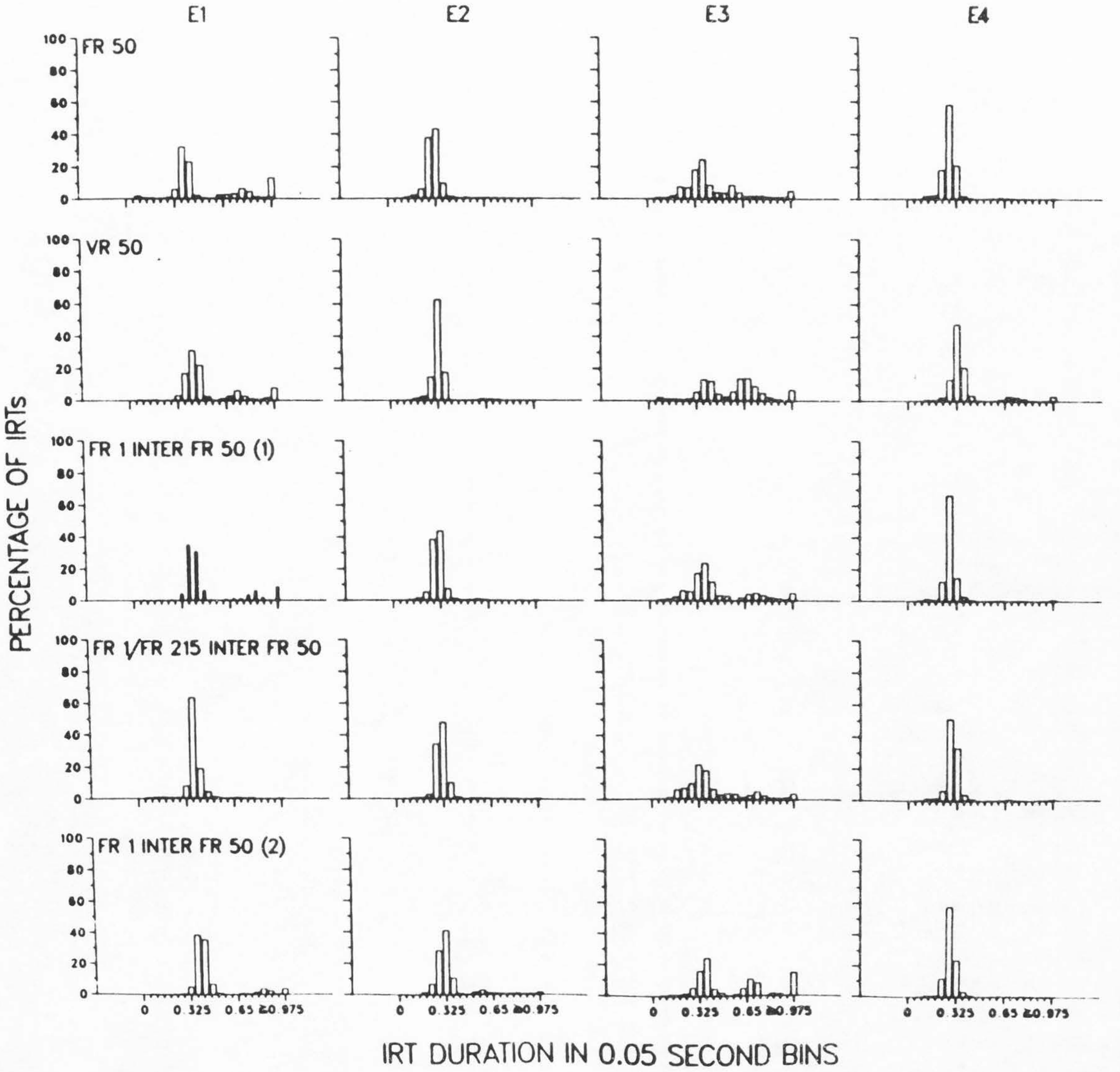
To evaluate session-to-session variability of PRP duration, Table 4 displays the the low and the high median PRP duration for the last five sessions of a condition. The five-session range of PRPs emitted on the FR 50 schedule was consistently greater than the range of median PRPs on any

Table 4

Low and High Duration of the Median PRP and Median IRT (Last Five Sessions) for Each Schedule Studied in Experiment I.

Subject	Condition	Median PRP in s		Median IRT in s	
		Low	High	Low	High
E1	FR 50	4.27	12.57	0.42	0.45
	VR 50	1.06	1.36	0.45	0.49
	FR 1 (1)	1.51	1.70	0.42	0.47
	FR 1/FR 215	0.93	1.03	0.38	0.41
	FR 1 (2)	0.96	1.21	0.42	0.43
E2	FR 50	1.70	2.12	0.31	0.31
	VR 50	1.05	1.11	0.32	0.35
	FR 1 (1)	1.37	1.58	0.29	0.31
	FR 1/FR 215	1.30	1.38	0.31	0.31
	FR 1 (2)	1.21	1.29	0.31	0.31
E3	FR 50	2.53	3.03	0.36	0.38
	VR 50	0.96	1.06	0.32	0.35
	FR 1 (1)	2.16	2.54	0.38	0.40
	FR 1/FR 215	1.29	1.98	0.36	0.40
	FR 1 (2)	1.60	2.91	0.38	0.42
E4	FR 50	2.23	2.73	0.27	0.29
	VR 50	1.25	1.32	0.54	0.63
	FR 1 (1)	2.02	2.40	0.27	0.29
	FR 1/FR 215	1.32	1.53	0.29	0.29
	FR 1 (2)	1.23	1.30	0.27	0.28

Figure 3. Relative frequency distributions of IRTs for each subject for each condition studied in Experiment I. The session selected for presentation was the session, from the last five sessions in a condition, which contained the median of the median PRP. Bin size was 0.05 seconds. Values on the X axis are the midpoints of the class intervals or "bins". The last bin includes all PRPs greater than, or equal 0.975 seconds.


E1
E2
E3
E4
FR 50
VR 50
FR 1 INTER FR 50 (1)
FR 1/FR 215 INTER FR 50
FR 1 INTER FR 50 (2)
PERCENTAGE OF IRTs
100
80
60
40
20
0
0
0.325
0.65
≥0.975
IRT DURATION IN 0.05 SECOND BINS

other schedule studied (with the exception of Pigeon E3 on FR 1/FR 215 *inter* FR 50). No differences were apparent among the ranges of median PRP durations for the other schedules studied.

IRT frequency distributions. Figure 3 contains plots of the relative frequency distributions of IRTs from the median session for all pigeons in each condition. The labels on the abscissa represent the midpoint of the boundary for each category of IRTs in 0.05 s bins. Thus the 0.325 category contains the percentage of IRTs that were between 0.30 s and 0.349 s in duration. The category furthest to the right includes all IRTs that were 0.975 seconds or longer. Table 3 presents some summary statistics which in conjunction with Figure 3, refine interpretation of the central tendency and variability of the IRT distributions.

For a given pigeon, the IRT frequency distributions present a characteristic profile which is remarkably consistent across conditions. The IRT frequency distributions for Pigeons E1 and E3 tend to be multimodal for all schedules with the exception of the distribution for Pigeon E1 on FR 1/FR 215 *inter* FR 50. For Pigeon E2, the IRT frequency distributions have a single predominant mode, with the most peaked distribution occurring on VR 50. The frequency distribution for Pigeon E4 on VR 50 is the exception to this generalization, with a secondary mode present at longer duration IRTs.

For three of the four pigeons, the modal IRT on VR 50 was longer than the modal IRT on any other schedule studied (the modal IRT was identical for all schedules studied for Pigeon E3). Additionally, IRT distributions for the VR 50 schedule were shifted slightly to longer values when compared to the other schedules studied. This is consistent with the relatively lower overall response rate observed on VR 50 schedules. In general, the distributions for the FR 50 and interpolated FR 50 schedules did not systematically differ from one another across conditions.

Median interresponse time. To provide a general measure of differences in IRT duration across conditions, the right column of Figure 2 displays median IRT duration as a function of the schedule of reinforcement. The error lines intersecting each bar are the quartile ranges of the IRT (25th to 75th percentiles) within the session presented. For a given subject, conditions with no overlap in quartile ranges were judged to differ from one another. Across subjects, conditions were judged to differ when at least three of four subjects showed no overlap in quartile ranges. For all pigeons, the median IRT on VR was consistently longest in absolute duration. Other differences between type of schedule and median IRT duration were either unreliable (overlapping quartile ranges) or inconsistent. Although there were no consistent differences in the within-session quartile range of IRTs for a given schedule (see

Table 3), there were differences in the variability of the median IRT duration across the last five sessions of a condition. Table 4 displays the low and the high median IRT duration for the last five sessions of each condition. For all pigeons, the five-day range of median IRT duration was consistently greater on the VR 50 schedule than on the FR 50 schedule. No other consistent difference in session to session variability of median IRTs was noted.

Cumulative records. Figures 4 through 7 show the cumulative records from the median session for all pigeons in all conditions studied. The number to the right of each cumulative record indicates the order in which a given schedule of reinforcement was presented. The long arrows indicate the location, within a session, of an interpolated FR 1 component. The short arrowhead indicates the location, within a session, of an interpolated FR 215 component.

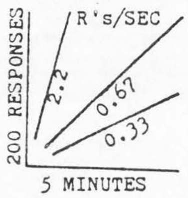
For three of four pigeons (Pigeon E3 is the exception), overall response rates on VR 50, FR 1 _inter_ FR 50 (2), and FR 1/FR 215 _inter_ FR 50 were not substantially different from one another. On all three schedules, pauses which followed reinforcement were brief and pauses within a ratio component were infrequent. For Pigeons E1, E2, and E4, a consistent pause followed reinforcement on the FR 50 schedule. Pausing was apparent early in the ratio for Pigeons E1 and E3 on FR 1 _inter_ FR 50 (for both first and second exposure). Brief pauses followed reinforcement on

Figure 4. Selected cumulative records for Pigeon E1 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 component. The arrowhead indicates the location of the FR 215 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

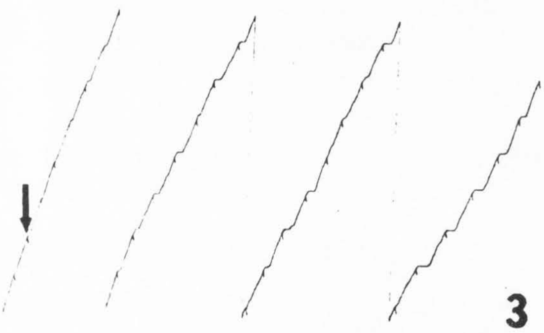
E1

VR 50

2

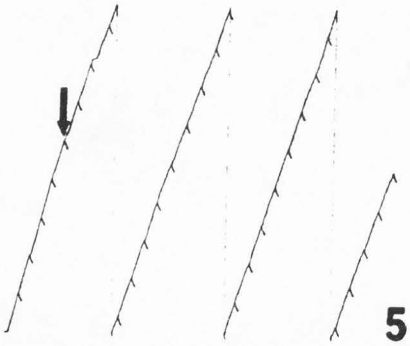


FR 1 INTER FR 50 (1)



3

FR 1 INTER FR 50 (2)



5

FR 1/FR 215 INTER FR 50

4

FR 50

1

Figure 5. Selected cumulative records for Pigeon E2 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 component. The arrowhead indicates the location of the FR 215 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E2

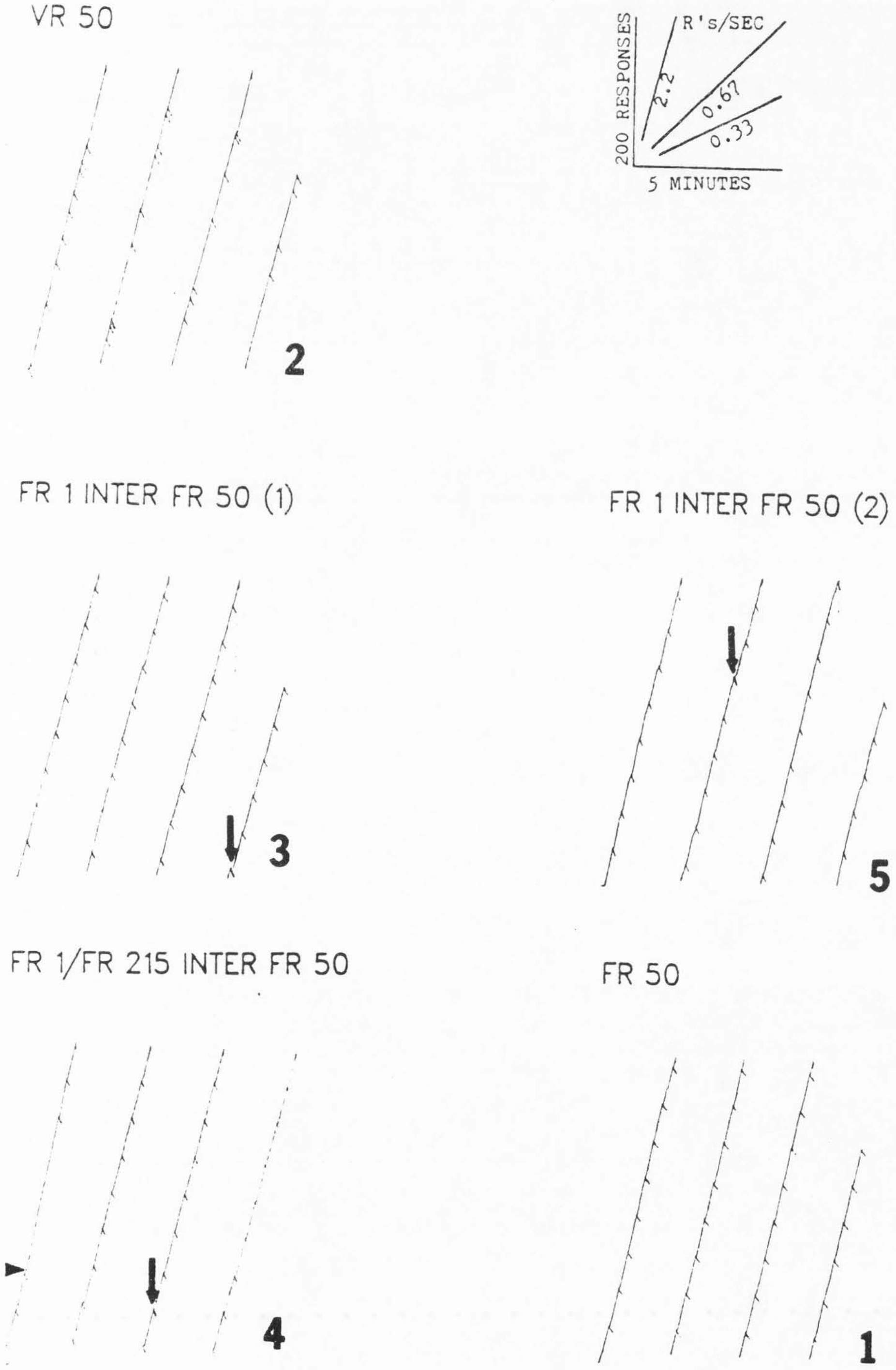
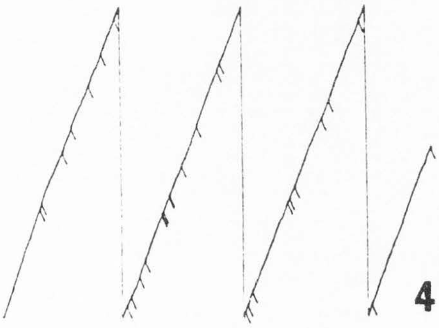
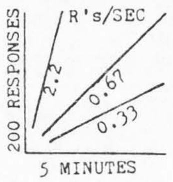

VR 50
R's/SEC
2.2
0.67
0.33
200 RESPONSES
5 MINUTES
2
FR 1 INTER FR 50 (1)
3
FR 1 INTER FR 50 (2)
5
FR 1/FR 215 INTER FR 50
4
FR 50
1

Figure 6. Selected cumulative records for Pigeon E3 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 component. The arrowhead indicates the location of the FR 215 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

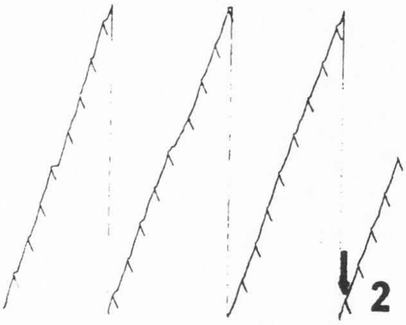
E3

VR 50



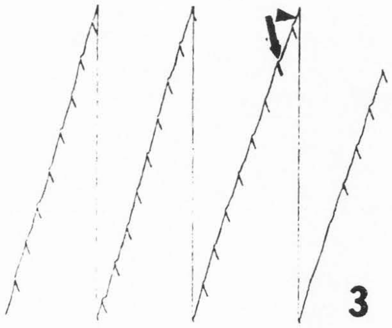


FR 1 INTER FR 50 (1)



FR 1 INTER FR 50 (2)

FR 1/FR 215 INTER FR 50



FR 50

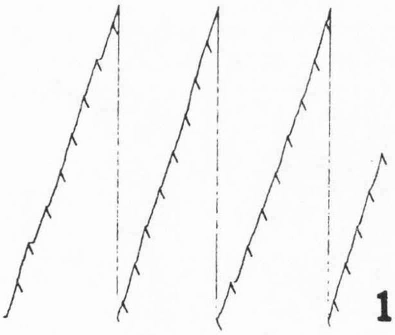
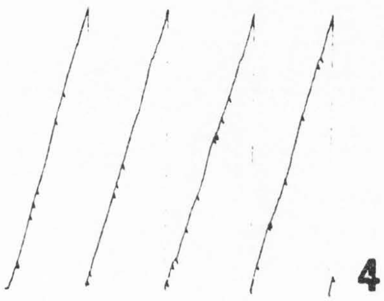
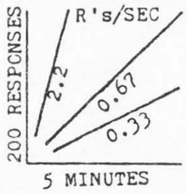


Figure 7. Selected cumulative records for Pigeon E4 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 component. The arrowhead indicates the location of the FR 215 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

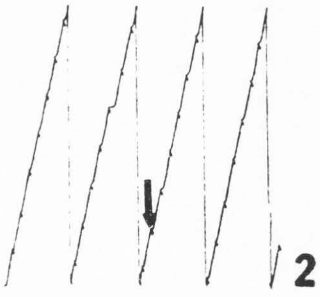
E4

VR 50

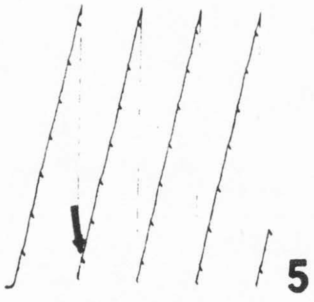




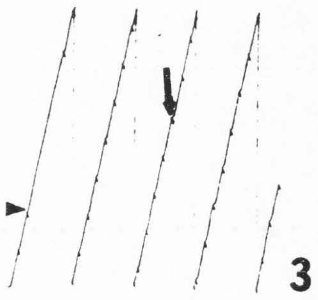
FR 1 INTER FR 50 (1)



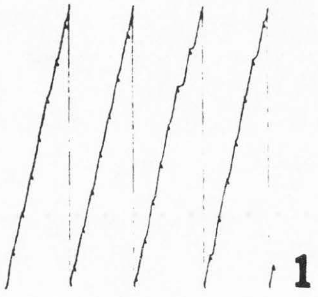
FR 1 INTER FR 50 (2)



FR 1/FR 215 INTER FR 50



FR 50



all schedules for Pigeons E2 and E4.

Cumulative records for Pigeon E3 displayed a pattern of behavior which differed from the pattern presented for the other pigeons. The behavior of Pigeon E3 was most stable on the VR 50 schedule of reinforcement. Behavior on the other schedules included both pauses after reinforcement and irregular response patterns within many ratio components. For example, on the FR 1 inter FR 50 (2) schedule of reinforcement, a minimal duration PRP was followed by a longer pause a few responses into the ratio. The response rate which followed this displaced pause was scalloped, and only slowly accelerated to a high asymptotic rate.

Comparisons Across Schedules in Experiment I

FR 50 and VR 50. Experiment I demonstrated a number of consistent differences on various dependent measures of behavior observed on FR 50 and VR 50 schedules. The overall response rate on the VR 50 schedule was generally slower and the time to complete a session longer than comparable measures of behavior on the FR 50 schedule. Additionally, the median PRP on the VR 50 schedule was shorter and the median IRT was longer on VR 50 than on an FR 50 schedule. The within-session variability of the PRPs (the SIR of the PRP) and the session-to-session range of median PRPs were smaller on the VR 50 than on the FR 50 schedule. There were no differences in the SIR of the IRT between the two schedules, but the session-to-session range of IRTs was greater on VR 50 than on the FR 50 schedule. The mode of the PRP frequency distribution occurred at a shorter value on VR 50, while the mode of the IRT frequency distribution occurred at a longer frequency on VR 50 than on FR 50 schedules. Finally, cumulative records displayed differences in patterning, with a substantial PRP found only on the FR 50 schedule.

VR 50 and FR 1 interpolated FR 50. Experiment I also evaluated the degree of similarity between VR 50 and FR 1 inter FR 50 performance to determine the control exerted by the smallest ratio schedule component present in a schedule of reinforcement. In general, the overall response rate was slower, and the session time longer on VR 50 than on FR 1 inter FR 50 (1 and 2). The median PRP was shorter on VR 50 than on the first exposure to FR 1 inter FR 50; upon second exposure, the two schedules did not differ in median PRP duration. The SIR of the PRP was greater on both FR 1 inter FR 50 schedules than on the VR 50 schedule, but the session-to-session ranges of the median PRPs were not consistently different across conditions. The mode of the PRP frequency distribution for the VR 50 schedule occurred at a shorter value than on FR 1 inter FR 50 (1), but did not consistently differ in location from FR 1 inter FR 50 (2). The median IRT on VR 50 was not consistently different from the median IRT on FR 1 inter FR 50 (1 or 2). Furthermore, the modal

IRT on VR 50 was longer than the modal IRT upon first exposure, but not second exposure to FR 1 inter FR 50 (1). There were no differences between the SIR of the IRT or the session-to-session range of the IRT between the VR 50 and either of the FR 1 inter FR 50 schedules. Thus, with the exception of overall response rate, performance on the VR 50 and the FR 1 inter FR 50 (2) did not consistently differ from one another.

FR 50 and FR 1 interpolated FR 50. Experiment I also evaluated the effect of adding an FR 1 component to an FR 50 schedule to determine the control exerted by the smallest ratio component present in a schedule of reinforcement. The primary difference between the two schedules was in the duration of the PRP. The median PRP on FR 50 was generally longer in duration than the median PRP on FR 1 inter FR 50 (1 and 2). Although the SIR of the PRP on the first exposure to FR 1 inter FR 50 was greater than the SIR on FR 50 (except E2), no consistent differences in the SIRs occurred during the second exposure to FR 1 inter FR 50. The session-to-session range of the median PRP on FR 50 was greater than the comparable range on either FR 1 inter FR 50 schedule. In general, there were no reliable differences between the FR 50 and FR 1 inter FR 50 (1 or 2) schedules of reinforcement in terms of overall response rate, session time, modal PRP, median or modal IRT, SIR of the median IRT, or session-to-session variability of the IRT.

FR 1 interpolated FR 50 and FR 1/FR 215 interpolated FR 50. Experiment I also evaluated the degree of similarity between FR 1 *inter* FR 50 and FR 1/FR 215 *inter* FR 50 performance. The basic issue was to determine what effect a large ratio component (i.e., FR 215) had on the dependent variables of interest. Overall response rate on FR 1/FR 215 *inter* FR 50 was faster than the overall response rate on FR 1 *inter* FR 50 (1) but not consistently different from the overall response rate on FR 1 *inter* FR 50 (2). The modal PRP on FR 1/FR 215 *inter* FR 50 was less than the modal PRP on FR 1 *inter* FR 50 (1), but equal to the FR 1 *inter* FR 50 mode (2). With the exception of Pigeon E2, the SIR of the PRP was greater on FR 1 *inter* FR 50 (1 and 2) than on FR 1/FR 215 *inter* FR 50. Session-to-session variability of the median PRP on FR 1/FR 215 *inter* FR 50 was consistently less than the variability on first exposure to FR 1 *inter* FR 50 (except Pigeon E3), but not on second exposure to FR 1 *inter* FR 50. Other consistent differences were not found between the FR 1/FR 215 *inter* FR 50 and FR 1 *inter* FR 50 (1 and 2) schedules in terms of session time, median PRP, median or modal IRT duration, SIR of the IRT, or session-to-session range of the IRT. Cumulative records of the two schedules displayed more within ratio pausing on the FR 1 *inter* FR 50 (1 and 2) schedule than on the FR 1/FR 215 *inter* FR 50 schedule (except Pigeon E2). Thus, the two schedules primarily differed in overall response rate which the cumulative records suggest was primarily a function of changes in within ratio pausing.

VR 50 and FR 1/FR 215 interpolated FR 50. Experiment I permitted comparison between the VR 50 and the FR 1/FR 215 inter FR 50 to determine the control exerted by both the largest and smallest ratio component present in a session. For all pigeons, the overall response rate was slower, and the session time was longer (with the exception of Pigeon E2) on the VR 50 than on the FR 1/FR 215 inter FR 50 reinforcement schedule. While there were no consistent differences in the modal PRP on the two schedules, the median PRP, the SIR of the median PRP, and the session-to-session range of the median PRP was greater on the VR 50 schedule than on the FR 1/FR 215 inter FR 50 reinforcement schedule (with the exception of Pigeon E1). For all pigeons, the median IRT and the SIR of the median IRT was greater on VR 50 than on FR 1/FR 215 inter FR 50. In general, the modal IRT (with the exception of Pigeon E2) and the session-to-session range of the median IRT (with the exception of Pigeon E3) was greater on VR 50 than on FR 1/FR 215 inter FR 50. Cumulative records of the two schedules displayed no large, reliable differences in response patterns between the VR 50 and the FR 1/FR 215 inter FR 50 schedules. These differences suggest that the addition of the FR 215 component to the FR 1 inter FR 50 schedule reduced PRP and IRT durations relative to the durations evoked by the VR 50 schedule.

Summary of Results of Experiment I

A fundamental difference between VR and FR schedule performances is the relatively shorter PRP duration emitted on the VR schedule. The major finding of Experiment I was that the addition of a single, FR 1 component to an FR 50 schedule reduced the median PRP duration from that found on the FR 50 schedule. On first exposure to the FR 1 *inter* FR 50 schedule, PRP duration was longer than on VR 50, but shorter in duration than on FR 50. Upon second exposure to the FR 1 *inter* FR 50 schedule, there were no reliable differences in median PRP duration between the FR 1 *inter* FR 50 and the VR 50 schedules. Consistent differences in median PRP or IRT duration were not observed between the schedule containing only an interpolated FR 1 component and the interpolated schedule with both an FR 1 and an FR 215 component. However, there were consistent differences in median PRP and IRT durations between the VR 50 and the FR 1/FR 215 *inter* FR 50 schedules.

Additional measures of session performance were compared across schedules to isolate sources of differential control between VR from FR performances. When evaluated across measures of behavior on the FR 50 schedule, the addition of the FR 1 component decreased the duration of the modal PRP, reduced the variability of the median PRP across sessions, but increased the SIR of the median PRP within sessions. When contrasted with measures of behavior on the

FR 50 schedule, the VR 50 schedule also decreased the modal PRP, decreased overall response rate, increased session-to-session variability of the PRP and did not differ in the within-session SIR of the median PRP. While the median IRT on FR 50 was shorter in duration than the median IRT on the VR 50 schedule, the interpolation of the FR 1 component resulted in no large, reliable differences in median IRT duration between the FR 1 inter FR 50 and the VR 50 schedules.

Discussion

A fundamental difference between VR and FR schedule performance is the relatively briefer PRP duration emitted on the VR schedule. The major finding of Experiment I was that the addition of a single, FR 1 component to an FR 50 schedule reduced the median PRP duration from that found on the FR 50 schedule. On first exposure to the FR 1 inter FR 50 schedule, PRP duration was longer than on VR 50, but shorter in duration than on FR 50. Upon second exposure to the FR 1 inter FR 50 schedule, there were no reliable differences in median PRP duration between the FR 1 inter FR 50 and the VR 50 schedules. Consistent differences in median PRP or IRT duration were not observed between the schedule containing only an interpolated FR 1 component and the interpolated schedule with both an FR 1 and an FR 215 component. However, there were consistent differences in median PRP and IRT durations between the VR 50 and the FR 1/FR 215 _inter_ FR 50 schedules.

The addition of an FR 215 component to the FR 1 _inter_ FR 50 schedule reduced PRP and IRT durations below those found on a comparably-sized VR 50 schedule. On VR 50, overall response rate was slower than on the FR 1/FR 215 _inter_ FR 50 schedule. A host of dependent variables (session time, median PRP, median IRT, session-to-session range of the median PRP, session-to-session range of the median IRT, SIR of the PRP and IRT, and modal IRT) were greater on the VR 50 than on the FR 1/FR 215 _inter_ FR 50 schedule. That is, all dependent measures (save modal PRP) used to contrast VR 50 performance from FR 1/FR 215 _inter_ FR 50 performance demonstrated differences in the behavior evoked by the two schedules.

Because the interpolation of the FR 1 component primarily controlled PRP duration, and because together the FR 1 and FR 215 components controlled both PRP and IRT duration, it could be assumed that a period of locally low reinforcement density interacts with the control exerted by the smallest ratio component to further reduce PRP duration. This reduction in PRP duration can be conceptualized as an example of positive induction, if the definition of induction is extended to include the comparison between PRP durations across conditions, as opposed to the traditional comparison between response rates within a session (e.g., multiple VI VI).

Positive induction is an increase in response rate in an unchanged schedule component which accompanies an increase in response rate in the changed component of multiple or concurrent schedules (Schwartz & Gamzu, 1977). In the context of Experiment I, positive induction is defined as any interaction between the ratio components comprising the schedule of reinforcement in which a decrease in PRP duration associated with the introduction of an interpolated schedule component reduces overall PRP duration relative to the duration evoked without the presence of the interpolated component. It is assumed that local effects produced by the FR 1 component modulate overall responding in such a way as to later determine overall response rates.

In general, Experiment I demonstrated that the schedule component with the highest local density of reinforcement, or the shortest delay to reinforcement, exerted predominant control over PRP duration on a moderately-sized ratio schedule. This conclusion is in opposition to the Mean-Ratio Hypothesis (Ferster & Skinner, 1957) which predicts that the interpolated schedules (all with identical mean ratios of 48.4) would produce similar PRP durations to those found on the baseline FR 50 schedule. Although the mean values of the interpolated ratio components were all approximately equal, mean PRP durations differed between the FR 50 and interpolated reinforcement schedules.

CHAPTER IV

EXPERIMENT II: CONTROL OF PRP DURATION BY THE HIGH-DENSITY, RESPONSE-DEPENDENT COMPONENT

When an FR 1 component is added to a session of 30 FR 50 components, a number of variables are simultaneously altered. Experiment I demonstrated that the interpolation of an FR 1 component on a baseline of FR 50 components reliably reduced PRP duration from that found on an FR 50 schedule. The purpose of Experiment II was to determine whether the response dependency in the FR 1 component was a necessary variable in reducing PRP duration, or whether the introduction of a short IRI was a sufficient condition for reducing PRP duration. Table 5 provides a summary of the variables which were investigated in Experiment II.

Method

Subjects and Apparatus.

Five experimentally-naive, common barn pigeons (age and gender unknown) served. Pigeons were food deprived and housed as described in the procedure section of Experiment I. The apparatus was the same as that used in Experiment I.

Procedure

Training. Pigeons were trained to key peck on a VR 40 reinforcement schedule as described in the Procedure section

Table 5

Matrix of Variables and Reinforcement Schedules Investigated in Experiment II

		Response Dependency	
		Present	Absent
Short Interreinforcement Interval	Present	FR 1 *inter* FR 50	FT 1 s *inter* FR 50
	Absent	FR 50	FT (Blackout) *inter* FR 50

in Experiment I. Pigeons were exposed to each training schedule for one session.

Experimental Phases

Following completion of the training phase, Experiment II consisted of five conditions. The FR 50 condition and the FR 1 *inter* FR 50 condition were identical to those described in Experiment I. Table 6 summarizes the order of conditions for the five pigeons.

Fixed-time interpolated FR 50. Five pigeons were exposed to a FT 1 s *inter* FR 50 schedule of reinforcement. Each session was conducted as described for the FR 1 *inter* FR 50 condition with one modification. Pigeons were exposed to a fixed-time 1 sec (FT 1 s) component instead of an FR 1 component. The FT procedure was conducted in the following manner. Following reinforcement, the red, center response key was transilluminated. When 1 s elapsed, the hopper was illuminated and raised for 3 s. The session then continued with FR 50 components until the food-hopper had been presented 31 times. This brief FT schedule component reduced the liklihood that a key-peck would occur contiguously with reinforcement. Daily placement of the FT 1 s component was identical to the daily placement of the FR 1 component used in the FR 1 inter FR 50 condition. (See Appendix B). Thus, with reinforcement density and session location of the short IRI the same as that found in the FR 1 *inter* FR 50 condition, the interpolated schedules in

Table 6

Summary of Conditions for Each Subject in Experiment II

Order	Conditions		
	Bird 5 and 6	Bird 7 and 8	Bird 13
1.	FR 50 (1)	FR 50 (1)	FT (Blackout) *inter* FR 50
2.	FT 1 s *inter* FR 50	FT (Blackout) *inter* FR 50	FT 1 s *inter* FR 50 (1)
3.	FT (Blackout) *inter* FR 50	FT 1 s *inter* FR 50	FR 1 *inter* FR 50
4.	FR 1 *inter* FR 50	FR 1 *inter* FR 50	FR 50
5.	FR 50 (2)	FR 50 (2)	FR 1 *inter* FR 50 (2)

the two conditions differed only in response dependency.

Fixed-time (blackout) interpolated FR 50. The five pigeons were also exposed to a fixed-time (blackout) inter FR 50 schedule of reinforcement. Each session was conducted as described in the fixed-time 1 s (FT 1 s) condition with one modification. Pigeons were exposed to a single FT component with a relatively long temporal delay (blackout) present between the lowering of the hopper and subsequent hopper lift. The FT (blackout) procedure operated in the following way. After the hopper was lowered, the chamber was darkened for a period of time identical to the duration of the IRI in the previous FR 50 schedule component. The duration of the IRI was computed as the time elapsed between the lowering of the hopper and the raising of the hopper for the next reinforcement. Following this blackout, the houselight and response key were again illuminated for one second. The response key was then darkened, and the food-hopper was raised for three seconds. A response during this one-second period had no scheduled consequence. Sessions ended following 31 hopper presentations. Daily location of the FT (blackout) component matched the locations of the FT 1 s component used in the FT 1 s inter FR 50 condition. (See Appendix B). Thus, the absence of a response dependency in the FT (blackout) component matched that found in the FT 1 s inter FR 50 condition. The FT 1 s and FT (blackout) conditions differed in reinforcer density (the presence or absence of a short IRI, respectively) and blackout duration.

Stability criteria. Decisions for changing conditions were controlled by the stability rules described in Experiment I for PRP stability.

Results

As in Experiment I, this analysis is based on data derived from the session which contained the median PRP of the last 5 sessions (the median session). Although more likely to highlight variability within a session, this approach is preferable since it preserves the stream of behavior typical of each individual subject. The SIR of the PRP and IRT for each bird, on each condition, are presented as measures of within-session variability. As a measure of session-to-session variability, the last five-day ranges for median PRP and median IRT are presented for each bird on each schedule investigated in Experiment II.

The following analysis presents comparisons of behavior on various schedules of reinforcement for each dependent variable studied. The primary comparisons which were carried out for each dependent variable were between schedules with and without response-independent reinforcement and between schedules with and without a short inter-reinforcement interval (IRI).

Session Measures

Overall response rate. The overall response rates for each subject on each ratio schedule are presented in Table 7. The overall response rate was calculated by dividing the number of responses by the sum of PRP and IRT durations. The hopper duration, response duration, and warm-up pause were excluded from the overall response rate calculation. The control exerted by response-independent reinforcement was evaluated by comparing overall response rates on schedules with an interpolated response-dependent component (the FR 1 *inter* FR 50 and FT 1 s *inter* FR 50) with the overall response rates on schedules with a response-independent component (the FT (blackout) *inter* FR 50 and FR 50 (1 and 2). In general, response-independent reinforcement had no effect on overall response rate when it was delivered following a short IRI, but had an inhibitory effect when it was delivered following a long IRI. That is, overall response rate on FR 1 *inter* FR 50 and FT 1 s *inter* FR 50 did not consistently differ. However, the overall response rate on FT (blackout) *inter* FR 50 was consistently slower than the overall response rate on FR 50 (2) (with the exception of Pigeon E7). There were no large, reliable differences between FR 50 (1) and FT 1 s *inter* FR 50, nor between FR 50 (1) and FT (blackout) *inter* FR 50.

The control exerted by the presence or absence of a short IRI was evaluated independent of whether the IRI was

Table 7

Summary Statistics for Experiment II Computed from the Median PRP Session from the Last Five Sessions of Each Condition

Subject	Condition	Sequence of Conditions	Sessions	Overall response rate (R's/s)	Session Time (min)
E5	FR 50 (1)	1	23	2.16	21.52
	FT (1 s)	2	22	2.48	19.39
	FT (Blackout)	3	22	2.48	20.51
	FR 1	4	25	2.66	18.07
	FR 50 (2)	5	28	2.52	18.80
E6	FR 50 (1)	1	23	2.50	18.87
	FT (1 s)	2	22	2.38	20.02
	FT (Blackout)	3	25	2.30	21.03
	FR 1	4	25	2.43	19.61
	FR 50 (2)	5	25	2.63	18.06
E7	FR 50 (1)	1	22	1.80	25.46
	FT (1 s)	3	25	1.04	41.95
	FT (Blackout)	2	28	1.72	27.44
	FR 1	4	23	1.79	25.54
	FR 50 (2)	5	29	1.41	31.80

(table continues)

Subject	Condition	Sequence of Conditions	Sessions	Overall response rate (R's/s)	Session Time (min)
E8	FR 50 (1)	1	24	2.19	21.30
	FT (1 s)	3	22	2.24	21.04
	FT (Blackout)	2	21	2.07	23.42
	FR 1	4	25	2.06	22.75
	FR 50 (2)	5	27	2.44	19.25
E13	FR 50	4	25	1.59	28.30
	FT (1 s)	2	25	1.91	24.06
	FT (Blackout)	1	25	1.75	32.77
	FR 1 (1)	3	27	1.91	24.13
	FR 1 (2)	5	29	2.21	21.17

response-dependent or response-independent. Overall response rate on FR 1 *inter* FR 50 did not differ from rates on either FR 50 schedule. Overall response rates on FT 1 s *inter* FR 50 did not differ from the rates on FR 50 (1), but were lower than rates on FR 50 (2) for all pigeons. Finally, there were no reliable differences in overall response rates between FT 1 s *inter* FR 50 and FT (blackout) *inter* FR 50 reinforcement schedules.

Session time. Session times among reinforcement schedules were compared and are presented in Table 7. Session time was calculated as the time elapsed between the initiation and termination of the experimental session. Temporal periods absent from the overall response rate measure but encompassed in the calculation of session time included (1) the warm-up pause which begins a session, (2) hopper duration, and (3) response duration. Any difference between the overall response rate measure and session time data is attributable to at least one of these three temporal periods. The control exerted by the response dependency was evaluated by comparing session times on response-dependent (the FR 1 *inter* FR 50 and FR 50) and response-independent (FT 1 s *inter* FR 50 and FT (blackout) *inter* FR 50) reinforcement schedules. With the exception of Pigeon E7, session time on FT (blackout) *inter* FR 50 was longer than on FR 50 (2). There was no reliable difference in session time between FT (blackout) *inter* FR 50 and FR 50, nor between FR

1 _inter_ FR 50 and FT 1s _inter_ FR 50.

The control exerted by the presence or absence of a short IRI was also evaluated independently of response dependency. Overall session times on FR 1 _inter_ FR 50 did not differ from session times on either FR 50 schedule. For all pigeons, the session time on FT 1 s _inter_ FR 50 was shorter than the session time on FR 50 (2), but not FR 50 (1). With the exception of Pigeon E7, the session time on FT 1 s _inter_ FR 50 was shorter than the session time on FT (blackout) _inter_ FR 50. These results are consistent with the overall response rate data and suggest that the warm-up pause, the duration of the response, and hopper time did not differentially control behavior on the schedules compared.

PRP frequency distributions. Figure 8 displays plots of the relative frequencies of PRPs (in 0.5 s categories) from the median session for all pigeons in all conditions. The labels on the abscissa represent the midpoint of the boundary for each category of PRPs. Thus the 3.25 category contains the percentage of PRPs that were between 3.0 s and 3.495 s in duration. The rightmost category includes all PRPs that were 9.75 seconds or longer. Table 8 presents some summary statistics which, in conjunction with Figure 8, refine interpretation of the central tendency and variability of the PRP distributions.

The modal values of the PRP frequency distributions were generally consistent across all schedules for all

Figure 8. Relative frequency distributions of PRPs for each subject for each condition studied in Experiment II. Bin size was 0.5 seconds. Values on the X axis are the midpoints of the class intervals or "bins". The last bin includes all PRPs greater than, or equal 9.75 seconds. Note that the condition in the bottom column for Pigeon E13 is differs from the last condition presented for the other subjects.

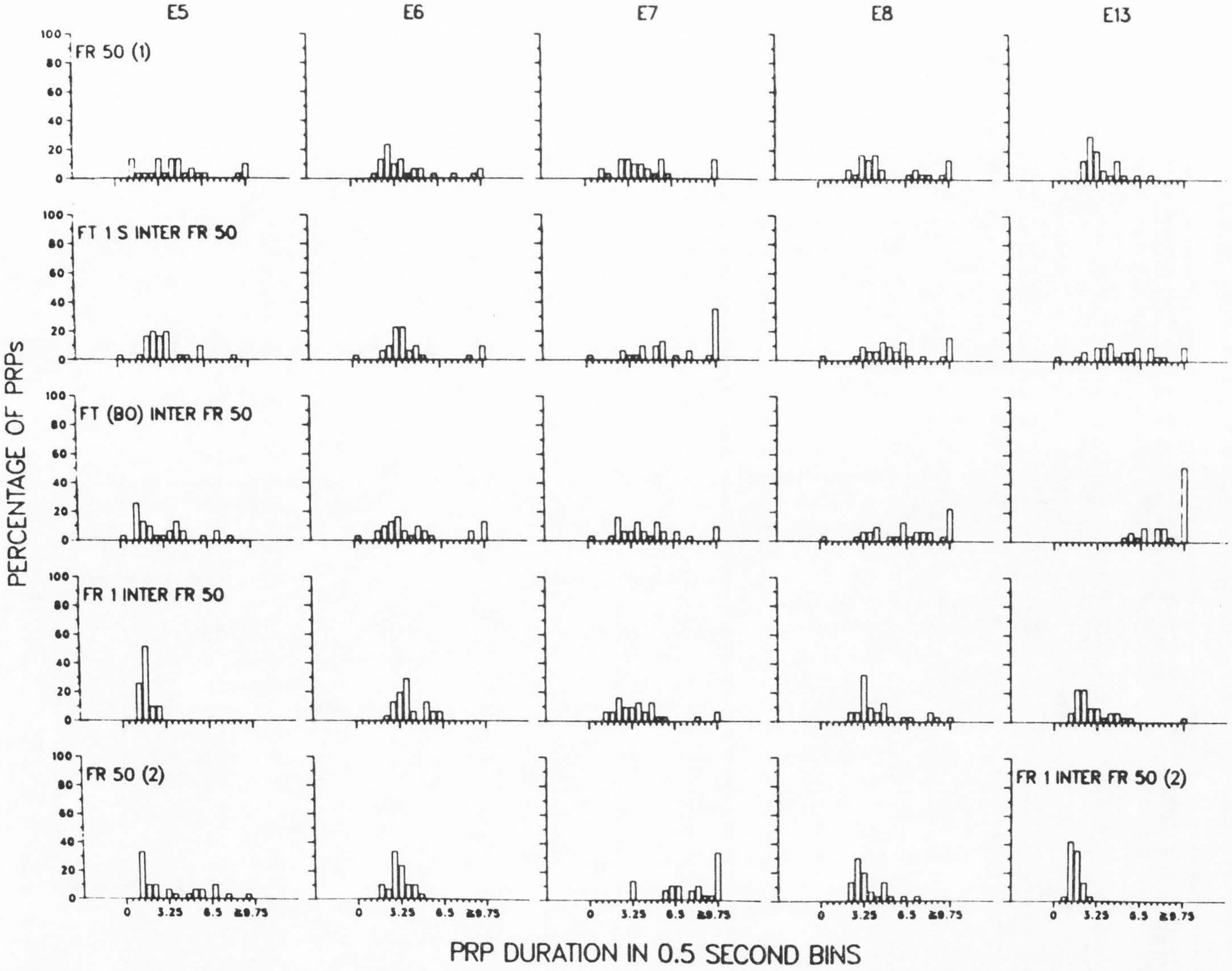

E5
E6
E7
E8
E13
FR 50 (1)
FT 1 S INTER FR 50
FT (BO) INTER FR 50
FR 1 INTER FR 50
FR 50 (2)
FR 1 INTER FR 50 (2)
PERCENTAGE OF PRPs
0
20
40
60
80
100
0
3.25
6.5
≥9.75
PRP DURATION IN 0.5 SECOND BINS

Table 8

Summary of Central Tendency and Variability Measures for Experiment II Computed from the Median PRP Session

		PRP			IRT		
Subject	Condition	Mdn	SIR	Mode	Mdn	SIR	Mode
E5	FR 50 (1)	4.11	1.61	2.25 3.25 4.25 4.75	0.31	0.02	0.33
	FT (1 s)	3.15	0.88	2.25 3.75	0.33	0.02	0.33
	FT (Blackout)	2.11	2.17	1.25	0.34	0.02	0.33
	FR 1	1.67	0.33	1.75	0.33	0.02	0.33
	FR 50 (2)	2.21	2.15	1.25	0.33	0.01	0.33
E6	FR 50 (1)	3.45	1.15	2.75	0.31	0.01	0.33
	FT (1 s)	3.63	1.18	3.25 3.75	0.31	0.02	0.33
	FT (Blackout)	3.51	2.26	3.25	0.31	0.03	0.33
	FR 1	3.77	1.42	3.75	0.31	0.02	0.33
	FR 50 (2)	2.99	0.49	2.75	0.31	0.03	0.33
E7	FR 50 (1)	4.17	1.40	2.75	0.40	0.05	0.38

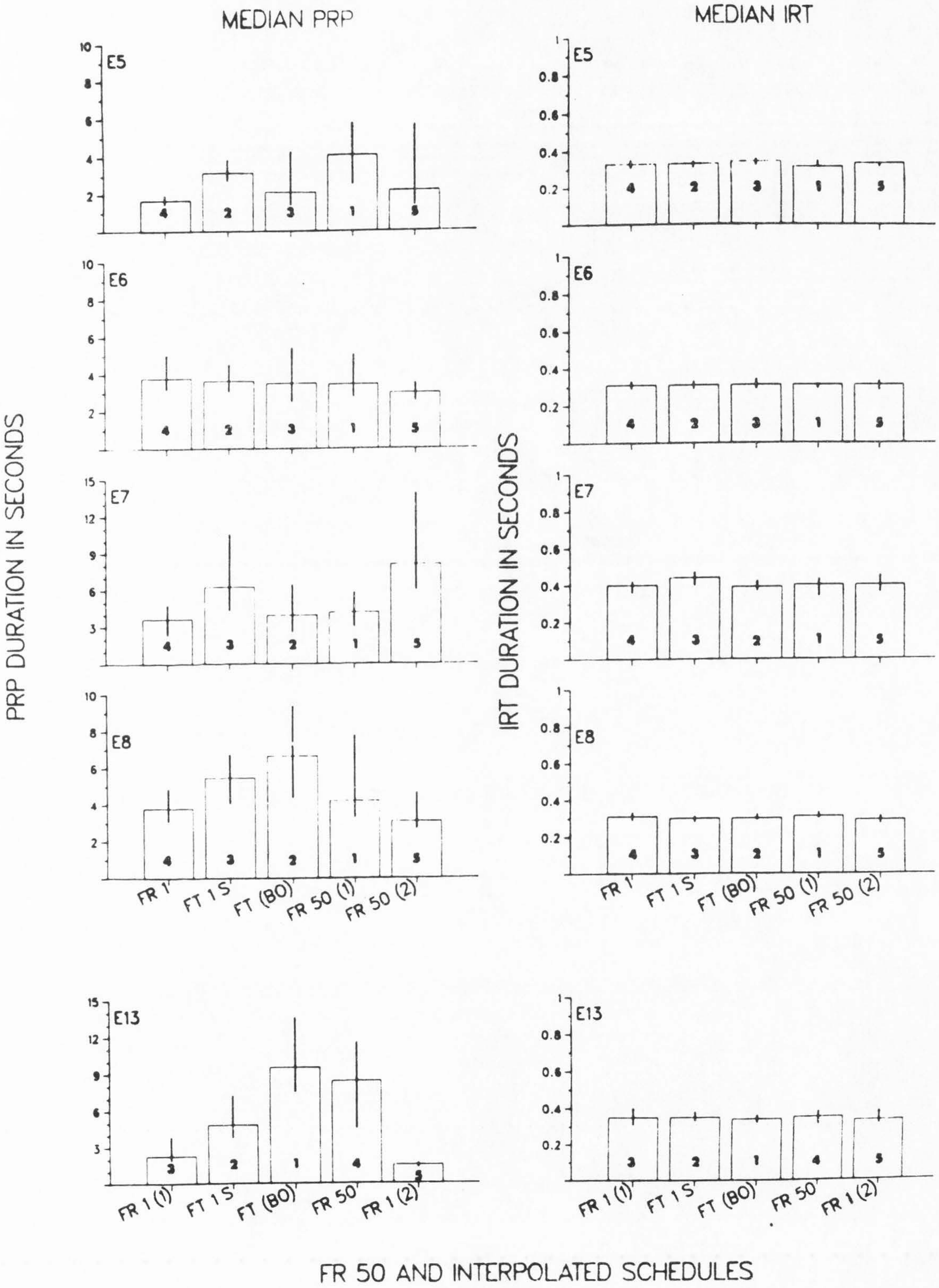
(table continues)

Subject	Condition	PRP			IRT		
		Mdn	SIR	Mode	Mdn	SIR	Mode
				3.25			
				5.75			
	FT (1 s)	6.24	6.81	5.75	0.44	0.04	0.43
	FT (Blackout)	3.94	2.24	2.75	0.39	0.03	0.38
	FR 1	3.63	1.77	2.25	0.40	0.03	0.38
	FR 50 (2)	8.06	3.92	3.25	0.40	0.05	0.43
E8	FR 50 (1)	4.20	2.22	3.25	0.31	0.02	0.33
	FT (1 s)	5.46	2.51	4.75	0.30	0.02	0.28
				6.25			
	FT (Blackout)	6.64	4.25	6.25	0.30	0.02	0.33
	FR 1	3.79	1.40	3.25	0.31	0.02	0.28
	FR 50 (2)	3.08	0.98	2.75	0.29	0.02	0.43
E13	FR 50	8.89	3.50	8.75	0.35	0.04	0.33
	FT (1 s)	4.86	2.60	4.25	0.35	0.03	0.33
	FT (Blackout)	9.55	4.97	6.75	0.34	0.02	0.33
				7.75			
				8.25			
				9.75			
	FR 1 (1)	2.28	1.51	1.75	0.35	0.05	0.33
				2.25			
	FR 1 (2)	1.53	0.28	1.25	0.35	0.05	0.33

pigeons (with the exception of Pigeon E5). Despite these consistencies, some prominant differences which should be noted. Differences in modal value, as a function of presence or absence of a response dependency, were evaluated through comparison of the modal values (presented in Table 8) on response-dependent and response-independent reinforcement schedules. The modal value of the PRP on FR 1 *inter* FR 50 was generally shorter in duration than the modal PRP value on FT 1 s *inter* FR 50 (with the exception of Pigeon E6). There were no differences in modal PRP value between FR 50 (1 and 2) and FT (blackout) *inter* FR 50 reinforcement schedules.

Median post-reinforcement pause duration. To provide a general measure of changes in PRP duration across conditions, the left column of Figure 9 displays median PRP duration as a function of the schedules of reinforcement studied in Experiment II. The error lines intersecting each bar are the quartile ranges of the PRP (25th to 75th percentiles) within the session presented. This measure of variability, or error term, is required to evaluate the reliability of differences in absolute duration among median PRP durations. The judgment of a difference between conditions was based on whether there was any overlap between the quartile ranges of the median PRP duration for two conditions. For an individual subject, any overlap in quartile ranges of the PRP between conditions were not

Figure 9. Median PRP and median IRT duration as a function of FR 50, and interpolated schedules for all subjects in Experiment II. The error line intersecting each bar represents the quartile range for that condition. The number inside each bar represents the order in which the bird was exposed to a particular condition. Note the different ordinate scale for Pigeons E7 and E13 on the the PRP figure. Also note that Bird E13 was exposed to an FR 1 inter FR 50 (2), whereas the other pigeons were exposed to an FR 50 (2).


MEDIAN PRP
MEDIAN IRT
PRP DURATION IN SECONDS
IRT DURATION IN SECONDS
E5
E6
E7
E8
E13
10
8
6
4
2
15
12
9
6
3
1
0.8
0.6
0.4
0.2
4
2
3
1
5
FR 1
FT 1 S
FT (BO)
FR 50 (1)
FR 50 (2)
FR 1 (1)
FR 50
FR 1 (2)
FR 50 AND INTERPOLATED SCHEDULES

judged to be reliably different from one another. Across subjects, two conditions were considered reliably different from one another if the data from four of five pigeons displayed no overlap in quartile ranges for that condition.

The importance of a response dependency is evaluated by comparing median PRP durations emitted on response-dependent (the FR 1 *inter* FR 50 and FR 50) and response-independent (FT 1 s *inter* FR 50 and FT (blackout) *inter* FR 50) reinforcement schedules. In general, the median PRP evoked by the interpolated FR 1 was shorter in duration than either the median PRP on the FT 1 s (except Pigeon E6), or the median PRP on the FT (blackout) *inter* FR 50 schedules. However, the overlap of quartile ranges among conditions makes even this difference unreliable. Thus, these data should be cautiously interpreted as suggesting that a response dependency in the interpolated component is a necessary condition for reducing overall median PRP duration.

The control over PRP durations exerted by the short IRI was also evaluated independently of whether the interpolated component was response-dependent or response-independent. Differences in median PRP duration were not systematically related to whether a short IRI was present in the interpolated schedule. Other comparisons between schedules also showed no reliable differences. There were no reliable differences in median PRP durations between the two response-indepedendent schedules, nor between the response-dependent schedules. Additionally, there were no reliable differences in PRP duration between the FR 50 (1 or 2) and the FT (blackout) _inter_ FR 50 schedules. Thus, the presence of a response dependency in the interpolated component reduced median PRP duration, whereas, the response-independent condition did not reduce median PRP duration.

Semi-interquartile range of the median PRP. A measure of the the amount of variability in PRP duration within the median session for each bird in each condition are presented in the PRP SIR column in Table 8. The control exerted by the presence of a response dependency was evaluated by comparing the SIRs on response-dependent reinforcement schedules (the FR 1 _inter_ FR 50 and FR 50) to the SIRs on response-independent (FT 1 s _inter_ FR 50 and FT (BO) _inter_ FR 50) reinforcement schedules. The SIR of the PRP was greater on the FR 1 _inter_ FR 50 than on FT 1 s _inter_ FR 50 (with the exception of Pigeon E6) reinforcement schedule. On first exposure to the FR 50 schedule, the SIR of the PRP was greater than on FT (blackout) _inter_ FR 50 for all pigeons. There were no consistent differences between the SIR of the PRP on FR 50 (2) and FT (blackout) _inter_ FR 50.

The control over the SIR of the PRP duration exerted by the short IRI was also evaluated independently of whether the interpolated component was response-dependent or response-independent. The SIR of the PRP on FT 1 s _inter_ FR 50 was consistently greater than the SIR on second exposure to FR 50 (with the exception of Pigeon E5), but was not consistently different from the SIR on FR 50 (1). Additionally, there were no consistent differences between the value of the SIR on FR 1 _inter_ FR 50 and FR 50 (1 or 2). With the exception of Pigeon E7, the SIR of the PRP on FT 1 s _inter_ FR 50 was less than the SIR on FT (blackout) _inter_ FR 50.

Five-day variability of the median PRP. The low and high values of the median PRP duration over the last five days of each condition are presented in Table 9. The five-day range of the median PRP duration was computed as the absolute difference between the low and high PRP duration. In terms of response dependency, there were no differences in session-to-session variability of the median PRP between the FT 1 s _inter_ FR 50 and the FR 1 _inter_ FR 50 schedules. The five-day range of the median PRP was greater on FT (blackout) _inter_ FR 50 than on the second exposure to the FR 50 schedule (except Pigeon E5), but not different from the five-day range on FR 50 (1). The five-day range of the median PRP was also evaluated, independently of response-dependency, to further determine the control exerted by the short IRI component. The value of the five-day range of the median PRP was generally less on FR 50 (2) than on FR 1 _inter_ FR 50 (with the exception of Pigeon E5, but greater than the median PRP range across sessions on FT 1 s _inter_ FR 50. There were no consistent differences in the five-day range

Table 9

Low and High Duration of the Median PRP and Median IRT (Last Five Sessions) for Each Schedule Studied in Experiment II.

Sub- ject	Condi- tion	*Median PRP in s*		*Median IRT in s*	
		Low	High	Low	High
E5	FR 50 (1)	3.17	4.72	0.31	0.33
	FT (1 s)	2.76	3.28	0.33	0.33
	FT (Blackout)	1.94	2.48	0.32	0.34
	FR 1	1.56	1.70	0.33	0.33
	FR 50 (2)	1.68	2.48	0.33	0.33
E6	FR 50 (1)	3.30	3.73	0.30	0.31
	FT (1 s)	3.57	4.25	0.31	0.31
	FT (Blackout)	3.25	4.47	0.30	0.31
	FR 1	3.16	4.04	0.31	0.31
	FR 50 (2)	2.77	3.55	0.29	0.31
E7	FR 50 (1)	3.27	4.18	0.40	0.42
	FT (1 s)	5.33	8.70	0.42	0.44
	FT (Blackout)	3.10	7.24	0.39	0.41
	FR 1	2.44	6.97	0.40	0.40
	FR 50 (2)	5.99	9.34	0.40	0.40
E8	FR 50 (1)	3.31	4.99	0.31	0.31
	FT (1 s)	5.21	6.19	0.29	0.30
	FT (Blackout)	5.52	9.99	0.29	0.30

(table continues)

Subject	Condition	Median PRP in s		Median IRT in s	
		Low	High	Low	High
E13	FR 1	3.60	4.83	0.29	0.31
	FR 50	2.52	4.14	0.29	0.29
	FR 50	5.77	14.49	0.34	0.36
	FT (1 s)	3.09	5.37	0.33	0.35
	FT (Blackout)	7.61	13.17	0.34	0.34
	FR 1 (1)	2.17	3.31	0.33	0.35
	FR 1 (2)	1.37	1.65	0.33	0.36

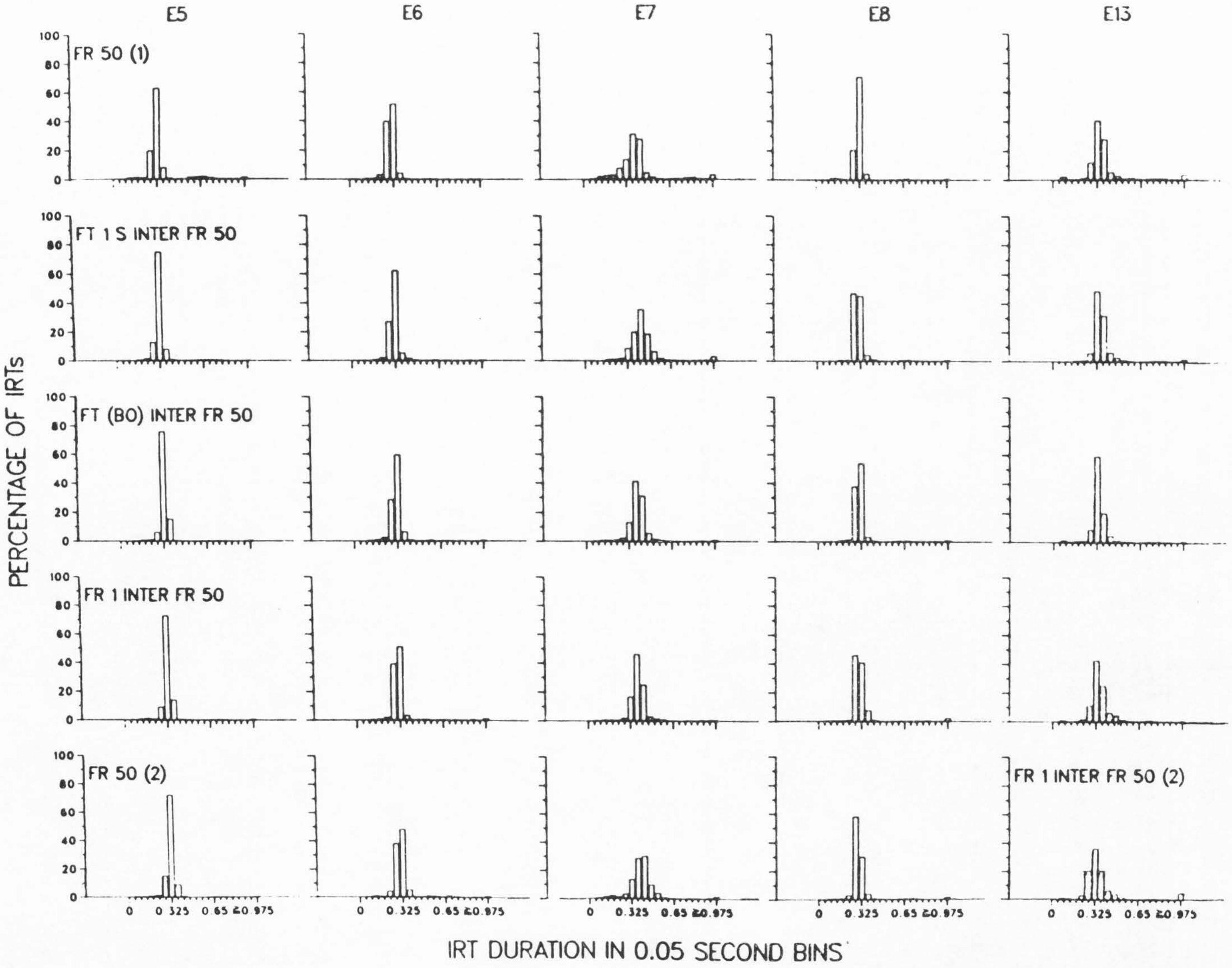
of the median PRP duration between FR 50 (1) and FR 1 *inter* FR 50, nor between FR 50 (1) and FT 1 s *inter* FR 50.

IRT frequency distributions. Figure 10 displays the relative frequency distributions of IRTs (in 0.05 s categories) from the median session for all pigeons in each condition. The labels on the abscissa represent the midpoint of the boundary for each category of IRTs, thus the 0.325 category contains the percentage of IRTs that were between 0.30 s and 0.349 s in duration. The category furthest to the right includes all IRTs that were 0.975 seconds or longer.

With the exception of Pigeon E7, the overall shape and variability of the IRT frequency distributions were remarkably consistent across all schedules for all pigeons. Although Pigeons E7 and E8 had nonsystematic, one-bin shifts in modal IRT under two conditions, the modal IRT was identical on all conditions for Pigeons E5, E6, and E13. This suggests that (1) the shape of the IRT frequency distribution was independent of whether the interpolated component was response-independent or response-dependent, and (2) the shape of the IRT frequency distribution was independent of whether the interpolated component was short or long in duration, and (3) the modal value of the median IRT was also independent of response dependency and the presence of a short inter-reinforcement interval.

Median interresponse time. To provide a general

Figure 10. Relative frequency distributions of IRTs for each subject for each condition studied in Experiment II. The session selected for presentation was the session, from the last five sessions in a condition, which contained the median of the median PRP. Bin size was 0.05 seconds. Values on the X axis are the midpoints of the class intervals or "bins". The last bin includes all PRPs greater than, or equal 0.975 seconds. Note that the condition in the bottom column for Pigeon E13 is differs from the last condition presented for the other subjects.


E5
E6
E7
E8
E13
FR 50 (1)
FT 1 S INTER FR 50
FT (BO) INTER FR 50
FR 1 INTER FR 50
FR 50 (2)
FR 1 INTER FR 50 (2)
PERCENTAGE OF IRTs
0
20
40
60
80
100
0
0.325
0.65
≥0.975
IRT DURATION IN 0.05 SECOND BINS

measure of any change in IRT duration across conditions, the right column of Figure 9 displays median IRT duration as a function of the schedule of reinforcement. The error lines intersecting each bar are the quartile ranges of the IRT (25th to 75th percentiles) within the session presented. For a given subject, conditions with no overlap in quartile ranges were judged to differ from one another. Across subjects, conditions were judged to differ when at least four of five subjects showed no overlap in quartile ranges. For all pigeons, there were no consistent differences among reinforcement schedules in the value of the median IRT, the size of the SIR of the median IRT, or the five-day range range of the median IRT.

Cumulative records. Figures 11 through 15 show the cumulative records from the median session for all pigeons in all conditions studied. The number to the right of each cumulative record indicates the order in which a given schedule of reinforcement was presented. The long arrows indicate the location, within a session, of an interpolated FR 1 or FT 1 s component. The short arrowhead indicates the location, within a session, of an interpolated FR 215 component.

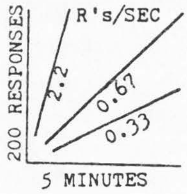
While the cumulative record is useful as a visual record of the ongoing stream of behavior which occurred on the various reinforcement schedules studied, comparisons across pigeons of these temporal records of responding

Figure 11. Selected cumulative records for Pigeon E5 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 and FT 1 s components. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E5

FR 1 INTER FR 50

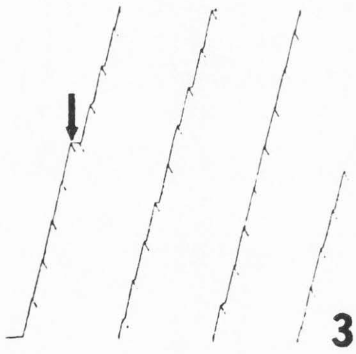
4



FT 1 S INTER FR 50

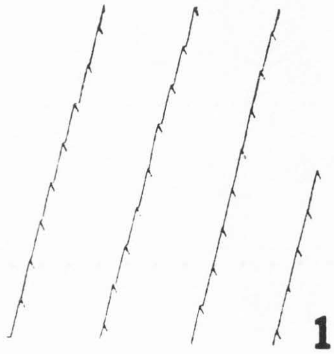
2

FT (BO) INTER FR 50



3

FR 50 (1)



1

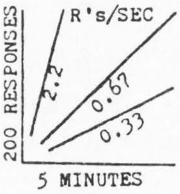
FR 50 (2)

5

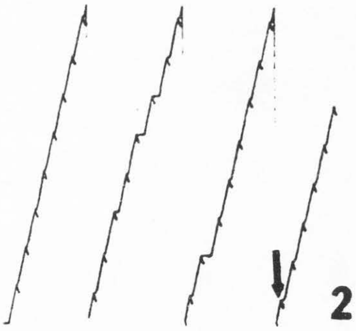
Figure 12. Selected cumulative records for Pigeon E6 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 and FT 1 s components. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E6

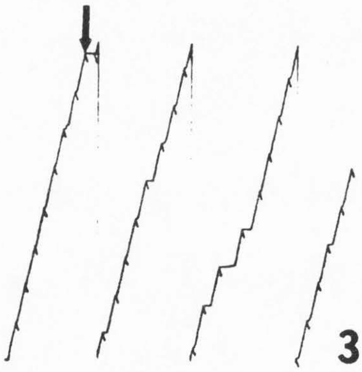
FR 1 INTER FR 50



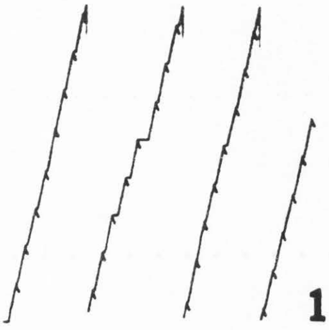
FT 1 S INTER FR 50



FT (BO) INTER FR 50



FR 50 (1)



FR 50 (2)

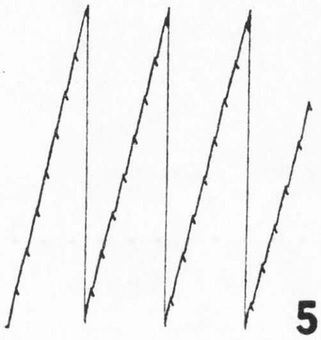


Figure 13. Selected cumulative records for Pigeon E7 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 or FT 1 s components. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E7

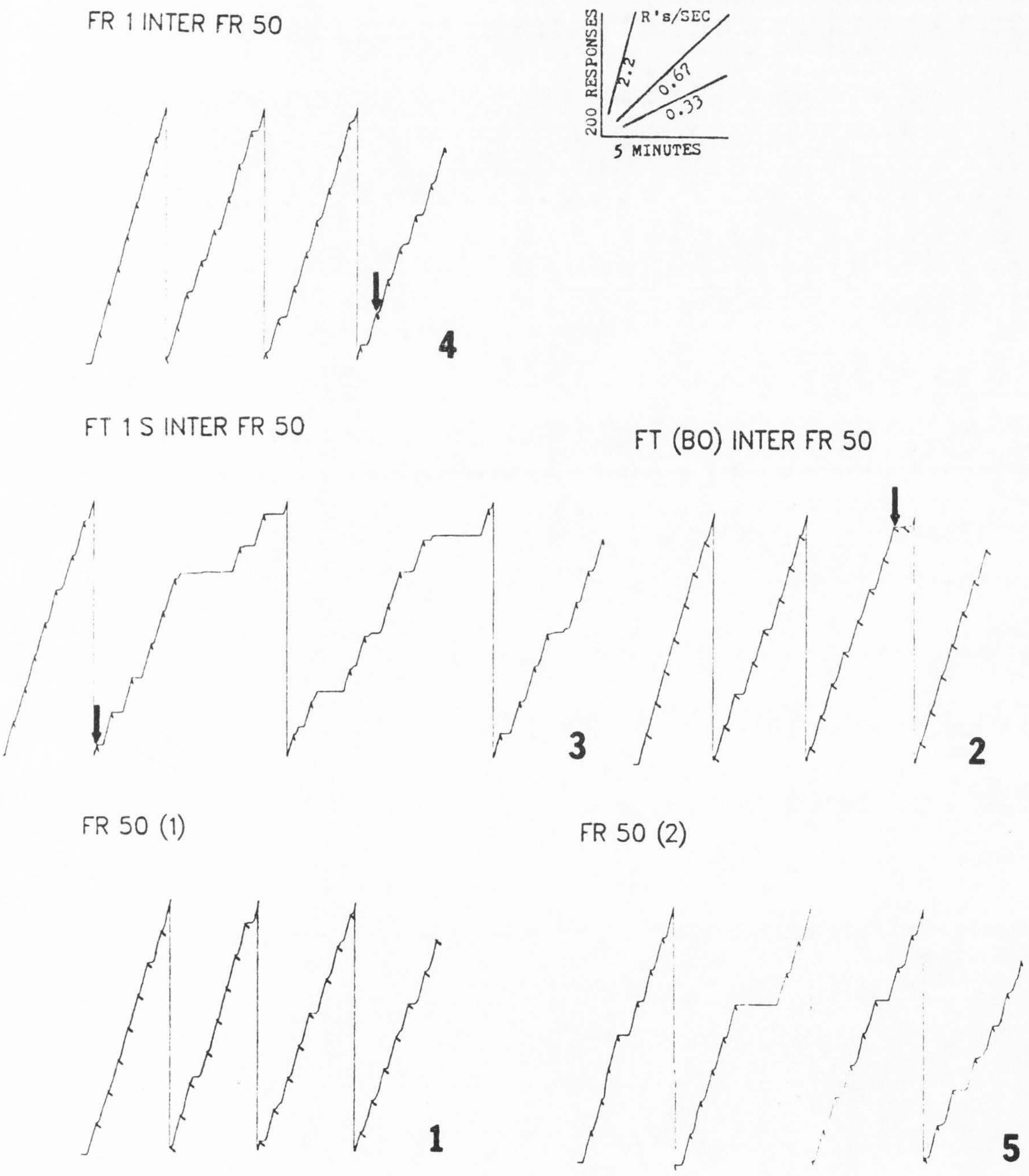
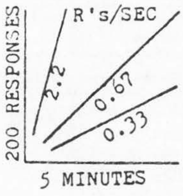

FR 1 INTER FR 50
R's/SEC
2.2
0.67
0.33
200 RESPONSES
5 MINUTES
4
FT 1 S INTER FR 50
FT (BO) INTER FR 50
3
2
FR 50 (1)
FR 50 (2)
1
5

Figure 14. Selected cumulative records for Pigeon E8 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 or FT 1 s components. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

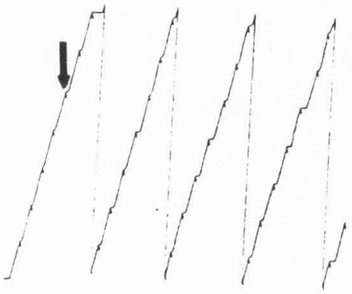
E8

FR 1 INTER FR 50

4

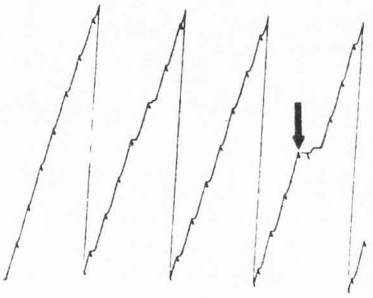


FT 1 S INTER FR 50



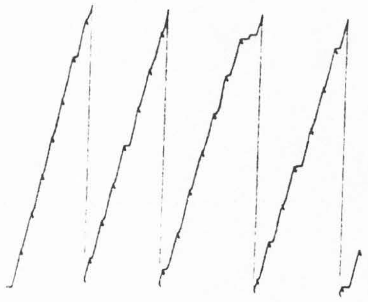
3

FT (BO) INTER FR 50



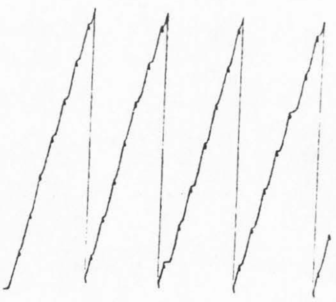
2

FR 50 (1)



1

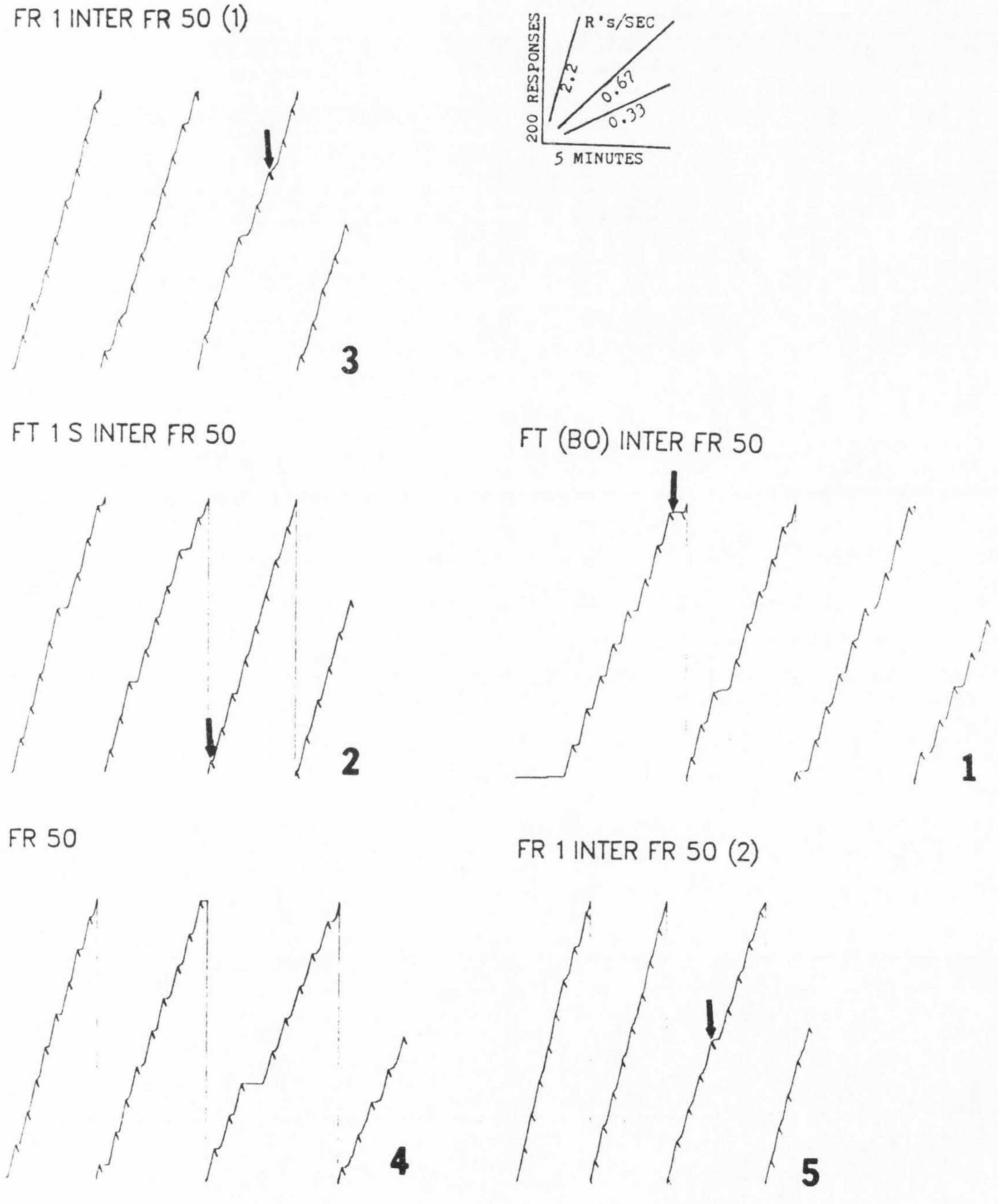
FR 50 (2)



5

Figure 15. Selected cumulative records for Pigeon E13 from each of the conditions studied. The sessions selected for presentation were, for a given condition, the session which contained the median of the median PRPs from the last five sessions of a condition. The arrows indicate the location of the FR 1 and FT 1 s components. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E13



FR 1 INTER FR 50 (1)

FT 1 S INTER FR 50

FT (BO) INTER FR 50

FR 50

FR 1 INTER FR 50 (2)

reveal few consistent differences across birds. An analysis of the cumulative records does not suggest any consistent difference in schedule patterning as a function of the response dependency or interpolated short IRI. Because consistent differences in schedule patterning were not observed for all pigeons, the performance of each bird will be briefly summarized. For Pigeon E5, a consistent PRP of substantial duration was most pronounced and consistent on the FR 50 (2) schedule, whereas the PRP was most consistently reduced on the FR 1 *inter* FR 50 reinforcement schedule. For Pigeon E6, the most pronounced pausing was on both response-independent schedules [FT (blackout) *inter* FR 50 and FT 1 s *inter* FR 50]. The pattern of behavior emitted by Pigeon E7 was inconsistent, with long duration PRPs and IRTs followed by short PRPs and IRTs for all schedules studied. The performance of Pigeon E8 had few within-ratio pauses, but frequent, relatively long-duration PRPs on all schedules studied. The pattern of behavior emitted by Pigeon E13 was scalloped in shape on all schedules, with short PRPs and only occasional long IRTs.

Summary of the Results for Experiment II

The control exerted by the presence of a response-dependent interpolated component over PRP duration was evaluated by comparing PRP durations on response-dependent (FR 1 *inter* FR 50 and FR 50) and response-independent (FT 1 s *inter* FR 50 and FT (blackout) *inter* FR 50) reinforcement schedules. The median PRP duration was consistently shorter in duration on the response-dependent schedule (FR 1 interpolation) than on the comparable response-independent (FT 1 s) schedule. However, when the quartile range of PRP durations across conditions was used as the basis of comparison, reliable differences in PRP durations were less consistent between conditions in which the interpolated component was an FR 1 or an FT 1 s, or between FR 50 (1 or 2) and FT (blackout) *inter* FR 50. Because the response-dependent schedule did evoke median PRPs of a shorter absolute duration than a comparable response-independent schedule (with the exception of Pigeon E6), a relatively strong case can be made that the response dependency differentially controlled median PRP duration.

The control exerted by the short interreinforcement interval was also evaluated independently of whether the interpolated component was response-dependent or response-independent. Differences in median PRP duration were not systematically related to the presence of a short, or a long interreinforcement interval. That is, the overlap of quartile ranges between conditions was too extensive to justify concluding that there were differences in median PRP duration between the FT 1s and the FR 50, or between the FR 1 and the FR 50 schedules.

Discussion

The interpolation of an FR 1 component into a session of FR 50 components can be conceptualized as adding a period of high reinforcement density to a baseline of relatively low reinforcement density. The purpose of Experiment II was to isolate the control exerted by two variables present when a brief alteration in schedule contingencies is presented on a schedule of constant schedule contingencies. These two variables, response dependency and high, local reinforcement density, could underlie the control exerted by the interpolated FR 1 component in reducing PRP duration.

The control exerted by the presence of a response dependency in the high density component (FR 1 or FT 1 s) was evaluated by comparing PRP durations on response-dependent (FR 1 *inter* FR 50, and FR 50) and response-independent (FT 1 s *inter* FR 50 and FT (blackout) *inter* FR 50) reinforcement schedules. A reliable difference in the absolute values of the median PRP duration was found between the interpolated response-dependent and interpolated response-independent schedules. That is, interpolation of the response-dependent FR 1 component reliably resulted in a shorter duration median PRP than was evoked by interpolation of a response-independent FT 1 s component. The presence of response-independent reinforcement did not independently reduce PRP durations. No systematic differences in median

PRP durations were found between the the FR 50 schedule and the FT (blackout) <u>inter</u> FR 50 schedule. That is, the presence of response-independent reinforcement did not independently reduce PRP duration. Because the schedule with a response-dependent, high-density component (FR 1) reduced median PRP duration, while the schedule with a high-density, response-independent component (FT 1 s) had no consistent effect on median PRP duration, it can be concluded that a response dependency associated with the high-density component is a necessary, but not a sufficient condition for reducing PRP duration.

The control exerted by the short interreinforcement interval (IRI) was also evaluated independently of whether the interpolated component was response dependent or response independent. Median PRP duration was not systematically related to the presence of a short, or a long IRI. That is, there were no differences in median PRP duration between the interpolated FT 1s and the FR 50 schedules, nor between the interpolated FR 1 and the FR 50 schedules. Additionally, there were differences in median PRP duration on schedules with nearly identical, short IRIs (FR 1 and FT 1 s). The difference in median PRP duration between schedules containing the interpolated FR 1 or FT 1 s components, and the similarity in median PRP durations between the FR 1 and FR 50, and between the FT 1 s and FR 50 schedules suggests that the interpolation of a short interreinforcement interval is not a sufficient condition for reducing PRP duration on a baseline of FR 50 components.

To further complicate the issue, the FT (blackout) _inter_ FR 50 functioned like the FT 1 s _inter_ FR 50 condition. Recall that the FT (blackout) _inter_ FR 50 condition maintained overall reinforcement density at approximately the FR 50 density, while presenting a brief increase in local density following a period of blackout. Operationally, a period of blackout of the same duration as the preceding interval, was followed by the high density, response-independent (FT 1 s) component. No reliable differences were found between behavior on the schedule with overall density of reinforcement controlled [FT (blackout) _inter_ FR 50] and the schedule with a slight increase in overall density (FT 1 s _inter_ FR 50). The fact that two response-independent schedules evoked similar median PRP durations also suggests that a local increase in reinforcement density is not a sufficient condition for reducing PRP duration.

Before these contrasts among schedules can demonstrate that response dependency and the short IRI are necessary conditions for obtaining the reduction in PRP associated with interpolation of an FR 1 component, one more comparison must be conducted. A result demanding discussion concerns the similarity in median PRP duration evoked by both the FR 50 and the FR 1 _inter_ FR 50 schedules. Recall that in

Experiment I, PRP duration evoked by the FR 1 <u>inter</u> FR 50 schedule was substantially shorter in duration (median PRP was generally between 1 and 2 s) than median PRP duration on the FR 50 schedule (median PRP duration was generally between 2 and 3 s). This difference in relative PRP durations between the FR 1 <u>inter</u> FR 50 and the FR 50 schedule was not present in Experiment II. Instead, all PRP durations were between 3 and 5 s. What accounts for the lack of control exerted by the FR 1 <u>inter</u> FR 50 schedule in Experiment II?

The similarity between PRP durations on the FR 50 and the FR 1 <u>inter</u> FR 50 schedules may reflect a difference in behavioral history; that is, whether the history included exposure to response-independent reinforcement. In Experiment I, the FR 1 <u>inter</u> FR 50 schedule followed either a history on VR 50 or the FR 1/FR 215 <u>inter</u> FR 50 schedules. Thus the history in Experiments I involved exposure to only response-dependent procedures.

In Experiment II, however, exposure to the FR 1 <u>inter</u> FR 50 schedule followed a history of exposure to one of the response-independent schedules (either FT 1 s <u>inter</u> FR 50 or the FT (BO) <u>inter</u> FR 50). It is possible that the minimal differentiation in PRP durations evoked by schedules studied in Experiment II reflects control by historical contingencies, i.e., prior exposure to interpolation of response-independent reinforcement. Other researchers have reported that the interpolation of response-independent reinforcement on a response contingent schedule suppressed response rate (Davison, Sheldon, & Lobb, 1980; Edwards et al., 1970; Stubbs, Hughes, & Cohen, 1978). Furthermore, it has been demonstrated that previous exposure to a particular schedule of reinforcement may substantially influence responding on a current schedule of reinforcement (see reviews by Barrett & Witkin, 1986; McKearney, 1979). Thus, it is reasonable to conclude that the similarity in PRP duration between the FR 50 and the FR 1 inter FR 50 schedule reflected prior exposure to response-independent reinforcement which blocked the control ordinarily exerted by the FR 1 component.

CHAPTER V

EXPERIMENT III: THE CONTROL EXERTED BY RANDOM PRESENTATION OF THE FR 1 COMPONENT

Variables other than increased reinforcer density (the presence or absence of a short IRI), and response dependency may also independently control the reduction in PRP duration which occurs when a single, unsignaled FR 1 component is randomly interpolated into 30, FR 50 components. The purpose of Experiment III was to determine whether two additional variables, location of the interpolated FR 1 component and the lack of a visual discriminative stimulus associated with the presence of the FR 1 component either separately, or in combination, control PRP duration under an FR 1 *inter* FR 50 reinforcement schedule.

In Experiment III, discriminative effects of the interpolated FR 1 component were manipulated while reinforcer density and response dependency were held constant. Operationally, the discriminative effects of the FR 1 component were manipulated in two ways: by signaling (different color) the presence of the FR 1 component and/or by fixing the session location (15th ratio component) of the FR 1 component. The ordinal session location of the signaled FR 1 component was matched to the location of the unsignaled FR 1 component in Experiment III (see Appendix B).

Discriminative effects associated with the session location of the FR 1 component were manipulated by presenting the FR 1 component as the 15th ratio component (throughout a condition) in sessions comprised of 30, FR 50 components. Because reinforcement density and response dependency were held constant across conditions, the control exerted by random session location of the FR 1 component was evaluated independent of whether the component was signaled or unsignaled. The specific variables investigated in Experiment III are summarized in Table 10.

Method

Subjects and Apparatus.

Five experimentally-naive common barn pigeons (age and gender unknown) served. Pigeons were food deprived and housed as described in Experiment I. The apparatus was the same as that described in Experiments I and II with one exception. The center response-key was transilluminated by either of two colors: red as described in Experiment I and green (Kodak Wratten Filter #56).

Procedure

Training. Pigeons were trained to key-peck under a VR 40 reinforcement schedule as described in Experiment I.

Experimental Phases.

After completion of the training phase, Experiment III

Table 10

Matrix of Variables and Reinforcement Schedules Investigated in Experiment III

		Location of Short Inter-reinforcement Interval	
		Fixed	Variable
Short Component Visual Stimulus	Present	FR 1 (Signaled-Fixed) *inter* FR 50	FR 1 (Signaled-Random) *inter* FR 50
	Absent	FR 1 (Unsignaled-Fixed) *inter* FR 50	FR 1 (Unsignaled-Random) *inter* FR 50

consisted of five conditions. The FR 50 condition and the FR 1 (Unsignaled-Random) _inter_ FR 50 condition were conducted as described in Experiment I as the FR 50 condition and the FR 1 _inter_ FR 50 condition, respectively. Table 11 summarizes the order of conditions for the five pigeons.

FR 1 (Signaled-Random) interpolated FR 50. Five pigeons were exposed to an FR 1 (Signaled-Random) _inter_ FR 50 schedule of reinforcement. Each session was conducted as described for the FR 1 (Unsignaled-Random) _inter_ FR 50 condition with one exception. The center response key was transilluminated green when the FR 1 component was available. Daily location of the signaled FR 1 component matched the location used for the FR 1 component in the FR 1 (Unsignaled-Random) _inter_ FR 50 condition in Experiment III. (See Appendix B). Thus, the presence of a response-dependent FR 1 component, located in a different ordinal position each session, was the same as in the FR 1 (Unsignaled-Random) _inter_ FR 50 condition. The interpolated schedules differed only in the discriminative properties of the exteroceptive stimulus associated with the FR 1 component.

FR 1 (Unsignaled-Fixed) interpolated FR 50. The five pigeons were also exposed to an FR 1 (Unsignaled-Fixed) _inter_ FR 50 schedule of reinforcement. Each condition was conducted as described in the FR 1

Table 11

Summary of Conditions for Each Subject in Experiment III.

Pigeons 9 and 10		*Pigeons 11, 12, and 14*	
Order	Condition	Order	Condition
1.	FR 1 (Unsignaled-Random) *inter* FR 50	1.	FR 1 (Signaled-Random) *inter* FR 50
2.	FR 1 (Unsignaled, Fixed) *inter* FR 50	2.	FR 1 (Signaled-Fixed) *inter* FR 50
3.	FR 1 (Signaled-Fixed) *inter* FR 50	3.	FR 1 (Unsignaled-Fixed) *inter* FR 50
4.	FR 1 (Signaled-Random) *inter* FR 50	4.	FR 1 (Unsignaled-Random) *inter* FR 50
5.	FR 50	5.	FR 50

(Unsignaled-Random) inter FR 50 condition with one modification. The FR 1 component was always presented as the fifteenth component in a session. The session began with houselight illumination and red transillumination of the center response key. Each of the first 14 components were programmed on an FR 50 reinforcement schedule. In the fifteenth ratio component, a single key-peck was followed by reinforcement. All subsequent ratios were FR 50 with red transillumination of the center response key. The session ended following 31 hopper presentations. The FR 1 (Unsignaled-Fixed) inter FR 50 condition and the FR 1 (Unsignaled-Random) inter FR 50 condition differed only in the placement of the FR 1 component (the short IRI component). That is, the only difference between these two conditions is the variable (Unsignaled-Random) versus fixed session location of the FR 1 component. Thus, this condition was designed to evaluate whether varying the location of the response dependent, short IRI component was necessary in order to reduce PRP duration.

FR 1 (Signaled-Fixed) interpolated FR 50. The five pigeons were also exposed to an FR 1 (Signaled-Fixed) inter FR 50 reinforcement schedule. Each session was conducted as described in the FR 1 (Unsignaled-Fixed) inter FR 50 condition with the exception of the presence of green, response-key transillumination when the 15th component (the FR 1) was in effect. All FR 50 components in the session were presented with red transillumination of the response key. The session ended following the 31st reinforcement. By presenting a signaled, FR 1 (short IRI) in a fixed ordinal location in the session, this condition determined whether it is necessary to present an unsignaled FR 1 (short IRI) in a different daily session location in order to decrease median PRP duration.

Stability criteria. Decisions for changing conditions were controlled by the stability rules described in Experiment I.

Results

The following analysis compares and contrasts behavior emitted on a variety of FR 1 interpolated FR 50 schedules of reinforcement. The control exerted by random presentation of the FR 1 component was evaluated by comparing schedules with random session location of the FR 1 component to schedules with a fixed session location of the interpolated FR 1 component. More specifically, schedules with random placement of the FR 1 were either FR 1 (Unsignaled-Random) *inter* FR 50, or FR 1 (Signaled-Random) *inter* FR 50, while schedules with a fixed location of the FR 1 component were FR 1 (Unsignaled-Fixed) *inter* FR 50, and FR 1 (Signaled-Fixed) *inter* FR 50. Only the terms in parenthesis will be used as descriptors in the remainder of this section.

As in Experiments I and II, this analysis is based on data derived from a single session within a given condition. The session selected for analysis contained the median of the median PRPs from a period of five days stability at the end of a condition (the median session). Although more likely to highlight variability within a session, this approach has the advantage of preserving the stream of behavior typical of each individual subject. Session-to-session variability is indicated by ranges (over the last five days of a condition for the median PRP and the median IRT for all pigeons in Experiment III.

Session Measures

Overall response rate. The overall response rate (includes the PRP and work time but omits warm-up pause, feeder time, and response duration) for each subject on each ratio schedule are presented in Table 12. The control exerted by random session location of the FR 1 component was evaluated by comparing overall response rates on schedules with random session placement of the FR 1 component (Unsignaled-Random or Signaled-Random) with overall response rates on schedules with identical session location of the FR 1 component (Unsignaled-Fixed or Signaled-Fixed).

In general, overall response rates emitted on the interpolated FR 1 (Signaled-Fixed) reinforcement schedule were lower than overall response rates on the interpolated FR 1 (Signaled-Random) reinforcement schedule (with the exception of Pigeon E12). There were no large reliable

Table 12

Summary Statistics for Experiment III Computed from the Median PRP Session from the Last Five Sessions of Each Condition

Subject	Condition	Sequence of Conditions	Sessions	Overall response rate (R's/s)	Session Time (min)
E9	Unsig/Random	1	23	2.71	17.96
	Unsig/Fix in 15	2	25	2.81	17.43
	Sig/Fix in 15	3	25	2.70	17.75
	Sig/Random	4	24	2.91	16.77
	FR 50	5	26	2.96	16.40
E10	Unsig/Random	1	23	3.57	14.25
	Unsig/Fix in 15	2	25	3.37	14.95
	Sig/Fix in 15	3	25	2.52	18.82
	Sig/Random	4	25	3.17	15.73
	FR 50	5	26	2.74	17.56
E11	Unsig/Random	4	28	1.84	24.86
	Unsig/Fix in 15	3	24	1.73	26.50
	Sig/Fix in 15	2	25	1.45	31.70
	Sig/Random	1	28	1.66	27.56
	FR 50	5	31	1.65	27.56

(table continues)

Subject	Condition	Sequence of Conditions	Sessions	Overall response rate (R's/s)	Session Time (min)
E12	Unsig/Random	4	25	2.28	20.51
	Unsig/Fix in 15	3	25	2.40	19.88
	Sig/Fix in 15	2	25	2.87	19.70
	Sig/Random	1	23	2.44	19.62
	FR 50	5	25	2.23	21.18
E14	Unsig/Random	4	25	1.76	15.88
	Unsig/Fix in 15	3	28	2.20	22.31
	Sig/Fix in 15	2	25	1.82	25.10
	Sig/Random	1	25	1.86	24.68
	FR 50	5	29	2.04	22.94

interpolated FR 1 (Unsignaled-Fixed) and FR 1 (Unsignaled-Random) reinforcement schedules.

The control exerted by the presence or absence of a discriminative stimulus associated with the FR 1 component was evaluated independently of whether the FR 1 component was randomly presented or repeatedly presented in the same session location. With the exception of Pigeon E12, the overall response rates on the FR 1 (Signaled-Fixed) was slower than the overall response rate on the FR 1 (Unsignaled-Fixed) reinforcement schedules. There were no consistent differences in overall response rates between the interpolated FR 1 (Signaled-Random) and FR 1 (Unsignaled-Random) reinforcement schedules.

Session time. The session times for all pigeons on all schedules studied are presented in the right column of Table 12. Session time was calculated as the time elapsed between the initiation and termination of the experimental session. Thus, temporal periods absent from the overall response rate measure but encompassed in the calculation of session time included (1) the warm-up pause which begins a session, (2) hopper duration, and (3) response duration.

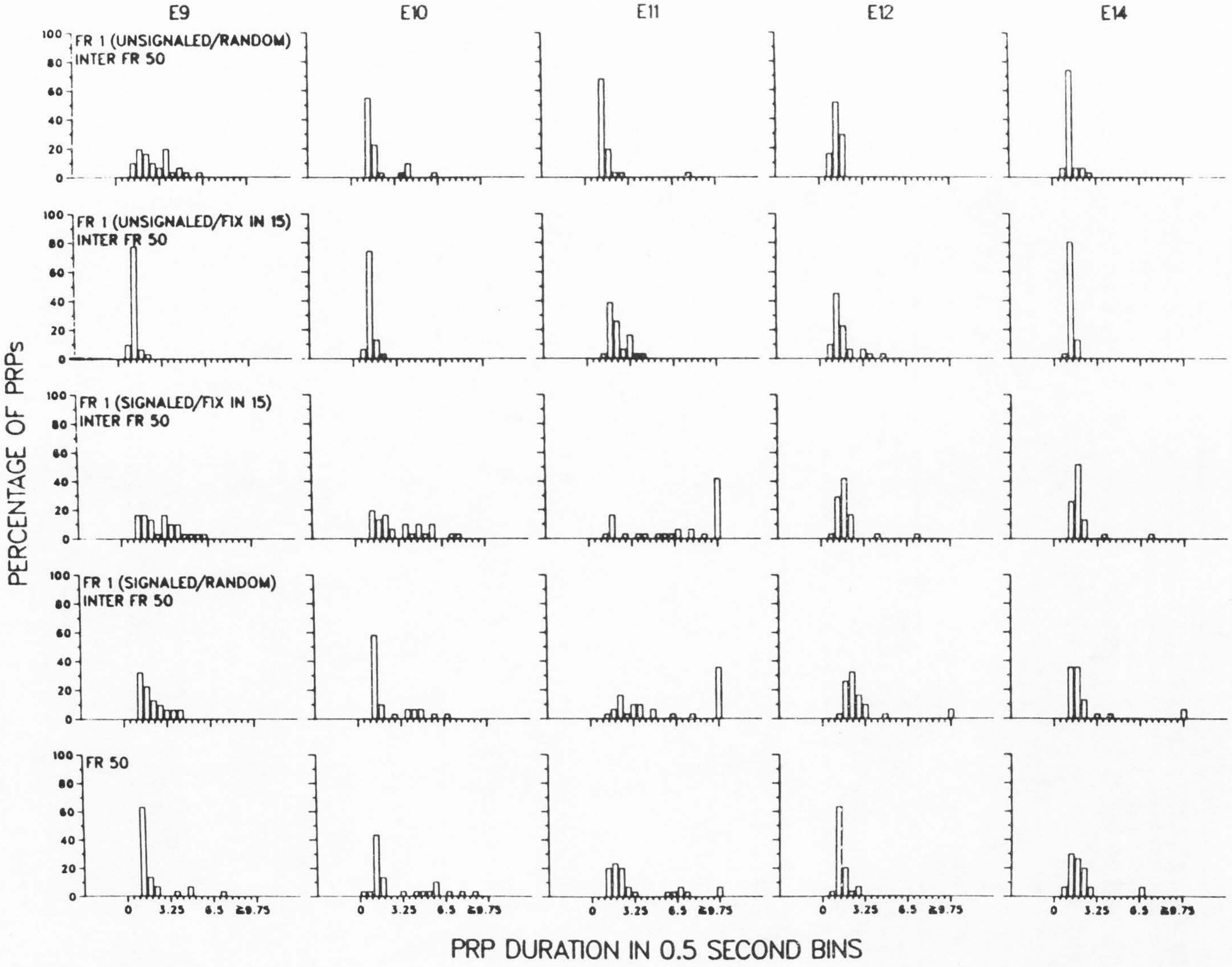
The discriminative property associated with random-versus fixed-session location of the FR 1 component differentially controlled the session time measure. Consistent with the overall response rate comparisons, session time was longer on the interpolated FR 1 (Signaled-

Fixed) schedule than on the interpolated FR 1 (Signaled-Random) schedule (for all pigeons). Also consistent with the overall response rate data was the lack of a reliable difference in session time between the interpolated FR 1 (Unsignaled-Fixed) and the FR 1 (Unsignaled-Random) schedules.

The control exerted by the presence or absence of the discriminative property paired with the FR 1 component (green key-light) resulted in a reliable difference in session time between the signaled and unsignaled conditions when the FR 1 component was presented in a fixed session location. Specifically, session time was longer on the FR 1 (Signaled-Fixed) schedule than on the FR 1 (Unsignaled-Fixed) schedule for 4 of 5 pigeons. There were no consistent differences in session time between the signaled and unsignaled conditions when the FR 1 component was randomly presented, i.e., between the FR 1 (Signaled-Random) and FR 1 (Unsignaled- Random) reinforcement schedules.

PRP frequency distributions. Figure 16 displays the relative frequencies of PRPs from the median session for all pigeons in all conditions. The labels on the abscissa represent the midpoint of the boundary for each category of PRPs, thus the 3.25 category contains the percentage of PRPs that were between 3.0 s and 3.495 s in duration. The rightmost category includes all PRPs that were 9.75 seconds

Figure 16. Relative frequency distributions of PRPs for each subject for each condition studied in Experiment III. The session selected for presentation was the session containing the median of the median PRP of the last five sessions of a condition. Bin size was 0.5 seconds. Values on X axis are the midpoints of the class intervals or "bins". The last bin includes all PRPs greater than, or equal to 9.75 seconds.


E9
E10
E11
E12
E14
FR 1 (UNSIGNALED/RANDOM)
INTER FR 50
FR 1 (UNSIGNALED/FIX IN 15)
INTER FR 50
FR 1 (SIGNALED/FIX IN 15)
INTER FR 50
FR 1 (SIGNALED/RANDOM)
INTER FR 50
FR 50
100
80
60
40
20
0
0
3.25
6.5
≥9.75
PERCENTAGE OF PRPs
PRP DURATION IN 0.5 SECOND BINS

or longer. To assist in interpretation of Figure 16, statistics summarizing the central tendency and variability of the PRP distribution are presented in Table 13.

The control exerted by random session location of the FR 1 component was evaluated by comparing PRP distributions derived from schedules with random placement of the FR 1 component, and from schedules with fixed session placement of the FR 1 component. In general, there were no large, reliable differences in modal location or shape between the FR 1 (Signaled-Fixed) schedule and the FR 1 (Signaled-Random) schedule, nor between the FR 1 (Unsignaled-Fixed) and the FR 1 (Unsignaled-Random) schedules. However, the modal location of the PRP frequency distribution from However, the FR 1 (Unsignaled-Random) schedule had a greater range than the FR 1 (Unsignaled-Fixed) schedule (with the exception of Pigeon E12).

The effect on the PRP distribution of signaling the presence of the FR 1 component was also evaluated. That is, PRP distributions were compared on the basis of whether a visual discriminative stimulus associated with the FR 1 component was present or absent in the schedule. The PRP distribution derived from behavior on the FR 1 (Signaled-Fixed) schedule had a larger modal value and was more variable (flatter in shape) than the FR 1 (Unsignaled-Fixed) distribution for 4 of 5 pigeons. Although the PRP distribution derived from behavior on the FR 1 (Signaled-

Table 13

Summary of Central Tendency and Variability Measures for Experiment III Computed from the Median PRP Session

Subject	Condition	PRP			IRT		
		Mdn	SIR	Mode	Mdn	SIR	Mode
E9	Unsig/Random	2.53	1.31	1.75	0.31	0.04	0.33
	Unsig/Fix in 15	1.13	0.24	1.25	0.31	0.03	0.33
	Sig/Fix in 15	2.87	1.72	1.25 1.75 3.25	0.31	0.04	0.33
	Sig/Random	1.68	1.00	1.25	0.31	0.03	0.33
	FR 50	1.32	0.33	1.25	0.31	0.04	0.33
E10	Unsig/Random	1.36	0.51	1.25	0.25	0.07	0.28
	Unsig/Fix in 15	1.24	0.10	1.25	0.27	0.10	0.13
	Sig/Fix in 15	2.72	2.37	1.25	0.29	0.08	0.28
	Sig/Random	1.28	1.93	1.25	0.28	0.06	0.28
	FR 50	1.38	2.13	1.25	0.29	0.08	0.28
E11	Unsig/Random	1.37	0.33	1.25	0.35	0.11	0.33
	Unsig/Fix in 15	2.18	0.90	1.75	0.35	0.13	0.33
	Sig/Fix in 15	7.80	9.20	1.75	0.35	0.11	0.33
	Sig/Random	4.24	8.00	2.25	0.35	0.12	0.33
	FR 50	2.14	2.15	1.75	0.33	0.13	0.33

(table continues)

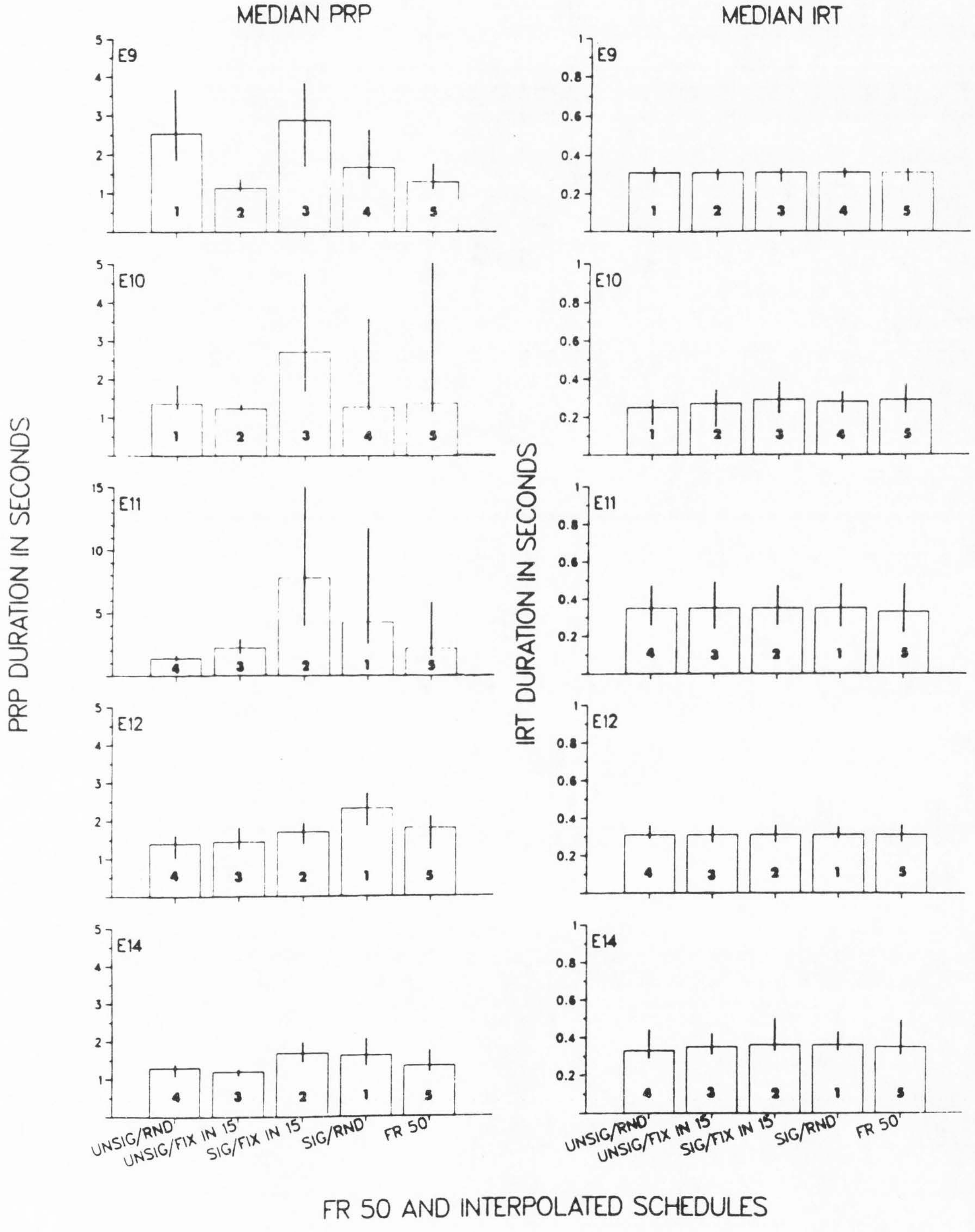
Subject	Condition	PRP			IRT		
		Mdn	SIR	Mode	Mdn	SIR	Mode
E12	Unsig/Random	1.40	0.43	1.25	0.31	0.04	0.33
	Unsig/Fix in 15	1.44	0.50	1.25	0.31	0.05	0.33
	Sig/Fix in 15	1.70	0.42	1.75	0.31	0.05	0.33
	Sig/Random	2.32	0.69	2.25	0.31	0.03	0.33
	FR 50	1.80	0.44	1.25 1.75	0.31	0.05	0.33
E14	Unsig/Random	1.30	0.22	1.25	0.33	0.08	0.33
	Unsig/Fix in 15	1.19	0.12	1.25	0.35	0.06	0.33
	Sig/Fix in 15	1.68	0.38	1.75	0.36	0.09	0.33
	Sig/Random	1.62	0.53	1.25 1.75	0.36	0.05	0.33
	FR 50	1.33	0.28	1.25	0.35	0.09	0.33

Random) schedule contained more outliers than the PRP distribution derived from the FR 1 (Unsignaled-Random) schedule, no consistent differences in modal values between the two schedules were identified.

Median post-reinforcement pause duration. To provide a general measure of any change in PRP duration across conditions, the left column of Figure 17 displays median PRP duration as a function of the schedules of reinforcement studied in Experiment III. The error lines intersecting each bar are the quartile ranges of the PRP (25th to 75th percentiles) within the session presented. The judgment of a difference between conditions was based on differences between quartile ranges of the median PRP. For a given pigeon, conditions were judged to be reliably different from one another in median PRP duration only when quartile ranges did not overlap. Across pigeons, two conditions were considered reliably different from one another if four of five pigeons had no overlap in quartile ranges for that condition.

Random session location of the FR 1 component exerted no large, reliable control over median PRP duration. There were no consistent differences in median PRP durations between the FR 1 (Signaled-Fixed) and the FR 1 (Signaled-Random) reinforcement schedules. Similarily, there were no large, systematic differences in median PRP duration between the FR 1 (Unsignaled-Fixed) and FR 1 (Unsignaled-Random)

Figure 17. Median PRP and median IRT duration as a function of FR 50, and interpolated schedules for all subjects in Experiment III. The session selected for presentation was the session, of the last five sessions in a condition, which contained the median of the median PRP. The error line intersecting each bar represents the quartile range for that condition. The number inside each bar represents the order in which the pigeon was exposed to a particular condition. Note the different scale for Pigeon E12 on the ordinate of the PRP figure.


MEDIAN PRP
MEDIAN IRT
E9
E10
E11
E12
E14
PRP DURATION IN SECONDS
IRT DURATION IN SECONDS
UNSIG/RND'
UNSIG/FIX IN 15'
SIG/FIX IN 15'
SIG/RND'
FR 50'
FR 50 AND INTERPOLATED SCHEDULES

reinforcement schedules.

The control exerted by the presence or absence of a discriminative stimulus associated with the FR 1 component was evaluated regardless of whether the FR 1 component was randomly presented or presented in the same session location each session. The presence of a discriminative stimulus associated with the FR 1 component exerted differential control over median PRP duration dependent on whether the FR 1 component was presented in a fixed, or random session location. For all pigeons, the median PRP duration on the FR 1 (Signaled-Fixed) schedule was longer than the median PRP duration on FR 1 (Unsignaled-Fixed) schedule, but not consistently different between the FR 1 (Signaled-Random) and FR 1 (Unsignaled-Random) schedules. There were no reliable differences in median PRP duration between the interpolated conditions and the FR 50 condition.

SIR of median PRP. The numerical values of the SIR of the median PRP are presented in the center column of Table 13. There were no large, systematic differences in SIR of the median PRP as a function of the random or fixed session location of the FR 1 component (independently of whether the FR 1 was signaled or unsignaled). However, there were differences in the SIR of the median PRP as a function of whether the FR 1 component was or was not signaled. The SIR of the PRP on the FR 1 (Signaled-Fixed) schedule was generally larger than the SIR on the FR 1 (Unsignaled-Fixed) schedule (with the exception of Pigoen E12). Similarly, the SIR of the PRP on the FR 1 (Signaled-Random) schedule was generally larger than the SIR on the FR 1 (Unsignaled-Random) schedule (with the exception of Pigeon E9).

Five-day variability of the median PRP. The low and high values of the median PRP duration over the last five days of each condition are presented in Table 14. The five-day range of the PRP duration was computed as the absolute difference between these two durations. The control exerted by random session location of the FR 1 component was evaluated by comparing the five-day range of the median PRP on schedules with random session placement of the FR 1 component with the five-day range of the median PRP on schedules with identical session location of the FR 1 component. A differential effect of random session location occurred dependent upon whether the FR 1 component was, or was not signaled. In general, the five-day range of the median PRP was greater on the FR 1 (Signaled-Fixed) schedule than on the FR 1 (Signaled-Random) schedule (with the exception of Pigeon E14). No reliable differences in five-day variability of the median PRP occurred between the FR 1 (Unsignaled-Fixed) schedule and the FR 1 (Unsignaled-Random) schedule.

The control exerted by the presence or absence of a visual stimulus associated with the FR 1 component was evaluated regardless of whether the FR 1 component was

Table 14

Low and High Duration of the Median PRP and Median IRT (Last Five Sessions) for Each Schedule Studied in Experiment III.

Subject	Condition	Median PRP in s		Median IRT in s	
		Low	High	Low	High
E9	Unsig/Random	2.42	2.62	0.30	0.31
	Unsig/Fix in 15	1.08	1.30	0.31	0.31
	Sig/Fix in 15	1.44	3.75	0.27	0.31
	Sig/Random	1.62	2.08	0.29	0.31
	FR 50	1.23	2.00	0.29	0.31
E10	Unsig/Random	1.23	1.59	0.25	0.26
	Unsig/Fix in 15	1.21	1.35	0.27	0.29
	Sig/Fix in 15	1.29	6.05	0.29	0.31
	Sig/Random	1.21	1.53	0.28	0.29
	FR 50	1.28	1.59	0.29	0.29
E11	Unsig/Random	1.25	1.47	0.33	0.35
	Unsig/Fix in 15	1.65	2.27	0.33	0.35
	Sig/Fix in 15	7.13	12.11	0.34	0.36
	Sig/Random	2.87	6.85	0.34	0.38
	FR 50	1.76	2.30	0.33	0.34
E12	Unsig/Random	1.13	1.79	0.31	0.34
	Unsig/Fix in 15	1.27	1.49	0.31	0.33
	Sig/Fix in 15	1.31	1.86	0.29	0.31
	Sig/Random	2.15	2.54	0.31	0.33

(table continues)

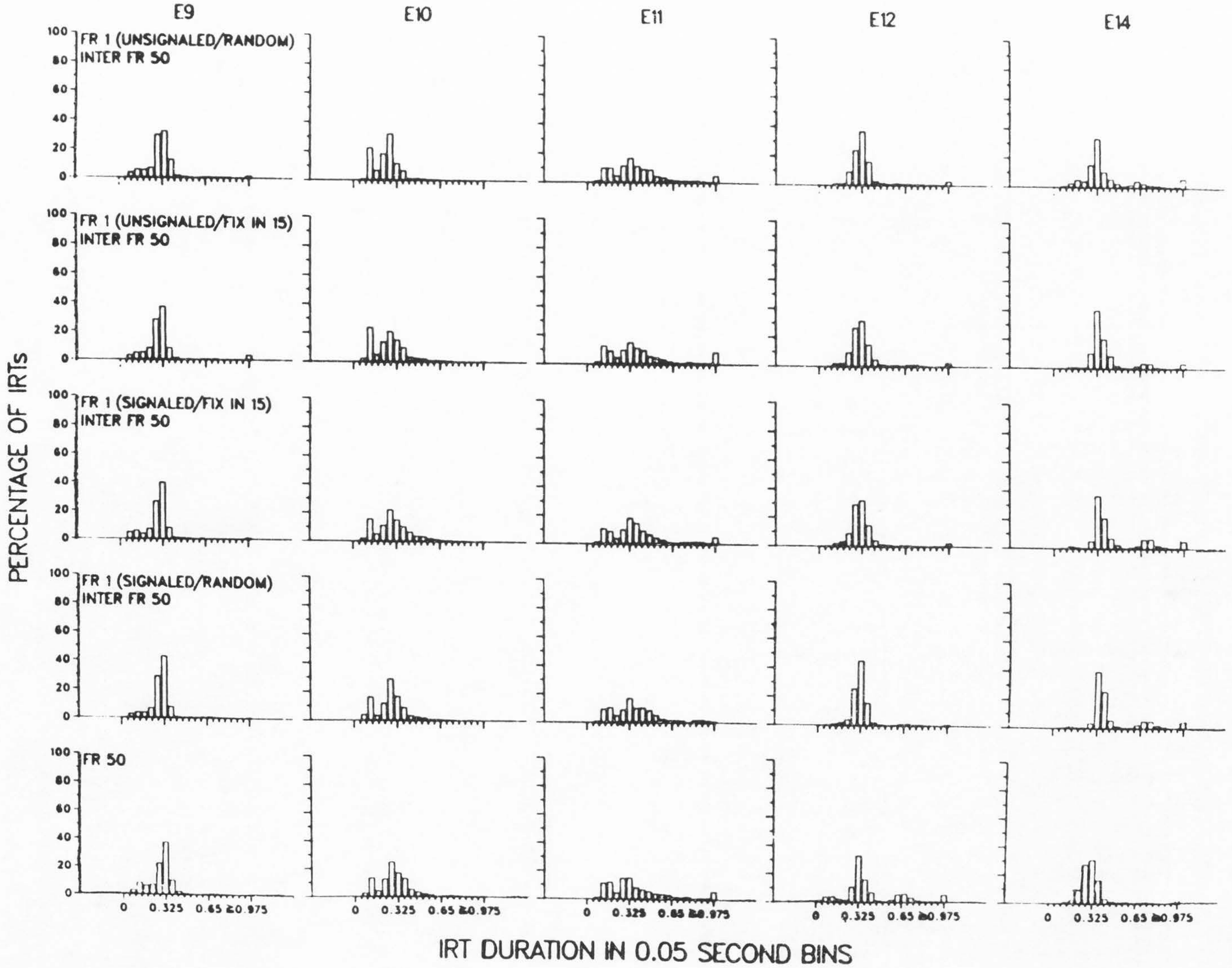
Sub-ject	Condi-tion	Median PRP in s		Median IRT in s	
		Low	High	Low	High
	FR 50	1.67	2.00	0.30	0.33
E14	Unsig/Random	1.22	1.50	0.33	0.34
	Unsig/Fix in 15	1.15	1.24	0.33	0.35
	Sig/Fix in 15	1.55	1.85	0.35	0.36
	Sig/Random	1.54	2.02	0.36	0.38
	FR 50	1.22	1.43	0.33	0.35

randomly presented or repeatedly presented in the same session location. Again, there was a differential effect between the value of the five day range of the PRP and the session placement of the interpolated FR 1 component. For all pigeons, the five-day range of the PRP was greater on the FR 1 (Signaled-Fixed) schedule than on the FR 1 (Unsignaled-Fixed) schedule. There were no large, reliable differences in session-to-session ranges of the PRP between the FR 1 (Signaled-Random) and the FR 1 (Unsignaled-Random) schedules.

IRT frequency distributions. Figure 18 displays plots of the relative frequency distributions of IRTs from the median session for all pigeons in each condition. The labels on the abscissa represent the midpoint of the boundary for each category of IRTs, thus the 0.325 category contains the percentage of IRTs that were between 0.30 s and 0.349 s in duration. The category furthest to the right includes all IRTs that were 0.975 seconds or longer. To assist in interpretation of Figure 18, statistics summarizing the central tendency and variability of the IRT distribution are presented in Table 13.

The control exerted by random session location of the FR 1 component was evaluated by comparing IRT frequency distributions from schedules with random session placement of the FR 1 component with IRT distributions from schedules with fixed session location of the FR 1 component. In

Figure 18. Relative frequency distributions of IRTs for each subject on each condition studied in Experiment III. The session selected for presentation was the session containing the median of the median PRP. of the last five sessions of a condition. Bin size was 0.05 seconds. Values on X axis are the midpoints of the class intervals or "bins". The last bin includes all IRTs greater than, or equal to 0.975 seconds.


E9
E10
E11
E12
E14
FR 1 (UNSIGNALED/RANDOM) INTER FR 50
FR 1 (UNSIGNALED/FIX IN 15) INTER FR 50
FR 1 (SIGNALED/FIX IN 15) INTER FR 50
FR 1 (SIGNALED/RANDOM) INTER FR 50
FR 50
100
80
60
40
20
0
0.325
0.65
≥0.975
PERCENTAGE OF IRTs
IRT DURATION IN 0.05 SECOND BINS

general, there were no large, reliable differences in the shape, variability, or modal values between the FR 1 (Signaled-Fixed) and the FR 1 (Signaled-Random) frequency distributions. Similarily, there were no consistent differences in the shape, variability, or modal values of IRT distributions derived from interpolated schedules with and without a discriminative stimulus associated with the FR 1 component. This suggests that IRT distributions were not controlled by either the session location, or the explicit discriminative properties of the interpolated FR 1 component.

Median interresponse time. To provide a general measure of any change in IRT duration across conditions, the right column of Figure 17 displays median IRT duration as a function of the schedule of reinforcement. The error lines intersecting each bar are the quartile ranges of the IRT (25th to 75th percentiles) within the session presented. For a given subject, conditions with no overlap in quartile ranges were judged to differ from one another. Across subjects, conditions were judged to differ in IRT duration when at least four of five subjects had no overlap in quartile ranges of the median IRT.

The control over median IRT duration exerted by random, versus fixed-session location of the FR 1 component was evaluated independently of whether the FR 1 component was signaled or not signaled. There were no systematic differences in median IRT durations between interpolated schedules with random session placement of the FR 1 component (Unsignaled-Random or Signaled-Random) and schedules with identical session location of the FR 1 component (Unsignaled-Fixed with Signaled-Fixed). Additionally, there was no reliable difference in the control exerted over median IRT duration as a function of the presence or absence of a discriminative stimulus associated with the FR 1 component. That is, there were no reliable differences in median IRT duration between interpolated FR 1 (Signaled-Fixed) and FR 1 (Unsignaled-Fixed) schedules, nor between interpolated FR 1 (Signaled-Random) and FR 1 (Unsignaled-Random) reinforcement schedules.

SIR of the IRT. The SIRs of the median IRT for all pigeons on each schedule studied are presented in Table 13. The control exerted by random session location of the FR 1 component was evaluated by comparing the SIR of the median IRT on interpolated schedules with random session placement of the FR 1 component (Unsignaled-Random or Signaled-Random) with the SIR of the median IRT on interpolated schedules with identical session location of the FR 1 component (Unsignaled-Fixed with Signaled-Fixed). In general, the SIR of the IRT was greater on the interpolated FR 1 (Signaled-Fixed) schedule than on the interpolated FR 1 (Signaled-Random) schedule (with the exception of Pigeon E11). There were no large, consistent differences in SIRs between the FR 1 (Unsignaled-Fixed) and the FR 1 (Unsignaled-Random) reinforcement schedules.

The control exerted by the presence or absence of a discriminative stimulus associated with the FR 1 component was evaluated independently of whether the FR 1 component was randomly presented or repeatedly presented in the same session location. In general, the SIR of the median IRT was smaller on the FR 1 (Signaled-Random) than on the FR 1 (Unsignaled-Random) schedule (with the exception of Pigeon E11). However, the SIR of the median IRT did not reliably differ between the FR 1 (Signaled-Fixed) and the FR 1 (Unsignaled-Fixed) reinforcement schedules.

Five-day range of the median IRT. The low and high values of the median IRT duration over the last five days of a condition are presented in Table 14. The five-day ranges of the median IRT durations was computed as the absolute differences between the low and the high IRT durations. The control of the five-day range of the median IRT exerted by random session location of the interpolated FR 1 component was evaluated through a comparison between interpolated schedules with and without random session placement of the FR 1 component. There were no consistent differences in the five-day ranges of the median IRTs as a function of random or fixed placement of the FR 1 component. That is, there were no systematic differences in five-day range of the median

IRT between the interpolated FR 1 (Signaled-Fixed) and FR 1 (Signaled-Random) reinforcement schedules, nor between interpolated FR 1 (Unsignaled-Fixed) and FR 1 (Unsignaled-Random) reinforcement schedules. Similarly, differential control over the five-day range of the IRT was not exerted by the presence or absence of a discriminative stimulus associated with the FR 1 component. That is, there were no systematic differences in the five-day range of the median IRTs between the interpolated FR 1 (Signaled-Fixed) and the FR 1 (Unsignaled-Fixed) schedules, nor between interpolated FR 1 (Signaled-Random) and FR 1 (Unsignaled-Random) schedules.

Cumulative records. Figures 19 through 23 show the cumulative records from the median session for all pigeons in all conditions studied. The number to the right of each cumulative record indicates the order in which a given schedule of reinforcement was presented. The long arrows indicate the location, within a session, of an interpolated FR 1 or component.

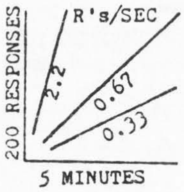
The control exerted by the presence or absence of the discriminative stimulus associated with the FR 1 component was evaluated independently of whether the FR 1 component was presented in a random, or fixed session location. The most consistent differences in the effect of the discriminative stimulus occurred when the FR 1 component was in a fixed session position. For all pigeons, there was at least one

Figure 19. Selected cumulative records for Pigeon E9 from each of the conditions studied. The session selected for presentation was the session which contained the median of the median PRP from last five sessions in a condition. The arrows indicate the location of the FR 1 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

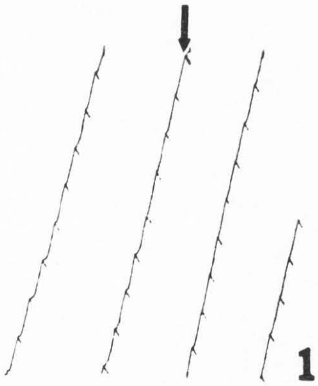
E9

FR 50

5

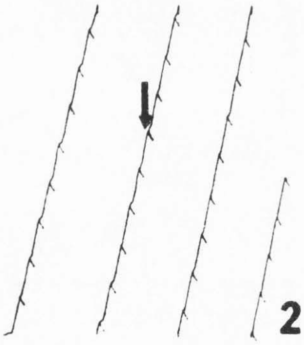


FR 1 (UNSIGNALED/RANDOM)
INTER FR 50



1

FR 1 (UNSIGNALED/FIX IN 15)
INTER FR 50



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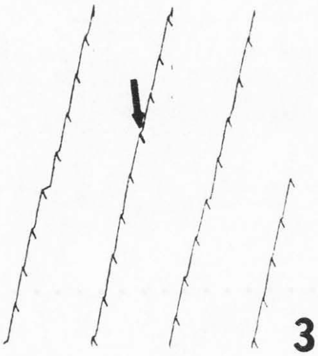
FR 1 (SIGNALED/RANDOM)
INTER FR 50

4

FR 1 (SIGNALED/FIX IN 15)
INTER FR 50

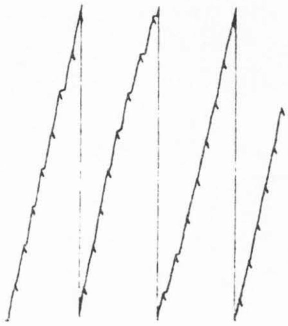


3

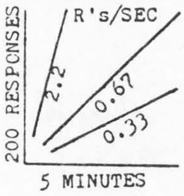
Figure 20. Selected cumulative records for Pigeon E10 from each of the conditions studied. The session selected for presentation was the session which contained the median of the median PRP from last five sessions in a condition. The arrows indicate the location of the FR 1 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E10

FR 50



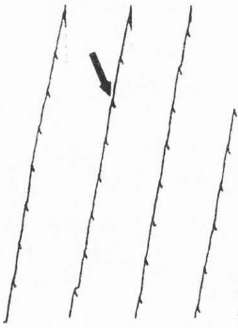
5



FR 1 (UNSIGNALED/RANDOM)
INTER FR 50

1

FR 1 (UNSIGNALED/FIX IN 15)
INTER FR 50



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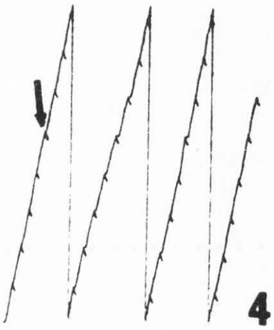
FR 1 (SIGNALED/RANDOM)
INTER FR 50



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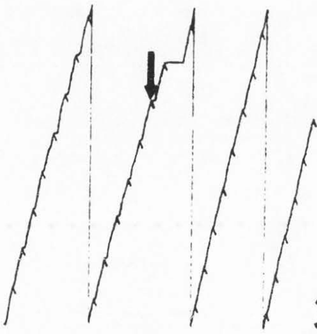
FR 1 (SIGNALED/FIX IN 15)
INTER FR 50

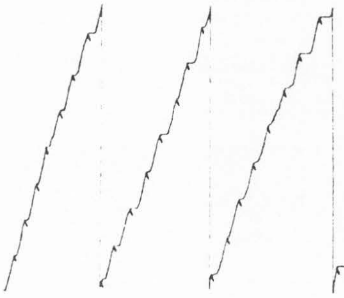


3

Figure 21. Selected cumulative records for Pigeon E11 from each of the conditions studied. The session selected for presentation was the session which contained the median of the median PRP from last five sessions in a condition. The arrows indicate the location of the FR 1 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E11

FR 50



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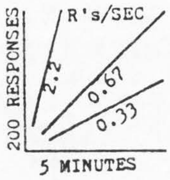
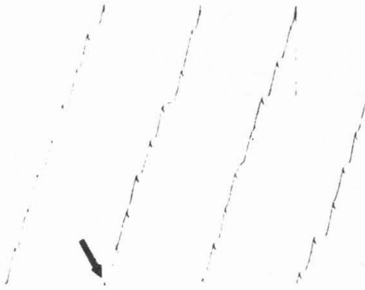
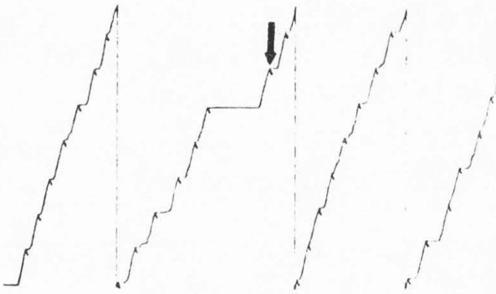


FR 1 (UNSIGNALED/RANDOM)
INTER FR 50



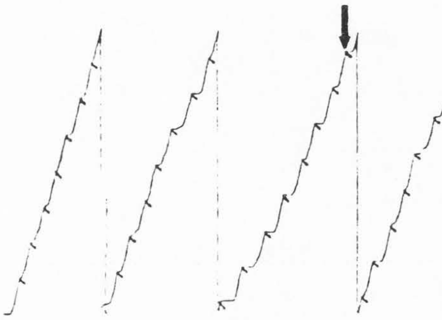
4

FR 1 (SIGNALED/FIX IN 15)
INTER FR 50



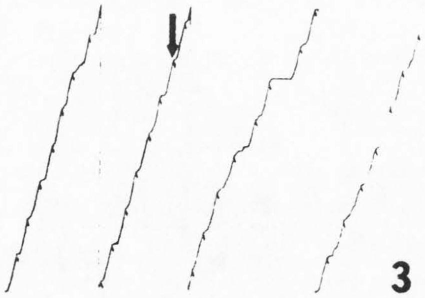
2

FR 1 (SIGNALED/RANDOM)
INTER FR 50



1

FR 1 (UNSIGNALED/FIX IN 15)
INTER FR 50

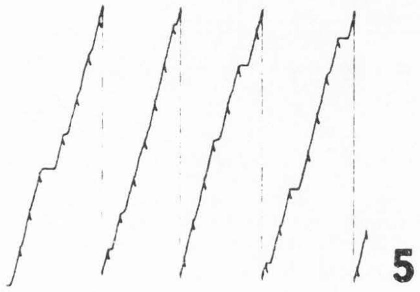


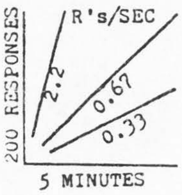
3

Figure 22. Selected cumulative records for Pigeon E12 from each of the conditions studied. The session selected for presentation was the session which contained the median of the median PRP from last five sessions in a condition. The arrows indicate the location of the FR 1 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

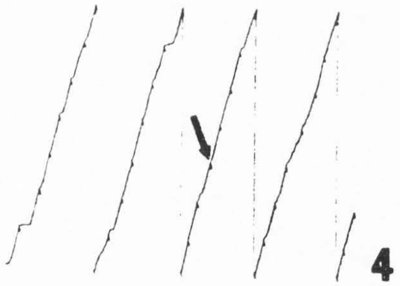
E12

FR 50

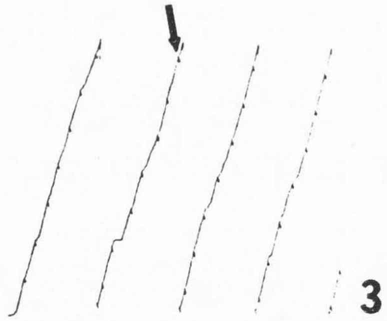




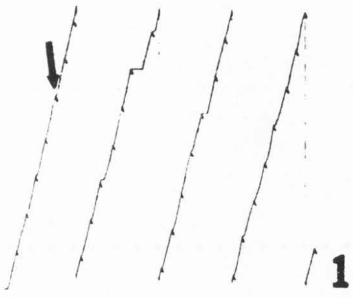
FR 1 (UNSIGNALED/RANDOM)
INTER FR 50



FR 1 (UNSIGNALED/FIX IN 15)
INTER FR 50



FR 1 (SIGNALED/RANDOM)
INTER FR 50



FR 1 (SIGNALED/FIX IN 15)
INTER FR 50

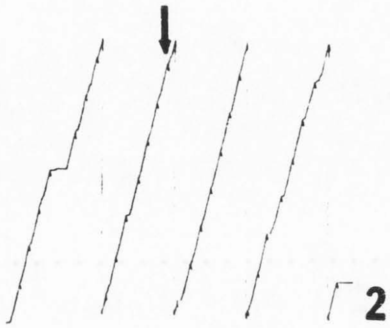
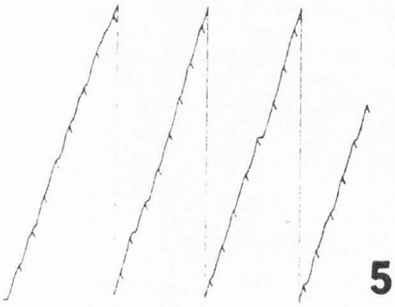


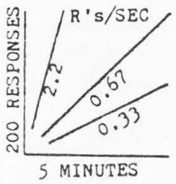
Figure 23. Selected cumulative records for Pigeon E14 from each of the conditions studied. The session selected for presentation was the session which contained the median of the median PRP from last five sessions in a condition. The arrows indicate the location of the FR 1 component. The numbers to the right of each cumulative record indicate the order in which the condition was presented.

E14

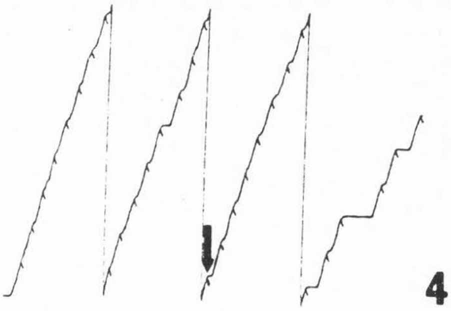
FR 50



5

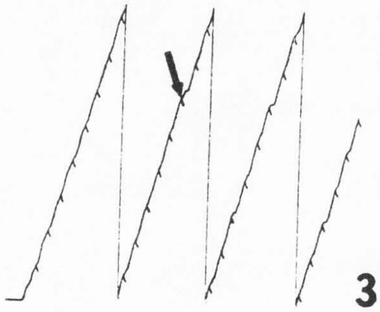


FR 1 (UNSIGNALED/RANDOM)
INTER FR 50



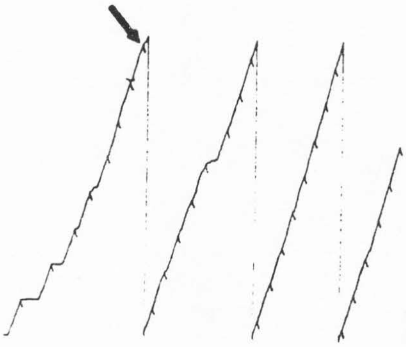
4

FR 1 (UNSIGNALED/FIX IN 15)
INTER FR 50



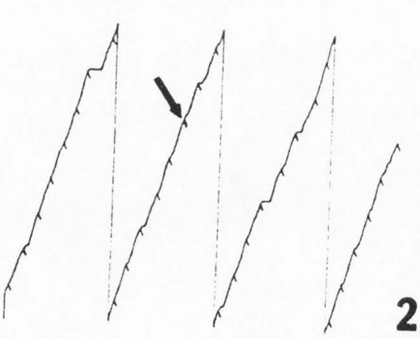
3

FR 1 (SIGNALED/RANDOM)
INTER FR 50



1

FR 1 (SIGNALED/FIX IN 15)
INTER FR 50



2

extremely long PRP on the FR 1 (Signaled-Fixed) schedule, but no comparable long-duration PRP on the FR 1 (Unsignaled-Fixed) schedule. Additionally, PRPs on the FR 1 (Signaled-Fixed) schedule were generally longer in duration than on the FR 1 (Unsignaled-Fixed) schedule. There were, however, no consistent differences in response patterns when the interpolated FR 1 component occurred in a random location each session. This suggests that the effect of visual discriminative stimulus presence or absence is dependent on whether the FR 1 component was in a fixed or a variable session location. In general, there were no large, reliable differences in response patterns between the FR 1 (Signaled-Fixed) schedule and the FR 1 (Signaled-Random) schedule. Similarly, there were no consistent differences in response patterns between the FR 1 (Unsignaled-Fixed) schedule and the FR 1 (Unsignaled-Random) schedule. This suggests that the effect of the interpolated FR 1 schedule is not dependent on whether the FR 1 component is presented in a fixed, or random session location.

Summary of the Results of Experiment III

The results of Experiment III demonstrated that random location of the FR 1 component, the temporal duration of the interpolated component, and visually signaling versus not signaling the presentation of the interpolated component did not affect IRT patterning.

The two schedules with the greatest number of differences between them were the FR 1 (Signaled-Fixed) and the FR 1 (Signaled-Random), whereas the conditions with the fewest differences between them were the FR 1 (Unsignaled-Fixed) and the FR 1 (Unsignaled-Random) conditions. When the FR 1 component was visually signaled and always presented as the 15th ratio component in a session, the overall response rate was lower, the median PRPs and session times were longer in duration, and the five-day ranges of the median PRP and the SIR of the median IRT were greater than when the FR 1 was signaled but presented in a different session location each session. There were no differences between conditions when the FR 1 component was not signaled and occurred in a fixed or random session location each session. This implies that discriminative responding occurred only when the stimulus compound (fixed session location which was signaled by a visual discriminative stimulus) was in effect. Discriminative performance did not develop when either element of the compound was presented in isolation.

Discussion

The results of Experiment III demonstrated that neither random session location of the FR 1 component, nor unsignaled presentation of the FR 1 component are necessary conditions for reducing the duration of the PRP. That is, all FR 1 interpolations reduced PRP duration to levels observed in Experiment I. With the exception of Pigeon E9, PRP durations evoked by the FR 1 component were generally 1 to 2 seconds in duration. In Experiment III, fixed versus variable session location of the FR 1 component did not, in isolation, control the duration of the PRP. The results of Experiment III also demonstrated that random location of the FR 1 component, and signalling versus not signaling the presence of the FR 1 component, did not affect IRT duration.

The FR 1 (Signaled-Fixed) inter FR 50 schedule differed from both the FR 1 (Signaled-Random) inter FR 50 and the FR 1 (Unsignaled-Fixed) inter FR 50 schedules on a variety of dependent measures. When the FR 1 component was signaled and always presented as the 15th ratio component in a session, the overall response rate was lower, the median PRP and session time were longer in duration, and the session-to-session range of the PRP and the SIR of the median IRT were greater than when the FR 1 was signaled but presented in a different session location each session. When the FR 1 component was fixed as the 15th ratio in a session, the interpolated schedule which did not signal the presence of the FR 1 component evoked a shorter duration PRP than a comparable interpolated schedule which did signal the presence of the FR 1 component. There were no reliable differences among conditions when the FR 1 component was not signaled and occurred in a fixed or random session location each session.

These comparisons among schedules suggest that in isolation, a visual discriminative stimulus associated with the presence of an FR 1 component does not exert strong stimulus control over PRP duration. Similarly, in isolation, fixed session-location of the FR 1 component does not exert strong stimulus control over median PRP duration. Stimulus control over PRP duration only developed when a schedule contained an an FR 1 component which was both visually signaled and fixed in a particular session location.

An implication of the results of Experiment III is that the reduction in median PRP duration observed on the FR 1 inter FR 50 schedule is a function of the lack of discriminative control exerted by the FR 1 component, or the minimal degree of the stimulus control associated with an unsignaled and randomly located FR 1 component. Differentiated responding (represented as the duration of the median PRP) was shortest in duration when the FR 1 component was unsignaled and random, intermediate in duration when the FR 1 component was either signaled or randomly presented, and was at its longest duration (strongly differentiated) when the FR 1 component was both signaled and presented in a fixed session location.

One surprising outcome of Experiment III was the extremely short PRP duration emitted on the FR 50 condition (about 1 to 2 s). Recall that in Experiment I, PRP durations on FR 50 were between 3 and 5 s. In Experiment III, the PRP duration evoked by the FR 50 schedule was apparently influenced by the prior history of the pigeon. That is, the removal of the FR 1 component from the FR 1 inter FR 50 schedule had no effect on PRP duration. As has been previously discussed, historical contingencies have been shown to exert control over responding on schedules presented later in training (e.g., Davison & Hunter, 1979). The control exerted by prior training history implies that once a rate of responding is established which is higher than the baseline rate, it will be difficult to reestablish the response rate initially observed on the same schedule of reinforcment. This may be due to the fact that behavior becomes less variable as the duration of key-pecking behavior decreases through exposure to schedules of reinforcement. For example, Korber, Cole, and Ramirez (1981) evaluated the variability of the PRP as a function of FR size and found that the absolute value of the standard deviation was dependent on the amount of training which preceded the measure of PRP variability. That is, the standard deviation of PRPs decreased substantially with extended exposure to a particular FR schedule. While the resulting behavioral stereotypy produced less variable performance, it also minimized (or blocked) the control exerted by additional contingencies programmed into the environment.

CHAPTER VI

GENERAL DISCUSSION

Fixed- and variable-ratio schedules can be distinguished on the basis of the response patterns they evoke. For example, FR 50 schedule performance is typified by a prominent PRP followed by a high, constant response rate. The VR schedule evokes a relatively brief pause after reinforcement, which is followed by a rapid, constant response rate (Ferster & Skinner, 1957). Crossman et al., (1987) demonstrated that the relative durations of the PRP and running response rate observed on ratio schedules are primarily controlled by the type of ratio schedule (fixed, variable, or random), whereas the overall rate of responding is controlled by the absolute size of the mean ratio. To identify the variable(s) responsible for differences in PRP durations evoked by the two schedules is to isolate the sources of control which distinguish VR from FR performance.

If schedule performances on FR and VR schedules differ primarily in PRP duration, and if PRP duration is controlled by the smallest ratio component present in a session, then PRP durations on the VR 50 and FR 1 *inter* FR 50 schedules should be indistinguishable. The results of Experiment I demonstrated that the interpolation of a single FR 1 component on an FR 50 schedule reduced the duration of the median PRP to a value roughly comparable to the PRP duration found on a comparably-sized VR 50 schedule. This result suggests that the duration of the PRP is controlled by the smallest ratio component. The results of Experiments II and III qualify the conditions under which the smallest ratio component exerts predominant control over PRP duration. The results of Experiment II demonstrated that while the presence of a short IRI (a brief increase in reinforcement density) was not a sufficient condition for evoking a reduction in median PRP duration, the presence of a response dependency in the interpolated component was a necessary condition for the reduction in median PRP duration observed in Experiment I on the FR 1 _inter_ FR 50 schedule. The results of Experiment III demonstrated that neither random session location of the FR 1 component nor unsignaled presentation of the FR 1 component are necessary conditions for reducing the duration of the PRP. Thus, it can be concluded that a brief, response-dependent increase in reinforcement density is a sufficient condition for reducing PRP duration given a subject free from historical exposure to response-independent reinforcement.

Experiments I and III provide support for a model of response patterning developed by Catania and Reynolds (1968). The model, which predicts that the smallest ratio component will control PRP duration, was supported because differential PRP durations were observed between the FR 50 and the interpolated schedules. Recall that Alferink and Crossman (1978) found that the shortest ratio component controlled PRP duration under mixed FR schedules. Using fixed-interval schedules, Catania (1970) similarly demonstrated that the presentation of a single, short fixed-interval component (FI 1 s *inter* FI 108 s) decreased mean PRP duration below that found under a standard FI 108 s schedule. Harzem, Lowe, and Spencer (1978) similarly found that pause duration was directly related to the contingency which controlled athe highest reinforcement density. That is, the duration of the PRP evoked by a schedule is not a function of some averaging process. What exerts predominant control over the duration of all PRPs present in a session is the contingency controlling the shortest PRP.

The Necessity of Aperiodicity

A major purpose of Experiment III was to determine whether aperiodicity of the interpolated FR 1 component was a necessary condition for the reduction in PRP duration observed in the FR 1 interpolated FR 50 condition. Aperiodic schedules are typically distinguished from periodic schedules based on (1) whether reinforcement delivery is predictable or unpredictable and (2) whether there are occasional opportunities for reinforcement after very few responses and/or time periods (Morris, 1986). Thus, in Experiment III, the presence of occasional high, reinforcement density was held constant while the discriminative effects of aperiodicity, or predictable versus unpredictable session location of the interpolated FR 1 component, were manipulated.

The results of Experiment III suggested that when presented as a compound stimulus, fixed session location and signaled presence of the FR 1 component attenuated the effect of the smallest ratio component. That is, when the stimulus compound signaled the presence of the FR 1 component, median PRP duration was similar to that found when the FR 1 component was absent. Thus, unpredictable presentation of the interpolated high-density schedule component (one aspect of aperiodicity) appears to be a necessary condition for producing median PRPs of a duration comparable to those found on VR schedules. Crossman (1971) reached a similar conclusion when he found pausing on multiple FR FR schedules produced longer PRPs than on comparable mixed FR FR schedules.

This conclusion is supported by the literature on choice behavior, wherein response strength is inferred by the relative allocation of responding to different alternatives. In this literature, aperiodic schedules have been found to be preferred to periodic schedules that provide the same, and in some cases reduced, arithmetic rates of reinforcement (Rider, 1983). For example, Fantino (1967) reported that a two-valued mixed-ratio schedule (MR

1/99) was preferred to an equivalent FR 50 schedule with the same density of reinforcement. Fantino also found that an MR 1/99 schedule was preferred to an FR 35 schedule which delivered a higher density of reinforcement than the MR 1/99. Similarly, Sherman and Thomas (1968) found that a VR 120 schedule was preferred to FR schedules as low as FR 60 when the VR schedule included reinforcement after one response.

Choice in concurrent chains is also strongly controlled by the smallest requirement for reinforcement present in a terminal link. Duncan and Fantino (1970) found that the value of the shortest possible time to reinforcement provided by a terminal link accurately described the outcomes of studies of choice by Herrnstein (1964), Fantino (1967), Killeen (1968) and Davison (1969a). The preference for two-valued mixed schedules to fixed schedules is inversely related to the mixed schedule's smaller requirement for reinforcement (Cicerone, 1976; Fantino, 1967; Hursh & Fantino, 1973).

Herrnstein (1964) has pointed out the apparent "irrationality" of the preference for aperiodic over periodic schedules, a tendency which is associated with increases in overall delay to reinforcement and decreases in overall rate of reinforcement. The PRP on FR schedules is similarily "irrational" in that pausing reduces overall density of reinforcement (Shull, 1979). These results, along with the results of Experiment III, suggest that the preference for aperiodic schedules and, by analogy, the duration of the PRP on FR schedules, is controlled by the schedule component (or choice alternative) associated with the shortest delay to reinforcement. That is, immediacy of reinforcement, rather than overall rate of reinforcement exerts primary control over both choice behavior and PRP duration.

Directions for Future Research

Although Experiment I clarified the control exerted by the FR 1 component over the duration of the PRP, further research is necessary to isolate the variables exerting control over IRTs. In Experiment I, the addition of the FR 215 component to the FR 1 _inter_ FR 50 reduced the durations of the median PRP and the median IRT from durations found on a comparably-sized VR schedule. Although it was noted that this change in duration is an example of positive induction, further research is necessary to determine the variable(s) operating to reduce IRT durations on the FR 1/FR 215 _inter_ FR 50 schedule.

Perhaps the most noteworthy aspect of Experiment II was the control exerted by exposure to response-independent reinforcement. Although historical exposure to this event was limited to once per day, later exposure to response-dependent reinforcement had an attenuated effect on exposure to response-independent presentations of the unconditioned stimulus has been found to "interfere" or retard later conditioning (Baker & Mackintosh, 1979). Similar effects have been reported in the operant conditioning literature, where the finding is referred to as behavioral momentum (Nevin, Mandell, & Atak, 1983), hysteresis (Davison & Hunter, 1979), or learned helplessness (Seligman & Beagley, 1975). Future research could clarify the relations between a given history of reinforcement and the observed performance on a schedule of reinforcement.

A related issue, with generality to experimental as well as govenmental practice, would be to identify techniques for attenuating the effects of exposure to response-independent reinforcement. For example, welfare is usually presented to receipients on a response-independent FT schedule. This produces few productive behaviors, unlike reinforcers tied directly to a behavior. Instead, payment of welfare on a response-independent schedule may actually produce a retardation in the learning of alternative income-producing behaviors. Thus, the FT schedule of welfare payment produces low rate behavior in the short run and retards learning of new behaviors in the long run.

The results of Experiment III demonstrated that the FR 1 component reduced PRP duration whether or not the component was signaled or fixed in the same session location. Yet in compound, fixed session location signaled location. Yet in compound, fixed session location signaled by a discriminative stimulus did not reduce PRP duration. Further research is necessary to determine the conditions under which an exteroceptive stimulus will exert control over responding on simple schedules of reinforcement.

Concluding Remarks

Mazur (1983) has suggested that the probability of a given behavior is a function of reinforcement proximity and rate of reinforcement. The results of the present set of experiments suggest a modification of this conclusion is in order. That is, the probability of a given behavior is a function of the highest local density of response-dependent reinforcement and, to a lesser degree, the overall rate of reinforcement. The issue of whether periodic or aperiodic schedules generate different response patterning (i.e., different PRP durations) fractures into a simpler issue: Is overall PRP duration controlled by the component with the highest density of response-dependent reinforcement present in a session?

The results of this series of experiments answer this question in the affirmative, with the qualification that pre-exposure to a history of response-independent reinforcement attenuated the control exerted by the interpolated FR 1 component. An important aspect of the control exerted by the interpolated FR 1 component was of induction to other PRP durations in the session was modulated by the degree of stimulus control associated with the FR 1 presentation (either signaling the presence of, or fixing the session location of the FR 1 component). Thus, the question of how to synthesize VR performance must be restated to encompass a given behavioral history and a given set of stimulus conditions.

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APPENDICES

Appendix A

Table 15

Seven Sequences of Presentation of the 31 Values of the VR 50 (actually a VR 48.5) Schedule Components in Experiment I

Ratio	Sequence Number						
Location	1	2	3	4	5	6	7
1	8	34	122	34	1	93	9
2	44	2	8	20	8	18	22
3	93	63	69	44	84	44	31
4	69	16	34	16	57	1	63
5	52	18	57	84	34	8	40
6	18	93	44	9	37	76	122
7	6	37	48	69	25	11	52
8	11	122	31	13	31	22	48
9	63	11	13	93	11	215	4
10	22	106	28	215	22	63	18
11	84	13	22	52	147	106	13
12	1	25	63	6	18	28	76
13	28	215	1	28	6	20	69
14	147	22	4	57	2	2	11
15	122	8	20	40	106	31	215
16	9	40	2	11	48	122	44
17	106	44	40	37	69	37	84
18	4	76	52	106	13	6	57

(table continues)

Ratio	Sequence Number						
Location	1	2	3	4	5	6	7
19	13	6	76	2	44	16	2
20	31	1	11	147	9	147	1
21	215	20	84	8	122	40	25
22	20	28	9	63	28	25	16
23	48	147	18	31	16	57	8
24	16	52	122	1	93	34	6
25	25	4	6	122	63	84	147
26	57	57	16	48	52	9	106
27	40	84	93	18	4	13	20
28	2	69	25	6	215	52	37
29	76	9	122	25	40	4	28
30	34	48	37	76	76	48	34
31	27	31	215	22	20	69	93

Appendix B

Table 16

Ordinal Location Within a Session and Sequence Across Conditions of all Interpolated Components for all Subjects in Experiment I, Experiment II, and Experiment III.

Session Number	Within Session Location of Interpolated FR 1 (1 & 2), FT 1 s, FT (Blackout), and FR 1 (Unsignaled & Signaled for Random or Fixed)	Within Session Location of Interpolated FR 215 component
1	13	26
2	16	5
3	28	21
4	6	20
5	9	7
6	30	12
7	11	28
8	1	13
9	29	4
10	17	3
11	26	27
12	6	18
13	3	9
14	24	8
15	22	15

(table continues)

Session Number	Within Session Location of Interpolated FR 1 (1 & 2), FT 1 s, FT (Blackout), and FR 1 (Unsignaled & Signaled for Random or Fixed)	Within Session Location of Interpolated FR 215 component
16	17	24
17	5	18
18	26	10
19	29	2
20	6	15
21	15	30
22	17	3
23	25	27
24	16	17
25	25	7
26	9	24
27	15	3
28	14	9
29	13	24
30	11	8

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1980	Systems Analyst, Mercy Hospital Child Development Center, Des Moines, Iowa. Responsible for conducting a performance analysis of infant care.
1978-1980	Graduate Teaching Assistant, Department of Psychology, Drake University, Des Moines, IA. Responsible for assisting with an Introductory Psychology class which used a modified Personalized System of Instruction.
1977-1978	Research Assistant, H.E.W. Dental Fear Project, Western Washington University, Bellingham, WA.

PUBLICATIONS

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PAPERS AND POSTERS

Bonem, E., & Alferink, L. A. Concurrent schedule performance with young infants. Paper presented at the Rocky Mountain Psychological Association in Alburquerque, New Mexico, 1982.

McConaughy, K., Bonem, E., & Crossman, E. K. Illuminating the blackout functions in small FRs. Poster presented at the Association for Behavior Analysis, Milwaukee, Wisconsin, 1982.

Bonem, E. The development of IRT patterning: The effect of small sequential increases in fixed-ratio size. In E. K. Crossman (Chair), *Development of temporal patterns in small FRs: A Microanalysis*. Symposium presented at the meeting of the Association for Behavior Analysis, Milwaukee, Wisconsin, 1982.

Cheney, C., Bonem, E., & Nittrouer, S. Travel cost effects on giving-up time in a pigeon model of foraging. Paper presented at the meeting of the Animal Behavior Society, Duluth, Minnesota, 1982.

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Bonem, E., & Crossman, E. Interpolated fixed-ratio schedules: The effects of frequency, position, and response dependency. Paper presented at the Rocky Mountain Psychological Association in Las Vegas, Nevada, 1984.

Bonem, E., & Cheney, C. Extended session length and performance in a foraging model. Paper presented at the Rocky Mountain Psychological Association in Tucson, Arizona, 1985.

Bonem, E. Synthesizing variable-ratio performance with two fixed-ratio components. In E. K. Crossman (Chair), *Current research with ratio schedules*. Symposium presented at the meeting of the Association for Behavior Analysis, Columbus, Ohio, 1985.

Phelps, B., Bonem, E., & Crossman, E. A comparison of response patterning under fixed, variable, and random-ratio schedules. Poster presented at the Association for Behavior Analysis, Milwaukee, Wisconsin, 1986.

DeWulf, M., Bonem, E, & Cheney, C. An experimental analysis of foraging. Poster presented at the Association for Behavior Analysis, Milwaukee, Wisconsin, 1986.

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PROFESSIONAL AFFILATIONS

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ACADEMIC AWARDS

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Awarded Non-resident tuition scholarship from Utah State University (1982 - 1987).

Membership in the honor society of Phi Kappa Phi, Utah State University Chapter (1987).

PROFESSIONAL INTERESTS

Teaching

Introductory Psychology
Descriptive and Inferential Statistics
Learning (operant and classical conditioning)
Computer Applications
Research Design (single subject and group)
Child Development

Research: Basic

Schedules of Reinforcement
Foraging behavior
Relation of the Relative-Waiting Hypothesis to direct CS-CR conditioning
Control procedures in classical conditioning.

Research: Applied

Human-computer interactions
Organizational behavior management
Program analysis
Schedule performance with humans
Verbal Behavior

Computer Experience

Computer Languages: FORTRAN, PASCAL, and BASIC programming.
Applications: Control and analysis of experimental events (both microcomputer and electromechanical)

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